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NORTH CAROLINA
Environmental Quality

February 12, 2025

MEMORANDUM

TO: North Carolina Governor's Office

From: Sushma Masemore, PE, Deputy Secretary for Environment

Subject: Executive Order 305 Updates and Deliverables

On behalf of the North Carolina Department of Environmental Quality (DEQ), the DEQ Executive Order 305 Team submits the following memo and attachments in fulfillment of the Department's EO 305 assignments. These assignments uphold the goal of protecting natural and working lands in the state. The summary of attachments and updates on efforts are as follows:

- In accordance with Executive Order Section 3a, DEQ has provided *Attachment A: Methodology to Update Wetland Maps & Determine Sacketts Effect.* This methodology aims to 'update existing wetland mapping data for North Carolina that may be employed to estimate the number of acres of wetlands that may lose protections as a result of *Sackett v. EPA,* and the North Carolina Farm Act of 2023.'

- In accordance with Executive Order Section 3b, DEQ has provided *Attachment B: Feasibility and Status of High-Resolution Land Use/Land Cover Mapping Project [NOAA Coastal Change Analysis Program (C- CAP)].* This attachment aims to 'evaluate the feasibility of obtaining updated high-resolution remotely sensed land cover data state-wide to assist in the assessment of type and extent of natural working lands, including wetlands.' Furthermore, the map aims to 'support planning for community resilience to climate change, prioritizing habitat and wetland conservation and protection, and providing a foundation to assess land use change over time.'

- In accordance with Section 3e, DEQ published a research opportunity announcement through the NC Office of Strategic Partnerships to study the social, economic, and environmental value of conserving natural and working lands and the impacts from the degradation of wetlands that lost federal and state protections between 2022 and 2023. Six groups responded to the information request. DEQ made five awards to interested parties to develop detailed scopes of work that addresses four targeted items listed under Section 4e (i) through 4e (iv) of Executive Order 305. Since each awarded party contained different expertise, DEQ encouraged the awarded parties to partner with each other to provide unified scopes of work. On January 21, DEQ received two detailed scopes of work from the awarded teams, one led by Research Triangle Institute (RTI), and one led by Resource Environmental Solutions (RES). The two SOWs are included as *Attachment C1: Value of Conserving Natural and Working Lands in North Carolina Scope of Work Report* (RTI) and *Attachment C2: Scope of Work for Phase II – Addressing Section 3(e) of Executive Order (EO) 305* (RES). DEQ is currently evaluating these scopes. At this time, no funding has been appropriated or secured to execute these scopes.

- In accordance with Executive Order Section 4, DEQ and its partner agencies completed publishing the geographic boundaries of Coastal Wetlands and Sea Marsh Corridors, Pocosins and Carolina Bays, and Mountain Bogs. The data is located on the DEQ Executive Order 305 HUB located at: https://nc-wetlands-data-hub-ncdenr.hub.arcgis.com/

Attachment A

Methodology to Update Wetland Maps & Determine Sacketts Effect

Attachment A. E.O. 305 Section 3a

Methodology to Update Wetland Maps & Determine Sacketts Effect

8/12/2024

North Carolina Department of Environmental Quality (DEQ) Executive Order 305 Wetlands Workgroup

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Executive Summary

When the *Sackett v. EPA* Supreme Court Case narrowed definitions of protected wetlands at the federal jurisdictive level, North Carolina Governor Cooper passed Executive Order 305, tasking DEQ and other state departments with various initiatives to increase knowledge of natural and working lands with the overarching goal of ecosystem protection. The purpose of this document, in accordance with Executive Order 305, is to address knowledge gaps about natural and working lands through efforts described in the order. In this report DEQ evaluates and proposes a method to produce an updated wetland map for North Carolina and proposes three methods for evaluating the potential effect of the Sackett decision on wetlands.

DEQ proposes to use and update the most accurate existing wetland mapping data, specifically the National Wetland Inventory (NWI), Division of Coastal Management (DCM) Wetland Data, and North Carolina Department of Transportation (NCDOT) Wetland Mapping Using Artificial Intelligence (AI) and Machine Learning. The NWI is the only comprehensive statewide mapping effort for North Carolina. The DCM Wetland Type Maps includes data in 40 coastal counties. The NCDOT wetland mapping effort uses machine learning, Light Detection and Ranging (LiDAR), and field delineations to produce maps that identify the probability of being jurisdictional under the Clean Water Act. NCDOT's mapping efforts are in process and currently incomplete but are promising. The efforts are yielding higher accuracy results in the mountain and piedmont regions, which have been historically difficult to map. This project proposes to combine the NWI and DCM data into a base map for North Carolina. Once the base map is created, current 1-meter resolution landcover data and NCDOT wetland AI machine learning data can be used to update the base map to produce an updated wetlands map for the state of North Carolina.

The methods proposed for evaluating the effects of Sackett include a method to evaluate risk based on wetland type, a method based on Hydrogeomorphic (HGM) class, and a Geographical Information System (GIS) method that evaluate hydrological connectivity.

I. Background

On May 25, 2023, the United States Supreme Court released its decision in Sackett v. Environmental Protection Agency (EPA). In Sackett, the Court reduced the reach of the Clean Water Act (CWA) by narrowing the criteria for which certain wetlands and waters may qualify as "waters of the U.S." (WOTUS). The Court concluded that wetlands and waterbodies that have no surface connection to navigable waters or other waters of the U.S. are, themselves, not waters of the US. The Sackett decision eliminated the federal protection status for approximately 50% of the nation's wetlands. There are 25 states that exclusively rely on federal rules, 6 states with limited state rule protection, and 19 states and the District of Columbia with broad state protection. The states that rely on broad state protection are fully protected by state law, while those who are not are either working to obtain protection through bills and other regulatory programs or are not moving forward to seek protection at all. North Carolina was one of the 6 states that had limited state protection, but that limited protection was eliminated shortly after the Sackett decision when North Carolina legislature passed the 2023 Farm Bill (SB582) that limited state wetland jurisdiction to be no more stringent than the federal jurisdiction.

Executive Order 305

On February 12, 2024, Governor Roy Cooper issued Executive Order 305. Executive Order 305 sets goals for the State of North Carolina to diligently protect, restore, and enhance natural and working lands that (i) facilitate carbon sequestration, (ii) strengthen ecosystem and community resilience, (iii) support biodiversity, (iv) provide vital ecosystem functions and services such as clean water and protection from floods, (v) support military training operations, (vi) facilitate tourism and enhance the State's economy, or (vii) provide opportunities for hunting, fishing, boating, and other recreational activities. By 2040, Executive Order 305 set goals for the State of North Carolina to permanently conserve 1 million new acres of North Carolina's natural lands with special focus on wetlands, restore or reforest 1 million new acres of North Carolina's forests and wetlands, and plant 1 million trees in urban regions of the state.

Executive Order 305 also set four specific tasks to the North Carolina Department of Environmental Quality: (1) feasibility of obtaining land cover data, (2) develop methodology to update wetland maps and determine Sackett Effect, (3) publish boundary maps of special wetlands, and (4) create a research project that outlines the values, costs, impacts of Natural and Working Lands, and benefits of conservation. This paper focuses on the second task of developing a methodology to update existing wetland mapping data for North Carolina and the methods that may be used to evaluate the potential acres of wetlands that have been affected by the Sackett decision.

Wetlands in North Carolina

The Clean Water Act defines a wetland as "areas that are inundated or saturated by surface water or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation adapted to life in saturated soil conditions." Wetlands comprise approximately 17% of North Carolina's total acreage (Hefner and Brown, 1985). Historically, North Carolina contained about 11 million acres of wetlands. Today, most estimates believe that North Carolina has about 5.7 million total acres, about 85 to 95% of these are located in the Coastal Plain (Wilson, 1962). Nearly one-third of the wetland alterations in the Coastal Plain have occurred since the 1950's. Most conversions have resulted from the transformation of wetlands into managed forests and agriculture. Approximately 70 percent of the rare and endangered plants and animals in the State are wetland dependent (USGS, 1996). According to the North Carolina Division of Coastal Management (DCM) (1999), 50 percent or more of the current landscape is comprised of wetlands in the North Carolina Coastal Plain. Wetlands are known to be of great ecological importance, for instance, their relationship to coastal water quality, estuarine productivity, and wildlife habitat makes this particular ecosystem quite diverse (Sutter & NCDCM, 1999).

Mapping Wetlands in North Carolina

Identifying wetlands that are subject or jurisdictional under the Clean Water Act has been a source of regulatory, political, legislative, and judicial debate throughout the history of North Carolina. Wetlands have been under litigation and have resulted in multiple U.S. Supreme Court Decisions over the last 30 years, the most recent being the Sackett decision.

There have been multiple efforts to identify and map wetlands in North Carolina. Table 1 shows a history of the significant wetland identification mapping efforts in North Carolina.

Table 1. Wetland Inventories for North Carolina

Year	Authors	Type of Wetland Mapping Effort
1860	Emmons	Swamplands owned by State of NC, swamplands in NC
1867	NC Literary Board	Swamplands
1883	Kerr	Principle Tracts Claimed by Board of Education
1889	Shaler	Freshwater Morasses
1916	Pratt	Swamp Overflowed Lands
1923	Gray et al.	"Land Mostly Too Rough…"
1949	Wooten and Purcell	Land Feasible to Drain
1956	Shaw and Fredine	20 wetland Types
1962	Wilson	Wetlands in 41 Coastal Counties
1967	Burdick	Marshlands
1968	Spinner	Marshlands
1974	Knight and McClure	Swamps and Bottomlands
1982	USFWS	Yadkin-Pee Dee River Basin
1981	Richardson et al.	Pocosins in 41 Counties
1982	East Carolina University	Atlas Project - Albemarle-Pamlico
1982	National Wetlands Inventory (USFWS)	Statewide - all wetland types
1999	NC Division of Coastal Management	40 Coastal Counties - all wetland types
2024	NCDOT	Jurisdictional Probability Maps – In process

The National Wetland Inventory maps produced by the U.S Fish and Wildlife Service (USFWS) is the only comprehensive statewide mapping effort for North Carolina. The DCM Wetland Type Maps were a significant upgrade in accuracy to the National Wetland Inventory maps but are only located in the 40 coastal counties of North Carolina. In recent years, NCDOT has experimented with using machine learning, LIDAR, and field delineations to produce wetland maps that identify the probability of being jurisdictional under the Clean Water Act. NCDOT's Wetland Predictive Modeling Program/AI Mapping uses ArcGIS data, LiDAR data, NCDWQ Headwater Stream Spatial Datasets, and other supporting spatial data to create high-level wetland maps. NCDOT has run the model statewide but is still reviewing and analyzing the results. This new technology is promising and can potentially improve upon the NWI maps in the Piedmont and Mountains. On the coast, the DCM wetland type data remains the most accurate and comprehensive source of wetland mapping in North Carolina. DCM conducted a thorough accuracy assessment of the DCM wetland type data that concluded 89.74 % of mapped wetlands were jurisdictional. The overall mapping accuracy was 81%. The overall mapping is lower due to the number of wetlands not captured by the DCM's mapping effort (meaning that the DCM data underrepresented actual wetlands in the field). Coastal marshes, freshwater marshes, bottomland hardwoods, swamps, and pocosins were mapped with the greatest accuracy (97% or higher), while headwater forests, hardwood flats, and managed pine wetlands were less accurate (between 65% and 75%). (Sutter & NCDCM, 1999).

Initial Evaluations of Sackett Decision

After the Sackett decision, politicians, natural resource agencies, and environmental organizations across the country began conducting analyses to determine the effects on wetlands jurisdiction. In 2023, The

North Carolina Department of Environmental Quality conducted two analyses using the DCM Wetland Type Data to predict the potential effects of Sackett:

1. Wetland Type Risk Analysis – DEQ identified the wetland types most likely to be affected by Sackett and grouped them into categories of high, moderate, or low risk.
2. Hydrogeomorphic (HGM) Risk Analysis – DEQ identified the risk to wetlands based on their HGM class. Wetlands that are riverine and estuarine are lower risk, headwater system HGM classes are moderate risk, and nonriverine classes are expected to be at higher risk. These risk associations correlate with their relative probability to be jurisdictional under the revised WOTUS definitions post-Sackett.

DEQ's initial analyses showed that between 57 and 64 percent of wetlands were at risk after analyzing both DCM's Used Wetland Type and HGM data. The results of these analyses were similar to other efforts. In 2024, the Environmental Defense Fund concluded that 63 to 66 percent of wetlands were at risk. The Environmental Defense Fund used the National Wetland Inventory data and its Cowardin Classifications to assess probabilistic risk (NCDEQ, 2024). Table 2 shows the total acreage and risk levels for the Used Wetland Type analysis from the DCM data. Table 3 shows the total acreage and risk levels for the HGM analysis from the DCM data. Although each assessment used different approaches, the similar results support the idea that the effects of the Sackett decision are significant.

Table 2: 2023 DEQ Analysis Results using DCM Wetland Types to Assess Risk

Total Acreage	Risk Levels
1,504,530	Low Risk
367,672	Moderate Risk
2,490,397	High Risk
4,362,599	Total

Table 3: 2023 DEQ Analysis Results using DCM HGM Classifications to Assess Risk

Total Acreage	Risk Levels
1,553,782	Low Risk
40,653	Moderate Risk
2,798,345	High Risk
4,392,780	Total

Wetland Protection Trends in the U.S.

The workgroup evaluated the wetland protection trends in the United States, both pre- and post-*Sackett v. EPA*. Only bills deemed applicable to the scope of this report were included. The general consensus is that the *Sackett v. EPA* Supreme Court decision significantly reduced wetland protections under the Clean Water Act. The Sackett case ruled that the Clean Water Act jurisdictional wetlands have a 'continuous surface connection' with a relatively permanent body of water that is, or is connected to, 'traditional interstate navigable waters' (Supreme Court of the United States 2023). Many states had comprehensive wetland protection policies and standards prior to the *Sackett v. EPA* Supreme Court case. According to the Environmental Law Institute, nineteen states have state laws that regulate waters and wetlands (California, Connecticut, Florida, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Tennessee, Vermont, Virginia, Washington, and Wisconsin). Most of these states utilize wetland permitting programs to facilitate these laws and protections (McElfish 2022). The other 31 states historically have relied on federal laws and regulations to protect wetlands.

Figure 1. Wetland Protection in US.

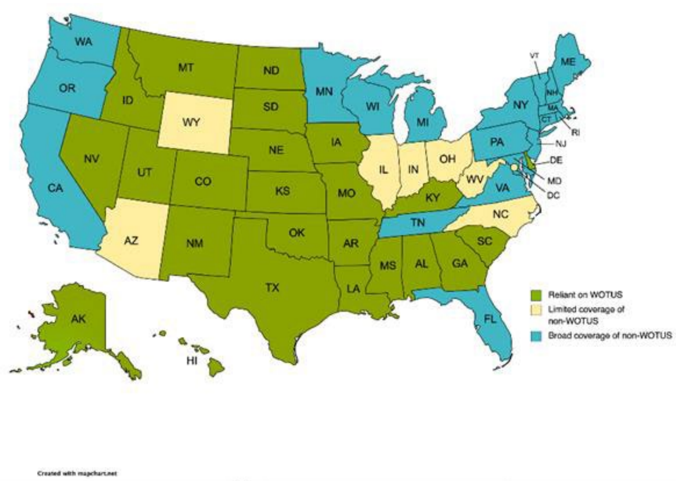


Figure 1 (McElfish 2023) on the left, provided by Environmental Law Institute, depicts the three categories of states according to their state wetland protections. States shaded in green are considered 'reliant on WOTUS,' meaning that, historically, these states have relied on federal laws and regulations to protect wetlands. States shaded in tan are considered to have 'limited coverage of the non-WOTUS,' meaning that, historically, these states have covered some wetlands not protected federally in their own states policies. States shaded in blue are considered to have 'broad coverage of non-WOTUS,' meaning that they do not rely on federal protections for wetlands in their states.

Some states have been rapidly introducing legislation to protect wetlands within their state boundaries since protections were reduced in *Sackett v. EPA*. In the State of Illinois, the Wetlands and Small Streams Protection Act, S 3669/H 3586, is pending. The bill aims to strengthen protections for wetlands (NCSL 2024). Similarly, the Forests Wetlands and Prairies Act (S 2781) has been sent to the Governor of Illinois for signature. This bill aims to develop a grant program for restoration of various ecosystems (NCSL 2024). The State of Indiana enacted S 246 into law and creates new rulemaking for wetland classification requirements (NCSL 2024). Similarly, H 1383, which relates to updated wetland definitions and rulemaking, has been sent to the Governor of Indiana for signature (NCSL 2024). New Mexico is in the process of developing a new wetland permitting program (New Mexico Wetlands Program 2024). Hawaii has adopted SR 192/HR 194, the West Maui Wetlands Bill, to promote collaboration between local, state, and federal government entities to protect wetlands statewide (NCSL 2024). The state of Tennessee adopted S 629, which updates wetland permitting regulations in the state (Tennessee General Assembly, n.d.). The State of Colorado, enacted H 1379 this year. This bill essentially created a state dredge and fill program to regulate wetlands that lost protections in the *Sackett* ruling (NCSL, 2024).

The State of Arizona received a $25 million dollar stipend from the federal government to protect the wetlands in the state (U.S. Department of the Interior, 2024). New Hampshire's H 472 creates wetland permit exemptions after a natural disaster or flooding event, and this bill was sent to the NH Governor in May (NCSL 2024). In the State of New Jersey, NJ A 3106, which would allow municipally managed Blue Acres lands to aid in freshwater wetlands mitigation projects, is pending committee signature (NCSL 2024). In the State of New York, NY S 9379/A 9712 is pending. This bill aims to ban pesticides from being applied in local freshwater wetlands that meet established criteria (NCSL 2024). The State of Vermont enacted VT S 213, which creates new regulations of wetlands, implements a goal of a net gain of wetlands acreage in the state, and requires Vermont Significant Wetlands Inventory maps to be updated and revised annually (NCSL 2024). In the State of Virginia, H 357 is pending committee approval. This bill mandates that the Virginia Department of Environmental Quality (VA DEQ) establish workgroups to develop strategies to protect existing wetlands in the state and other wetland restoration efforts in response to *Sackett v. EPA* and the climate change phenomenon at large (NCSL 2024).

Some states that had previous statewide protections independent of the *Sackett v. EPA* Supreme Court ruling are still working to substantiate their wetland protections and requirements. In the State of California, CA A 828 is pending. This policy adds the requirement of including a Groundwater Sustainability Plan, which includes wetlands and other water systems, onto an existing state law (NCSL 2024). CA A 2875 is also pending. An ambitious policy, A 2875 aims to ensure a no net loss, long-term gain for wetlands in the state at large (NCSL 2024). The State of Massachusetts has S 457/H 906 pending approval of committee. This bill aims to implement more wetland restoration in the state (NCSL 2024). The State of Colorado attempted to pass S 127, a similarly ambitious bill that would have implemented a permitting program for regulating pollutants into water sources and established a wetland protection commission and division (NCSL 2024).

Since *Sackett v. EPA,* some states have introduced bills to protect wetlands at the state level but have failed. Delaware failed to modify their wetlands program in S 290 (NCSL 2024). New Hampshire attempted to enact NH H 1503 to exclude certain areas in the state from the definition of a 'wetland,' but the bill failed (NCSL 2024). In Tennessee, H 1054 attempted to prohibit the TN Department of Environment and Conservation from implementing standards classifying real property as a wetland, unless said wetland is protected under federal law, but this bill also failed (NCSL 2024). TN H 2149 attempted to categorize an ephemeral wet weather conveyance as a non-wetland, also failing (NCSL 2024).

Connecticut also has failed attempts to implement new wetland rulemaking. H 5218 aimed to revise wetland provisions and incorporate a wetland training program (NCSL 2024). The State of Minnesota failed to modify existing wetland rulemaking in S 4876/H 5011, the Wetland Conservation Act, which relates to updated wetland permitting processes (NCSL 2024). MN H 350/S 3559 attempted to modify provisions for wetland management, wetland banking and conservation management, and other rulemaking modifications, but failed (NCSL 2024). MN S 4629/S 4666 attempted to increase funding for a local road wetland replacement program, but the bill also failed (NCSL2024). The State of Florida attempted to disallow counties from implementing their own wetlands protections, but this bill failed. However, Florida passed H 1379, which increased conservation funding for state lands and established greater protections for various ecosystems in the state (Florida Senate, n.d.). The State of Wisconsin failed to pass A 254 regarding a wetland assured delineation program, but WI S 255 was enacted, which aims to prohibit reduction of public wetland access (NCSL 2024). In the State of Mississippi, S 2647 failed in the legislature. This bill aimed to create an advisory board that would ensure habitat protection, water quality, storm protection, and more (Mississippi State Legislature, n.d.).

Table 4. Trackable State Legislative Bills, most of which were obtained from the NCSL Environment and Natural Resource Policy Database, 2023-2024.

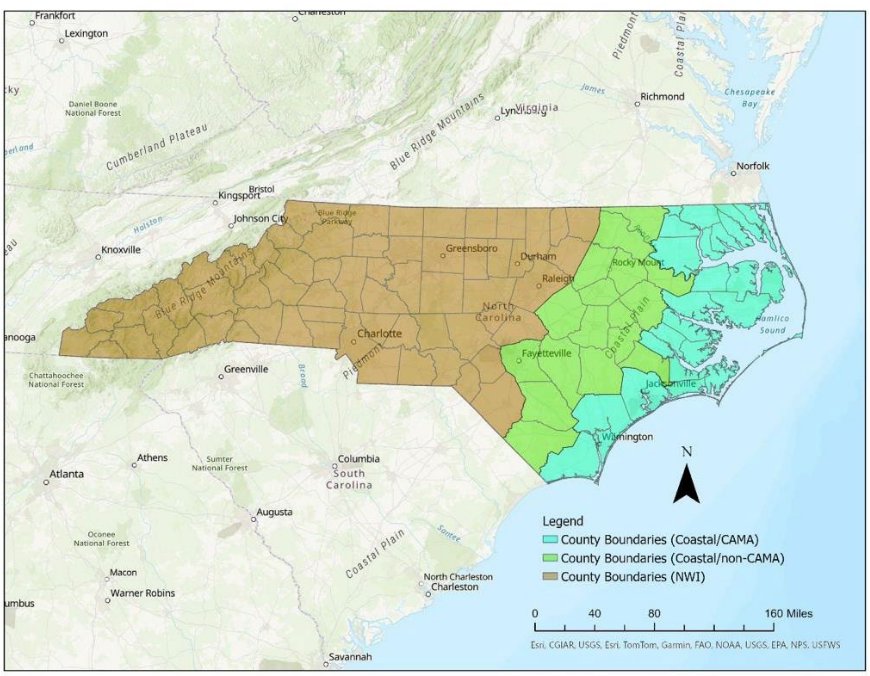
State	Status	Topic/Effect
California	A 828 pending	No net loss, long-term gain for wetlands in the state
California	A 2875 pending	Inclusion of Groundwater Sustainability Plan
Colorado	S 127 failed	Pollutant regulation permitting program, wetland protection commission and division
Colorado	H 1379 enacted	Requires a commission to create a dredge and fill (permitting) program to regulate wetlands.
Connecticut	H 5218 failed	Revise wetland provisions, incorporate wetland training program
Delaware	S 290 failed	Wetland program modification
Florida	S 1240 failed	Disallow counties from implementing their own wetland protections
Florida	H 1379 passed	Increases conservation planning and funding for state lands, establishes greater protections for various basins and river lagoons in the state.
Hawaii	SR 192/HR 194 passed	Local, state, and federal wetland protection collaboration
Illinois	S 3669/H 3586 pending	Strengthen wetland protections
Illinois	S 2781 sent to Governor for signature	Ecosystem restoration grant program
Indiana	S 246 enacted	Wetland classification requirements
Indiana	H 1383 sent to Governor for signature	Wetland definitions and rulemaking
Massachusetts	S 457/H 906 pending	Wetland Restoration
Minnesota	S 4876/H 5011 failed	Modify existing wetland rulemaking and permitting processes
Minnesota	S 3559/H 350 failed	Modify existing wetland management, banking, and conservation management procedures
Minnesota	S 4629/S 4666 failed	Increase funding for local road wetland replacement program
Mississippi	S 2647 failed	Create a Technical Advisory Board to develop an annual comprehensive plan for habitat protection, water quality, and more.
New Hampshire	H 1503 failed	Wetland permit exemptions
New Hampshire	H 472 sent to Governor	Exclude some areas from being classified as a wetland
New Jersey	A 3106 pending signature	City-managed Blue Acres lands aid in freshwater mitigation projects

New York	S 9379/A 9712 pending	Pesticide banning in local freshwater wetlands
Tennessee	H 1054 failed	Prohibit state from implementing real property wetland classification standard
Tennessee	H 2149 failed	Categorize ephemeral wet weather conveyance as a non-wetland
Tennessee	S 629/H 1057 enacted	Updates wetland permitting in the state.
Vermont	S 213 enacted	Wetland regulations, net gain of wetlands acreage, updating/revising of VT Significant Wetlands Inventory Maps
Virginia	H 357 pending	VA DEQ workgroups to develop wetland protection strategies
Wisconsin	A 254 failed	Wetland assured delineation program
Wisconsin	A 255 enacted	Prohibit reduction of public wetland access in state

II. Establishing an Existing Wetland Basemap for North Carolina

The workgroup evaluated the available wetland data for North Carolina. Two datasets stand above the rest: 1) the North Carolina Division of Coastal Management Wetland data sets and 2) the U.S. Fish & Wildlife National Wetland Inventory data sets. The workgroup proposes to combine these two data sets as shown in Figure 2 to establish the basemap from which to apply additional enhancements to improve the accuracy for wetland mapping for North Carolina. Detailed backgrounds and summaries for each of these data sources are summarized below.

Figure 2: Source Data for Basemap (NWI counties and DCM Wetland data (Coastal counties)).



NC Division of Coastal Management Wetlands Mapping Background

In the 1990s, the North Carolina Division of Coastal Management (DCM) developed a five-year strategy (DCM, 1992b) for improving wetlands protection and management in the coastal area using funds provided under the Coastal Zone Enhancement Grants Program established by 1990 amendments to §309 of the federal Coastal Zone Management Act (CZMA). The §309 Program is administered by the Office of Ocean and Coastal Resource Management (OCRM) in the National Oceanographic and Atmospheric Administration (NOAA), U.S. Department of Commerce. Funds provided under this Program were used to establish the wetlands conservation, protection, and mapping initiatives at DCM. The work was also partially funded by a separate grant from the U.S. Environmental Protection Agency (EPA) for a Wetlands Advance Identification project in Carteret County, North Carolina.

The key element of DCM's strategy for improving wetlands protection was the development of a Wetland Conservation Plan for the North Carolina coastal area. The Plan has several components:

- Wetlands Mapping & Inventory
- Functional Assessment of Wetlands
- Wetland Restoration Identification & Prioritization
- Coordination with Wetland Regulatory Agencies
- Potential Coastal Area Wetlands Policies
- Local Land Use Planning

The first step outlined in the Wetland Conservation Plan was to describe the type, location, and extent of the wetland resource, which provides a factual basis for policy and decision-making. To address this, DCM developed an extensive Geographic Information System-based (GIS) wetlands mapping program, which produces GIS wetland data by wetland type for the entire coastal area of North Carolina. Using the GIS coverage, paper maps can be generated for areas within any boundaries available in GIS format.

DCM Wetland Definitions & Identification

In North Carolina there are two laws that define wetlands. Section 404 of the Federal Water Pollution Control Act ("the Clean Water Act") defines wetlands as "areas that are inundated or saturated by surface water or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation adapted to life in saturated soil conditions." The North Carolina Coastal Area Management Act (CAMA) defines "coastal wetlands" as "any salt marsh or other marsh subject to regular or occasional flooding by tides, including wind tides (whether or not the tidal waters reach the marshland areas through natural or artificial water courses), provided this shall not include hurricane or tropical storm tides." Coastal wetlands contain at least one of 10 specified species of marsh plants. The wetlands defined by these two laws, "404 wetlands" and "coastal wetlands," are the only wetlands directly regulated by state or federal agencies in North Carolina.

There are several limitations to relying on only a technical or legal definition in wetland management. Comprehensive wetland maps indicating where "404" or coastal wetlands occur or are likely to occur can be an invaluable tool as guidance for planning and policy-making purposes. While a definition of wetlands is necessary from a regulatory standpoint, a planning tool that shows the location and type of wetlands could improve wetland impact through avoidance and minimization, thus improving the ability to make planning and policy-making decisions. For example, with only a technical definition, a landowner or developer is less able to determine in advance whether wetlands are present in a given area. This makes decision-making and land use planning more difficult and time-consuming because, legally, wetland delineations and determinations require on-site field visits. Wetland delineations include an on-site assessment of wetland criteria present including vegetation, soils, and hydrologic conditions that must meet certain requirements to qualify as a wetland. Wetland delineations or "jurisdictional calls" must be verified and approved by a representative from the U.S. Army Corps of Engineers or, for coastal wetlands, a representative from the NC Division of Coastal Management.

Relying solely on a technical definition effectively limits wetland protection from land use planning where the objective is to guide development into areas best suited for it and away from ill-suited areas. Environmental considerations play a significant role in land use decision-making and are one of the major objectives of the local land use planning mandated by the NC Coastal Area Management Act. Yet, except for areas obviously recognizable as wetlands, a technical definition does not provide local governments with the information needed to guide development away from ecologically important wetlands.

DCM's Wetland Mapping

The chief value of broad scale wetland mapping is to provide guidance for planning and policy-making purposes. The limitations of remotely sensed wetland maps from a regulatory perspective, however, do not lessen their value for the other purposes discussed above. Whether the plans are for development projects or general land use management, knowing in advance where wetlands are likely to exist with a high degree of confidence can be of great value. As users realize that, for regulatory purposes, on-site wetland delineation is still required, wetland maps based on remotely sensed data are a useful planning tool. Having at least a close approximation of the extent and location of wetlands in various categories will provide a sound basis for wetland policy decisions. These planning and policy-making applications form the context of DCM's wetland mapping as a component of the Wetland Conservation Plan.

In application, however, the question of the relationship of mapped wetlands to jurisdictional wetlands under the §404 Program remains significant. If the primary interest in avoiding wetland impacts is to avoid the difficulties and limitations of the wetlands regulatory program, then this is a very pertinent question. DCM conducted an accuracy assessment to provide users with the various accuracies of this product. As described in the rest of this report, DCM's wetland mapping was based on an analysis of overlays of several data sets that indicate the likely presence or absence of wetland characteristics on a given site. It is highly probable that any area identified as a wetland by DCM will be functioning as a wetland and that portions or all of the area will, indeed, be a jurisdictional wetland as defined in the 1987 *Corps of Engineers Wetland Delineation Manual* (Environmental Laboratory, 1987).

A general difficulty of relating mapped wetlands to jurisdictional boundaries is that jurisdictional boundaries are the result of political decisions and are subject to change. In the past 30 years, the generic wetland definition upon which boundary delineation is based has changed at numerous times. For example, the boundaries changed with the introduction of the 1987 Manual (Environmental Laboratory, 1987); again, when the 1989 Manual (Federal Interagency Committee for Wetland Delineation, 1989) was introduced; and still again with the return to the 1987 Manual. The boundaries have also changed with each major U.S. Supreme Court Case (e.g., Rapanos, Tulloch, Sackett). Each time the jurisdictional boundaries have changed. Continuing controversy over wetlands regulation make additional changes in the definition of jurisdictional wetlands, and thus the boundary, probable.

It is important to recognize that the wetland to upland transition is often a broad continuum and that placement of a delineated wetland boundary is subjective to some extent. Impacts to areas immediately adjacent to wetlands often have direct impact on the wetland's ability to function. In the final analysis, however, a specific boundary line somewhere along the continuum between dry land and open water is arbitrary (Mitsch and Gosselink, 1986). A regulatory program that must decide on a daily basis whether a given spot is within or beyond its jurisdiction must incorporate such an arbitrary line and specify as precisely as possible how it is to be located in the field. How closely this line relates to the presence or absence of wetland functions depends upon many factors and varies from site to site.

DCM's wetland mapping objective was to identify areas greater than one acre in size that are highly likely to display specific wetland characteristics and to perform wetland functions. Areas smaller than one acre could not be reliably identified with the remotely sensed data and interpretation techniques used. If the objective of wetland management is to protect wetland functionality, then the DCM wetland mapped areas should be considered worthy of protection. How stringently they will be protected under the §404 or other regulatory programs is a separate, political decision.

DCM's Method of Overlay Analysis

When developing methods for mapping, DCM quickly realized that the 9000+ square mile coastal area was too large for any exhaustive field mapping effort. To efficiently map the coastal area, DCM found it necessary to use existing data compatible with Geographic Information Systems (GIS). A review of the existing data revealed that most are not applicable for one of two reasons: (1) available wetlands data are based on older photography or (2) more recent data are not classified with the intent of wetlands identification. Both of these data types, used independently, are inappropriate for use in a coastal area wetlands conservation plan. In addition, the classification schemes used in the existing methods are either too complex or not focused on wetlands. The primary data layers selected for use were the US Fish & Wildlife National Wetlands Inventory (NWI), the County Soil Surveys, and 30-meter Thematic Mapper (TM) Satellite Imagery.

The NWI was selected because its primary purpose was to map wetlands. Unfortunately, these maps were created with photography from the early 1980s in coastal North Carolina, and many changes have occurred in the landscape. In North Carolina, NWI also omitted many pine-dominated wetland areas. It also tended to exaggerate the boundary of linear wetlands (based on field data collected at random sites with representatives from USFWS, NC Division of Soil and Water Conservation and DCM). DCM wished to improve upon the NWI, and in particular include pine-dominated wetlands, as these areas are important to the ecology of the coastal area.

Detailed soils information from the county soil surveys were also selected for use in DCM's mapping efforts. While soils alone should not be used to identify wetlands, they can be very useful in identifying marginal areas. They are also extremely useful in helping to define the type of wetland one should expect to find in an area. Pocosins, for example, would only be expected to occur on a limited range of organic and certain sandy soil types.

DCM employed Thematic Mapper (TM) Satellite Imagery in the development of a mapping methodology as well. DCM used imagery that had been classified in the late 1980s in much of coastal North Carolina to support the Albemarle-Pamlico Estuarine Study, a National Estuary Program, to identify developed areas, pine monocultures and other habitat types. Because this data layer was not developed as a wetlands inventory, many of the classes were not directly applicable to DCM's approach. However, the imagery was more recent than that from the soil surveys and NWI, and it provided additional habitat data not available in either of the other sources.

DCM chose to incorporate the benefits of each of these data sources into its mapping techniques.

DCM's Wetland Classification

When the wetland mapping project began in the early 1990s, the North Carolina Natural Heritage Program had developed a very detailed classification system of all natural areas in the state. These breakdowns were based on vegetative composition and assumed complete homogeneity at all sites (Schafale and Weakley, 1990). Although the Natural Heritage Program's classification system is very thorough, DCM chose not to use their classification system for two reasons. First, DCM's mapping approach uses remotely sensed data which cannot provide the level of detail necessary to accurately support the Natural Heritage classification system. Second, the Natural Heritage classification system uses numerous habitat types that would result in complex maps. A product of this type would require users to have a strong technical understanding of the classification system, thus limiting the use of the maps to only those with appropriate technical training.

At the same time DCM was developing a wetlands classification scheme, the NC Division of Water Quality (then the Division of Environmental Management and currently the Division of Water Resources) also was developing a comprehensive classification for wetlands statewide. Obviously, a statewide program would encounter wetland types elsewhere that would not apply to the coastal region. DCM staff worked with staff from all of these agencies to develop a classification scheme that met the needs of its clients without introducing conflict into the existing classification schemes.

Each wetland polygon was assigned to one of DCM's classes based on all the attributes it contains from input data sources. Classification of the Cowardin types into DCM wetland types has been reviewed by personnel from the National Wetlands Inventory and the NC Department of Environment and Natural Resources (now Department of Environmental Quality) Division of Soil and Water Conservation (DSWC). Further soils breakdown was reviewed by certified soil scientists at DCM and the DSWC. The classes currently recognized by DCM are salt/brackish marsh, estuarine shrub scrub, estuarine forest, maritime forest, pocosin, bottomland hardwood or riverine swamp forest, depressional swamp forest, headwater swamp, hardwood flat, pine flat and managed pineland. Polygons that do not have criteria designating them as wetlands were considered non-wetlands. On the maps, cleared and or cutover areas were classified, but were not considered wetlands based on DCM's classifications.

The hydrogeomorphology of a wetland is unique in defining the wetland's function (see Brinson 1993). Because these data serve as the base for additional wetland projects, an accurate determination of this characteristic is essential. Immediately following the overlay procedure, technicians add a new item (HGM) to the wetland coverage. DCM uses three hydrogeomorphic (HGM) classifications to describe wetlands in the North Carolina coastal plain. The three HGM classes of wetlands are riverine, headwater and flat/depressional. Because DCM considers both vegetation and landscape position in its classification (discussed later), riverine, headwater and flat/depressional wetland polygons are assigned an HGM class of 'r', 'h' or 'f', respectively. Digital line graphs of hydrography are relied upon in this step of the procedure. All wetlands that are adjacent to streams or rivers are considered to be in the riverine HGM class and are designated as riverine polygons. This class should include all bottomland hardwood swamps and some swamp forests. It rarely includes any of the interfluvial wetland types. On the occasion that it does, it is a small section of a large flat from which a small stream emerges. Only the polygons adjacent to the stream are considered riverine. Headwaters are defined as linear areas adjacent to riverine areas that do not have a stream designated on the hydrography data layer. Since these are unique systems that form the transition between flatwoods and riverine wetlands, they are treated specially. Finally, polygons that exist on interfluvial divides are designated as flat/depressional wetlands. No wetlands along streams should be found in this class, unless field verification showed otherwise.

DCM Field Verification

As methods were being developed, field verification was ongoing to ensure that the classification system reflected reality. DCM visited approximately 400 wetlands in and around Carteret County. The Division randomly selected sites within a stratification of watersheds (14-digit hydrologic units). Within each watershed, DCM classified sites based on landscape position, vegetative cover, and soil and hydrologic characteristics. Ongoing field verification also allowed staff the opportunity to adequately assess the classification assigned by NWI. If a particular Cowardin class was found to be systematically misidentified, the algorithm for automation was updated. While this method does not provide for a usable accuracy assessment, it allowed the most accurate methods to be developed. None of the data collected for this purpose were applied to the final accuracy assessment.

A concurrent accuracy assessment was made possible by a grant from the EPA. The assessment provides details about the likelihood of finding a wetland where DCM indicates one should exist as well as an indication of how likely a user is to find the mapped wetland type in that location.

DCM Final Mapping

DCM mapped more than 2.8 million acres (1,150,000 ha) of wetlands within the 20 coastal counties (Table 5) and more than 1.5 million acres (600,000 hectares) in the 20 Inner Coastal Plain counties. Salt/Brackish marshes, which do enjoy additional state protection under the state Coastal Area Management Act and the Dredge and Fill Act, are only 8% of the wetlands that fall within the jurisdictional area of the North Carolina Coastal Management Program.

To better understand the accuracy of these data, DCM obtained a grant from the EPA. Based on a sample size of at least 50 sites per wetland type (selected in a stratified random sample), data indicate that the overall probability of a mapped wetland being jurisdictional was 89%. This means that if an area is shown as a wetland in DCM data, there is only an 11% possibility that it is not actually a wetland. Conversely, upland areas identified on the map had a 73% probability of actually being an upland. In other words, any upland area on a DCM map has a 27% chance of containing a wetland (Shull III 1999).

It should be noted that not all jurisdictional wetlands were captured in DCM's mapping process. DCM was more successful identifying some classes than others. This is expected because the natural system is a continuum from one community, ecosystem and landscape to another. Placing a wetland area into one of several classes means that there will be cases where there is not a clear fit. The DCM Wetland Type maps are, therefore, more accurate for some community types than for others. For example, as one might expect, there was some difficulty distinguishing headwater swamps from riverine swamp/bottomland hardwood wetlands because these habitat types often grade into one another. Determining a precise boundary between them can be difficult even in the field.

DCM's GIS wetland data can be viewed on DCM's online map viewer or downloaded by county on the Division's website. These data and maps are not designed to replace an on-site jurisdictional evaluation of any wetland. They are intended to be used in a planning context and to help understand the environment in which we live.

National Wetlands Inventory Background

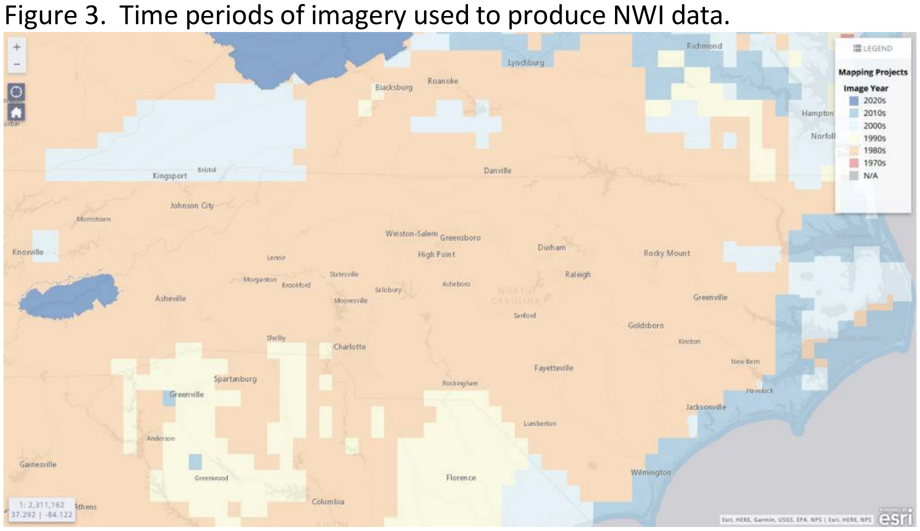
The National Wetlands Inventory (NWI) dataset, first published in 1988, is a national dataset created in response to the Emergency Wetlands Resources Act of 1986 and is maintained by the U.S. Fish and Wildlife Service (FWS). This dataset was developed to support the protection, restoration, and management of wetland resources by providing detailed spatial and thematic information to biologists. The NWI is the wetlands layer for the National Spatial Data Infrastructure (NSDI), and the FWS is the principal federal agency charged with maintaining geospatial wetland data. NWI data conforms to standards set forth by the Federal Geographic Data Committee (FGDC) Wetlands Mapping Standard.

The NWI dataset categorizes wetlands into several types based on their hydrological, ecological, and vegetative characteristics, and follows the classification standard set forth by the FGDC in the Classification of Wetlands and Deepwater Habitats of the United States. The FGDC wetland classification system is based on Cowardin et al. (1979) and employs a system, subsystem, class model. It is important to note that NWI data is not intended to be used to support legal, regulatory, or jurisdictional analysis of wetlands and deepwater habitats, as the scale of the data and methods used to produce the data are insufficient for such applications.

Historically, the NWI dataset covers wetlands of at least 1 acre in size, but 2009 standards specify a target mapping unit of 0.5 acre using 1 meter or better resolution imagery. NWI data across North Carolina varies, with most of the wetland data reflecting imagery from the 1980's. Figure 2 illustrates the time period for the images used to create NWI data. Data production reflects standards in place at the time it was produced, so much of North Carolina's wetland data was produced using lower quality base data and likely had a target mapping unit of greater than 0.5 acres. The NWI is the only spatial data layer that provides statewide coverage in North Carolina, so despite its age and limitations, it serves an important need for statewide analysis.

Updates to the NWI dataset are carried out periodically to reflect changes in wetlands over time due to natural processes or human activities. This ongoing maintenance ensures that the data remains relevant and useful for tracking wetland trends, assessing the impacts of development, and guiding restoration projects. At present, there are no active or recent updates to North Carolina NWI data.

Figure 3. Time periods of imagery used to produce NWI data.



https://fwsprimary.wim.usgs.gov/wetland-projects-v2/

III. Limitations of Existing Data and Landcover Overlay Analyses

National Wetland Inventory Accuracy

Analysis of National Wetland Inventory data across the state indicates high errors of omission (70 to 92%) for smaller wetlands (<1.0 ac), which particularly affects areas of the state where smaller wetlands are common, such as the Piedmont and Mountain ecoregions (Gale 2021a).

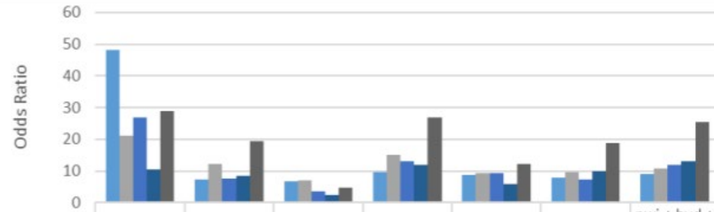
DEQ has conducted two major landcover overlay analyses that evaluate wetland map accuracies. The Division of Water Resources evaluated National Wetland Inventory data and the subsequent accuracy results of overlay analysis. Specifically, DWR assessed the accuracy of using the NWI as a base layer overlaid with hydric soils and/or statewide digital elevation model (DEM) terrain derivatives (hydrologic sinks) Table 5. DWR applied this method in four major ecoregions covering the entire state of North Carolina (Blue Ridge, Piedmont, Southeastern Plains, Middle Atlantic Coastal Plain). Deep water, open water, and lotic systems were removed from the NWI layer prior to overlay.

Table 5. Descriptions of the different overlay models tested. From Gale 2021b.

Model	NWI	Hydric soils	Sink	Wetland indicator
nwi	X			NWI wetland feature present
hyd		X		Soil mapping unit >25% hydric soil components by area
snk			X	Hydrologic sink present
nwi + hyd	X	X		NWI wetland **or** hydric soil presence
nwi + snk	X		X	NWI wetland **or** hydrologic sink presence
hyd + snk		X	X	Hydric soil **or** hydrologic sink presence
nwi + hyd + snk	X	X	X	NWI wetland **or** hydric soil **or** hydrologic sink presence

Overlaying the additional layers of hydric soil and/or hydrologic sinks did not improve the accuracy of NWI alone (Figure 4). Nearly all of the overlay models showed low overall accuracy for the majority of ecoregions and statewide. The odds ratio reflects accuracy of correctly identifying both wetlands and non-wetlands; higher ratios are desirable. A manual review of spatial data for the unexpectedly high odds ratio in the Blue Ridge suggested that NWI captured the largest wetlands in this area and missed the majority of the smaller wetlands (NCDWR 2021). The "nwi" model may also reflect a higher rate of correct identification of non-wetlands, since the odds ratio reflects the accuracy of all classifications. The higher rate of correct identification of non-wetlands may have contributed to the high odds ratio in the Blue Ridge ecoregion. Overall, the "nwi" model had higher odds ratios for individual ecoregions than most of the other models, though the "nwi" model varied widely across ecoregions, suggesting it may have inconsistent reliability statewide. The hydrologic sinks ("snk") provided the lowest overall performance based on odds-ratios, particularly in the eastern portions of the state (Southeastern Plains and Middle Atlantic Coastal Plain). The addition of other model variables to "nwi" did not lead to an increase in the odds ratio for any of the combined models ("nwi + hyd", "nwi + snk", "nwi + hyd + snk").

Figure 4. Odds ratios for overlay models by ecoregion and statewide. From Gale 2021b



	nwi	hyd	snk	nwi + hyd	nwi + snk	hyd + snk	nwi + hyd + snk
Blue Ridge	48	7	7	10	9	8	9
Piedmont	21	12	7	15	9	9	11
Southeastern Plains	27	7	3	13	9	7	12
Middle Atlantic Coastal Plain	10	8	3	12	6	10	13
Statewide	29	19	5	27	12	19	25

Summary of DCM's overlay method and resulting accuracy

DCM used an overlay method applied to the 20 coastal counties; the Division used NWI as the base layer, overlaid with soils and satellite (Landsat) imagery data (Shull III 1999). The presence of hydric soils was required to classify pocosins, hardwood flats, and pine flats as wetlands. DCM used Landsat imagery to detect evergreen vegetation and cleared or otherwise altered wetlands. DCM also used hydrography layer to identify streams and other features.

When compared to field data, the overall accuracy was 81%. Errors of inclusion and exclusion were both generally low (<25%) in determinations of wetland location as well as upland location, however the errors of exclusion were higher than errors of inclusion. Most of these wetlands were small (<1 acre, which were excluded from NWI dataset) or drier-type wetlands. Minimum mapping unit for soils was 1 acre. Accuracy rates were higher for marshes than for woody wetlands. The accuracy of mapped wetlands was 89%. It is important to note that *"DCM's maps are an underestimation of wetlands in the 20 coastal counties under CAMA, and many wetland types are confused."* (Shull III 1999).

IV. Proposed Methodology for Updating NC Wetland Maps

The workgroup determined that the best available wetland mapping currently available is DCM maps for the 40 coastal counties, followed by NCDOT wetland location probability models, followed by National Wetland Inventory data, which is also used as a basis for wetland locations and types in C-CAP landcover mapping. A proposed methodology for generating the most accurate/updated wetland map for the state is as follows:

1. 40 Coastal North Carolina Counties
    a. Start with DCM wetland maps for the 40 coastal counties. Use new C-CAP landcover mapping (canopy/impervious/water) to identify areas of existing DCM wetlands that have been converted to other land cover types. Note: A 2025/2026 initiative will result in C-CAP mapping of high and low marsh areas, and the workgroup recommends that this data may be evaluated as a possible update and/or replacement of the coastal marsh features in DCM wetland maps.
2. Remainder of North Carolina

a. Utilize the NWI data as the base layer for all areas where DCM data is not available. Utilize the new C-CAP canopy/impervious/water data to identify areas of wetland conversion to other land cover types. However, the workgroup recommends that the new 1-meter resolution C-CAP detailed land cover data be used when it becomes available. North Carolina is currently in the process of obtaining the new C-CAP data, and it is expected to be available in 2025.
b. Alternate Method: NCDOT has developed an innovative wetland mapping approach that uses machine learning, artificial intelligence, elevation models, jurisdictional field data and other variables to map wetland location probability. NCDOT has found that these new probability models have much higher accuracy results than historical NWI data, especially in the mountain regions. The workgroup believes the NCDOT machine learning wetland probability models (where available and vetted) are likely to be more accurate than the updated NWI/C-CAP maps and could be used to map the presence and absence of wetlands in the Piedmont and Mountain ecoregions. NCDOT wetland mapping could also be used to identify wetlands not on DCM wetland maps, especially smaller wetlands. [Note: utilizing NCDOT wetland mapping models may take a long time (years) unless funding is made available to NCDOT. As of July 2024, NCDOT has created wetland location probability models for 75 counties and is working to verify the models in 20 to 25 counties. Location prediction is based on detailed elevation data and slope locations to create a flow analysis. Models have also been trained with field wetland delineations. An accuracy assessment in a 28-mile corridor in Kinston, NC showed the model correctly predicted the location of wetland areas 86 to 87% of the time. The wetland location probability maps will be published on NCDOT's ATLAS *webservice.*]

The workgroup recommends the NOAA's C-CAP data layers and land cover classes be utilized to identify areas where wetlands from the base map (the combined DCM wetland data and NWI data with NCDOT supplements) have been converted or altered:

REMOVE from wetland base map where the following C-CAP categories overlap with wetlands:

- Developed, High intensity - DCM mapping considered this as "cleared wetland" if NWI showed wetland
- Developed, Medium intensity - DCM mapping considered this as "cleared wetland" if NWI showed wetland
- Developed, Low intensity - DCM mapping considered this as "cleared wetland" if NWI showed wetland
- Developed, Open space
- Ag. Land, Cultivated - DCM mapping considered this as "cleared wetland" if NWI showed wetland
- Open Water
- Bare Land
- Unconsolidated Shore - DCM mapping identified these as open water (non-wetland)

CLASSIFY on wetland base map the following C-CAP categories as "cleared" and "cutover" (these are unlikely to still be wetlands):

- Ag. Land, Pasture/Hay - DCM mapping considered this as "cleared wetland" if NWI showed as wetland.
- Grassland/Herbaceous - DCM mapping considered this as "cleared wetland" if NWI showed as wetlands.

RETAIN wetlands with the following C-CAP categories. These are areas remain probable wetlands:

- Deciduous Forest
- Evergreen Forest – would include managed pinelands that are wetlands
- Mixed Forest
- Scrub/Shrub
- Palustrine Forested Wetland
- Palustrine Scrub/Shrub Wetland
- Palustrine Emergent Wetland
- Estuarine Forested Wetland
- Estuarine Scrub/Shrub Wetland
- Estuarine Emergent Wetland
- Palustrine Aquatic Bed
- Estuarine Aquatic Bed

A Note on a Machine Learning Method Tested by DWR

Maximum entropy (MaxEnt) is a machine learning method often used in data science and artificial intelligence that automates complex statistical model building. One significant advantage of the MaxEnt approach is that it only requires presence data for model training, whereas almost all other modeling approaches require absence data as well.

Gale (2021b) ran two models using the MaxEnt procedure. Gale ran an initial complete model with input from 22 different statewide variables, which soil attributes (5), terrain derivatives (11), climate (3), vegetation (2), and NWI. Gale then ran a second model ("minimal model") after removal of covarying variables and variables with too many missing values. The final minimal model included hydric soils, vegetation community type, minimum temperature (30-year average; proxy for precipitation), elevation, sink depth, slope, topographic position index, and plan curvature (curvature perpendicular to slope), with the majority of the contributions to the model coming from the first five variables. Gale ran both models in a focus area, the Northern Outer Piedmont ecoregion, because of limitations on time resources available. *Gale (2021a and 2021b) found that both MaxEnt models resulted in very large increases in Producer's Accuracy relative to NWI, suggesting that the MaxEnt models were capturing many more true wetlands in the landscape. General accuracy of all classifications by the minimal model were greater than NWI accuracy in all size classes.*

Results showed that MaxEnt models as well as NWI showed inverse trends depending on the wetland size class, with under-prediction more prevalent in smaller features and over-prediction more prevalent in larger features. Both MaxEnt models, however, outperformed NWI in identifying smaller wetland features (<0.5 ac) based on both Producer's Accuracy and User's Accuracy.

Generating this model for the entire state (especially the Piedmont and Mountains) and verifying its accuracy would require funding and time, but results are promising and should be considered in future wetland mapping updates.

IVB. Alternative Method for Updating NC Wetland Maps

An alternative method for updating NC wetland maps is to contract with the U.S. Fish & Wildlife Service (USFWS) to update the National Wetland Inventory (NWI) for North Carolina. The current NWI maps in North Carolina are mostly based on based on a 1:58,000 scale color infrared photography from the 1980s. USFWS current methodologies follows the FGDC Wetland Mapping Standard, which creates minimum requirements for metadata, projection, spatial resolution of imagery, omission errors, horizontal accuracy with a 95% confidence level of 5-meters for wetlands and 15-meters for estuarine and deepwater habitats, and feature and attribute accuracy. The targeted mapping unit (TMU) has been enhanced from 1.0 acres to 0.5 acres. Current USFWS methods capture wetland features larger than 0.5 acres and 1 acre of estuarine and lacustrine habitats. Narrow features with discernible interior area are visible at 1:12,000. Features as small as 0.01 acres will be accepted into the dataset. Overall, the improved accuracy using new NWI standards would result in a significant improvement in wetland mapping for the piedmont and mountain regions of North Carolina. An updated NWI data set could also be utilized to update or augment the DCM wetland mapping in the coastal plain.

USFWS also produces an NWI+ dataset. The NWI+ dataset is not a standard product of NWI and are only created as a special product when external users or partners provide the funding. The goal of NWI+ was to integrate the concept of HGM classifications into the NWI mapping dataset (similar to how DCM integrated HGM into the DCM wetland type datasets.) The value of these enhancements would allow the user to better predict wetland functions at the landscape level. In the NWI+ dataset, descriptors for landscape position, landform, water flow path, and waterbody type are added to the NWI dataset (a.k.a., "LLWW Descriptors"). These enhancements would more accurately evaluate the potential effect of the USSC Sackett decision. The NWI+ LLWW data can also be used to assess carbon sequestration, bank and shoreline stabilization, streamflow maintenance, sediment and other particulate retention, and surface water detention.

Five landscape positions for wetlands are recognized: marine (ocean intertidal shores), estuarine (estuarine intertidal shores), lentic (lake or reservoir shores), lotic (river, stream shores, floodplains), and terrene (isolated or not subject to overflow). Landforms include basins, flats, floodplains, fringes, and slopes. Several water flow paths can be defined: inflow, outflow, throughflow, bidirectional-tidal, bidirectional-nontidal, and isolated (geographically) (Cowardin et al. 2023). These resources can be valuable in protecting wetlands due to wetlands' flood storage and flood resiliency functions.

The wetlands workgroup highly recommends that North Carolina funds the development of updated NWI+ data sets for the state. The estimated cost to conduct this work is 0.12 cents per acre. North Carolina currently has 34.4 million acres of land. The total cost of the project would be around $4.1 million for USFWS to create the state's map.

V. Approaches to Determining the Effect of Sackett v. EPA on Protection of North Carolina Wetlands

Purpose

The Supreme Court's decision in Sackett vs. EPA notes that the Clean Water Act refers only to streams, oceans, rivers, and lakes and to "adjacent wetlands that are 'indistinguishable' from those bodies of water due to a continuous surface connection." They require that a jurisdictional wetland "has a continuous surface connection with that water, making it difficult to determine where the ‘water’ ends, and the ‘wetland’ begins.” The workgroup identified three separate approaches that can be used to estimate the probability that the wetland may be negatively affected by the Sackett decision.

Approach I. Wetland Type

Wetland types differ based on water source, geomorphology, soil, vegetation, landscape position, and numerous other environmental factors. The water source can be precipitation, groundwater, or surface flow, which is especially important for this analysis. Below Table 6 categorizes wetlands into low risk, moderate risk, and high risk. Wetlands labeled as high risk do not have predominant surface flow inputs and can be geographically isolated. They are seasonally saturated, therefore dry for part of the year, and occur in generally flat or nearly flat areas. Descriptions of the individual wetland types can be found here.

DCM wetland data published in the late 1990s/early 2000s represents forty coastal counties that contain 85% of all of NC’s wetlands. The wetland data was derived from 1:24,000 scale National Wetlands Inventory data, 1:24,000 scale county detailed soils data, and Landsat Thematic Mapper 30-meter resolution satellite imagery. This is the only dataset for North Carolina wetlands that provides wetland type information. To assess the risk to wetlands, the sum of acreage for each wetland type can be calculated using ArcGIS Pro software. Those sums can then be added up based upon the table below to understand the number of acres at high risk, moderate risk, or low risk due to the Sacketts Appeal.

Table 6: Risk effects by wetland type.

Metric	Low Risk	Moderate Risk	High Risk
Wetland Type	Salt/Brackish Marsh Estuarine Shrub Scrub Estuarine Forest Bottomland Hardwood Riverine Swamp Forest	Headwater Swamp Freshwater Marsh Depressional Swamp Forest	Hardwood Flat Pine Flat Pocosin Managed Pineland Human Impacted Area Maritime Swamp Forest

Approach II. Hydrogeomorphic Classification

Similar to the wetland type approach, the same dataset mentioned above includes data on each wetland’s hydrogeomorphic classification: Estuarine, Riverine, Headwater, or Flat/Depressional. Vegetation, landscape position, and hydrology are used to identify these classifications. Riverine classified wetlands are wetlands that are adjacent to perennial streams and rivers, estuarine wetlands are found near estuaries/sounds, headwater wetlands are found at the uppermost reaches of watersheds, and lastly, flat/depressional wetlands generally are not hydrologically connected to surface water, are geographically isolated, and their water input comes from primarily precipitation, runoff, and groundwater.

To assess the risk of wetlands to the Sacketts Appeal, the sum of acreage for each hydrogeomorphic classification can be calculated using ArcGIS Pro. The acreage result of each risk category can then be compared to the results of Approach I.

Table 7: Risk effects by HGM classification.

Metric	Low Risk	Moderate Risk	High Risk
HGM Classification	Estuarine (e) Riverine (r)	Headwater (h)	Flat/depressional (f)

Approach lll. Hydrological Connectivity

The Supreme Court's decision in Sackett vs. EPA notes that the Clean Water Act refers only to streams, oceans, rivers, and lakes and to "adjacent wetlands that are 'indistinguishable' from those bodies of water due to a continuous surface connection". They require that a jurisdictional wetland "has a continuous surface connection with that water, making it difficult to determine where the 'water' ends, and the 'wetland' begins." Therefore, analysis of hydrologic connections of streams to existing wetlands is needed.

Mapped streamflow duration

- NC NCDOT's Hydro-ATLAS has the most up-to-date maps of perennial and intermittent streams, but these two stream types may be combined into "perennial/intermittent".

- NHDPlus HR (high resolution) (2018 latest version) has NHD Flowlines coded as Perennial or Intermittent (and others like ditch, connector, pipeline, artificial path, etc.). The end of the "perennial" segment may be used to differentiate between perennial and intermittent in the ATLAS layer, if there is no differentiation in the ATLAS information.

Ponds/Waterbodies

ATLAS is missing approximately 70% of the ponds that NHD has due to a difference in minimum collection size (2 acres for ATLAS vs 0.25 acre for NHD). NHD is recommended for including ponds and smaller waterbodies. However, for future plans, note that NC Hydro-ATLAS is currently the best NC specific data, but it will be evolving into "NC Hydro", which will have the ponds to a minimum size of 0.25 acre and also double line streams added into it.

Proposed Methodology

There could be different outcomes depending on how regulators apply the Sackett decision. In determining which wetland features would be included in the federal jurisdiction definition, several different scenarios should be considered. Hydrologic (stream/river) features would be considered connected/touching if the wetland boundary is within 100 feet. This considers the fact that NWI polygon boundaries have a 40-foot error in any direction plus additional spatial error in remote mapping of hydrologic features. The hydro lines represent the approximate center of a given stream, and those stream widths can be up to 50 feet (or 100 feet total). NHD specifications capture large rivers as waterbodies, with a minimum of 50-foot width to be displayed as a waterbody instead of a line. ATLAS has a minimum of 100 feet width for a feature to be captured as a waterbody. A 100-foot buffer on a wetland feature is expected to capture the margin of error on both the stream and wetland side.
Wetland polygons of different wetland types would be merged for the purposes of this assessment; wetlands of different types adjacent to each other would be considered one larger wetland.
Scenarios:

- Type of stream:
    - Include wetland if it connects to intermittent or perennial stream

    - Include wetlands if it connects to perennial stream only
- Floodplain criterion:
    - Include wetland if it is within 50-year floodplain mapped area
    - Include wetland if it is within 100-year floodplain mapped area
- Ditches (Ditches may or may not be considered a surface connection.):
    - Include wetland if it connects to WOTUS with a ditch
    - Exclude wetland that connect to WOTUS with a ditch

Alternate Hydrological Connection Method

The Environmental Defense Fund completed a study of potential Sackett effects using NWI Cowardin classifications and stream connectivity to estimate jurisdictional risk. They used 3 models combining NWI classifications to (updated with developed lands from NCLD removed from NWI) and NHDPlus HR for streams and waterbodies:

- Perennial streams
- Perennial streams + intermittent
- Perennial streams + intermittent + canals/ditches

DEQ's and EDF's preliminary analyses had similar results (50 to 70% wetland area not federally protected after Sackett, and up to 90% depending on how federal regulators interpret and apply the phrase from Sackett, "indistinguishable from Waters of the U.S.").

VI. Estimated Resources Needed

Estimated Resources Needed for Updating NC Wetland Maps

The estimated resources needed to facilitate the methodology detailed in Section IV (DCM) include:

- 2 Full Time Employee (FTE) GIS Specialist I for 1 year if performed in-house
- Estimated $400,000 if contracted out (the actual amount will vary based on the contractor.
- Recommended: A pilot project can provide more accurate estimates of personnel and processing time requirements.

Alternative Method for Updating NC Wetland Maps (NWI Updated Statewide)

The estimated cost to conduct this work is 0.12 cents per acre. North Carolina currently has 34.4 million acres of land. The total cost of the project would include

- $4.1 million for USFWS to create the state's updated NWI map. Estimated time to complete 2.5 years.
- Additional resources necessary to complete would include:
- 1/2 FTE for 2.5 years as project manager at GIS specialist (II) level or above

Approaches to Determining the Effect of Sackett v EPA on Protection of North Carolina Wetlands

- Assuming the NC Wetland Maps have been updated, the time and effort to complete the three Sackett Analyses are modest:
    - Wetland Type Assessment – 14 Days FTE GIS specialist (II) level or above
    - HGM Assessment – 14 Days FTE GIS specialist (II) level or above
    - Hydrological Connectivity – 90 days FTE GIS specialist (II) level or above
- If substantive mapping enhancements are needed or included in the Sackett Analyses, the timeline is much longer. For reference, these are the CGIA estimates to Facilitate the Statewide Additions of CGIA and HWG Recommendations to the NCDOT ATLAS Hydrography Dataset.
    - Waterbody additions
        - Capture small waterbodies (1D and 2D) - 1,700 person days of ATLAS Hydrography Team
        - Addition of 2D stream/river polygons. - 272 person-days of effort and processing
    - Feature attributes and connectivity 272 person-days of effort and processing
    - Z-enabled features – 314 person-days of effort and processing
    - Water Boundary Dataset 156 person-days of effort and processing
    - Polyline Issues - 5 person-days annually

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Attachment B

Feasibility and Status of High-Resolution Land Use/Land Cover Mapping Project [NOAA Coastal Change Analysis Program (C-CAP)]

Attachment B E.O. 305 Section 3b

Feasibility and Status of High-Resolution Land Use/Land Cover Mapping Project [NOAA Coastal Change Analysis Program (C-CAP)]

Objectives: To improve the spatial accuracy and timeliness of areal extent estimates and change detection for major land cover and land use types within the State, thus supporting habitat protection actions such as developing conservation and restoration strategies for natural and working lands and wetlands. Enhanced natural and working lands and wetlands classifications within the proposed mapping project will not only provide data specific to Section 3b, but also provide information that can assist with fulfilling Section 3a of this Executive Order.

Description: On behalf of DEQ partners including the Divisions of Marine Fisheries (DMF) and Coastal Management (DCM), the Division of Water Resources (DWR), the Albemarle-Pamlico National Estuary Partnership (APNEP) is coordinating with the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management's Coastal Change Analysis Program (C-CAP) to produce a Level 2 (20-class) interpretation of the State of North Carolina at one-meter resolution. Through APNEP, DEQ is securing grant funds to provide to NOAA, whose contractors will perform the work. Additionally, APNEP has been able, through NOAA, to secure mapping of the watersheds that drain to South Carolina with funding from the SC Office of Resilience. The Division Water Resources obtained a grant from the Environmental Protection Agency (EPA) to support mapping in the western watersheds.

APNEP is also coordinating with NC Coastal Habitat Protection Plan (CHPP) partners and the Statewide Mapping Advisory Committee (SMAC), a statutory committee of the N.C. Geographic Information Coordinating Council (GICC). The SMAC advances the use of geographic information systems technology in North Carolina's decision-making by coordinating statewide geospatial data efforts and is primarily responsible for producing data specifications and recommendations for statewide datasets. The SMAC represents a wide GIS community including federal, state, and local governments, universities, and the private sector.

APNEP pursued additional funds to enable the same protocol to be applied to the Upper Roanoke, thus allowing the entire Albemarle-Pamlico Basin to have the same Level 2 high- resolution C-CAP interpretation and expanded the boundary of the project to encompass the remaining watersheds in NC with funding from the DEQ State Energy Office. DCM is providing additional funding to support mapping high and low salt marsh in the 20 coastal counties that will help to track a variety of environmental indicators and inform management actions. Additional funding may be required to complete all 20 CAMA counties.

Background: Land cover mapping is foundational for understanding complex and pressing issues related to climate equity, hazard mitigation, and sustainability. High-resolution land cover data is used to document key geographic and landscape features covering Earth's surface for communities across the country.

For more than two decades, NOAA's Office for Coastal Management has been producing consistent, accurate 30-meter land cover and change information through its Coastal Change Analysis Program (C-CAP). Thanks to funding from the Bipartisan Infrastructure Law and other sources, new 1-meter land cover data are now available for the coastal United States, including the Great Lakes. Communities are provided open access to C-CAP land cover data with an unprecedented 1-meter resolution. These data provide communities with the foundation needed to assess coastal resources, analyze land use and land cover changes, prepare for disaster risks, and adapt to a changing climate. [Learn more about NOAA C-CAP].

Initial high-resolution land cover products, released in January 2024, include three feature layers—impervious surfaces, tree canopy, and water features. By providing more detail (900 times that of the 30-meter regional land cover), these new land cover datasets support a wide range of local and site-level applications that are critical for climate adaptation and resilience planning.

Updated natural and working lands and wetlands data are a common need in North Carolina, as the scale and age of existing data severely limits its uses. The SMAC's Landcover Working Group was given the task of documenting user needs and data specifications for a statewide landcover dataset. Working Group members reviewed stakeholder needs across multiple agencies and industries and documented 15 common use cases for landcover data, 8 of which are directly related to water quality. They recommended the C-CAP 1-meter product as the most cost-effective and comprehensive solution to meet stakeholder needs. Beyond the identified needs from DEQ, this wider community will also benefit from updated landcover and wetlands mapping to support transportation planning, resiliency and recovery, local stormwater planning, flood and other hazard mitigation, forest health, wildlife habitat, riparian buffer protection, urban heat impacts, important agricultural land protection, land use change detection, environmental justice analysis, and community planning.

Feasibility and Progress to Date: DEQ finds that the feasibility of obtaining updated high-resolution remotely sensed land cover data state-wide to assist in the assessment of type and extent of natural and working lands, including wetlands, is very good given existing momentum, coordination, funding availability, and federal partnership. The outcome will provide a statewide, full 20-class, one-meter resolution land use/land cover map. The map will support planning for community resilience to climate change, prioritizing habitat and wetland conservation and protection, and provide data to continue assessing land use and land use change over time. It is important to note that the NOAA partnership includes the State of South Carolina, promoting regional analysis, cooperation, and data continuity.

DEQ, through APNEP, is collaborating with NOAA to establish a contract to allow collective funding from various partners to be transferred to NOAA, who in turn will negotiate with their contractors to produce the deliverables. In early May 2024, NOAA contacted APNEP to relay that changes in their financial system have resulted in the inability, at least temporarily, for the Agency to accept funds directly from states, resulting in the states, including North Carolina, being unable to contract with NOAA for services including C-CAP. This issue is expected to be resolved by late September-early October. Once the system allows for the transfer of funds, APNEP expects the final product from NOAA within 6-9 months.

Attachment C1

North Carolina Office of Strategic Partnerships
Government Research-Partnership Opportunity

Value of Conserving Natural and Working Lands in North Carolina Scope of Work Report
by
Research Triangle Institute (RTI)

Value of Conserving Natural and Working Lands in North Carolina

Scope of Work Report

Prepared for

North Carolina Department of Environmental Quality

Prepared by

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January 2025

RTI Project Number 0219854.000.001

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Tables

1 Introduction

North Carolina's natural and working lands, which include 27 million acres of wetlands, forests, farms, and grasslands connected to thousands of miles of rivers, streams, and coastline, are critical to the well-being of its residents and the vitality of its economy. However, recent federal- and state-level decisions have created new challenges for optimally managing and protecting these resources against the development pressures from a growing economy and population. In particular, many of the state's wetlands are likely to have lost protection due to the U.S. Supreme Court's 2023 decision in Sackett v. Environmental Protection Agency (EPA) and the state's 2023 Farm Bill (SB 582).

Pursuant to Section 3(e) of Executive Order 305, which directed the North Carolina Department of Environmental Quality (NCDEQ) to work with partner organizations to investigate the social, environmental, and economic impacts of these actions, and to RTI International's subsequent award from NCDEQ, the purpose of this document is to propose a scope of work (SOW) for addressing the requirements of Section 3(e). More specifically, the SOW addresses the following four main research questions (RQs):

- **RQ1**: What is the estimated social, economic, and environmental value of conserving natural and working lands in North Carolina by land type, with a special focus on wetlands?
- **RQ2**: What are the estimated social, economic, and environmental impacts, including estimated flood risk, to the state associated with the degradation of wetlands that lost federal or state protections between 2022 and 2023?
- **RQ3**: What would be the expected costs to the state associated with ongoing and projected wetlands loss over the next 5 and 10 years?
- **RQ4**: What regulatory and legislative policy options could be proposed for NCDEQ to address this issue? What are their estimated social, resilience, economic, and environmental benefits, with specific focus on conservation policies, such as the reinstitution of conservation tax credits?

1.1 Our Proposed Team

To fully address these questions, we propose a North Carolina-based interdisciplinary research team (referred to in this document as the RTI Team) led by **RTI International** and supported by five main research organizations (described below) who will provide key analytical and modeling expertise. RTI is an independent, nonprofit, applied research institute headquartered in Research Triangle Park, NC. Our Environment Practice Area has more than 175 staff who research, design, implement, and evaluate evidence-based environmental strategies and solutions to help clients address real world challenges. Our goal is to promote informed decision-making by delivering excellence in research, science, and technical solutions and strategies. Our primary areas of expertise are air quality, water resources, environmental health and risk, and applied economics, and we routinely collaborate with internal and external partners to address challenges at the intersection of environment/climate and other sectors.

The other members of the RTI Team include:

- **SkyTec**, a global leader in remote sensing, AI-powered analytics, and geographic information systems (GIS) technologies, based in Chattanooga, Tennessee with a remote office in Asheville, NC. With over 60 years of combined experience in GIS and environmental and earth sciences, SkyTec delivers industry-leading products and consulting services. Specializing in satellite-based remote monitoring and mapping, it offers a full suite of services, including multiscale monitoring, change detection, and digital twin solutions. Through its partner network that includes Esri, it provides clients with the most advanced technologies and data sources.
- **East Carolina University (ECU)** is a public research university in eastern North Carolina and the largest institution of higher education in the Coastal Plains of North Carolina. It is situated in a rural, relatively impoverished region of eastern North Carolina and serves a mainly rural, needy, and culturally diverse student population. ECU provides a hub for multidisciplinary research, with team members spanning multiple departments and specialties with extensive collaborative experience to tackle questions associated with working lands and wetlands. In addition, the team has a broad array of technology that members can combine to analyze ecological conditions, including fixed-wing and copter drones equipped with multispectral, thermal, LiDAR and RTK technology, geoscience equipment, computing capacity, in-house modeling capacity, and all of the survey equipment and lab space necessary to conduct wetland field research.
- **North Carolina A&T State University** (NC A&T), a doctoral, land-grant, HBCU research university located in Greensboro, NC. It is the largest HBCU in the nation and

Key Benefits of the RTI Team

- RTI International is an independent, nonprofit research institute dedicated to improving the human condition. Clients rely on us to answer questions that demand an objective and multidisciplinary approach.
- RTI does not have a financial stake in the findings of this study that would undermine its objectivity or credibility.
- Based entirely in North Carolina, the RTI Team has intimate knowledge and experience with the state’s natural assets and the issues and challenges involved in protecting them.
- RTI specializes in conducting contract-based research for government agencies to develop data, tools, and analyses that meet our clients’ needs and deadlines.
- The RTI Team has well-developed and proven modeling tools that are ideally suited for mapping North Carolina’s natural and working lands and quantifying and valuing the ecosystem services they provide.
- We present a diverse and multidisciplinary team skilled at integrating natural and social science methods to assess the environmental, economic, and social benefits of natural and working lands (NWLs).

the greatest producer of African American engineers and data analysts. The NC A&T student body consists of over 13,000 students enrolled in Baccalaureate, Master, and PhD programs. The NC A&T mission is to prepare students to advance the human condition and facilitate economic growth in North Carolina and beyond by providing a preeminent and diverse educational experience through teaching, research, and scholarly application of knowledge.

- **Ecosystem Planning and Restoration (EPR)** is a small business specializing in providing services to support a sustainable environment through ecosystem planning & restoration. EPR's Data Science Team possesses specialized expertise in leveraging machine learning and GIS technologies to model wetlands in North Carolina and conduct sophisticated geospatial analyses. Over the past 3 years, they have collaborated with the North Carolina Department of Transportation (NCDOT) to model wetland presence across the state.
- **Esri** is the global market leader in GIS software, location intelligence, and mapping. Since 1969, it has supported customers with geographic science and geospatial analytics, what it calls The Science of Where. Esri takes a geographic approach to problem solving, brought to life by modern, enterprise-grade GIS technology and it is committed to using science and technology to build a sustainable world.

1.2 Overview of Our Proposed Approach

Our team proposes to address NCDEQ's research questions through the seven main tasks outlined in **Table 1.1** and described in detail in Section 2 of this report. As shown in the table, each task will build on the output and findings of the previous task, in a way that collectively addresses the four research questions.

Table 1.1 Proposed Tasks for Addressing the Four Research Questions

Task	Task Name	Research Questions			
		RQ1	RQ2	RQ3	RQ4
1	Mapping and identification of NC's wetlands and other NWLs	✓	✓	✓	
2	Identification of NC wetlands losing federal and state protection in 2023		✓	✓	
3	Identification of NC wetlands and other NWLs most vulnerable to land use change	✓	✓	✓	
4	Development of wetland function and ecosystem service indicators	✓	✓	✓	
5	Modeling environmental impacts of wetland and NWL loss	✓	✓	✓	
6	Modeling economic value and societal impacts of wetland and NWL loss	✓	✓	✓	
7	Identification and analysis of policy alternatives				✓

1.3 Proposed Project Management Team and Key Personnel

The proposed project team, including the project management team, the task leaders, and other key personnel supporting specific tasks are shown in **Figure 1.1**.

George Van Houtven, PhD (RTI) will serve as the overall **Project Manager**. Dr. Van Houtven is a Senior Environmental Economist at RTI with more than 30 years of experience conducting environmental policy and natural resource management research. He specializes in economic valuation of ecosystem services, nature-based solutions, water resources, and environmental health benefits in support of cost-benefit and other economic analyses. He will serve as the team's primary contact for NCDEQ, responsible for coordinating communications regarding progress, findings, and recommendations, and for ensuring the quality and timeliness of all tasks and deliverables. Applying his expertise in environmental economics, ecosystem services valuation, and conservation policy, he will also serve as the **Task 6 Lead** (Modeling economic value and societal impacts) and **Task 7 Lead** (Identification and analysis of policy alternatives).

Michele Eddy (RTI) will serve as the **Deputy Project Manager**, supporting Dr. Van Houtven and serving as a secondary point of contact. Ms. Eddy is a Senior Research Environmental Engineer at RTI with more than 20 years of experience leading projects focused on water quality and quantity for clients in all sectors. She leads development of RTI's Watershed Flow and ALLocation model (WaterFALL®). She is experienced in hydrologic, ecologic, and geospatial assessments, including identifying opportunities for implementing nature-based solutions such as wetland construction, enhancement, and rehabilitation. Applying this expertise, she will also serve as the **Task 5 Lead** (Modeling environmental impacts of wetland and NWL loss).

Chris Fleming (SkyTec) will serve as the **Task 1 Lead** (Mapping and identification of NC's wetland and other NWLs). Chris is a Senior Solutions Engineer who uses his 20+ years of experience as an environmental consultant to help clients better understand how satellite imagery and geospatial analysis can empower them to answer important questions. As an environmental consultant, he has focused on aquatic resources (e.g., streams, wetlands), botany of the southeastern United States, rare, threatened or endangered species, ecological restoration, and the varied regulations pertaining to each.

Sean Charles, PhD (ECU) will serve as the **Task 2 Lead** (Identification of NC wetlands losing federal and state protection in 2023) and **Task 4** Lead (Development of wetland function and ecosystem service indicators). Dr. Charles is a Research Assistant Professor and Scientist at the Coastal Studies Institute and within the ECU Department of Coastal Studies. His research has focused on plant-soil interactions in coastal ecosystems, restoration, and disturbance ecology. He has published over 15 peer-reviewed manuscripts in venues such as *Estuaries and Coasts*, *Ecology*, and *Ecological Applications*. He combines remote sensing, GIS, and field botany to assess changes in wetland environments.

Figure 1.1 Project Leadership, Task Leadership, and Key Personnel

Project Leadership	
Project Manager: George Van Houtven (RTI)	**Deputy Project Manager**: Michele Eddy (RTI)

Task 1: Mapping and identification of NC's wetlands and other NWLs	
Task Leader: Chris Fleming (SkyTec)	**Key Personnel**: Andy Caroll (SkyTec), Jordyn Miller (Esri), Will Saulnier (EPR),

Task 2: Identification of NC wetlands losing federal and state protection in 2023	
Task Leader: Sean Charles (ECU)	**Key Personnel**: Stu Hamilton (ECU), Will Saulnier (EPR), Leila Hashemi Beni (NC A&T)

Task 3: Identification of NC wetlands and other NWLs most vulnerable to land use change	
Task Leader: Robert Beach (RTI)	**Key Personnel**: Jay Rineer (RTI)

Task 4: Development of wetland function and ecosystem service indicators	
Task Leader: Sean Charles (ECU)	**Key Personnel**: Stu Hamilton (ECU), Leila Hashemi Beni (NC A&T), Kim Matthews (RTI)

Task 5: Modeling environmental impacts of wetland and NWL loss	
Task Leader: Michele Eddy (RTI)	**Key Personnel**: Michael Crouch (RTI), Kim Matthews (RTI), Sean Charles (ECU)

Task 6: Modeling economic value and societal impacts of wetland and NWL loss	
Task Leader: George Van Houtven (RTI)	**Key Personnel**: Robert Beach (RTI), Michele Eddy (RTI), Leila Hashemi Beni (NC A&T)

Task 7: Identification and analysis of policy alternatives	
Task Leader: George Van Houtven (RTI)	**Key Personnel**: Bill Holman (Independent Senior Advisor), Kim Matthews (RTI)

Robert Beach, PhD (RTI) will serve as the **Task 3 Lead** (Identification of NC wetlands and other NWLs most vulnerable to land use change). Dr. Beach is an RTI Fellow and Senior Economist with more than 25 years of experience working on environmental projects and leads research on agriculture, forestry, and land use; energy and environment modeling; bioenergy; land conversion; greenhouse gas (GHG) mitigation; and climate impacts and adaptation. He is lead developer of the RTI EcoShift land use change modeling framework.

Leila Hashemi Beni PhD (NC A&T) is Associate Professor of Remote Sensing and GIS at the Department of Built Environment at the College of Science and Technology, NC A&T. She is director of NC A&T's DEAP Institute of Data Science Harnessing for Flood Mapping and Impacts, funded by NASA. She is the Co-Chair of the LiDAR, Laser Altimetry and Sensor Integration Working Group, International Society of Photogrammetry and Remote Sensing. She will support development of the GIS data viewer for Tasks 1 through 4 and develop the environmental justice layers for conducting Task 6.

William Saulnier (ECR) is a Senior Level Data Scientist with 10 years of experience working in geospatial analysis and application development. He has expertise designing, developing, and deploying machine learning algorithms and performing geospatial analyses in multiple GIS platforms. His past projects include utilizing machine learning to predict wetlands in North Carolina, large dataset compilation and analysis, custom dashboard development, environmental and social impacts assessments, stream and wetland delineation analysis, and wetland mitigation tract searches. He will primarily support Tasks 1 and 2 with guidance on training data creation, sourcing hydrography data, analyzing the hydrography datasets for accuracy and applicability, and developing methods for the connectivity analyses.

Bill Holman (Consultant) is one of North Carolina's foremost experts on conservation policy and water and land resource management and will serve as **Senior Advisor** for identification and analysis of policy alternatives (Task 7). He was North Carolina's State Director for the Conservation Fund and chaired the state's Land for Tomorrow Coalition from 2013 to 2023 where he successfully advocated for increased appropriations from the General Assembly for the Land & Water Fund, Parks and Recreation Trust Fund, Great Trails State Fund, and other programs. He also served as Secretary of the Department of Environment & Natural Resources from 1999 to 2001 and as Assistant Secretary from 1998 to 1999 where he led efforts to reduce nutrient pollution in the Neuse and Tar-Pamlico Rivers, protect wetlands, and conserve 1 million acres of land and to recover from Hurricane Floyd.

Stuart Hamilton, PhD (ECU) is the Chair of Coastal Studies at ECU and a professor in the department. He is a remote sensor and GISs specialist interested in coastal wetland environments. He has published over 30 peer-reviewed manuscripts on wetland-related topics in venues such as *PNAS*, *Nature Ecology and Evolution*, *Nature Climate Change*, and the *Journal of the American Water Resources Association*. He operates a suite of custom drones for use in wetland environments and is a certified remote pilot. He combines wetland modeling and field measurement to assess changes in global wetland environments. He will directly support Dr. Charles in the conduct of Tasks 2 and 4.

James Rineer, PE (RTI) is director of RTI’s Geospatial Science and Technology program, a registered professional civil engineer in North Carolina, and a spatial data scientist specializing in the creation of geospatial data, systems, and analytic tools. He has over 24 years of experience as a GIS software developer, engineer, and program manager, with a project history that includes development of feature classification artificial intelligence/machine learning algorithms leveraging satellite and drone images. He will support all geospatial related tasks including leading development of the geospatial assets to be delivered as part of the final report. He and his team will provide QA/QC for all geospatial data produced by the RTI Team (in particular for Tasks 1 through 4) including review and finalization of associated metadata and documentation.

Andy Carroll (SkyTec) is co-Founder and Chief Technology Officer of SkyTec who maintains over 25 years of professional experience in GIS and remote sensing technologies and specializes in developing geospatial decision-support tools and analytical methods for regional planning, environmental management, and resource conservation. His recent research and entrepreneurial projects focus on the intersection of macro- and micro-scale remote sensing systems for natural resources and environmental applications. He will be directly supporting Chris Fleming in developing and implementing the enhanced Wetland Identification Model under Task 1.

Kim Matthews (RTI) is a Senior Environmental Research Scientist with more than 25 years of experience leading projects monitoring wetlands and conducting research on wetland functions. For the past 15 years, she has worked with North Carolina Division of Water Resources and NC State University on wetland-related projects collecting long-term water quality, hydrology, and biological data. She was a member of the state Natural and Working Lands Stakeholder Group from 2019 to 2022. She will apply her background in wetland science and policy to support environmental modeling (Task 6) and policy analysis (Task 7)

Jordyn Miller, PhD (Esri) joined Esri's Professional Services Division in 2022. Her responsibilities include consulting and technical leadership on the Advanced Analytics team and development with Esri's Arc Hydro team. She has over 10 years of experience working with hydrological data and models, and data science workflows. Dr. Miller assesses user needs, develops conceptual workflows, and coordinates with project managers and other technical staff. At Esri she specializes in Python development, but she also has experience in R. She is passionate about science communication, has delivered in-person data science workshops to customers, and supports a team at Esri focused on connecting their developers. She will primarily support development and application of data science methods for wetland identification (Task 1).

Additional details regarding the qualifications and expertise of all these key personnel are provided in the resumes included in **Appendix A.**

2 Proposed Methodology, Justification, and Limitations

As previously summarized in Table 1, we propose to address NCDEQ's needs for this project through the conduct of seven main interconnected tasks. In this section, we describe the proposed methodology underlying each task, provide a justification for the proposed approach, and discuss limitations of the approach.

To initiate the project, we propose to conduct a kickoff meeting between the RTI Team, NCDEQ, and other stakeholders or experts as specified by NCDEQ. The purpose of this meeting, which would be held within the first weeks of the project, will be to (1) review the approach, timeline, milestones, and deliverables to ensure common understanding and agreement about each item, and (2) agree on a plan for communications, progress reporting, and resolving technical issues as they arise.

To ensure that the project successfully addresses NCDEQ's needs, one approach that we recommend is for NCDEQ to establish an advisory panel composed of stakeholders and experts to review progress and deliverables as they are developed and shared with NCDEQ.

Task 1. Mapping and Identification of North Carolina's Wetlands and Other NWLs

We propose the development of an enhanced version of the Esri Arc Hydro Wetland Identification Model (WIM) to produce a predictive model of wetlands for North Carolina. The bulk of this is task will be led by Chris Fleming (SkyTec), with support from Andy Carroll (SkyTec) and William Saulnier (ECR) and in close collaboration with technology partners, Esri and Microsoft, leveraging the software and high-performance cloud computing environments proven to efficiently scale a statewide assessment. SkyTec recently successfully completed a similar wetland modeling project with these same technology partners for Tennessee in collaboration with the Tennessee Department of Environment and Conservation (TDEC). Through this effort, they have refined their methodologies and developed techniques to efficiently process datasets covering expansive geographic areas, while integrating machine and deep learning of model data inputs.

The development of the enhanced WIM integrates state-of-the-art machine learning and deep learning techniques to produce a scientifically rigorous and ecologically comprehensive wetland mapping tool. The project is structured around key task categories:

- Model development
- Model inference
- Results refinement
- Administrative and documentation

Within each phase, the RTI Team will adhere to a commitment of best practices for transparency, quality control, precision, collaboration, and the development of the highest quality model products.

Model Development

Model development proceeds through four main phases: input data preparation, validation data creation, model training, and accuracy assessment.

Input Data Preparation

This phase involves the acquisition and processing of statewide LiDAR and imagery datasets. These include recent satellite imagery, 1-meter resolution USDA National Agricultural Imagery Program (NAIP) imagery, 3DEP LiDAR data, high-resolution land use/land cover datasets, soil data, and hydrography datasets. We will leverage our existing relationship and experience with Microsoft's Planetary Computer to efficiently transfer bulk imagery and terrain datasets. Next, these datasets are resampled to 3-meter resolution, analyzed, and managed in a cluster of cloud-hosted virtual high-performance computing machines, ensuring uniform compatibility across North Carolina's physiographic provinces.

All compiled datasets are processed and partitioned into geographic units corresponding to physiographic provinces or smaller areas. This ensures efficient processing and allows the models to account for regional variations while maintaining statewide consistency. Separate models will be developed for each of the four EPA Level III Ecoregions defined in North Carolina: Blue Ridge, Piedmont, Southeastern Plains, and the Middle Atlantic Coastal Plain. Each of these models will be run on separate virtual machines located in the Microsoft Azure cloud computing environment.

Validation Data Creation

In this phase, geospatial datasets depicting known wetland boundaries are compiled to serve as model training data. This curated training dataset may consist of, but will not be limited to, the following sources:

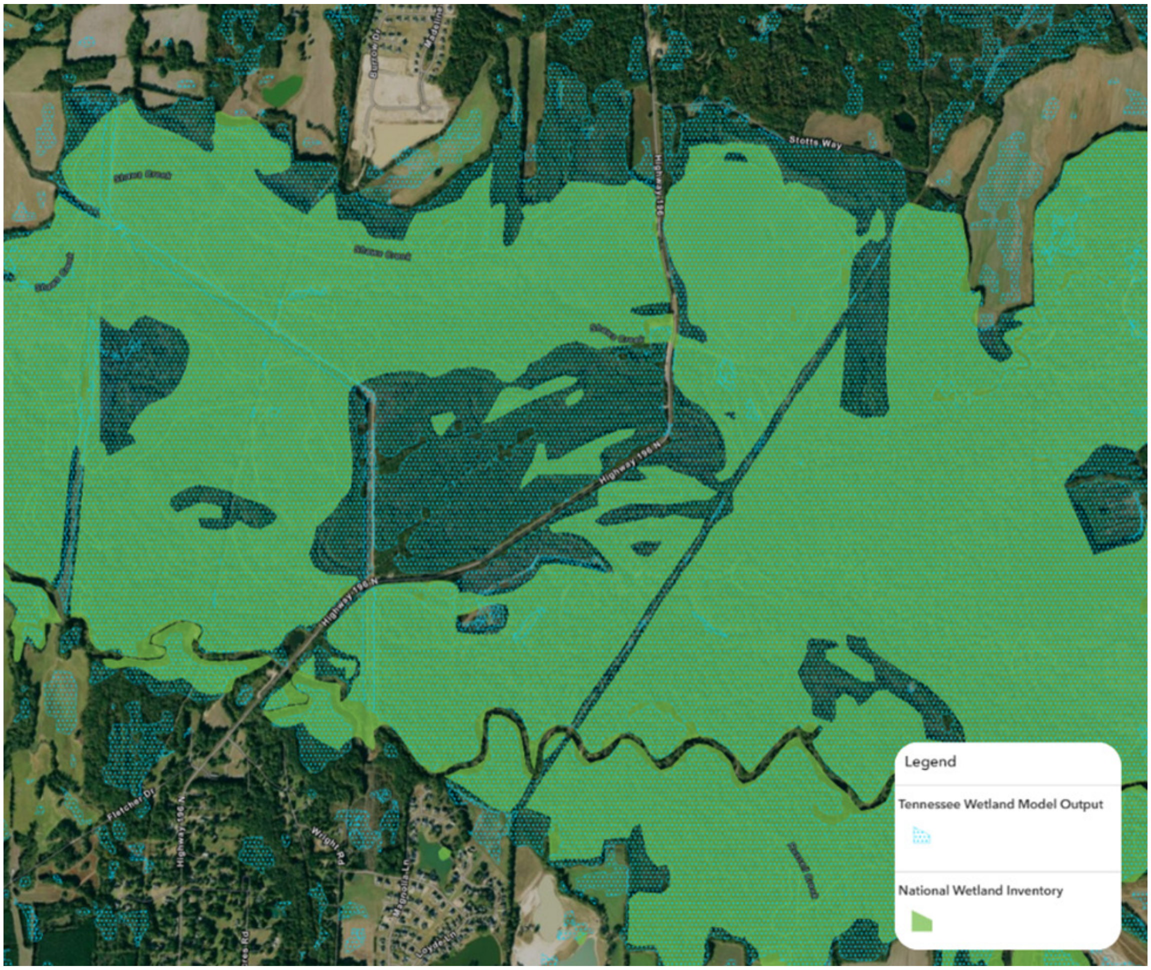
- Wetland delineation data from hard copies of regulatory submittals that would be extracted and digitized, creating a geospatial dataset
- North Carolina Division of Coastal Management's (DCM) wetland data
- North Carolina Department of Transportation wetland inventories
- National Wetlands Inventory (NWI) features that have been recently assessed or have been vetted using remote sensing techniques
- Existing wetland datasets that may exist from previous modeling efforts
- Element occurrences of rare hydrophytic species and their associated habitats that are tracked by the North Carolina Natural Heritage Program
- Delineation data from the environmental consulting community
- Wetland data maintained by other state or federal wildlife agencies
- Wetland data provided by regional scientists and academic institutions

This phase ensures that all major wetland types are well represented and that sufficient features are distributed across each physiographic province. The data are reviewed by wetland scientists to ensure accuracy and ecological relevance, providing a comprehensive benchmark for model validation.

Model Training

The model training phase employs advanced deep learning techniques, based upon neural network models, to predict wetland locations. The UNet model architecture is particularly well-suited for this application due to its ability to handle large datasets, incorporate diverse input variables, and minimize overfitting. Using the curated validation data and resampled 3-meter resolution parameter inputs, the model is trained separately for each physiographic province, accounting for regional variations in geology, soils, vegetation, and hydrology. Continuous monitoring of model outputs allows for iterative refinements, ensuring high predictive performance across all regions. An example of WIM model output compared to NWI data for the same location in Tennessee is shown in **Figure 2.1**

Figure 2.1. Example Output from Wetland Predictive Model in Northeast Tennessee Generated by SkyTec LLC Using Enhanced WIM.



Accuracy Assessment

The accuracy assessment phase evaluates model outputs against the training data, resulting in precision metrics. Values for precision, recall, and F1 scores are used to determine the effectiveness and quality of predictions made in predicted wetland model outputs. Depending on results, fine tuning and calibration of model parameters related to number of iterations, sample sizes, and computing allocation requirements often occur. When results are deemed acceptable the project transitions to the model inferencing task.

Model Inference

In this phase, the trained models are executed across the geographic units to classify areas as wetlands or uplands. SkyTec's existing cloud computing infrastructure and methods used in previous projects are optimized for this intensive processing stage. This stage can require days to a week of processing depending on the size of the ecoregion or physiographic zone selected for generating subsets of model inputs. Model outputs for each ecoregion or zone are merged into a cohesive statewide dataset. The composite results provide a preliminary wetland map, integrating predictions from diverse datasets and physiographic provinces into a single, unified product.

Results Refinement

The results refinement phase involves analyzing model outputs with feature layers or polygons representing land uses and landscape conditions, such as hydric soils. This post-processing cleanup is performed to remove artifacts, address inconsistencies, and validate outputs against field data. This step ensures that the final dataset is both accurate and comprehensive, providing a reliable tool for decision-making.

Another key processing step of this phase is the use of deep learning techniques to enhance the accuracy and resolution of the wetland map. Specifically, a 1-meter resolution land cover dataset for the state is generated using high resolution imagery, such as NAIP, and advanced convolutional neural networks (CNNs). The 1-meter resolution land cover dataset enables the attribution, querying, and removal of predictions occurring in incompatible land cover types. This process removes artifacts, such as ponding of water on impervious surfaces, and general model predictions occurring in highly developed urban settings.

Importantly, this 1-meter land cover dataset will also provide a high-resolution representation of non-wetland NWLs such as forests, cropland, and grasslands. Examples of these high resolution landcover layers compared to lower resolution National Landcover Dataset (NLCD) are shown in **Figure 2.2** and **Figure 2.3** for the same locations in Tennessee.

Figure 2.2. Dense Urban Area in Northeast Tennessee as Visualized by the 2021 National Landcover Dataset (Left) Versus SkyTec LLC-Generated 1-Meter Resolution Landcover (Right) That Was Derived from Deep Learning and 2023 NAIP Imagery.

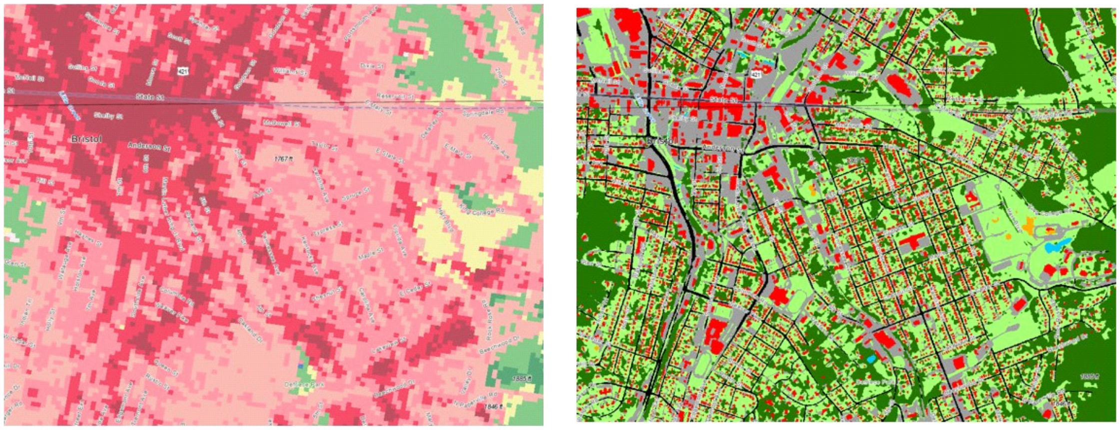
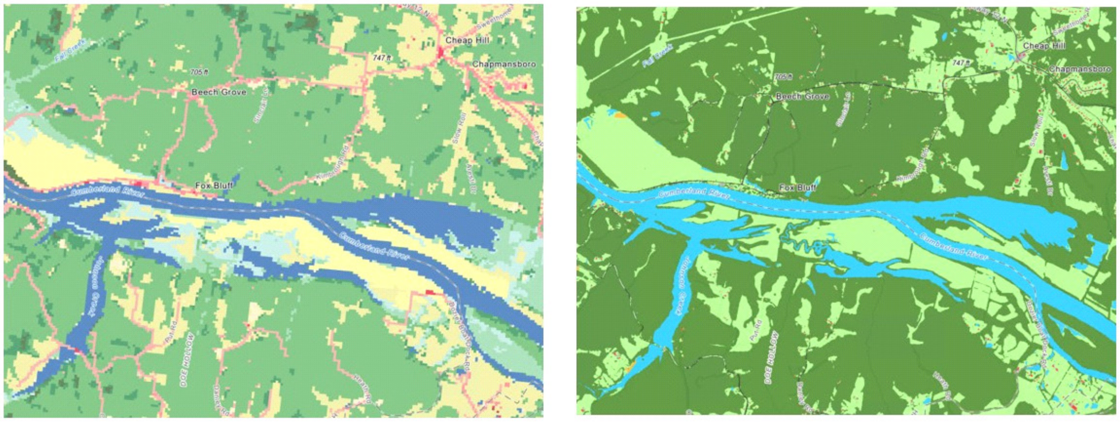


Figure 2.3. Rural Area in Middle Tennessee as Visualized by the 2021 National Landcover Dataset (Left) Versus SkyTec LLC-Generated 1-Meter Resolution Landcover (Right) That Was Derived from Deep Learning and 2023 NAIP Imagery.



Accuracy Assessment

In addition to precision metrics obtained from the model development task, a final QA/QC step occurs in the results refinement task. This process involves the assessment of 200 random features from each ecoregion using remote sensing techniques. Each random feature is classified as entirely wetland, partially wetland, upland, or unknown. These results inform the need for any additional refinement requirements to the models, which are then fully documented to ensure transparency and reproducibility.

Documentation of Results

Throughout the project, the team will engage in stakeholder meetings to align development efforts with project objectives and respond to feedback. Comprehensive documentation will capture all methodologies, tools, and datasets used in the project, including the details of model training, deep learning techniques, validation processes, and accuracy assessments. The final deliverables will include the enhanced wetland dataset, detailed technical documentation, and recommendations for future use and updates.

Development of Esri Experience Builder–based viewer in parallel and starting with Task 1

RTI will lead, with support from NC A&T, development and hosting of a geospatial viewer for all geospatial output. The viewer will provide narrative context and interactive mapping in support of each of the key data layers and spatial analyses that are outcomes of this work. The viewer will be updated regularly and hosted for the duration of the projects funding.

Justification for Proposed Task 1 Methodology

The WIM represents an innovative and systematic approach to wetland mapping built on a foundation of unbiased modeling, collaborative training data generation, and ecoregion-specific customization. By leveraging the wealth of existing datasets in North Carolina, including DCM wetland maps, NWI, NCDOT machine learning-based probability models, natural heritage records, and the location of known delineated wetlands, the proposed methodology ensures the development of a scientifically rigorous and ecologically comprehensive training set and high-quality results.

Unbiased modeling lies at the heart of the enhanced WIM approach. By integrating objective, carefully curated, high-quality training datasets, the model minimizes errors or biases introduced by individual datasets or subjective interpretations. This ensures that the outputs are consistent, reliable, and suitable for both regulatory and conservation applications. The inclusion of training data from diverse sources provides a well-rounded dataset for robust model development.

A cornerstone of this effort is collaboration. The generation of training data is enhanced through partnerships with nonprofit organizations, regulatory and wildlife agencies, and academic institutions. These collaborators contribute field-verified data and local expertise, ensuring that the model is grounded in real world conditions. This cooperative approach not only elevates the quality of the curated training dataset but also fosters buy-in and trust among stakeholders who rely on the model for critical decision-making.

This methodology has already been successfully applied by SkyTec in Tennessee, where they demonstrated the enhanced WIM model’s ability to integrate diverse datasets and produce actionable insights for wetland mapping and conservation. The success in Tennessee underscores the model’s flexibility and scalability, providing a compelling precedent for its application in North Carolina. By tailoring the model to account for the state’s unique ecological and regulatory challenges, the enhanced WIM builds on proven capabilities while adapting to regional needs.

To capture the variability of North Carolina's distinct ecoregions, the WIM uses individual models and associated training data tailored to each region's geology, topography, soils, and vegetation. For example, coastal wetlands benefit from DCM's detailed maps, while NCDOT's probability models can help address the complexities of smaller, isolated wetlands in upland areas. This ecoregion-specific approach ensures that the model reflects the full spectrum of environmental variability, enabling precise wetland identification and characterization across the state.

By emphasizing unbiased modeling, fostering collaboration, and employing ecoregion-specific datasets, WIM offers a scientifically robust and proven solution to wetland mapping. It aligns with the goals of Executive Order 305 by addressing gaps in existing data and providing a scalable framework for protecting and managing North Carolina's critical wetland resources in an era of evolving environmental and regulatory pressures.

Limitations of the Proposed Task 1 Methodology

Certain limitations are inherent to all wetland modeling efforts. The significance of these limitations can be directly correlated to the age of the data, quality of the model inputs, and their resolution. Given that the primary predictor variable inputs for the WIM model are LiDAR-derived, the age of this dataset can obviously factor in the precision of the model outputs. It is understood that North Carolina implements a phased approach to LiDAR data collection and processing and that available higher resolution datasets have been collected between 2015 and 2024. We further understand that additional LiDAR data were collected more recently in response to Hurricane Helene impacts in the western portion of the state. SkyTec has been collecting and processing high-resolution LiDAR data for over ten years and has the technical capability to merge the most updated datasets into one seamless layer for processing.

The age, resolution, and seasonal variations in imagery sources are also potential limitations. We understand that there is 1-meter resolution NAIP imagery from 2022 currently available for use, but we are also aware that the NAIP program has collected statewide imagery from 2024 that is scheduled for processing and may be released in early to mid-2025. Either of those datasets can be used for our deep learning processes, but of course the more recent collection is preferred given the rate of landscape change that is occurring. It is also worth noting that substantial amounts of imagery have recently been collected in response to Hurricane Helene. If we are provided access to this imagery, we could potentially explore utilizing that dataset coupled with recent LiDAR collections in the western portion of the state to better understand how wetlands may have been affected by geomorphological changes attributed to historic flooding.

Like other predictive models, the WIM does not definitively confirm the presence or absence of jurisdictional wetlands, nor does it precisely delineate their location or areal extent; however, it does precisely identify areas where wetlands should or could exist based on what is learned from model inputs. That is why our methodology is focused on using the best possible geospatial datasets at the highest resolution and curating a training dataset that is representative of the diverse wetland types occurring upon the landscape.

Our proposed approach for this task does not include field sampling and data collection regarding the presence, location, or characteristics of wetlands across the state, which would be needed for rigorous ground-truthing verification of the WIM model predictions. We have assumed that the extensive resources required for such data collection are beyond the scope of this project, but we do recommend future efforts by NCDEQ to conduct this type of verification.

One notable limitation of the WIM is the prediction of wetlands occurring within densely developed urban areas. This issue is universal to any predictive model utilizing terrain data to better understand how water interacts with the landscape. This is due to several factors, which can include:

- **Altered hydrology**: Urban areas often have significantly modified hydrology due to the prevalence of engineered structures, surfaces, or roadways (e.g., large impervious areas, culverts). These can all artificially alter water flow patterns and obscure what is occurring on the ground for the model.
- **Data resolution and noise**: LiDAR data can occasionally be affected by the densely built environment, leading to noise and inaccuracies in the digital elevation models (DEMs) used by the WIM.
- **Surface water management**: Densely developed areas typically have engineered stormwater management solutions (e.g., ponds, bioretention) that may confuse the model since they can mimic wetland characteristics but are not functioning wetlands.

To address the issues encountered with the wetlands predictive model in these types of environments, SkyTec has employed various techniques using high resolution landcover in post processing to ensure that false positives in these areas are minimized.

The final limitation of the WIM is that it is not a wetland classification tool, but instead it provides a binary output of wetland features vs. non-wetland areas. However, post processing of the raw dataset using high resolution landcover, approximate canopy height, and soils datasets allows for a coarse classification of each feature to better understand their general characteristics.

Task 2. Identification of North Carolina Wetlands with Loss of Federal and State Protection in 2023

Given the enhanced wetland identification layer provided in Task 1, the purpose of this task will be to identify which of these identified wetlands are most likely to have lost protection as a result of the 2023 federal Sackett decision and 2023 North Carolina Farm Bill. This task will be led by Dr. Sean Charles (ECU) in close collaboration with Dr. Stuart Hamilton (ECU) and support from William Saulnier (ECR).

We will use the Task 1 wetland layer and North Carolina's ATLAS Hydrography (version 1.4) to categorize wetlands based on the connectivity to continuous surface waters of the United States. This process will provide a 3-level classification reflecting different levels of connectivity and thus protection: (i) Protection Remains (PR), (ii) Protection Lost (PL), or (iii) At Risk (AR) (Table 2.1). PR indicates that the wetland most likely remains protected post-Sackett. PL indicates that the wetland was most likely federally protected before the Sackett decision but has likely lost federal protection post-Sackett. AR wetlands are at risk of loss of protection under section 404 of the Clean Water Act and are subdivided into subgroups.

Table 2.1. Wetlands Categorizations Based on Connectivity to Surface Waters

Code 1	Class 1	Definition
PR	Protection remains	<= 50 ft perennial stream
PL	Protection lost	> 100 ft perennial stream
AR	At-risk	> 50 ft – <=100 ft perennial stream (additional details in **Table 2.2**)

Wetlands considered PR will be 50 feet or closer to a perennial stream, river, or waterbody. Wetlands categorized as PL will be greater than 100 feet from a perennial stream, river, or waterbody. Wetlands considered AR will typically be greater than 50 feet but less than or equal to 100 feet from a perennial stream, river, or waterbody (**Table 2.1**). The at-risk category will be further subgrouped into five categories (**Table 2.2**).

Table 2.2. Categorizations of At-Risk Wetlands

Code 2	Class 2	Definition
ARPB	At-risk perennial buffer	> 50 ft – ≤ 100 ft perennial stream
ARIT	At-risk intermittent	≤ 50 ft to an intermittent stream
AR50	At-risk 50-year floodplain	≤ 50 feet of a 50-year floodplain
AR100	At-risk 100-year floodplain	≤ 50 feet of a 100-year floodplain
ARDC	At-risk ditch or culvert	≤ 50 feet from a ditch or culvert

The first at-risk category will be those wetlands in the *perennial buffer,* meaning they are located 50–100 linear feet from perennial streams, rivers, or bodies of water. The second at-risk category will be *intermittent* and located 50 feet or closer to an intermittent stream. The third at-risk category will be those located within 50 feet of a *50-year flood plain.* The fourth at-risk category will be those located within 50 feet of a *100-year flood plain*. The final category will be wetlands located within 50 feet of a *ditch or culvert*. These proposed categories may be refined through consultation with our team and NCDEQ but represent our best assessment at this time to address the needs of this project.

Justification for the Proposed Task 2 Methodology

To identify North Carolina wetlands that lost federal and state protection in 2023, ECU and colleagues will use the updated wetland maps produced in Task 1 to identify wetlands likely to have lost protection based on wetland connectivity derived from the North Carolina ATLAS Hydrography (version 1.4). Sackett vs. EPA reclassifies wetland protection to only include *wetlands with a continuous surface connection to water of the United States*. Wetlands will be considered hydrologically connected to the waters of the United States if the wetland boundary is within 50 feet of a perennial stream or waterbody. These wetlands will continue to be protected under federal and North Carolina state policy after 2023 and will be categorized as protection remains. Because hydrolines represent the center of a given stream and the "stream" class can be 100 feet wide, wetlands within 50 feet of stream hydrolines are connected to the waters of the United States.

Wetlands located further from streams, rivers, and waterbodies risk losing protection depending on the exact interpretation of Sackett vs. EPA. Therefore, we will create risk categories based on hydrologic connectivity. Wetlands will be categorized as protection lost (PL) if they are over 100 feet from perennial streams and waterbodies. Wetlands located 50–100 feet from perennial streams and waterbodies will be categorized as at-risk (i.e., "likely to lose protection") to account for buffer areas in wetland boundaries and streams.

Sackett vs. EPA excludes wetlands from protection under section 404 of the Clean Water Act that were previously protected based on a "significant nexus" between waters of the United States (Rapanos, 547 US at 742, 755). Thus, federal protection only applies to wetlands with a continuous surface connection to U.S. waters and "coastal wetlands." Given different interpretations of the Sacket decision, we will further categorize the at-risk wetland areas to provide scenarios of potential protections lost. We will use geospatial methods to determine wetland areas connected to intermittent streams, ditches, culverts, and floodplains (50-year and 100-year floodplains). Our methods will provide a quantitative estimate of wetlands that will lose protection and include categories that may be interpreted as hydrologically connected based on future interpretation (including buffers, intermittent streams, river flood plains, and hydrologic connectivity via ditches).

Limitations of the Proposed Task 2 Methodology

Our method uses proximity to streams and waterbodies as evidence of a hydrologic connection. A stricter interpretation of permanent surface connectivity is possible; however, available data limits the determination of direct connectivity.

The proposed method only determines hydrologic connectivity and limits the interpretation of "wetness" used in a national estimate of loss of protection under Sackett (Gold et al., 2024). An interpretation of "wetness" often relies on NWI data, which requires updating in North Carolina. To make a direct comparison possible, we will calculate the potential loss of wetland protection with the improved NC ATLAS Hydrography but including the same NWI wetness categories as in Gold et al. (2024). In our interpretation of Sackett vs. EPA, wetlands will still be delineated by U.S. Army Corps of Engineers standards; therefore, the interpretation is likely to hinge on wetlands' hydrologic connectivity to "waters of the United States" rather than the level of inundation in individual wetlands. However, we will also estimate flooding frequency with the Water in Wetlands Index, which will be calculated across the state's wetlands using Sentinel Imagery and Google Earth Engine (Lefebvre et al., 2019).

In the end, the Sackett ruling is open to many interpretations, some known and some unknown, and not all interpretations are included in this proposal. We propose an approach that we believe makes best use of available data and potential interpretations.

Like Task 1, our proposed approach for this task does not include field sampling or data collection regarding connective or other characteristics of wetlands across the state, which would be needed for rigorous ground-truthing verification of our wetland classification and characterization. We have assumed that the extensive resources required for such data collection are beyond the scope of this project, but we do recommend future efforts by NCDEQ to conduct this type of verification.

Task 3. Identification of NC Wetlands and Other NWLs Most Vulnerable to Land Use Change

An important factor that will influence the estimated social, economic, and environmental value of conserving NWLs in North Carolina (RQ1), as well as the expected impacts associated with the degradation of wetlands that lost federal or state protections (RQ2 and RQ3), is projected changes in future land cover and land use under different scenarios. One of the primary threats to NWLs in North Carolina is the continuing high pace of population growth and urban development. For example, a recent study by RTI estimated that more than 1 million acres of natural lands present in 2020 have a high probability of development by 2050 (Van Houtven et al., 2021). In addition, conversion between categories of NWLs (e.g., wetland to cropland, cropland to grassland) has important impacts on the function and benefits provided by these lands. Thus, it is important to incorporate potential changes in land cover and land use within model scenarios.

To estimate changes in land cover and land use most relevant for this study, we will use the RTI EcoShift model (Holt et al., 2023) to spatially disaggregate projected changes in land cover and land use associated with land development as well as conversion between different types of NWLs. This task will be led by Dr. Robert Beach (RTI) working closely with GIS experts on the RTI Team including Jay Rineer (RTI). As a starting point, we will utilize aggregate-level model simulation results characterizing projected changes in land cover and land use in North Carolina over the next decade under alternative scenarios. These results will include projections from the literature (e.g., Hunter et al., 2024; Mihiar et al., 2023) or we will generate state-level projections of developed, agricultural, and forestry land areas using an existing model such as Forest and Agricultural Sector Optimization Model (FASOM) or the GLObal BIOsphere Management (GLOBIOM) model.

State-level estimates of land cover and land use change under each scenario of interest will then be utilized within the RTI EcoShift model, which is used to downscale land cover and land use change projected by models such as FASOM, GLOBIOM, the U.S. Forest Service county-level land-use projections (Mihiar et al., 2023), or others such as ICLUS, SLEUTH, and FUTURES. EcoShift utilizes time series data from the USGS Land Change Monitoring, Assessment, and Projection (LCMAP) framework and a number of variables expected to explain changes in land cover and land use over time (e.g., population, income, soil productivity, precipitation, temperature, proximity to recent land conversion, etc.) (Holt et al., 2023). We apply a machine learning model to predict the relative likelihood of land conversion at the pixel level of resolution based on the values of explanatory variables. We then utilize available aggregate projections for scenarios of interest to determine the total quantity of land conversion within a given period and use the relative likelihood values from EcoShift to implement a given type of land conversion between types starting from the pixels with the highest relative likelihood of that conversion and continuing to select the next highest likelihood pixel until reaching the total quantity of land conversion estimated at the state, county, or other level at which these projections are available. To further improve the accuracy of our projections of potential changes in land use, we will augment the existing version of EcoShift with additional explanatory variables relevant for determining the likelihood of converting wetlands to cropland, development, and other uses in North Carolina.

This highly disaggregated characterization of projected future land cover and land use will be overlaid with spatial data on existing unprotected wetland areas to identify the areas and categorizations of at-risk wetlands at greatest risk of conversion to other uses. In addition to these estimates of potential impacts on wetlands, we will assess broader projected development of other NWLs and conversion between land types. We will also use data on currently protected areas such as the USGS Protected Areas Database[1] and the North Carolina Natural Heritage Program's resources[2] to exclude NWL areas that are currently protected from land conversion.

The first output of this component of the project will be predicted land cover/land use for the selected subset of land categories at a disaggregated spatial resolution (30m x 30m pixels or smaller). Second, when combined and overlaid with results from Task 1 and Task 2, it will provide mapped scenarios of where wetlands and other NWLs are expected to be lost in the next 10 years (1) due to land use change and (2) because they are no longer protected at the federal or state level.

Two main mapped scenarios that will be produced through this task are:

- A **low-NWL-loss scenario**, which will assume that only PL category wetlands from Task 2 will lose protection and include lower-bound land use change predictions from the Task 3 EcoShift model
- A **high-NWL-loss scenario,** which will assume that PL and selected AR category wetlands from Task 2 will lose protection and include upper-bound land use change predictions from the Task 3 EcoShift model

[1] https://www.usgs.gov/programs/gap-analysis-project/science/pad-us-data-download
[2] https://ncnhde.natureserve.org/content/data-download

These priority scenarios will be used as inputs for assessing state-level environmental, economic, and social changes in Tasks 4, 5, and 6.

Justification for the Proposed Task 3 Methodology

The proposed methodology will build on existing alternative models that project land cover change (e.g., ICLUS, SLEUTH, FUTURES) focused on changes in developed areas but with less consideration of other types of land conversion. Given the importance of these regions for assessing the social, economic, and environmental benefits provided by NWLs, we will improve upon existing characterizations of projected land cover and land use change for rural areas. It is not only the quantity of land conversion taking place, but which land that is being converted that determines outcomes for water demand, flooding, water quality, endangered species habitat, biodiversity, carbon sequestration, and other environmental, economic, and social impacts. Assessing which wetlands losing protection are most vulnerable to development or conversion to agriculture or forestry will inform analyses of the potential loss in ecosystem services as well as calculation of the opportunity costs of land conservation. This analysis will also provide valuable insights for design of policies such as those aimed at efficiently incentivizing conservation of areas expected to provide the largest net benefits.

Limitations of the Proposed Task 3 Methodology

There are large inherent uncertainties with projecting where, when, and how land use changes will occur. Although our approach is designed to make the best use of available data and the evidence from historical patterns and determinants of land use change, the resulting estimates will be subject to forecast errors. In documenting our approach and results we will be sure to describe and, to the extent feasible, quantify these uncertainties and error bounds.

Importantly, our land use change projections will be based on observed historical patterns that occurred before the Sackett decision; therefore, it cannot directly account for how the change in federal or state protection status will affect the pace or location of development and other land use changes. Over time, as evidence of differences in land use change before and after the decision accumulate, it will be possible to improve on these methods but most likely not within the timeframe of this project. However, our reporting on this project will include recommendations for how Sackett-induced changes in land conversion patterns can be incorporated into future projections.

Task 4. Development of Wetland Function and Ecosystem Service Indicators

To assess the potential loss of wetland function and ecosystem services, we will create a new map identifying wetlands (Task 1), identify and quantify the potential for wetland loss due to the Sackett vs. EPA decision (Task 2), quantify the type and areas of projected wetland losses due to land cover and land use changes (Task 3), and, in Task 4, assess and quantify the loss in wetland function and services associated with wetland loss. This task will be led by Dr. Sean Charles (ECU) in close collaboration with Dr. Stuart Hamilton (ECU).

The only statewide wetland inventory in North Carolina is the NWI, but it has been proven inaccurate for identifying and classifying wetlands, particularly outside of the Coastal Plain physiographic region (Gale, 2021). In coastal North Carolina, the DCM provides improved wetland mapping, which was assessed for quality control and indicators of wetland function to produce maps of wetland types and function provided through the North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS). For all functional evaluations, this dataset will be prioritized in the coastal plain, with supplemental datasets used to classify wetlands and evaluate the functional implications of loss of protection.

Outside of the coastal plain, we will prioritize (1) data collected by the North Carolina Wetland Assessment Method (NCWAM) and (2) ground-truthed wetland data collated by the NC DWR consisting of more than 400 wetland studies since 2004. In locations lacking data, we will classify wetlands identified in Task 1 of this project. We will use a combination of datasets to establish wetland hydrogeomorphic (HGM) classes and types, as described in NC-CREWS (Sutter, 1999). As a first step toward estimating the functional loss of wetlands, we will use average values for three wetland functional groups: (1) hydrologic (functions, 2) water quality functions, and (3) habitat quality functions from each ecosystem type by physiographic province. We will also quantify the loss of soil carbon storage based on a national wetland soil database (Uhran et al., 2022).

To characterize the specific habitat type of wetland loss, we will rely on the USGS LANDFIRE Terrestrial Ecological Classifications categories remapped in 2023 (based on NatureServe vegetation assessment). Wetland HGM classifications have been used to categorize the functions provided by different wetland types for decades (Cowardin et al., 1979), and they provide the basis for developing indices of functional assessments. The NCWAM uses indicators to rank wetlands (1-3) on three wetland functions (hydrology, water quality, and habitat) that influence hydrology compared to reference wetlands in terms of water storage, water quality enhancement, and habitat value.

We will use a combination of datasets and models to create a range of loss of wetland functions for water storage (flood control), water quality enhancement, carbon storage, and habitat for each wetland type. We will use the best available field data from across the state (based on data collated by NC DWR and others) and an updated LiDAR-based statewide wetland map created in Task 1. These wetland data will inform subsequent tasks to estimate hydrologic and water quality changes, quantify carbon loss, and assess habitat loss based on type, hydrogeomorphic setting, and habitat quality of individual wetlands based on ecological indicators.

Task 4A. Flood Control

Wetlands reduce flooding through surface and subsurface water storage and can improve water quality downstream (Cowardin et al., 1979). A study by the U.S. EPA across the Southeast United States (including North Carolina) assessed wetlands with NCWAM (and other functional wetland assessment indices). It quantified their functional impacts on hydrology (percent change in physical parameters upstream vs. downstream of forested wetlands), water quality (NO_2, NO_3

phosphorus, ammonia, lead, copper, zinc, calcium, magnesium, organic carbon), and habitat (floristic quality, amphibian and invertebrate assessment) values (U.S. EPA, 2015). They demonstrate the dampening of flooding impacts downstream of wetlands, particularly during the growing season, as vegetation increases evapotranspiration. As these wetlands flood, they store water, reducing water flow and erosion, capturing sediment, and storing and cycling excess nutrients in biomass and soils (Mitsch and Gosselink, 2000).

As an indicator of water storage and flood reduction and to estimate the likelihood of loss of wetland protection, the NWI is often used to determine the frequency of wetland flooding (e.g., Gold et al., 2024). However, NWI data have proven insufficient for wetland identification, frequently underestimating wetlands, and in North Carolina, wetlands were particularly undercounted in mountainous regions (Gale, 2021). Therefore, NWI classifications will be evaluated for comparison but not used as a primary classifier.

The majority of wetland area (>80%) in the Southeast occurs in the coastal plain (Omernik, 1987), followed by the piedmont, with only 1% occurring in the mountain region (Mitsch and Gosselink, 2000). Wetland classification in 40 counties in the coastal plain was updated by the DCM to 1 m^2 resolution. The DCM data will be used to classify wetlands in the 40 acres covered in the DCM dataset. In contrast, wetlands in the remaining coastal counties will be classified by NOAA's Coastal Change Analysis Program (C-CAP) to <1 m^2 precision.

In the coastal plain, we will use NC-CREWS data (Sutter, 1999) to estimate the potential loss of hydrologic function and flood control associated with reduced wetland protection. Outside of the coastal plain, we will use NC WAM Hydrology data where available and average values for the wetland type and physiographic region. Both datasets provide ranked values (1-3) based on functional indicators of (1) surface storage and retention and (2) subsurface storage and retention, which will be used as input and training data for the WaterFALL model in Task 5.

Finally, to estimate water stored in wetlands, we will use the Water in Wetlands Index (WIW; Lefebrve et al., 2019), which uses Sentinel imagery to estimate wetland surface water. This index will allow us to estimate wetlands with a "permanent surface connection" to waters of the United States and, while not qualitative independently, can be used as an input to the WaterFALL model in Task 5, and changes can be linked to upstream changes in water storage or supply.

Task 4B. Water Quality Control

Wetlands have been proven to improve water quality by filtering suspended solids and removing and cycling excess nutrients, ultimately improving water quality downstream (Mitsch and Gosselink, 2000). However, the specifics of their impact on water quality vary by wetland type, HGM setting, and wetland condition. In addition, improvements vary based on opportunity (i.e., removing excess nutrient loads requires excess nutrients). Along the coast, NC-CREWS provides ranked water quality functions based on ecological indicators (1-3), while NCDWR studies (particularly NCWAM) provide data from more than 400 wetlands across the state. NC WAM and NC-CREWS provide overall functional rankings for water quality function, as well as for specific subfunctions: (1) particulate change, (2) soluble change, (3) pathogen change,

(4) physical change, and (5) pollution change. When no data are available, we will estimate water quality improvement functions based on average ranked valuation within wetland type, HGM class, and physiographic province. We will use average water quality improvement data from a study that measured water quality upstream and downstream of wetlands to estimate percent change across various wetlands. These functional rankings by wetland type, HGM class, and physiographic province will provide the underlying data for differentiating inputs to the water quality modeling to be conducted in Task 5.

Task 4C. Habitat Quality

To quantify the potential statewide loss of habitat associated with potential wetland loss, we will start by quantifying the overall area of wetlands of each HGM class and type within each of North Carolina’s physiographic provinces. We will then characterize the quality of habitat lost based on data provided by NC-CREWS, NC WAM, and the wetland quality/functional assessment data provided by NCDWR where available.

Vascular flora is an effective bioindicator for estimating the habitat quality of wetlands. It has been used to develop the Floristic Quality Assessment to monitor habitat quality and anthropogenic impacts on wetlands (Swink and Wilhelm, 1979). NCDWR provides wetland vegetation species quality maps (Floristic Quality Index, NCWAM, Ohio Rapid Assessment Methods, Hydrologic Condition), and NC WAM classifies wetlands into 16 general wetland types in state and estimates habitat condition based on bioindicators (1-3).

For wetlands without habitat evaluation from NC-CREWS or NC DWR, we will combine the statewide wetland map created in Task 1 with (1) USGS LANDFIRE existing vegetation layers, (2) NWI wetland classification, and (3) U.S. Fish and Wildlife Service National Wetland Inventory Wetlands Data Verification Toolset in combination with high precision orthoimagery provided by NC ONEmap. The USGS LANDFIRE existing vegetation layer dataset is based on predictive landscape models derived from extensive field-referenced data (NatureServe), Landsat Satellite imagery, and Environmental Site Potential. The LANDFIRE dataset provides an iterative ecosystem classification system powered by field data. It provides a habitat value estimate and an estimate of ecosystem development, which may prove valuable in quantifying the impact on specific species of interest for further study.

Task 4D. Carbon Storage and Sequestration

To estimate changes in carbon storage and sequestration, we will use NC-CREWS data in the coastal plain (Sutter, 1999) and the national wetland soil carbon storage dataset provided by USGS (Uhran et al., 2022). The USGS wetland soil carbon dataset created a harmonized wetland soil carbon data based on 2011 data (Uhran et al., 2022) to a depth of 1 meter, based on integrated field and modeling studies. For previously unmapped wetlands, we will use established methods to model SOC (Uhran et al., 2021) and compare modeled data to average values for each ecosystem type and physiographic region. We will then estimate a range of carbon loss that ranges from the loss of 43% to 100% of soil carbon stock in the surface meter of soil based on the range of loss identified in coastal wetland studies (Atwood et al., 2017; Sanderman et al., 2018).

To determine aboveground biomass carbon at risk of being lost, we will use the NOAA C-CAP dataset for coastal wetlands, and for inland areas, we will use average values from each wetland type and physiographic province from NCWAM.

Justification for the Proposed Task 4 Methodology

Wetlands are among the most valuable ecosystems in the world, by some estimates providing more value than any other ecosystem, with coastal wetlands providing 40% of all ecological value globally (Davidson et al., 2019). However, the Sackett vs. EPA decision may reduce protections for these extremely valuable ecosystems with uncertain impacts on ecosystems and the services they provide.

To estimate which wetlands are likely to lose protection, studies have relied mainly on National Wetland Inventory (NWI) data (i.e., Gold et al., 2024), the only "complete" nationwide wetland inventory. However, NWI data are outdated and have proven insufficient for wetland identification, often underestimating wetlands in North Carolina. Wetlands were particularly undercounted in mountainous regions (Gale, 2021). Therefore, we plan to combine datasets to estimate ranges of functional loss.

Loss of wetland function and value can be estimated based on literature values, but our methods provide additional value by quantifying functional change in four categories.

Limitations of the Proposed Task 4 Methodology

The significant limitations of this task are based on the misclassification of wetland types and limited data directly quantifying wetland functions. This study will significantly improve wetland classification by combining a new statewide wetland map (Task 1), the best available field-based wetland data, and expert determination from orthoimagery. In addition, the biggest problem with NWI data is that incorrect identification of wetlands and wetland classes persists for decades without update, thus diminishing all studies that rely on it. Using LANDFIRE data will avoid this pitfall by providing annual updates as initial field data and modeling methods arise.

As wetland functions vary based on wetland type, conditions, and opportunity, our model will provide a range of potential functional changes. Similarly, modeling habitat quality is fraught with uncertainty, but by providing a baseline with the opportunity to optimize, future researchers and managers can optimize the resulting products for their needs.

Task 5. Modeling Environmental Impacts of Wetland and NWL Loss

RTI is in a unique position to evaluate the environmental impacts of wetland and NWL loss as we have developed the Watershed Flow and Allocation model (WaterFALL®) over the last 12 years to address such questions (Eddy et al., 2017a; Eddy et al., 2019; Eddy et al., 2022). WaterFALL provides a modeling system that enables stakeholders from local communities to regional and larger management agencies to examine numerous “what if” scenarios relating to practical applications of watershed management under past, current, and projected future conditions.

This task will be led by Michele Eddy (RTI), the lead developer of WaterFALL, in close collaboration with Dr. Robert Beach (RTI) and Dr. Sean Charles (ECU), to ensure seamless incorporation of key Task 3 and 4 outputs, and with RTI environmental staff who regularly support WaterFALL development and application.

Model Description

WaterFALL simulates daily streamflow and water quality loads over long periods of time at the scale of the medium resolution enhanced National Hydrography Dataset (NHDPlus; Moore and Dewald, 2016). These catchments are networked through a routing procedure to determine the cumulative streamflows and water quality loads at the outlet of every catchment within a watershed providing clarity on how the local conditions accumulate to impact the river basin overall. The recently redesigned model lets us

(1) Explicitly differentiate between riparian and upland areas;

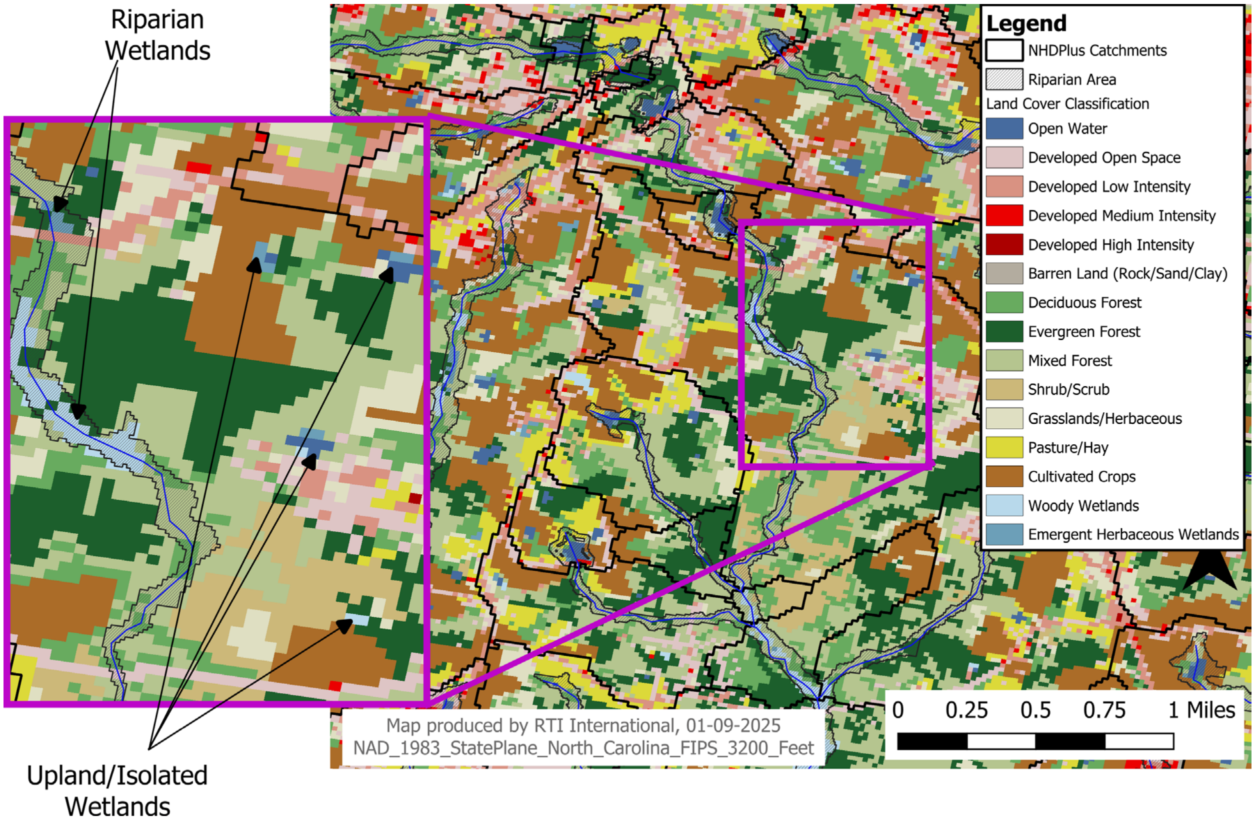
(2) Better represent waterbodies and their storage properties with separation between open water and wetland types; and

(3) Simulate the generation, loading, and transport of sediment and nutrients (nitrogen and phosphorus) from a variety of sources, including natural and human, within the watershed (**Figure 2.4**).

The ability to locate different waterbody types by their position within the landscape (i.e., upland with geographic isolation from the stream network or riparian with direct connection to flowing waters) (**Figure 2.5**) and within a watershed (i.e., headwaters, tributaries, mainstem, downstream) with WaterFALL provides an advantage over watershed models like the Soil and Water Assessment Tool (SWAT), which has been used extensively in North Carolina and beyond to look at the benefits of wetlands and other land management options but only with adaptation through special modules for the study (Evenson et al., 2015; Kurki-Fox et al., 2022a; Lee et al., 2018).

Figure 2.4. Depiction of the WaterFALL Simulation Framework Across the Catchments within a Watershed

Figure 2.5. Wetland Representation within WaterFALL When Using 30-Meter Resolution Land Cover Data



With WaterFALL, we simulate each NHDPlus catchment as its own watershed. Across the land surface we differentiate between the upland and riparian areas. Then within each of those areas we characterize the different land cover and the underlying dominant soil conditions. We simulate the daily surface runoff from each of those upland land covers where a portion of the runoff is captured by upland/isolated open water or wetland areas. These waterbodies are characterized by a maximum surface area, maximum fill depth, infiltration rate, and first order loss rate for sediment and nutrients during water quality analysis. Therefore, each waterbody has a daily mass balance of water storage subject to evaporation, infiltration, and, when the maximum storage level is reached, overflow back to runoff conditions.

Once the total runoff for the upland for the day is computed, the runoff volume is transferred to the riparian areas where it is dispersed across the land use types there allowing for further infiltration within the land surface or retention by wetland or open water complexes along the stream network, which are characterized in the same way as the upland waterbodies. Any runoff from riparian lands or overflow from riparian wetlands or open water contributes to the streamflow for that catchment on that day.

Any water that does not runoff infiltrates to the subsurface of the catchment, where water is first captured in the unsaturated area based on the available water capacity of the soils. When this capacity is reached, water percolates to the saturated zone from which baseflow to the stream reach and recharge of the deeper groundwater aquifer are simulated providing a full accounting of the catchment hydrologic processes and a linkage between surface conditions and subsurface hydrologic water processes.

Water quality loads for sediment, nitrogen, and phosphorus are generated from the land surface during runoff events. Natural lands within the riparian area are assigned an efficiency rate that represents removal and storage of water quality loads. Infiltrated precipitation transports dissolved loads to the subsurface where loads can accumulate and be transported into the stream with base flow. Nitrogen and phosphorus can be added to the surface of cropped areas and contribute to surface runoff loads. Septic systems contribute nitrogen to base flow loads in the catchment where they occur. The water quality loads transported into the waterbody with runoff are mixed into the waterbody with its current concentration by parameter. Loads are reduced within the waterbody by first order loss. Dissolved loads are infiltrated from the waterbody into the saturated subsurface at the concentration within the waterbody. Within the stream channel, the streambank erosion can occur and point sources can contribute to the loads generated from surface runoff and baseflow.

WaterFALL is calibrated to observed streamflow and water quality concentrations where available. WaterFALL's parameterization is simpler than other watershed models like SWAT, Hydrologic Simulation Program-FORTRAN, or Precipitation Runoff Modeling System, which allows us to more rapidly spin up simulations, although WaterFALL's spatial scale allows us to achieve comparable model performance in daily simulations of hydrology and water quality.

With this scale of analysis, we can readily simulate the impacts of land use/land cover changes. For instance, we can simulate land restoration or land development by changing the area of land covers within the catchment. We can simulate the impact of riparian buffers and their land use/land cover make up and quality. The spatial design and scale of WaterFALL will allow us to explicitly analyze the benefits of the PL and AR category wetlands in watersheds (identified in Task 2) throughout the inland areas of the state.

Inputs to Model and Assessment Plan

WaterFALL will be parameterized with the land use/land cover data gathered and formatted under Task 3, which, if schedules allow, will include the new high-resolution 20-class land use/land cover dataset. These data will also include the spatial definition and categorized wetlands from Task 2 with functional attributes by type detailed within Task 4. These data will be substantial improvements over previous WaterFALL parameterizations relying on the 30-meter National Land Cover Dataset with only two wetland classes (e.g., **Figure 2.5**). When necessary, we will use the Cropland Data Layer (NASS, 2025) to gain further information on working lands (i.e., crop types, rotations, and field areas) to detail nutrient inputs and refine hydrologic parameters.

The wetland characteristics determined in Tasks 2 and 4 will be used to create a set of inputs by wetland type (e.g., headwater forests, riverine swamp forests) to use in parameterizing the upland/isolated and riparian wetlands. Within WaterFALL each type of wetland will be assigned to riparian and/or non-riparian status and have the following characteristics assigned via crosswalk to each instance of the wetland type located within a catchment within the WaterFALL database:

- **Maximum storage depth:** Estimated via measurements (field or satellite) when available from modeled or field validation data or based on wetland type and riparian status
- **Initial runoff conditions** (i.e., Curve Number): Developed via wetland type and underlying soils hydrologic group determined from geospatial overlays with SSURGO or from soils information used in earlier tasks
- **Infiltration rate:** Based on wetland type and underlying soils
- **Evaporation coefficient:** Based on vegetation type in wetland and, if necessary, physiographic region.

To capture the range of wetland conditions and impacts, we will work with the state to select three approximately HUC8 watersheds within each of the three non-tidally influenced EPA Level III Ecoregions within the state (i.e., Blue Ridge, Piedmont, and Southeastern Plain). We will simulate each of these watersheds under the baseline, current conditions and then under the two future loss scenarios (low-NWL-loss scenario and high-NWL-loss scenario) under a period of approximately 20 years to capture a range of storm events and climate patterns under which the benefits of NWL can be examined. The baseline period will use the last 20 years of available climate data from the PRISM dataset (PRISM Climate Group, 2025) as the climate driver. The climate drivers for the loss scenarios will be discussed with NCDEQ to determine if those should rely on historic climate conditions or should include a measure of climate change.

Each of these simulations will be conducted according to the WaterFALL modeling procedures, which ensures direct comparability between any scenarios by catchment, subbasin, and watershed over time allowing for analysis of the impacts of the scenario drivers. The catchment-level time series data simulated by WaterFALL will be assessed through tabular and graphical means to illustrate the quantitative changes to hydrologic processes and water quality loads due to loss of NWL. The following subtasks describe what information from the WaterFALL simulations will be used to address the impacts to flooding, water quality, aquatic habitat, carbon loss, and groundwater recharge/availability due to changes in wetland size, position, and quality throughout the state. The results will be detailed in a technical memo and summarized in the final report described under Task 7.

Task 5A. Flood Control

To examine the impact of NWL loss on flooding events directly from WaterFALL we will first examine the increase in number of flood events, where the threshold for a flood event is either the 75th or 90th percentile of historic flows, downstream of the wetlands at key subbasin outlets and the watershed outlet. We will also map these changes by catchment to display the length of the stream/river impacted by these event changes. We will also examine whether there are corresponding increases in the duration of such events in the loss scenarios compared to the baseline. Second, we will calculate the change in the magnitude of peak discharge over the 20-

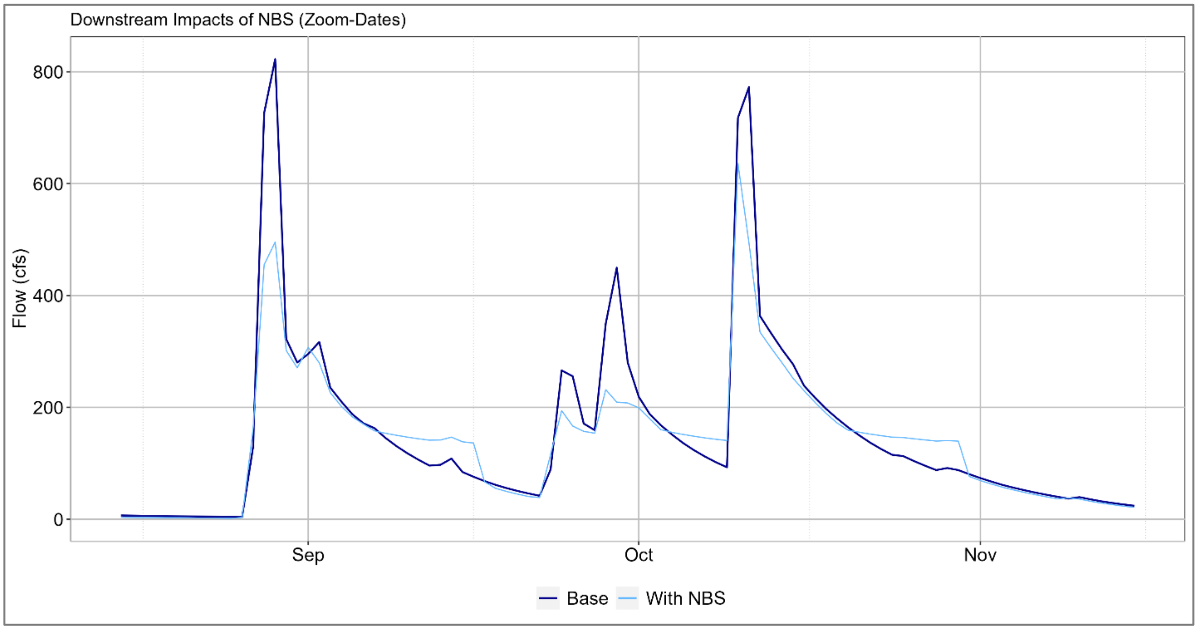
year period at the same outlets following on the work of several studies (e.g., Martinez-Martinez et al., 2014; Kurki-Fox et al., 2022b). An example of how RTI has previously used WaterFALL for assessing wetland flood control is provided in **Exhibit 2.1**

For selected areas, we will isolate events within the climate record that represent the FEMA Flood Insurance Study (FIS) streamflow events (corresponding with 10-, 50-, 100-, and 500-year return periods) to support an annualized economic impact under Task 6. We will also translate these streamflow changes into estimates of flood depths for selected locations. With the availability of the USACE's River Analysis System (HEC-RAS) hydraulic models for the state as well as the 100-year and 500-year FEMA flood inundation maps, we will translate daily peak flow event volumes into river stage and then inundation depth using methods similar to either Watson et al. (2016) or Javaheri and Babbar-Sebens (2014) after discussions with NCDEQ on locations and desired level of effort for these more detailed look at flood impacts. These inundation maps will inform economic and social impacts in Task 6A.

Finally, in addition to the flood impacts based on peak flows and inundation, we will quantify social metrics from the overlay of geospatial information on the selected watersheds. We will quantify for each catchment the population living within the floodplain locally and downstream and identify whether a socially vulnerable community or a flood hazard area that provides insurance credits is included within the local area or downstream area impacted by flood changes. These population and community counts will then be used to support environmental justice impacts within Task 6H.

Exhibit 2.1. Project Highlight: Impacts of Restoring a Wetland for Flood Control in Rural Louisiana

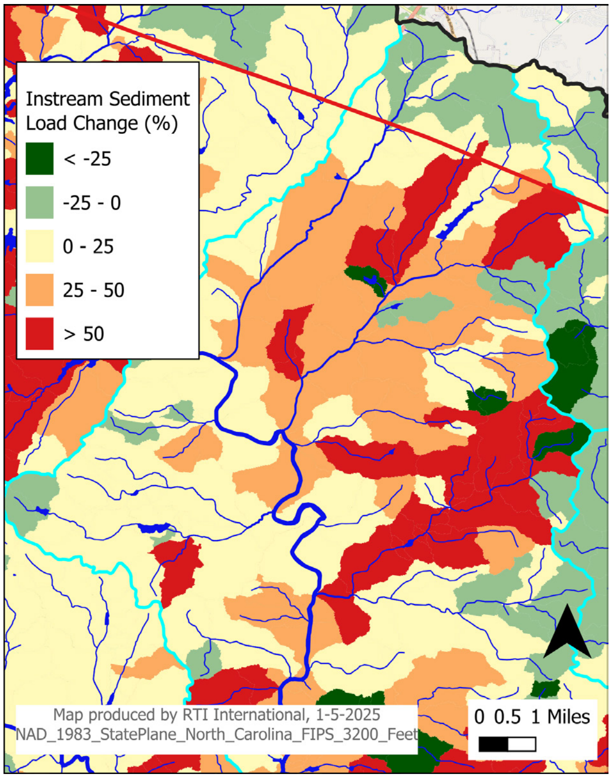
The Village of Natchez has experienced numerous floods in recent years around its town hall and the residences along Main Street and another street with lower income residences. However, this area did not qualify for funds from the state watershed resilience program due to higher income areas adjacent to the flooded areas and in other areas of the village. The cause of the flooding was flow modifications along Cane Creek to create a long narrow reservoir and to control water at the confluence with the Red River. Due to this complex hydrology, where flow backup was partially responsible for the flooding, RTI devised a two-prong approach to flood reduction using WaterFALL modeling while working with the local stakeholders. First, we identified a former wetland area to the west of the village along Old River. Restoring this area into a more functional wetland, which includes a weir system that allows for flood storage, provides a reduction in the downstream flows and alleviates some of the backup flow that causes localized flooding in the village. Second, within the village itself, and working from local knowledge of drainage issues and cooperative landowners, we identified and evaluated a set of three green infrastructure practices. As shown below, the restored wetland would have provided dramatic reductions in peak flows during several historic flood-producing events. With this additional information, flood mitigation projects were able to be approved for Natchez despite the lack of social vulnerability ranking.



Task 5B. Water Quality Control

Wetlands are known to provide the benefit of reducing nutrient and sediment loads in the waters moving through them reducing instream loads directly downstream of the wetlands. Several studies have shown that having increasing portions of larger watersheds covered with wetlands extends reductions in loadings from just downstream of wetlands further downstream to watershed outlets (e.g., Melles et al., 2010). Kurki-Fox et al. (2022a) recently showed that varying levels of wetland restoration within subbasins of the Neuse River Basin can lead to substantial reductions in nutrient and sediment loads. WaterFALL's wetland processing of nutrients is similar in functionality to the SWAT model used by Kurki-Fox et al.(2022a), although WaterFALL's spatial scale and definition of wetlands is more complex. We therefore expect we will be able to quantify the increase in nutrient and sediment loads that result due to the loss of wetlands in the two loss scenarios, both locally and downstream through to each wetland outlet (e.g., **Figure 2.6**). However, losses in working lands may have the opposite effect in areas using high fertilizer and/or manure inputs. The differences in these impacts will be examined within each watershed to ensure conclusions can be drawn on the impacts of different types of NWL loss. These resulting changes in loads can also be mapped against impairments and other water quality conditions that may be of interest to the stakeholder to show areas of increased concern from NWL loss. In addition to locating and quantifying the changes in loads, the instream concentrations of nitrogen, phosphorus, and sediment from these analyses will be used in Task 6C to aid in determining changes to property values due to changes in water quality.

Figure 2.6. Example of Percent Change in Instream Sediment Loads Due to Land Use/Land Cover Changes

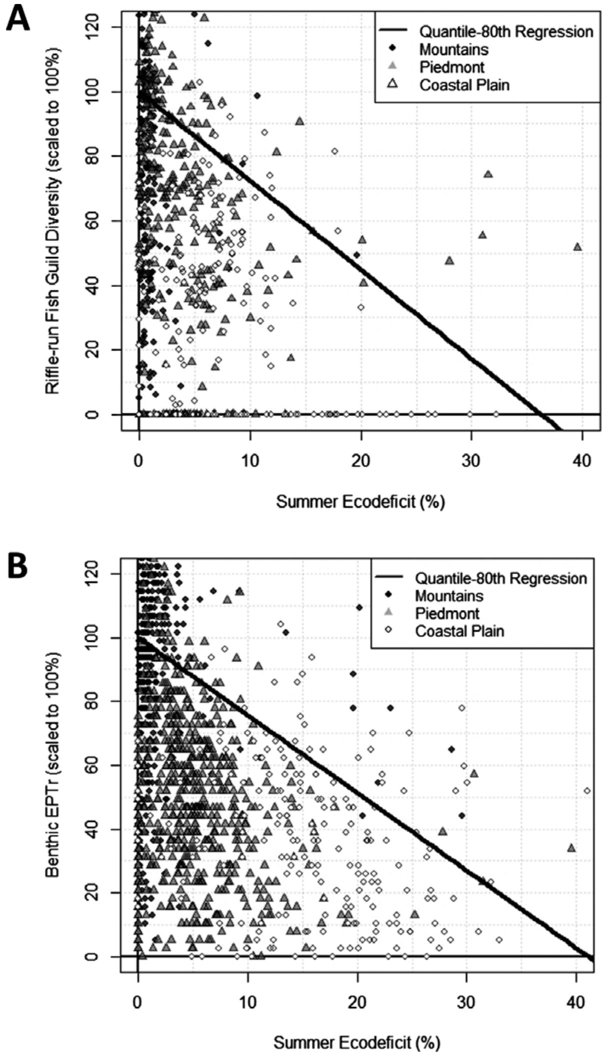


Task 5C. Aquatic Habitat Quality

This quantitative aquatic habitat analysis will supplement the habitat quality analysis of Task 4C.

To locate and quantify reductions in aquatic habitat we will use ecological flow relationships developed for the state by Phelan et al. (2017). This past statewide analysis relying on WaterFALL found statistically significant relationships between reductions in summer flow volumes, calculated as an ecodeficit, and biologic condition for both fish and macroinvertebrates (**Figure 2.7**) Using the change in summer flows between the baseline and two wetland loss scenarios for each catchment, we will be able to map the stream reaches that are expected to have significant increases in summer ecodeficits (i.e., reductions in summer flow volumes) due to the lower baseflows expected as wetlands are lost (Evenson et al., 2015). This outcome will provide the location and length of stream channels with likely reductions in biologic condition due to wetland loss. As with the other outcomes of this modeling effort, these spatial results can be overlaid with locations of species of concern or other aquatic concerns to further define the costs of wetlands lost.

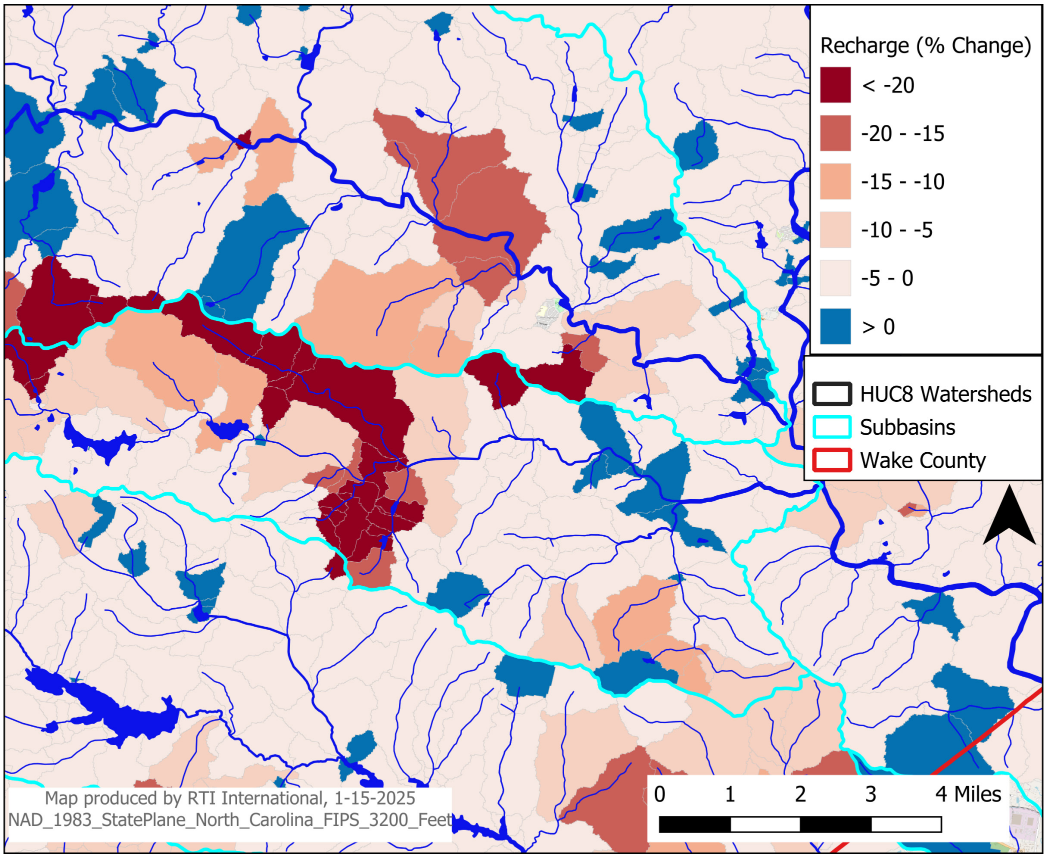
Figure 2.7. Relationships Between Hydrologic Measure (Summer Ecodeficit) and Biologic Condition for North Carolina Fish and Macroinvertebrates (Phelan et al., 2017)



Task 5D. Groundwater Recharge

The final modeling analysis for wetland loss will be an assessment of the changes in the volume of water going to recharge of deep groundwater aquifers with the loss of wetlands. Deep groundwater provides the source water for domestic, industrial, and irrigation uses through pumping. Although the simulation of the volumes and movement of deep groundwater are not included within the WaterFALL model, the water leaving the saturated zone as seepage within each catchment in WaterFALL simulates the recharge of the deep groundwater based on surface characteristics and climate conditions. Infiltration of water from the surface to the saturated subsurface will decrease with the loss of wetlands thereby reducing the recharge to deep groundwater (Nepal et al., 2024). In areas of high groundwater use, reductions in recharge from the surface can lead to reductions in water availability, especially in light of changing climate conditions. This analysis will quantify the percent reduction in annual groundwater recharge volume due to wetland and NWL loss (e.g., **Figure 2.8**) and will compare these areas of reduced recharge to maps of groundwater use to highlight areas of concern. These reductions will be particularly important in coastal plain where saltwater intrusion is of increasing concern.

Figure 2.8. Example Assessment Showing Percent Change in Annual Average Groundwater Recharge Volumes Due to Land Use/Land Cover Changes



Justification for the Proposed Task 5 Methodology

WaterFALL has been applied throughout the Southeast, including statewide applications in North Carolina (Eddy et al., 2017a; Eddy et al., 2017b; Patterson et al., 2017; Phelan et al., 2017) and South Carolina (Bower et al., 2022; Eddy et al., 2022) for development of ecological flows and stream assessment and classification. RTI is also engaged in efforts in the Catawba River Basin (Eddy et al., 2019; CWWMG, 2024) and in Wake County (Wake County's One Water Plan) to use WaterFALL to establish integrated watershed management plans, including the conservation and management of NWL. Finally, working with The Nature Conservancy (TNC) for the Louisiana Watershed Initiative (LWI), RTI has conducted statewide watershed modeling of current and projected hydrologic and water quality conditions under climate and development drivers to evaluate the impact of nature-based solutions (NBS) for flood resilience and co-benefits such as the improvement to water quality and aquatic habitat (Eddy, 2023). The NBS included in the evaluation include the restoration or preservation of riparian vegetation, prairies and forests, and wetlands in both the riparian and upland areas. Also included are agricultural conservation practices around wetland restoration/creation and enhancement and enhancement of vegetation on working lands. Finally, at the interface of inland and coastal areas, the application can assess the benefits of protecting wetland migration corridors anticipated due to sea level rise. A publicly available tool, the NBS Explorer, will be released for Louisiana in fall 2025.

WaterFALL's spatial framework and definition of riparian and upland/isolated wetlands improves upon the gap in wetlands modeling noted by many recent papers (Evenson et al., 2015; Lee et al., 2018) and therefore provides a step forward in the simulation of the impacts of wetlands on the surrounding and downstream conditions.

Limitations of the Proposed Task 5 Methodology

All models have limitations, and it is important to be clear on those limitations when discussing the set up and findings of any modeling effort. There are two main limitations to discuss up front. Other model limitations pertinent to results findings will be discussed within the technical memo documenting the results of Task 5.

First, WaterFALL has been designed to reduce as many spatial uncertainties as possible in the simulation of catchment-based hydrology and water quality analyses. In its design, the model explicitly differentiates between riparian areas (those directly connected to the stream reach) and upland areas (those not directly connected to the stream reach). This differentiation allows for simulation of connected and non-connected waterbodies, although non-connected waterbodies still contribute to subsurface processes. The model is unable to directly link specific land uses as contributors of overland flow (i.e., runoff) into each defined waterbody. Rather the model calculates a proportion of the total runoff volume from the region (i.e., either the upland or riparian lands depending on the wetland position) to direct to the waterbody. Also, if more than one wetland area of the same type is included within the same region of a catchment, these wetlands will be simulated as single lumped wetland within the region of the catchment. Despite these limitations, WaterFALL provides the most complex representation of wetlands available from current widely used watershed models.

Second, for the simulation of working lands, particularly cultivated crops, WaterFALL does not represent specific agricultural practices. It relies on the curve number and surface concentrations for dissolved and sediment forms of nitrogen and phosphorus and the Modified Universal Soil Loss Equation for the generation of sediment loadings for all land surfaces, including working lands. There is differentiation between the growing and dormant seasons for evapotranspiration simulation. Additionally, a time period and rate of application of nitrogen and phosphorus as fertilizer or manure is defined by catchment to simulate the external input of nutrients to cultivated crop areas. Beyond that external input, cultivated crop working areas are not treated differently than other pervious land areas. While these inputs and simulation methods have been found to satisfactorily simulate nutrient and sediment loadings from agricultural areas, more intensive agricultural management practices may differ from the model simulated values.

Task 6. Modeling Economic Value and Societal Impacts of Wetland and NWL Loss

In addition to and as a result of the environmental impacts addressed under Task 4 and Task 5, loss of wetlands and other NWLs has the potential to significantly reduce the economic and social well-being of state residents in several ways. The purpose of this task is to develop and apply a customized approach that builds on the findings of the previous tasks to estimate as many of these economic and societal impacts as feasible.

This task will be led by Dr. George Van Houtven (RTI) who specializes in economic valuation of ecosystem services, and it will build on his long-standing collaboration with Task 5 leader, Michele Eddy (RTI) linking environmental (in particular WaterFALL) and economic benefit assessment models. Dr. Leila Hashemi Beni (NC A&T) will also have a key role, particularly in mapping and assessing the environmental justice implications of wetland and NWL loss.

We propose to conduct this task through a series of eight subtasks, which are described in detail in the following subsections. In combination, these subtasks will provide estimates of the economic and societal impacts associated with the low-NWL-loss and high-NWL-loss scenarios, The data inputs, methods, and results of this task will be documented in technical memo and summarized the final report described under Task 7.

Task 6A. Flood Damages

North Carolina incurs millions of dollars in average annual flood damages, and the loss of NWLs, and wetlands in particular, will certainly add to that toll. To estimate the magnitude and monetary value of these additional damages for the wetland loss scenarios developed and investigated in the previous tasks, we will use a two-tiered approach.

First, we will develop state-level estimates of incremental damages, using a benefit transfer approach based on best available average unit values ($/hectare) for the state or region. For example, for inland wetland and flooding we will apply results from Taylor and Druckenmiller (2022), which estimated the property damage impacts of wetland loss across the United States from 2001 to 2016 and calculated an average flood damage annual value of $3,200/hectare for the ecoregion including North Carolina. For coastal wetlands, we will most likely draw from Sun and Carson (2020) who estimated average annual county-level values of coastal wetlands for storm protection that range from $20 to $2,740/hectare for North Carolina's coastal counties. We will apply these unit-value estimate to the two main aggregate wetland loss scenarios.

Second, we will conduct more targeted and site-specific analyses of flood risk hotspots identified in Task 4, using an approach we developed to assess the benefits of natural infrastructure in the Chesapeake Bay Watershed (Van Houtven et al., 2020). For selected hotspot sites in North Carolina, we will use WaterFALL to estimate the incremental change in watershed-level runoff and instream flows based on a long-term period of record. Events will be selected that represent the FEMA FIS streamflow events (corresponding with 10-, 50-, 100-, and 500-year return periods) for the selected sites so that an annualized economic impact can be calculated. We will then apply the WaterFALL flows to estimate increases in runoff and peak flows associated our wetland loss scenarios in the selected watersheds, and we will use the USACE's River Analysis System (HEC-RAS) hydraulic model to estimate changes in flood depth extent in the selected areas. Next, we will apply FEMA's Flood Assessment Structure Tool (FAST), using tax parcel data to specify building inventories in each study area, to estimate structural damage and content losses for each flood event, and calculate the change in the value of total expected flood damages. The results from the return periods events will be used to calculate an expected average annual flood loss with and without the jeopardized wetlands in place.

Task 6B. Recreation Values

Loss of wetlands and other NWLs can also have significant negative effects on the wide range of outdoor recreation activities that take place in and near North Carolina, which currently include roughly 23 million fishing days, 7 million hunting days, and more than 150 million wildlife viewing days in the state each year (Rockville Institute, 2020). Although there are many ways in which NWLs support recreation, including by providing outdoor recreation sites, our analysis will focus on recreational impacts that can most reliably be estimated given currently available data and methods.

For this task we will focus on recreation values that are affected by water quality impairments resulting from our specified wetland (and other NWL) loss scenarios. Adapting and expanding methods that we developed to estimate the benefits of land conservation in the Catawba River Basin (Eddy et al., 2019), we will estimate how changes in lake water quality across the state due to NWL loss (as measured in Task 4) will affect water-based recreation benefits. This approach uses a recreation valuation model developed by Phaneuf et al. (2013) for analyzing lake water quality improvements in the southeastern United States (based on a stated preference survey of households in the region), which calculates the change in recreation value per lake visit for defined changes in lake water quality parameters. Multiplying the estimated per-trip values from this model by estimates of the average number of annual recreation visits to each lake (based on state and local visitation statistics), we will estimate the total reduction in annual recreation values at affected lakes.

Using a related approach, we will also estimate how changes in lake water quality are expected to affect spending in the local economy by recreational visitors to the affected lakes. Although evidence for North Carolina is limited, one economic study of recreational fishing elsewhere in the US (Feather et al., 1995) estimates an average 0.5% decrease in lake recreational visits per 1% decrease in water clarity (measured by Secchi depth). Applying this relationship to the average annual estimate of $27 in spending per person per trip for local water-based recreational day trips (White et al. 2013, White 2017) and multiplying by our annual recreational visitation estimates, we will estimate the total reduction in annual recreation-related spending in localities surrounding the affected lakes.

In addition to lake water quality, we will adapt and apply a modeling approach used by U.S. EPA to estimate the economic value of changes in river and stream water quality (USEPA, 2023). For this approach, we will convert the catchment-level nitrogen, phosphorus, and sediment water quality estimates from Task 4 to a unidimensional 100-point water quality index (WQI) scale (Corona et al., 2020; Van Houtven et al., 2014) and estimate a change in WQI (ΔWQI) for each catchment and wetland and NWL land loss scenarios. To value those changes, we will apply the meta-analytic willingness to pay (WTP) function developed by U.S. EPA, which converts ΔWQI into an estimate of average annual WTP per household by Census block group (CBG). These WTP estimates will include households' recreation-related values for water quality changes, as well as other aesthetic and nonuse values as well. As the final step, we will multiply the WTP estimates by the number of households in each CBG to estimate the aggregate value of water quality changes associated with land loss scenarios.

Wetlands also support recreation by providing essential habitat for waterfowl and other bird species that are of interest to hunters and wildlife viewers. To our knowledge, there are no studies that have estimated the effect of wetland loss in North Carolina on recreation values; however, a recent study of isolated freshwater wetlands in the Prairie Pothole region (Thogmartin et al., 2023) concluded that those wetlands are directly responsible for on average $1,300 to $1,400/hectare/year in duck hunting and wildlife viewing benefits. For this analysis we will interpret these unit values as upper-bound estimates for North Carolina's wetlands and apply them to our wetland loss scenarios for lost waterfowl hunting and wildlife viewing benefits.

Task 6C. Property Values

Wetlands and other NWLs can also provide important benefits to nearby residents that are reflected in property values; however, evidence from several empirical studies indicates that the spatial relationships between open space and housing values are complex and difficult to summarize and capture through simple benefit transfer methods (Mei et al., 2018). For this task, we will therefore focus on the indirect effect that these lands have on property values through their effects on water quality, by again adapting and expanding our previously developed methods for estimating the benefits of land conservation in the Catawba River Basin (Eddy et al., 2019). That is, in addition to estimating the effects of changes in lake water quality on recreation benefits (Task 6B), we will estimate how changes in lake water quality across the state due to NWL loss (as measured in Task 5) will affect housing prices for near-shore property owners.

For lakes where we find measurable changes in water quality (in particular, water clarity due to changes in sediment loads) due to loss of wetlands and other NWLs, we will first estimate the total value of existing lakeshore properties by overlaying county-level parcel tax assessment data with GIS layers of lake shorelines. Using benefit transfer, we will then apply results from an existing property value analysis in the Southeastern United States (Walsh et al., 2011), which found that a 1 m decrease in Secchi depth decreased lakefront property values in their sample by an average of 4.3%. For the estimated water quality changes from Task 5, we will apply this relationship to calculate the total reduction in lakeshore property values associated with water quality changes from our wetland and NWL land loss scenarios.

Task 6D. Water Supply

NWLs also provide important protections for water supplies used by state residents and businesses, not only by recharging groundwaters, but also by reducing sediment, nutrient, and other contaminant loads to water stored in reservoirs and aquifers. For this task, we will focus on how drinking water treatment costs are impacted by reductions in reservoir water quality due to loss of upstream wetlands and other NWLs. We will again adapt and expand methods used to assess these impacts in the Catawba River Basin (Eddy et al., 2019). This approach relies on results from a meta-analysis of nine studies in the United States (Price and Heberling, 2018), which concludes that, on average, a 1% increase in source water turbidity leads to a 0.14% increase in annual chemical and energy costs for drinking water treatment. Based on data acquired from eight facilities in the Catawba Basin, we estimated that average annual treatment (chemical plus energy) costs per unit of capacity were roughly $60,000/MGD. We will apply this average value to estimate baseline treatment costs at other facilities that draw from reservoirs where we find measurable changes in water quality (in particular, water clarity due to changes in sediment loads).

Task 6E. Health Impacts and Values

NWLs with tree cover also provide important benefits to local populations by filtering and removing pollutants from the air and thereby reducing the harmful health impacts caused by air pollution. For this task we will estimate how the loss of wetlands and other NWLs will reduce the spatial extent of tree cover and reduce these health benefits, by applying the i-Tree Landscape software tool developed by the U.S. Forest Service (USFS; Nowak et al., 2014). The i-Tree model (1) calculates changes in air quality for four pollutants—fine particulates ($PM_{2.5}$), ozone (O_3), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2)—due to changes in tree cover at a county level, (2) applies epidemiological concentration-response functions to estimate changes in respiratory and other health effects, and (3) uses health valuation functions (based, for example, on costs of illness) to estimate resulting changes in economic values.

Based on these value estimates and estimates of the number of forested acres we can estimate average per-acre air quality benefits from tree cover in each county in North Carolina. For example, under current conditions, the average annual health benefit value of tree cover varies from less than $3/year in the least populated counties to almost $400/year in high density counties such as Mecklenburg County. We will apply these average per-acre benefits to estimate the total value of air quality-related health losses associated with our wetland and other NWL loss scenarios.

Task 6F. Carbon Loss Values

The development of wetlands and other NWLs in our state will cause a portion of carbon stored on those lands to be released into the atmosphere, contributing to climate change and associated impacts around the world. To estimate the value of those carbon releases, we will first use the land-specific carbon storage and sequestration estimates from Task 3 to estimate the total magnitude of short-term and long-term carbon losses associated with our wetland and NWL loss scenarios. Then, to assign a monetary value to the carbon losses, we will apply estimates of the social cost of carbon (SCC) drawn from the U.S. EPA's most recent assessment (U.S. EPA, 2023), which provides an average global damage estimate (in dollars per metric ton [MT] of CO_2 equivalent) for carbon released to the atmosphere. For example, assuming a 2% discount rate for future damages, the present value cost of carbon released to the atmosphere between 2020 and 2030 is estimated to be between $190/MT and $230/MT.

Task 6G. Economy-Wide Impacts of Losses of Working Lands

The loss of working lands, such as farm and timberland, will also have an impact on the state's economy. To measure these impacts at the county and state level, we will use an economic input-output modeling approach, focused on the flow of goods and services through a regional economy, which we have widely used in other applications, including economic impact analyses of coastal environmental restoration investments in North Carolina (Lawrence et al., 2015; Callihan et al., 2016). For these analyses, we apply commercially available IMPLAN Cloud software and data, which assumes fixed relationships between producers and their suppliers, based on demand, and that inter-industry relationships within a given region's economy determine how that economy responds to changes such as increases or decreases in economic activity within specific sectors. Decreases in production of a good or service, such as crop or timber production, cause a multiplier effect—a series of ripples through the economy. This decreased production affects the producer's employees, the producer's suppliers, the supplier's employees, and others, ultimately generating a total impact on the economy that significantly exceeds the initial change in production.

For this analysis, in addition to using RTI-owned IMPLAN economic data for North Carolina, we will apply estimates for forest and agricultural land conversion derived from our NWL land loss scenarios, overlaid with USDA Census of Agriculture data from 2022, to estimate how many acres of timber, pasture, or cropland would be diverted from production accounting for acreage enrolled in an existing conservation program such as conservation reserve program (CRP). Once these factors are assessed, we would match the decline in production to specific IMPLAN activity sectors, such as those listed in in **Table 2.3**. IMPLAN can model impacts at the county, MSA, congressional district, state, and national levels. Customized regions, which consist of many different counties, also may be created to model impacts for a specific area of interest.

Table 2.3. Agricultural and Forestry Activities in IMPLAN

Oilseed farming	Sugarcane and sugar beet farming
Grain farming	All other crop farming
Vegetable and melon farming	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming
Fruit farming	Dairy cattle and milk production
Tree nut farming	Poultry and egg production
Greenhouse, nursery, and floriculture production	Animal production, except cattle and poultry and eggs
Tobacco farming	Forestry, forest products, and timber tract production
Cotton farming	Commercial logging

We will report the following results for the desired geographies:

- Employment (Jobs)
- Labor income
- Total value added
- Local and state taxes

Task 6H. Environmental Justice Impacts

In addition to deriving aggregate economic value and impact estimates for wetland and NWL losses, as described in the previous subtasks, for this subtask we will assess whether and to what extent these impacts are differentially distributed across North Carolina communities and residents, especially low-income or minority populations and those already disproportionately burdened by poor environmental quality.

To conduct this analysis, we will conduct GIS analyses that overlay the results of the previous tasks (i.e., showing where wetland and NWL loss is expected to occur and where the largest resulting environmental and economic impacts will be experienced) with environmental justice layers incorporating socioeconomic factors, and other environmental hazards. These layers will include:

- Demographic characteristics of populations in neighboring communities that will be collected through U.S. Census Bureau, EPA's EJSCREEN Tool, the Climate and Economic Justice Screening Tool (CEJST website), and state and local health departments.
- Existing environmental hazards and stressors that will be collected from various sources, including EPA's Toxic Release Inventory (TRI).

Through spatial analysis, the datasets will be integrated and analyzed to identify vulnerable populations near wetlands and to assess how the estimated flood, water quality, health, and other impacts are spatially distributed in relation to these populations, and to create an environmental justice index that combines these layers.

Justification for the Proposed Task 6 Methodology

To conduct this task, we recognize that the resources required for conducting data-intensive primary studies of economic values, such as through household survey data collection or detailed micro-data analysis, are most likely beyond the scope of this study. Therefore, we recommend an approach that, to the extent feasible uses existing modeling systems such as IMPLAN and i-TREE, and that otherwise relies on evidence from existing valuation studies using an approach commonly referred to as “benefit transfer” (Johnston et al., 2018). This approach requires careful selection of studies and value estimates that most closely match conditions in North Carolina. Although the ecosystem service values provided by wetlands and other NWLs have been extensively analyzed across the United States and globally, a relatively small subset of these studies have been conducted regionally. For example, a recent compilation and systematic review of the ecosystem services literature (de Groot et al., 2020) identified over 3,700 valuation studies worldwide, including almost 250 value estimates for inland wetlands. The average annual value of wetland ecosystem services from these studies was found to be $48,647 per hectare per year, with the largest contribution coming from moderation of extreme events (27%) and existence and bequest values (24%). Although this global average value provides a useful point of reference, only three of the included studies were conducted in the Southeastern United States.

The benefit transfer and other modeling methods that we propose for this task are based on our team’s extensive experience in conducting similar ecosystem service valuation analyses for North Carolina (e.g., Eddy et al., 2019; Van Houtven et al., 2016; Phaneuf et al., 2013) and the Atlantic region (e.g., Van Houtven et al., 2020; USEPA, 2011). Through this experience we have developed an in-depth familiarity with the relevant literature, studies, and models that are best suited for this type of analysis.

Limitations of the Proposed Task 6 Methodology

Due to data and resource limitations and continuing gaps in the available science, we will not be able to estimate all the economic and societal impacts associated with loss of wetlands and other NWLs in North Carolina. Rather, we have selected the areas that we believe are best supported by available evidence and where we have the most confidence for deriving quantitative estimates. For example, we are not proposing to quantify losses in nonuse values related to the potential loss of species and biodiversity protection. Although studies have estimated individuals’ values for protecting threatened, endangered, or rare species (Richardson & Loomis, 2009) and some have focused specifically on nongame wildlife protection in North Carolina, their results cannot be easily adapted and scaled to assess the specific scenarios analyzed as part of this study. However, in our reporting for this task, we will discuss and describe these and other relevant impacts in a more qualitative way.

The methods we propose for quantifying selected economic and societal impacts will inevitably involve judgments, simplifying assumptions, and measurement errors which will contribute to uncertainty in the resulting value estimates. In our reporting for this task, we will discuss and characterize these uncertainties and to the extent feasible report confidence bounds on those estimates.

Task 7. Identification and Analysis of Policy Alternatives

The focus of this task will be on addressing RQ4 which has two main components:

- What regulatory and legislative policy options could be proposed by the research team for DEQ to address this issue?
- What are their estimated social, resilience, economic, and environmental benefits, with specific focus on conservation policies, such as the reinstitution of conservation tax credits?

The task will be led by Dr. George Van Houtven (RTI), who has led and participated in several RTI studies evaluating the benefits and costs of alternative conservation approaches and the needs for conservation funding in North Carolina (**Figure 2.9**), and conducted in close collaboration with Kim Matthews (RTI), who has worked extensively with the state of North Carolina on wetland monitoring and assessment. Mr. Bill Holman will serve as senior advisor on this task. Mr. Holman was the State Director for the Conservation Fund and chaired the Land for Tomorrow Coalition from 2013 to 2023. He also served as Secretary of North Carolina's Department of Environment & Natural Resources from 1999 to 2001 and as Assistant Secretary from 1998 to 1999.

Figure 2.9. Examples of RTI Reports Assessing the Benefits of and Needs for State-level Conservation in North Carolina

Task 7A. Identification of Policy Alternatives

To identify a broad range of potential regulatory and legislative policy options to be considered for counteracting the loss of federal and state protections for wetlands in North Carolina and other development pressures, we will draw from our team's experience to develop a preliminary list and classification of options and then expand on this by contacting and surveying key stakeholders and experts across the state. We will ask these individuals to review a list of options, to suggest additional approaches, and to identify main advantages and limitations of these approaches. The contacts for these interviews will include, for example:

- State legislators and their legislative staff
- State environmental and natural resource agency staff, including from NCDEQ, NC Department of Natural and Cultural Resources, NC Department of Agriculture & Consumer Services, NC Wildlife Resources Commission, and in particular staff responsible for managing the NC Land & Water Fund, the Parks and Recreation Trust Fund, and the Agricultural Development and Farmland Preservation Trust Fund
- Members of the Environmental Management Commission (EMC) and Coastal Resource Commission (CRC)
- Experts from environmental organizations like EDF, SELC, TNC, NC Coastal Federation and NC Wildlife Federation
- Business organizations like NC Farm Bureau, NC Realtors, NC Homebuilders, Duke Energy, and mitigation banks
- American Flood Coalition staff and leaders
- State and local Soil and Water staff and local stormwater utilities managers

Based on their input, we will compile and categorize the list of identified approaches, summarize key features, advantages, and limitations and distill them into a list of key options. We expect that some of the key features of these options will be:

- Expanding the conservation tax credit. Although the 2024 Farm Act reinstated a modified version of the conservation tax credit, the new policy is more restrictive than the one that was discontinued in 2013, leaving scope for revisions that could strengthen its incentives for wetland and NWL conservation.
- Developing a framework for prioritizing conservation that accounts for factors such as the environmental, social, and economic benefits provided by the lands, the risks of development without protection, and the costs of conservation. In particular, the methods developed in this report could be extended into the development of decision-support tools for prioritizing the location and timing of land conservation investments.
- Expansion and revisions of the state's three conservation trust funds—PARTF, NCLWF, and ADF—including an increase in the level of recurring state funding dedicated to these funds, which would ensure a long-term commitment to protection of NWLs and allow for more systematic conservation planning, and specific initiatives to protect and restore wetlands.

- Additional leveraging of federal funding programs that provide cost-sharing opportunities for conservation in North Carolina, such as Department of Defense's Readiness and Environmental Protection Integration (REPI) program, the Department of the Interior's Land and Water, the Federal Emergency Management Agency's Building Resilient Infrastructure in Communities (BRIC) program, and the National Coastal Resilience Fund (NCRF).
- Expanding the use and commitment to species conservation banking programs, particularly those that protect endangered and threatened aquatic and wetland dependent species.

Task 7B. Analysis of Environmental, Economic, and Social Impacts of Policies

Based on the identified policy alternatives and other findings of subtask 7A, we will work with NCDEQ to select a subset of 2-3 alternatives for detailed analysis using the modeling framework develop in Tasks 1 through 6. This selection will be based on careful consideration of both the feasibility of available options and confidence in quantifying their effects on wetland and other NWL loss across the state.

Using the low- and high-NWL-loss scenarios as reference points representing conditions without new protections, we then will (1) identify the wetland and NWL losses that would be avoided through the selected policy action and (2) apply our modeling framework to assess the environmental, economic, and social benefits of the selected alternatives. The methods and findings of this approach will be summarized in a technical memo to NCDEQ.

Task 7C. Development of Final Report

To complete the project, we will compile a final report that summarizes the methods and findings of the seven tasks described in this section. Leveraging our team's experience in effective science communication, this report will be written for a non-technical audience and designed to highlight the key connections between North Carolina's wetlands and other NWLs and the well-being of its citizens. The report will use graphics and highlighted call outs to convey key points of the study justifying the need for additional policy and for detailing the selected alternatives. The report will first be submitted in draft form for review by NCDEQ. Based on the feedback received, we will incorporate final revisions and updates into a final report submitted to NCDEQ.

Justification for the Proposed Task 7 Methodology

The approach we propose for this task is one that will take advantage of the insights and expertise of a wide variety of experts and stakeholders, by surveying these individuals and acquiring their input on potential policy alternatives. It will also utilize our team's expertise in conservation policy and analysis to review, summarize, and distill these options, analyze their implications, and develop evidence-based recommendations for steps forward.

Limitations of the Proposed Task 7 Methodology

The ability of state policies to avoid wetland and other NWL losses will depend not only the type of policy approach used but also the level of funding and resources that are committed to those efforts. For example, as described above, conservation objectives could be obtained by expanding the trust funds or increasing conservation tax credits, but in both cases the extent of protections will also depend on the size of the revenue or tax expenditure. For our analysis, we will examine past experience with these mechanisms to determine whether there are systematic differences in cost effectiveness (i.e., conserved acres per dollar allocated) across options. However, to define and conduct scenario analyses, we will need to work with NCDEQ to agree on assumptions regarding either the total level of funding or the total acreage targeted for protection.

3 Timeline, Milestones, and Deliverables

For the project, we propose a 2-year period of performance, as shown in **Figure 3.1**, which assumes a starting date of March 1, 2025, and completion date of February 28, 2027. The figure also displays the proposed timing and period of performance for each of the seven tasks described in Section 2 of this report.

Figure 3.1 Proposed Timeline of Tasks

		2025										2026												2027	
Task	Task Name	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
1	Mapping and identification of NC's wetlands and other NWLs																								
2	Identification of NC wetlands losing federal and state protection in 2023																								
3	Identification of NC wetlands and other NWLs most vulnerable to land use change																								
4	Development of wetland function and ecosystem service indicators																								
5	Modeling environmental impacts of wetland and NWL loss																								
6	Modeling economic value and societal impacts of wetland and NWL loss																								
7	Identification and analysis of policy alternatives																								

The proposed schedule of deliverable and milestones for the project, and their relation to each of main tasks is presented in **Table 3.1**.

Table 3.1 Proposed Schedule of Deliverables and Milestones

Task	Deliverable/Milestone	Date of Completion (Months from award)
	Kickoff Meeting	< 1
1	GIS data layers for Task 1 wetlands predictive model and other land cover	5
1	Task 1 memo summarizing input data, methods, results	5
1	Accessible and customizable visualizations of Task 1 layers	6
	First Project Update Meeting	6
2	GIS data layers of Task 2 wetlands characterizations based on connectivity	10
2	Task 2 memo summarizing input data, methods, results	10
2	Accessible and customizable visualizations of Task 2 layers	11
3	GIS data layers for land use change and NWL scenarios projections	10
3	Task 3 memo summarizing input data, methods, results	10
3	Accessible and customizable visualizations of Task 3 layers	11
	Second Project Update Meeting with NCDEQ	12
4	GIS data layers representing wetland and NWL characteristics for ecosystem functions (water storage, habitat, carbon)	15
4	Task 4 memo summarizing input data, methods, results	15
4	Accessible and customizable visualizations of Task 4 layers	16
	Third Project Update Meeting with NCDEQ	18
5	Task 5 memo summarizing input data, methods, results	19
6	Task 6 memo summarizing input data, methods, results	21
7	Task 7 memo summarizing input data, methods, results	22
7	Draft Final Report	23
7	Final Report	24

The Task 1 GIS data layers and other datasets delivered to NCDEQ will include

- Geodatabase of all manually digitized wetland delineations from NCDEQ
- Raw binary outputs of predictive wetland model for each ecoregion and the associated precision metrics
- 1-meter resolution classified landcover for the State of North Carolina created using deep learning analysis of most recent available NAIP Imagery and terrain indices

- Post processed predicted wetland dataset with attributes reflecting coarse classification using:
  - 1-meter landcover
  - SSURGO hydric soils
  - Approximate canopy heights
- QA/QC results for 200 random features per ecoregion model that are remotely assessed using high resolution geospatial data to determine whether the features are entirely wetland, partially wetland, upland, or unknown

The Task 2 GIS data layers will include wetland connectivity and at-risk categorizations, as described in Table 2.1 and Table 2.2.

The Task 3 GIS data layers will include

- State-level land use/land cover status and change projections for 2035
- Wetland and other NWL loss projections for low-NWL-loss and high-NWL-loss scenarios as described in Task 3 section of this report

The Task 4 GIS data layers will include

- Wetland classifications and indicators related to water storage and water quality regulation and habitat quality
- Estimates and ranges of carbon content stored in biomass and soils and annual sequestration for identified wetlands and other NWLs

As shown in Table 3.1, as these task-specific data layers are delivered for Tasks 1 through 4, we will also:

- Develop and submit technical memos describing the task-specific data inputs, methods, and results
- Develop and host for the duration of the project an Esri Experience Builder–based, publicly accessible, viewer which will at a minimum contain each of the non-sensitive geospatial output layers developed under each high-level task. The dashboard will be hosted by RTI. The project data will be stored and disseminated via an interactive and flexible GIS-based data portal. The viewer will provide an outlet to increase synergies between community and academic partners that facilitate the co-production of community science and environmental awareness.

RTI will lead the effort for development and maintenance of the viewer with close support from NC A&T starting in Task 1 and continuing through out the project.

The main deliverables for Tasks 5, 6, and 7 will be technical memos describing the input data, methods, and findings of each task. In addition, at 6-month intervals from the start of project, we will schedule project update meetings, where we will present to NCDEQ (and other experts and stakeholders, as directed by NCDEQ) the methods we are developing and interim results as they are available.

The final deliverable for the project will be a report, summarizing the approach and main findings of the project. This report will be written for a non-technical audience and designed to highlight the key connections between North Carolina's wetlands and other NWLs and the well-being of its citizens.

4 Cost Estimate for Implementing the Proposed Approach

Based on our assessment of the level of effort and computer resources that will be required across our team to implement the proposed methodology, **Table 4.1** presents our estimates of costs at both a task level and for the entire project.

Although we recommend that NCDEQ establish an advisory panel composed of stakeholders and experts to review project progress and deliverables, the estimates reported in Table 4.1 do not include the costs of recruiting, managing, or compensating these advisors. These estimates also do not include costs beyond the proposed 2-year period of performance that will be needed for maintaining the data visualization website and, as needed, updating the underlying data layers.

As described in Section 2 of this report, our proposed approach and corresponding cost estimates also do not include field sampling and data collection regarding presence, location, connectivity, or other characteristics of wetlands across the state, which would be needed for rigorous ground-truthing verification of the model predictions. We have assumed that the extensive resources required for such data collection are beyond the scope of this project. However, we do recommend future efforts by NCDEQ to conduct this type of verification, and we are prepared to develop a proposed approach and cost estimate for conducting a verification and error analysis if requested by NCDEQ.

Table 4.1 Estimated Costs by Task

Task	Task Name	Cost Estimate ($)
1	Mapping and identification of NC's wetlands and other NWLs	$695,000
2	Identification of NC wetlands losing federal and state protection in 2023	$250,000
3	Identification of NC wetlands and other NWLs most vulnerable to land use change	$125,000
4	Development of wetland function and ecosystem service indicators	$320,000
5	Modeling environmental impacts of wetland and NWL loss	$325,000
6	Modeling economic value and societal impacts of wetland and NWL loss	$265,000
7	Identification and analysis of policy alternatives	$150,000
	TOTAL	**$2,140,000**

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Van Houtven, G., Mansfield, C., Phaneuf, D. J., von Haefen, R., Milstead, B., Kenney, M. A., & Rechow, K. H. (2014). Combining expert elicitation and stated preference methods to value ecosystem services from improved lake water quality. *Ecological economics, 99*, 40-52.

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Appendix A: Resumes

ROBERT H. BEACH

Summary of Professional Experience

Robert Beach is an RTI Fellow and Director, Agricultural, Resource & Energy Economics and Policy, with more than 25 years of experience managing and conducting applied agricultural and natural resource management research. Dr. Beach specializes in the development and application of economic models to analyze agricultural, environmental, and natural resource regulations, programs, and policies. Research applications include studies evaluating the potential for and economic impacts of mitigating greenhouse gases from agriculture, forestry, and land use; low emissions development strategies; economic impacts of climate change and adaptation on health and agricultural productivity; risk management; the economic and environmental impacts of large-scale bioenergy production; land use change and associated greenhouse gas and other environmental and ecosystem impacts; and factors influencing forest investment and management. Dr. Beach recently led the RTI Grand Challenge effort focused on identifying changes in land cover and land use and improving agricultural resilience to climate change and food security through the use of remote sensing and machine learning. Dr. Beach is a member of the modeling teams contributing to the development, documentation, and application of the EcoShift model for downscaling projected land conversion; the Applied Dynamic Analysis of the Global Economy (ADAGE) model, which is a dynamic CGE model used for energy, environmental, and trade policy analysis; the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG); and the International Marginal Abatement Cost (IMAC) model.

Education

PhD, Economics, North Carolina State University, Raleigh, NC, 2000.
BSE, Biomedical Engineering with Economics minor, Duke University, Durham, NC, 1994.

Selected Professional Experience

1999 to date. RTI International, Research Triangle Park, NC. ***Fellow***, Food and Agriculture (2014 to date); ***Director***, Agricultural, Resource & Energy Economics and Policy (2012 to date); ***Senior Economist***, Environmental, Technology, and Energy Economics Program (2009 to 2012); ***Senior Economist***, Food and Agricultural Policy Research Program (2004 to 2009); ***Research Economist***, Environmental and Natural Resource Economics Program (1999 to 2004).

2016. International Institute for Applied Systems Analysis, Laxenberg, Austria. ***Visiting Scholar***, Ecosystem Services and Management.

2006 to date. North Carolina State University, Raleigh, NC. ***Adjunct Assistant Professor***, Department of Agricultural and Resource Economics.

Selected Project Experience

Economic Research Support (2024 to present)—*Principal Investigator*. Supporting The Nature Conservancy in assessing the economic impacts of conservation and clean energy projects, including exploration of land conversion and associated impacts on ecosystem services. Planning to assess the impacts of alternative dam water management strategies on surrounding land and ecosystem services.

Nature-Based Solutions Modeling for the Louisiana Watershed Initiative (2022-2024)—*Senior Advisor*. Led application of EcoShift model to downscale U.S. Forest Service projections of future land conversion between developed, agricultural, forest, and wetlands areas for the State of Louisiana under different scenarios. Also analyzed potential conversion of cropland between crops to inform estimation of potential irrigation water demand and nutrient application. Land cover and land use projections were used to inform estimates of implications for water quality and quantity as well as estimation of the spatial distribution of costs and benefits associated with alternative nature-based solutions.

Machine Learning for Projecting Land Conversion (2022 to present)—*Principal Investigator*. Leading an RTI effort to develop a model that can be used in conjunction with multiple large-scale economic models of agriculture, forestry, and land use to downscale their projections to a 30m x 30m resolution. Ecosystem benefits vary spatially so it is vital to increase the accuracy and resolution of projected land conversion in order to better assess the potential impacts and develop strategies for land management that consider costs and benefits associated with alternative management of highly disaggregated land areas.

Promoting Agricultural Resilience and Enhancing Food Security: Building Decision-Support Tools to Advance Sustainable and Cost-Effective Strategies (2018 to 2020)—*Principal Investigator*. Led RTI-funded Grand Challenge project that utilized remote-sensing data and developed machine learning algorithms for land classification. We applied our algorithms to estimate when crops were planted and harvested as well as crop type. This information was used to inform estimates of production at harvest and guide resource allocation and advance planning for addressing food security issues in Rwanda. We also assessed potential impacts of climate change on food production at a spatially disaggregated scale.

Selected Publications

Holt, J.R., S. Lee, G. Martin, C. Cowell, and R.H. Beach. (2023). Using Machine Learning to Downscale Projected Land Conversion: Application to Cropland Expansion into Endangered Species Habitats. 2023 Big Data Meets Survey Science (BigSurv), Quito, Ecuador. https://doi.org/10.1109/BigSurv59479.2023.10486653.

Lapidus, D., S. Zayed, M. Salem, R. Beach, and I. Ortiz-Monasterio. (2022). Environmental Benefits and Profitability of the GreenSeeker Handheld NDVI Sensor: Evidence from Mexico. Precision Agriculture 23: 2388–2406. https://doi.org/10.1007/s11119-022-09925-z

Ren, S., J. Malof, T.R. Fetter, R. Beach, J. Rineer, and K. Bradbury. (2022). Utilizing geospatial data for assessing energy security: Mapping small solar home systems using unmanned aerial vehicles and deep learning. ISPRS International Journal of Geo-Information 11(4):222. https://doi.org/10.3390/ijgi11040222

Roe, S., Streck, C., Beach, R., et al. (2021). Land-based measures to mitigate climate change: potential and feasibility by country. *Global Change Biology* 27(23): 6025–6058. https://onlinelibrary.wiley.com/doi/10.1111/gcb.15873

Austin, K., R. Beach, D. Lapidus, M. Salem, N. Taylor, M. Knudsen, and N. Ujeneza. (2020). Impacts of climate change on the potential productivity of eleven staple crops in Rwanda. Sustainability 2020, 12(10), 4116. https://doi.org/10.3390/su12104116.

Chew, R., J. Rineer, R. Beach, M. O'Neil, N. Ujeneza, D. Lapidus, T. Miano, M. Hegarty-Craver, J. Polly, and D.S. Temple. (2020). Deep Neural Networks and Transfer Learning for Food Crop Identification in UAV Images. Drones 4(1), 7. https://doi.org/10.3390/drones4010007.

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Beach, R. H., Cai, Y., Thomson, A., Zhang, X., Jones, R., McCarl, B. A., et al. (2015). Climate change impacts on US agriculture and forestry: benefits of global climate stabilization. *Environmental Research Letters* 10 (2015) 095004 http://dx.doi.org/10.1088/1748-9326/10/9/095004

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EXPERIENCE

2015 – Present – Co Founder / Chief Technology Officer
Skytec LLC – Unmanned Aerial System Mapping, Satellite Remote Monitoring, and GIS Consultancy

- Lead development and operations for all geospatial and remote sensing activities and services at Skytec
- Recently served as Principal Technical Project Lead for TN Wetland Mapping project with focus on cloud systems architecture, deployment, and management and geospatial AI research, development, and production.
- Recently served as Lead Consultant and Project Manager for satellite remote monitoring for Tennessee Valley Authority transmission siting and Right-of-Way vegetation management projects
- Recently served as Lead Consultant and Project Manager for International Paper's development of an Enterprise GIS Fiber Supply Risk Assessment system: ForSite

5/2013 – 04/2018 – Founding Director
The University of Tennessee at Chattanooga, Interdisciplinary Geospatial Technology Lab (IGTLab)
2008 – 4/2018 - Adjunct Graduate Faculty
The University of Tennessee at Chattanooga, Department of Biological and Environmental Sciences
3/2011 – 04/2013 – **Co Founder**
Second|Site LLC – Augmented Reality Software Development Firm
4/2003 – 04/2013 – GIS Manager
The University of Tennessee at Chattanooga, Academic and Research Computing Services (ARCS)
3/2002 – 3/2003 – Project Manager
Tennessee Department of Environment and Conservation – Division of Superfund

EDUCATION

5/2002 University of Tennessee at Chattanooga
Master of Science in Environmental Science
5/2000 Furman University
Bachelor of Science in Earth and Environmental Sciences

AFFILIATIONS, LICENSURES, and Certifications

- *10/2016 – Present* FAA Part 107 sUAS Pilot license
- *03/2008 – Present* Certified Geographic Information Systems Professional (GISP)
- *08/2004 – Present* Member of the Society for Conservation GIS
- *06/2002 – Present* Licensed Professional Geologist – TN 00004702
- *06/2001 – Present* Member of the Tennessee Geographic Information Council
- *11/2019 – Present* Board of Trustees of the Lyndhurst Foundation

AWARDS and HONORS

- Awarded with Special Achievement in GIS at the ESRI International User Conference, July 2024 for work building International Paper's Fiber Supply and Risk Mitigation Enterprise GIS System: ForSite.
- Served as Co-Principal Investigator for THEC EXCEL STEM project, award $73,991, January 2017
- Served as Co-Principal Investigator for Cumberland Trail Conference project, award $68,267, August 2016
- Awarded $19,966 to serve as Principal Investigator for Land Trust for TN. conservation planning tool project, April 2016
- Awarded $90,000 to serve as Principal Investigator for Tennessee Valley Authority Blueways mapping initiative, April 2015
- Awarded $300,000 to serve as Principal Investigator for development of Interdisciplinary Geospatial Technology Lab by Lyndhurst Foundation, March 2015
- Awarded $75,000 to serve as Principal Investigator for regional planning and mapping support initiative funded the Benwood and Lyndhurst Foundations of Chattanooga, TN, July 2013
- Awarded $25,000 to serve as Principal Investigator for creation of GIS decision support software by the Lyndhurst Foundation of Chattanooga, TN, June 2012
- Awarded $50,000 to serve as Principal Investigator for "Regional Resource Inventory" project by the Lyndhurst Foundation of Chattanooga, TN, June 2011
- 2006 – Awarded $149,875 to serve as Co-Principal Investigator for bioinformatics research by National Biological Information Infrastructure
- Invited to study at the Global Biodiversity Information Framework-HerpNET International Georeferencing Workshop at Tervuren, Belgium, December 2006.
- Awarded a letter of commendation in September of 2002 from the Commissioner of the Tennessee Department of Environment and Conservation for the development of a GIS and Remote Sensing based environmental screening tool for remediation efforts at the Volunteer Army Ammunition Plant
- Honored with the 2001-2002 University of Tennessee at Chattanooga, Outstanding Graduate Student Award for Environmental Sciences

PUBLICATIONS

- Cartographer for "Cook, Joe. Ocmulgee River User's Guide. Athens, GA, University of Georgia Press,2021." 2019."
- Cartographer for "Cook, Joe. Oconee River User's Guide. Athens, GA, University of Georgia Press, 2019."
- Hunt, N., Carroll, A. and Wilson, T.P. (2018) Spatiotemporal Analysis and Predictive Modeling of Rabies in Tennessee. Journal of Geographic Information System, 10, 89-110. doi: 10.4236/jgis.2018.101004.
- Cartographer for "Cook, Joe. Flint River User's Guide. Athens, GA, University of Georgia Press, 2017."
- Cartographer for "Cook, Joe. Broad River User's Guide. Athens, GA, University of Georgia Press, 2015."
- Cartographer for "Cook, Joe. Chattahoochee River User's Guide. Athens, GA, University of Georgia Press, 2014."
- Cartographer for "Cook, Joe. Etowah River User's Guide. Athens, GA. University of Georgia Press, 2013."
- Cartographer and contributing analyst for "Cumberland Voices: A Conservation Vision for the South Cumberland Region" Sewanee Environmental Institute, 2011.
- Miller R. J., Carroll A.D., Wilson T.P., Shaw J., 2009, Spatiotemporal Analysis of Three Common Wetland Invasive Plant Species Using Herbarium Specimens and Geographic Information Systems: Castanea, vol. 74 iss. 2, pp. 133-145.
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(a) PROFESSIONAL PREPARATION

William and Mary, Williamsburg VA	Environmental Science English (Double Major)	B.A., 2007
Virginia Institute of Marine Science, Gloucester Point, VA	Marine Science	M.S., 2013
Florida International University, Miami FL	Biology	Ph.D., 2018
Florida International University, Miami FL	Biology	Postdoc, 2019-2020
East Carolina University, Wanchese, NC	Coastal Studies	Postdoc, 2020-2024

(b) PROFESSIONAL APPOINTMENTS

2024-present	Assistant Research Professor, East Carolina University, Wanchese, NC
2020–2024	Postdoctoral Research Associate, East Carolina University, Wanchese, NC
2018–2020	Post-doctoral Research Associate, Florida International University, Miami, FL
2013–2018	Graduate Research and teaching Assistant, Florida International University, Miami, FL.
2010-2013	Graduate Research Assistant, Virginia Institute of Marine Science, Gloucester Point, VA.

(c) PRODUCTS

1. Sloey, T. M., **Charles, S. P**., Xiong, L., Castañeda-Moya, E., Yando, E. S., & Lagomasino, D. (2024). Challenges to and importance of considering early and intermediate ontogenetic stages in mangrove forest recovery and restoration. *Marine Pollution Bulletin*, *209*, 117287.
2. **Charles, S. P.**, Kominoski, J., Troxler T. G., Gaiser, E., Servais, S., Wilson, B., Davis,S. E., Sklar, F., Coronado-Molina, C., Madden, C.J., Kelly, S, Rudnick, D. T. 2019. Experimental saltwater intrusion drives rapid soil elevation loss and long-term reduction in carbon accumulation in coastal wetlands. *Estuaries and Coasts*, 42 (7), 1868-1881.
3. **Charles, S. P.**, J. S. Kominoski, A. R. Armitage, C. Weaver, H. Guo, S. C. Pennings. 2020. Mangroves increase organic carbon storage in an experimental marsh-mangrove gradient despite reduced marine subsidies. *Ecology*, 101 (2), e02916.
4. Poulter, B., F. Adams, C. Amaral, A. Campbell, **S. P. Charles**, R. Roman-Cuesta, E. Delaria, C. Doughty, T. Fatoyinbo, J. Gewirtzman, T. F. Hanisco, D. Lagomasino, L. Lait, S Malone, P. Newman, P. Raymond, J. Rosentreter, N. Thomas, G. M. Wolfe, L. Xiong, Q. Ying, Z. Zhang. 2022. Multi-scale observations of mangrove blue carbon fluxes; the NASA Carbon Monitoring System BlueFlux field campaign. Accepted. *Environmental Research Letters*.
5. Amaral, C., Poulter, B., Lagomasino, D., Fatoyinbo, T., Taillie, P., Lizcano, G., Canty, S.,

Silveira, J.A.H., Teutli-Hernández, C., Cifuentes-Jara, M. and **Charles, S.P**., 2023. Drivers of mangrove vulnerability and resilience to tropical cyclones in the North Atlantic Basin. *Science of The Total Environment*, *898*

6. Xiong, L., Lagomasino, D., **Charles, S.P**., Castañeda-Moya, E., Cook, B.D., Redwine, J. and Fatoyinbo, L., 2022. Quantifying mangrove canopy regrowth and recovery after Hurricane Irma with large-scale repeat airborne lidar in the Florida Everglades. *International Journal of Applied Earth Observation and Geoinformation*.
7. Ishtiaq, K. S., Troxler, T. G., Lamb-Wotton, L., Wilson, B. J., **Charles, S. P**., Davis, S. E., ... & Sklar, F. H. (2022). Modeling net ecosystem carbon balance and loss in coastal wetlands exposed to sea-level rise and saltwater intrusion. *Ecological Applications*, 32(8), e2702.
8. Campbell, A. D., Fatoyinbo, T., **Charles, S. P.**, Bourgeau-Chavez, L. L., Goes, J., Gomes, H., ... & Lagomasino, D. (2022). A review of carbon monitoring in wet carbon systems using remote sensing. *Environmental Research Letters*, *17*(2), 025009.
9. Wilson, B. J., S. Servais, **S. P. Charles**, V. Mazzei, J. S. Kominoski, E. Gaiser, J. Richards, T. Troxler. 2019. Phosphorus alleviation of salinity stress: effects of saltwater intrusion on an Everglades Freshwater peat marsh. *Ecology*, 100 (5). https://doi.org/10.1002/ecy.2672
10. Servais, S., J. S. Kominoski, **S. P. Charles**, E. E. Gaiser, V. Mazzei, T. G. Troxler, B. J. Wilson. 2019. Saltwater intrusion and soil carbon loss: Testing effects of salinity and phosphorus loading on microbial functions in experimental freshwater wetlands. *Geoderma*, 337: 1291-1300.

(e) ARCHIVED DATASETS

1. Khandker S. Ishtiaq, Troxler, T., Lamb-Wotton, L., Wilson, B., **Charles, S.P.**, Stephen E. Davis, John S. Kominoski, David T. Rudnick, and Fred H. Sklar. 2022. Modeling net ecosystem carbon balance and loss in coastal wetlands exposed to sea level rise and saltwater intrusion. *Ecological Applications.* e2702
2. Kuhn, L. A., J. S. Kominoski, A. R. Armitage, **S. P. Charles**, S. C. Pennings. C. A. Weaver, T. R. Maddox. 2021. Hidden hurricane legacies; elevated sulfide and decreased root biomass in coastal wetlands. *Ecosphere,* 12 (8), e03674.
3. Wilson, B. J., S. Servais, **S. P. Charles**, V. Mazzei, J. S. Kominoski, E. Gaiser, J. Richards, T. Troxler. 2019. Phosphorus alleviation of salinity stress: effects of saltwater intrusion on an Everglades Freshwater peat marsh. *Ecology*, 100 (5). https://doi.org/10.1002/ecy.2672

MICHAEL CROUCH

Summary of Professional Experience

Michael Crouch, a senior water resources engineer at RTI International, has more than 20 years of experience in the water resources field. He is particularly adept at flood and hydraulic modeling, in particular, for damage estimation, including direct and indirect economic losses. Through his career, Mr. Crouch has performed and or managed nearly 200 hydraulic modeling studies for various federal agencies and power companies. Mr. Crouch has been extensively involved with RTI's support of the Tennessee Valley Authority's downstream consequences assessments since 2014 and helped to transition the program into use of the US Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Flood Impact Analysis (FIA) software for the Pickwick Landing Dam risk project and more recently into the HEC-LifeSim framework. Michael has extensive experience working with the USACE and provided project management and technical guidance for the USACE's Modeling, Mapping, and Consequences (MMC) Production Center's modeling efforts, which recently has included Probable Maximum Flood studies for Stockton and Truman Dams and support for the Rogue, Boise, and Willow Creek Basin Corps Water Management System (CWMS) models in Oregon and Idaho.

Education

MS, Environmental Engineering, Concentration in Water Resources, University of Tennessee, Knoxville, TN, 2004.
BS, Civil Engineering, University of Tennessee, Knoxville, TN, 2002.

Certifications and Licenses

Professional Engineer, #00110838, 2007
Certified Floodplain Manager, #US-08-03454, 2008

Selected Project Experience

TVA Dam Major Modification Consequences Support (2023 to date)—*Project Manager/Technical Lead.* RTI supported TVA's major modification studies for two dams that are currently in the planning process for risk reduction measures. A risk-informed approach is being utilized to determine the most appropriate structural measures that can be implemented to reduce risk for each of the dams. RTI developed LifeSim consequences models to reflect the future without action condition (FWAC) that included development of a future structure inventory based on EPA ICLUS land use data and population projections. HEC-RAS and LifeSim simulations were also developed to support the risk modeling representing the implementation of each of the modification alternatives.

TVA HEC-RAS FY23 Downstream Consequences Assessments (2022 to 2023)—*Project Manager/ Technical Lead.* RTI supported TVA in development of HEC-RAS and HEC-LifeSim models for their downstream consequences assessments completed in FY 2023. RTI created HEC-RAS and LifeSim models to support the Tims Ford, Norris, Melton Hill, and Beaver Creek risk assessments under tight deadlines. Managed the modeling efforts and provided technical direction and model review for the HEC-RAS and LifeSim models.

TVA Rapid Inundation Mapping Tool Support (2021 to 2023)—*Project Manager/Technical Lead.* Under this task order RTI supported TVA in development of inputs for the USACE Rapid Inundation Mapping tool. Managed RTI staff and provided technical guidance in hydraulic model updates and creation of inundation grids for reaches within the Tennessee River Valley.

Idaho National Labs Flood Hazards Assessment (2021 to 2023)—*Technical Lead.* RTI worked with Idaho National Labs to combine a hydrologic and two-dimensional hydraulic routing model to determine frequency-based flood depths on the site of the Advanced Test Reactor. Precipitation frequency estimates and temporal patterns were combined with distributions of potential hydrologic parameters to determine the precipitation excess on the site. A 2D hydraulic model grid embedded within the HEC-HMS model was used to route flow overland and determine the return frequency for a range of flood depths at each critical location. Provided technical guidance on the hydraulic model development, software validation and verification plan and performed model review and documentation consistent with Department of Energy nuclear regulation.

U.S. Army Corps of Engineers Missouri River Flow Frequency Update (2021 to 2022)—*Project Manager.* For the USACE update to the Missouri River flow frequency analysis, RTI was tasked with facilitating the technical review group (TRG), providing technical review of data and modeling products. Managed the project and provided the TRG with a SharePoint platform to access pertinent data and provided feedback as necessary. Also, coordinated review of models and data with RTI staff and created summary reports.

Chesapeake Bay Trust BMP Flood Damage Reduction Study, VA (2019 to 2020)—*Senior Flood Consequences Modeling Lead*. The focus of this project was to develop a methodology that could be used to estimate annualized flood damage reduction estimates due to implementation of green infrastructure best management practices in the Chesapeake Bay watershed. To estimate reduction in flow output from the Chesapeake Bay watershed, an HSPF model was used to determine runoff reductions based on a variety of hypothetical land use change. The resulting flow estimates were input into HEC-RAS hydraulic models to analyze reductions in flood extent and depth. FEMA Hazus depth damage relationships were then applied estimate damage reduction at flood prone structures.

Presentations and Proceedings

Van Houtven, G. L., Decker, E. C., Crouch, M. M., Pickering, C., & Angelis, L. (2024). *Value of information and the benefits of flood forecasts: A case study of Saint Paul, Minnesota*. Paper presented at American Geophysical Union 2024, Washington, DC.

Crouch, M. (2018). *Mactaquac Loss of Life Assessment Case Study*. Presented at the 2018 Dam Failure Life Loss Consequences Workshop, Toronto, ON.

Crouch, M., Srivastava, A., & Ruark, M. (2017). Consequence estimation for a large system of dams: Our experiences from TVA projects. In *United States Society on Dams* (pp. 219-231), proceedings of the 37th USSD Annual Meeting and Conference, Anaheim, CA.

Crouch, M. (2017, April). *Consequence estimation for a large system of dams: Our experience from TVA projects.* Presented at the 2017 United States Society of Dams Conference, Anaheim, CA.

Crouch, M. (2015). *Recognizing uncertainty for a dam breach analysis*. Presented at the 2015 Fall Conference of the Association of State Dam Safety Officials, New Orleans, LA.

Crouch, M. (2013). *Measuring loss of life: Are more standards necessary for a highly detailed approach?* Presented at the Fall Conference of the Association of State Dam Safety Officials, Providence, RI.

MICHELE C. EDDY

Summary of Professional Experience

Michele Eddy has more than 20 years of experience designing, creating, and using watershed and water quality models and database systems to manage and examine water quality data. Ms. Eddy has managed projects and served as the key technical lead on several high-visibility projects for the U.S. Environmental Protection Agency (EPA). Her work generally focuses on the development, analysis, and application of spatially based watershed models for watershed management, ecological and climatological analyses, and investigation of policy initiatives. She leads the research and development of RTI's Watershed Flow and ALLocation modeling system (WaterFALL®), a modeling framework used to support water use and allocation and benefits of nature-based solutions during times of changing climate and landscapes. Ms. Eddy is an expert in the use of the enhanced National Hydrography Dataset Plus (NHDPlus) for domestic applications of watershed analysis. In recent work, Ms. Eddy has developed frameworks that allow stakeholders to harness watershed modeling data for decision making, such as prioritizing conservation action and developing ecological flow relationships for setting water use regulations. In past work, she led the development of total maximum daily loads (TMDLs) for a number of waterbodies and impairments. She has also authored, reviewed, or amended Quality Assurance Project Plans (QAPPs) for many projects focusing on the topics of secondary data use, environmental modeling, and geospatial processing of data. Ms. Eddy has authored or coauthored several peer-reviewed journal articles.

Education

MS, Environmental and Water Resources Engineering, Tufts University, Medford, MA, 2005.
BS, Environmental Engineering, Tufts University, Medford, MA, 2003. Graduated summa cum laude.

Selected Project Experience

Wake County One Water Plan (2022 to date)—*Project Manager and Technical Leader*. Working on a multi-company team to develop a One Water Plan for Wake County, North Carolina. Conducts project management activities for RTI's portion of the project, which includes schedule and budget monitoring, monthly reporting, and leading RTI's technical contributions. Facilitated sessions at a visioning summit to bring together stakeholders from multiple agencies and organizations across the county. Summarized findings from summit sessions and contributed to a report on the One Water Vision. Leading the development of a watershed modeling assessment for current and projected future climate and land use conditions examining water quantity (i.e., flooding timing, location, and magnitude) and water quality (sediment, nitrogen, and phosphorus) loadings. Gathering water quality observations and datasets that characterize loading sources and magnitudes to configure model inputs and establish calibration and validation locations. Upon completion of the initial modeling scenarios, will participate in workshops with stakeholders to develop management strategies to simulate within the model to project changes to water quantity and quality. Developing initial modeling report and will contribute to future reports.

Nature-Based Solutions (NBS) Explorer (2021 to date)—*Project Manager and Technical Leader*. Developed project framework and assessment methodology. Led/leads virtual meetings and webinars to review framework and receive feedback from regional watershed coordinators and subject matter experts. Guiding geospatial analysis to develop opportunity maps for various NBS. Developing modeling methods to assess NBS within watershed context for water quantity and quality impacts. Leading a team of data analysts and modelers to create modeling inputs from geospatial and observed data related to watershed characteristics and water quality. Collaborating with economists to examine economic and social metrics that can be evaluated in relation to water quantity and quality changes. Coordinating virtual meetings, including content, attendees, and feedback mechanisms. Completed reports and technical memos documenting findings and task progress for Phases 1 through 4. Phase 5 will include public release of the NBS Explorer.

Assessing Community Vulnerability to Pollutant Releases Due to Extreme Events (2016 to 2023)—*Data Analyst*. Excessive heat, prolonged droughts, extreme floods, and wildfires affect communities directly and indirectly through impacts to infrastructure and the surrounding landscape. Participates on a multidisciplinary team involving EPA's Office of Research and Development and Office of Land and Emergency Management and RTI to develop a method to assess potential vulnerability to contaminants from the impacts of extreme events. Develops indicators related to surface water vulnerabilities during floods and droughts. Coordinates with geospatial analysts to produce indicator values and maps. Creates data processing algorithms of downscaled climate model output to calculate various precipitation-related and drought indicators for consideration by EPA.

Catawba-Wateree Integrated Water Resources Plan (IWRP) (2021 to Present)—*Project Manager and Technical Leader*. The IWRP is intended to represent the holistic and integrated focus of long-term planning for water quantity and quality for multiple uses of the water resources throughout the Basin. Year 1: Managed investigation into different water quality topics to scope water quality assessment for IWRP and coordinated selection of future scenarios. Year 2: Guided WaterFALL modeling update of past model inputs and calibration data. Prepared baseline model scenario. Performed QC on model inputs and outputs. Documented model performance. Documented further research into final approaches for water quality topics to be quantified and qualified. Year 3: Engaged with the Stakeholder Advisory Team to obtain feedback on model inputs, scenario assumptions, and presentation of results. Model analysis of nutrient and sediment loading hot spots and changes expected due to climate and land use change. Developed management scenarios for conservation of natural lands, preservation of agriculture, and extended use of riparian buffers. Year 4: Finalizing modeling and analysis. Drafting IWRP document chapters on water quantity and quality findings. Managing all aspects of the project for RTI.

Professional Experience

2005 to date. RTI International, Research Triangle Park, NC. ***Senior Research Environmental Engineer***.

2002 to 2005. Tufts University, Medford, MA. ***Research Assistant for Nutrient Project***, Civil and Environmental Engineering Department.

Selected Peer-Reviewed Publications

Eddy, M. C., Lord, B., Perrot, D., Bower, L. M., & Peoples, B. K. (2022). Predictability of flow metrics calculated using a distributed hydrologic model across ecoregions and stream classes: Implications for developing flow–ecology relationships. *Ecohydrology*, *15*(2), e2387.

Eddy, M., Van Houtven, G., Lord, B., van Werkhoven, K., Serago, J., & Kovach, S. (2019). *Quantifying the potential benefits of land conservation on water supply to optimize return on investments*. Prepared for the Water Research Foundation. https://www.waterrf.org/research/projects/quantifying-potential-benefits-land-conservation-water-supply-optimize-return

Eddy, M. C., Moreda, F. G., Dykes, R. M., Bergenroth, B., Parks, A., & Rineer, J. (2017). The Watershed Flow and Allocation Model: An NHDPlus-based watershed modeling approach for multiple scales and conditions. *Journal of the American Water Resources Association*, *53*(1), 6–29.

Phelan, J. N., Cuffney, T., Patterson, L., Eddy, M. C., Dykes, R. M., Pearsall, S., ... Tarver, F. (2017). Fish and invertebrate flow-biology relationships to support the determination of ecological flows for North Carolina. *Journal of the American Water Resources Association*, *53*(1), 42–55.

Caldwell P. V., Kennen, J. G., Sun, G., Kiang, J. E., Butcher, J. B., Eddy, M. C., … McNulty, S. G. (2015). A comparison of hydrologic models for ecological flows and water availability. *Ecohydrology*, *8*(8), 1525-1546.

Chris A. Fleming

Asheville, NC
candrewfleming@gmail.com
615.294.2556

Chris Fleming is an ecologist with over two decades of experience in the environmental consulting industry. His professional experience includes water resource documentation and permitting, rare species surveys and reporting, water quality monitoring, Environmental Site Assessments, groundwater contamination, and remediation. The use of GIS and GPS technologies have been integral tools in all facets of his academic and professional careers. His consulting experience includes extensive collaboration with municipal, state, and federal agencies on behalf of clients. His professional expertise resulted in his selection for technical guidance committees overseen by regulatory agencies and enabled him to lead workshops and panel discussions on topics such as plant identification and the use of field and geospatial applications in the consulting industry.

Education:

- BA Biology, Berea College, 1999
- MS Botany, University of Tennessee, 2003

Award:

- Thomas J. Watson Fellow, 1999

Additional Training:

- USACE Wetland Delineation Training
- Eastern Bat Acoustic Field Techniques Workshop
- NC State Stream Morphology Assessment Training
- NC State Natural Channel Design Principals

Experience:

Skytec LLC – Senior Solutions Engineer
(Dec 2023 – Present)
Provide SME for strategic industry alignment, business development, product development, and industry marketing strategy.

Ecobot - Senior Solutions Engineer
(Feb 2023 – Sep 2023)
Provide SME for strategic industry alignment, business development, product development, and industry marketing strategy.

Davey Resource Group - Principal Consultant
(Jul 2022 – Feb 2023)
Performed consulting and managerial activities to facilitate the transition of BDY Environmental LLC to DRG post-acquisition. This role also included human resource, project management, and marketing activities to promote the seamless transition.

BDY Environmental LLC
Senior Scientist/Co-owner (Jun 2007 – Jul 2022)
In addition to performing environmental consulting tasks (see below), co-ownership required a more intensive focus on the aspects of business management. This included client development, development of business strategies based on market demands, high-profile project management, and identification and participation in the hiring of skilled personnel to expand the team and business services.

Professional development included understanding evolving regulatory requirements, participating on technical guidance committees, attendance of appropriate training programs, and obtaining relevant permits/certifications.

This role culminated in the sale of the firm to Davey Resource Group in July 2022.

BDY Environmental LLC
Staff Scientist (Sep 2003- Jun 2007)
This role included field environmental data collection, data analysis, and preparation of permit applications and reports for clients and regulatory agencies. Represented clients as part of public forums and hearings associated with zoning or regulatory matters. Applied GIS included cartography, geodatabase management, and spatial analysis.

Representative Skills:

Regulatory Experience:
- Aquatic resource permitting (Sections 401/404/10)
- Section 7 Consultation for rare species
- Municipal/County stormwater variances
- NEPA

Ecological Knowledge:
- Jurisdictional determinations of aquatic resources
- Stream morphology assessments
- Ecological restoration
- Groundwater sampling & remediation
- Species identification and monitoring

Technical Skills:
- ArcGIS (desktop, field, and web-based applications)
- Geodatabase Design (mobile & enterprise)
- Spatial Analysis and Modeling, including 3D

Publications:

Ecobot (C. Fleming primary author), 2023. How does SCOTUS' Sackett v. EPA Decision Affect You? A Supreme Court ruling has once again changed the definition of Waters of the United States (WOTUS). What does it mean this time around?
< https://storymaps.arcgis.com/stories/b8a68e789e4d45a5af8483b7053ec20c>

Tennessee Flora Committee (Member of). 2015. Guide to the Vascular Plants of Tennessee. The University of Tennessee Press.

Estes, D., C. Fleming, A. Fowler, and N. Parker. 2010. Status of monoecious *Hydrilla verticillata* in the Emory River Watershed, Tennessee.

Estes, D. and C. Fleming. 2006. *Clematis morefieldii* (Ranunculaceae) new to Tennessee. Sida 22(1):821-824.

Thompson, R.L. and C.A. Fleming. 2004. Vascular flora and plant communities of the John B. Stephenson Memorial Forest State Nature Preserve (Anglin Falls Ravine), Rockcastle County, Kentucky. Castanea 69:125-138.

Fleming, C.A. and B.E. Wofford. 2004. The vascular flora of Fall Creek Falls State Park, Van Buren and Bledsoe Counties, Tennessee. Castanea 69:164-184.

Presentations:

Fleming, C.A. (Moderator). Optimizing Data Management on a Statewide Energy Program with Technology. Georgia Environmental Conference, Jekyll Island, GA. August 23, 2023.

Fleming, C.A. (Moderator). Adoption of Technology to Streamline Successful Wetland Mitigation Efforts. National Mitigation & Environmental Markets Conference, Jacksonville, FL, May 10, 2023.

Fleming, C.A. and S. Samoray. Environmental for Planners, Tennessee Chapter American Planning Association, Franklin, TN. October 10, 2019.

Fleming, C.A. Guide to the Vascular Plants of Tennessee. Southern Festival of Books, Nashville, TN, October 9, 2015.

Workshops:

Fleming, C.A. (Instructor). Applied Technology, Field & Geospatial Applications and Tools for More Efficient Wetland Assessments, Monitoring, and Delineations. Society of Wetland Scientists 2023 Annual Meeting, Spokane, WA, June 27, 2023.

Hamilton Biographical Sketch

Stuart E. Hamilton, Ph.D.
Professor, Department of Coastal Studies
Greenville, NC 27858
Tel.: 252-328-6220
E-mail: hamiltons22@ecu.edu

A. PROFESSIONAL PREPARATION

2011	Ph.D. Geography *University of Southern Mississippi*
2003	M.A. Geography *State University of NY at Buffalo*
1988	B.S. Geography *Canterbury Christ Church College*

B. APPOINTMENTS

Professor, Department of Department of Coastal Studies, East Carolina University, 8/2022 – present.
Senior Scientist, Coastal Studies Institute, Wanchese, North Carlina, 8/2022 – present.
GIS Graduate Director, Depart. of Geography & Geoscience, Salisbury University, 8/2016 – 6/2/2022.
Associate Research Professor, Department of Geology, College of William and Mary, 8/2010 - 8/2014.
GIS Program Director, Center for Geospatial Analysis, College of William and Mary, 7/2008 - 8/2014.
GIS Coordinator, GeoData Center, University of West Florida, 2003 – 2008.
Field Analyst, Navteq, 1999 – 2003.

C. PRODUCTS

C1. PRODUCTS MOST CLOSELY RELATED TO THE PROPOSED PROJECT

1. Hancock, G., *Hamilton*, S. E., Stone, M., Kaste, J., & Lovette, J. (2015). A GIS and Lidar-based Methodology to Identify Locations of Concentrated Flow and Riparian Buffer Bypassing on Agricultural Fields. Journal of the American Water Resources Association (JAWRA), 51(6),1613-1625, IF 2.07.
2. Lovette, J., Stone, M., Shintani, C. Hancock, G. & *Hamilton*, S. E. (11/2013). Utilization of high-resolution lidar to assess flow accumulation through agricultural riparian buffers within the Virginia coastal plain. Southeastern Division AAG, Roanoke, VA (peer-reviewed, presented by Lovette). http://dx.doi.org/10.13140/2.1.23s1.9683.
3. *Hamilton*, S. E., et al. (5/2014). Buffer Bypassing in Agricultural Runoff. Keynote Speaker. Virginia Association of Wetland Professionals, Richmond, VA (invited and funded).
4. *Hamilton* S.E., et al (2022) High-resolution bathymetries and shorelines for the Great Lakes of the White Nile basin. Scientific Data, 9(642), IF5 11.211.
5. *Hamilton*, S. E. & Casey, D. (2016). Creation of a high spatiotemporal resolution global database of continuous mangrove forest cover for the 21st Century (CGMFC-21). Global Ecology and Biogeography, 25(6), 729-738, IF5 7.18.

C2. OTHER SIGNIFICANT PRODUCTS

1. *Hamilton*, S.E. (2020) Mangroves and Aquaculture: A Fifty-Year Remote Sensing Analysis of Ecuador's Estuarine Environments. Coastal Research Library (COASTALRL) Vol 33, Springer

Nature. ISBN 303022239X & 9783030222390, (pp. 1-195) https://www.springer.com/gp/book/9783030222390.

2. *Hamilton*, S.E, Castellanos, G., Millones, M., Chen, M. (3/2018). Remote Sensing of Mangrove Forests: Current Techniques and Existing Databases. In Makowski, C., & Finkl, C. W. (Eds.), Threats to Mangrove Forests: Hazard, Vulnerability, and Management., Coastal Research Library (COASTALRL) Vol 25, ISBN 978-3-319-73016-5, Springer Nature, Cham, Switzerland, Book Chapter. doi: 10.1007/978-3-319-73016-5_22 (Chapter 22, pp. 497-520).
3. *Hamilton, S.E.*, Gallo, S. M., Krach, N., Nyamweya, C. S., Okechi, J. K., Aura, C., ... & Kaufman, L. (2020). The use of unmanned aircraft systems and high-resolution satellite imagery to monitor tilapia fish-cage aquaculture expansion in Lake Victoria, Kenya. Bulletin of Marine Science, 96(1), 71-93. IF 2.263.
4. Friess D.A., Rogers K., Lovelock C., & *Hamilton S. E.* et al. (2019). Mangrove deforestation in the 20th Century. The past, present, and future state of the world's mangrove forests. Annual Review of Environment and Resources, 44, 89-115. IF 8.065.
5. Lee, S.Y., *Hamilton, S.E.*, Barbier, E.B., Primavera, J., & Lewis III, R.R.. (2019). Conservation of mangrove ecosystems requires sound restoration policies: Nature Ecology & Evolution, 3, 870-887 IF 12.54.
6. Barbier E., Hochard, J.P., & *Hamilton* S. E**.** (2019). Mangroves Shelter Coastal Economic Activity from Cyclones. Proceedings of the National Academy of Sciences, 16(25), 12232-12237. IF 9.504.
7. *Hamilton*, S.E. & Friess, D. A. (2018). Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012. Nature Climate Change (NCC), 8, 240-244 (2018). IF5 21.108.
8. *Hamilton*, S. E., Lovette, J., Borbor-Cordova, M. J., & Millones, M. M. (2017). The Carbon Holdings of Northern Ecuador's Mangrove Forests. Annals of the Association of American Geographers, 1107(1), 54-71. IF5 5.02.

D. SYNERGISTIC ACTIVITIES

1. Chair of East Carolina Universities Coastal Studies Department. Responsible for the operation and oversight of an academic department.
2. Salisbury University GIS Graduate Program Director, Responsible for operation and oversight of an academic program.
3. GIS Program Director, Center for Geospatial Analysis, The College of William and Mary. Responsible for operation and oversight of an academic program and research center.
4. Frontiers in Forests and Global Change, Review Editor, Frontiers, 2018 – present.
5. 4-Open Editorial, Editorial Board Member, EDP Open Access, 2017 – present.

LEILA HASHEMI-BENI

Associate Professor, Director of Geospatial and Remote Sensing Research Laboratory, and Graduate Coordinator for Geomatics Program, Department of Built Environment, College of Science and Technology, North Carolina Agriculture and Technology State University

Co-Chair, WG I/4 - LiDAR, Laser Altimetry and Sensor Integration

International Society of Photogrammetry and Remote Sensing

Member of Center for Intelligent Water Resources Engineering (Michigan State University)

EDUCATION

Ph.D., Geomatics (Geographic Information Science), Department of Geomatics Science, Laval University, Canada (2005-2009)

M.Sc. in Civil-Surveying Engineering (Photogrammetry and Remote Sensing), Department of Geomatics Engineering, College of Engineering, University of Tehran, Iran (1998-2001)

B.Sc. in Civil-Surveying Engineering, Department of Geomatics Engineering, College of Engineering, University of Isfahan, Iran (1994-1998)

REFEREED ARTICLES

Hashemi-Beni, L., Puthenparampil, M., & Jamali, A. (2024). A low-cost IoT-based deep learning method of water gauge measurement for flood monitoring. Geomatics, Natural Hazards and Risk, 15(1), 2364777.

Agboola, G., Beni, L. H., Elbayoumi, T., & Thompson, G. (2024). Optimizing landslide susceptibility mapping using machine learning and geospatial techniques. Ecological Informatics, 81, 102583.

Wasehun, E. T., Hashemi Beni, L., & Di Vittorio, C. A. (2024). UAV and satellite remote sensing for inland water quality assessments: a literature review. Environmental Monitoring and Assessment, 196(3), 277.

Jamali, A., Roy, S. K., Beni, L. H., Pradhan, B., Li, J., & Ghamisi, P. (2024). Residual wave vision U-Net for flood mapping using dual polarization Sentinel-1 SAR imagery. International Journal of Applied Earth Observation and Geoinformation, 127, 103662.

Dorbu, F., & Hashemi-Beni, L. (2024). Detection of Individual Corn Crop and Canopy Delineation from Unmanned Aerial Vehicle Imagery. Remote Sensing, 16(14), 2679.

Anokye, M., Fawakherji, M., & Hashemi-Beni, L. (2024, July). Flood Resilience Through Advanced Wetland Prediction. In IGARSS 2024-2024 IEEE International Geoscience and Remote Sensing Symposium (pp. 5516-5520). IEEE.

Agboola, G., & Beni, L. H. (2024, July). Geospatial Insights: Unraveling Howard Landslide Suspectibility. In IGARSS 2024-2024 IEEE International Geoscience and Remote Sensing Symposium (pp. 3014-3017). IEEE.

Blay, J., Fawakherji, M., & Hashemi-Beni, L. (2024, July). Flood Impact Risk Mapping in Settlement Areas from a 3D Perspective: A Case Study of Hurricane Matthew. In IGARSS 2024-2024 IEEE International Geoscience and Remote Sensing Symposium (pp. 3939-3942). IEEE.

Tariq, A., Beni, L. H., Ali, S., Adnan, S., & Hatamleh, W. A. (2023). An effective geospatial-based flash flood susceptibility assessment with hydrogeomorphic responses on groundwater recharge. Groundwater for Sustainable Development, 23, 100998.

Yang, J., El Mendili, L., Khayer, Y., McArdle, S., & Hashemi Beni, L. (2023). Instance Segmentation of LIDAR Data with Vision Transformer Model in Support Inundation Mapping Under Forest Canopy Environment. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 48, 203-208.

Tanoh, V., & Hashemi-Beni, L. (2023). Spatial analysis of socioeconomic factors contributing to food desert in North Carolina. Sustainability, 15(10), 7848.

Salem, A., & Hashemi-Beni, L. (2022). Inundated vegetation mapping using sar data: A comparison of polarization configurations of uavsar l-band and sentinel c-band. Remote Sensing, 14(24), 6374.

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BILL HOLMAN

Mr. Holman is one of North Carolina's foremost experts on conservation policy and water and land resource management. From 2013 to 2023, he was NC State Director for the Conservation Fund and chaired NC's Land for Tomorrow Coalition. Since then he has served as Senior Advisor to the Conservation Fund.

At the Conservation Fund he successfully advocated for increased appropriations from the NC General Assembly for the NC Land & Water Fund, Parks and Recreation Trust Fund, Great Trails State Fund, and other programs. He assisted NC State Parks with major expansions of Mt. Mitchell and Hammocks Beach State Parks and the Deep River State Trail. He assisted the NC Wildlife Resources Commission with establishment of the Silver Game Land for elk and with the expansion of the South Mountains and Pond Mountain Game Lands. He worked with Alamance County to establish the Cane Creek Mountains Natural Area. He worked with the National Park Service to protect Waterrock Knob. He worked with the US Fish & Wildlife Service to expand Mackay Island National Wildlife Refuge and to improve fish passage on the Dan River.

His previous experience and accomplishment include:

- served as Governor Jim Hunt's Secretary of the Department of Environment & Natural Resources from 1999-2001 and as Assistant Secretary from 1998-1999. He led Governor Hunt's efforts to reduce nutrient pollution in the Neuse and Tar-Pamlico Rivers, to protect wetlands, to reduce air pollution from coal-fired power plants and motor vehicles, to conserve one million acres of land and to recover from Hurricane Floyd.

- served as Executive Director of the NC Clean Water Management Trust Fund (now NC Land & Water Fund) from 2001-2006. The Trust Fund invested in conservation, restoration and infrastructure projects to protect and restore water quality. The General Assembly increased funding from $30,000,0000 to $100,000,000 per year during Holman's tenure.

- directed Duke University's Nicholas Institute for Environmental Policy Solutions State Policy Program from 2007-2012. He advised state and local officials on water allocation policy, watershed protection, energy policy and planning for and adapting to climate change.

- served on the Board of the Environmental Research Institute of the States (ERIS), the research arm of the Environmental Council of the States (ECOS) for nine years. He currently serves on the Board of Directors of the Appalachian Trail Conservancy.

- graduated magna cum laude with a BS in biology from NC State University in Raleigh in 1978. He completed hiking the Appalachian Trail from Maine to Georgia in 1975.

- member of the Order of the Long Leaf Pine. He has been inducted into the NC Wildlife Federation's Conservation Hall of Fame and has received many other awards.

KIMBERLY Y. MATTHEWS

Summary of Professional Experience

Kimberly Y. Matthews is an environmental scientist with over 25 years of experience in watershed sciences, with expertise in wetland ecology, stormwater management, and climate impact assessments. She has successfully worked with multidisciplinary teams of university researchers, environmental scientists, modelers, and statisticians to develop research plans, worked with the team to ensure that the research plans were implemented, and responded to changing priorities. Ms. Matthews has experience working closely with stakeholder groups and incorporating their input into project methods and analyses. For the U.S. Environmental Protection Agency (EPA), she has led regional workgroups of state, academic, and nongovernmental organization wetland scientists to improve wetland monitoring and assessment methods and priorities across the Southeast. She was a member of North Carolina's Natural and Working Land Stakeholder Group serving on the Urban Lands and Wetland teams. She is founding member and current Board President of the Carolina Wetlands Association.

Education

MS, Natural Resources, North Carolina State University, Raleigh, NC, 2003.
BA, Biology, Wittenberg University, Springfield, OH, 1996.

Selected Project Experience

Volunteer Wetland Monitoring Program (2020 to 2024)—*Outreach and Data Coordinator*. Partners with North Carolina State University and the Carolina Wetlands Association to develop a volunteer-based wetland monitoring and assessment program. This pilot project is funded by EPA Region 4 to compare methods and procedures for different monitoring approaches to determine whether a long-term monitoring program by volunteers is feasible. Leads the data management and web-based data-sharing platform to facilitate communication among volunteers and support data visualization of results.

Technical Support for Assessment and Watershed Protection (2020 to date)—*Program Manager*; *Deputy Program Manager (2012-2020)*. Supports EPA's Office of Water assessment and watershed protection efforts. Assists with the technical and financial management of this multiple-year contract to help meet the goals of the Clean Water Act by providing innovative and cost-effective solutions to reduce pollution, restore impaired waters, and identify and protect healthy watersheds. Also, manages a large team of subcontractors to assemble project teams that best meet EPA's needs on individual project assignments. Manages individual task orders under the contract.

Great Lakes Basin Compensation Sites: Lake Erie Basin Revaluation (2016 to 2018)—*Project Manager*. Led project to resample 60 wetland mitigation projects sampled in 2011 to evaluate the ongoing status of mitigation sites in meeting performance standards in the Lake Erie watershed of Ohio. Data collection focused on vegetation index of biological integrity, involved the landscape development intensity index and soil chemistry, and used EPA's protocols developed for the National Wetland Condition Assessment. Responsible for communicating with the client and subcontractors, providing technical and financial oversight, ensuring that the project was on time and produced quality results, and helping prepare the final report and data deliverables.

Economic Valuation of the Albemarle-Pamlico Watershed's Natural Resources (2016)—*Environmental Scientist.* For the Albemarle-Pamlico National Estuary Program and NC DEQ, this study assessed the economic value of the Albemarle-Pamlico watershed's natural resources. Assessed the carbon storage potential of coastal wetlands within the estuary. A benefit transfer method was used to assess the annual value of ecosystem service flows to market sectors (e.g., agriculture, forestry, commercial fishing) and directly to households in the watershed (e.g., via outdoor recreation and aesthetic benefits).

North Carolina Wetland Monitoring Database (2015 to 2018)—*Wetland Scientist.* Supported design of a database for North Carolina's Department of Environmental Quality's (NC DEQ's) wetland monitoring data. Coordinated with NC DEQ to obtain and understand its wetland data, which were collected over 10 years for different grants and were not organized in a standardized format. Organized and reviewed data before entry into the database. Facilitated discussions with technical workgroup of statewide experts to elicit requirements for the database structure and query functions.

Support for Improving the Quantity and Quality of Coastal Wetlands in the U.S. South Atlantic (2015 to 2016). Established and coordinated a regional Coastal Wetland Monitoring Workgroup to help the Governors' South Atlantic Alliance (GSAA) improve the quantity and quality of coastal wetlands in the South Atlantic states. The workgroup provided input to Ms. Matthews through monthly Webinars and three in-person meetings. Compiled data and information about existing coastal wetlands monitoring in the region and developed a searchable database based on input from the workgroup. Prepared a report that summarized the monitoring efforts of the four GSAA member states, including monitoring efforts by federal and nongovernmental agencies, and provided recommendations for future monitoring efforts.

Healthy Watersheds Program Support (2013 to 2016)—*Project Manager*. Served as the project manager for this 5-year, multi-task project providing support to EPA's Healthy Watersheds Program. Led a team to develop and implement regional and statewide integrated assessments of aquatic habitat, biotic communities, water chemistry, and watershed processes. For each project, coordinated with the client and stakeholders to obtain relevant data and elicit feedback on the technical approach and results through a series of Webinars and in-person meetings. Managed the technical and financial aspects of the assessments, as well as the project schedule to ensure that goals were achieved on time and within budget. Facilitated communication among the client, stakeholders, and team and ensured that data quality practices were implemented to deliver scientifically based results that are applicable to project stakeholders.

Estimating the Benefits of the Chesapeake Bay Total Maximum Daily Load (TMDL) Using Benefits Transfer (2012 to 2014). For EPA's National Center for Environmental Economics (NCEE), this project applied benefit transfer techniques to estimate selected benefits of the nutrient and sediment load reductions expected to be achieved by the Chesapeake Bay TMDL based on the jurisdiction's Phase II Watershed Implementation Plans. Helped develop method to estimates of changes in forest cover and wetland acres from implementing agricultural and urban best management practices (BMPs).

Southeast Wetland Workgroup (2009 to 2015). Led the coordination of this workgroup that provided technical assistance to reinforce and strengthen the capacity of states within EPA Region 4 to build and improve their wetland monitoring and assessment programs. Facilitated Web-based training opportunities on wetland and other surface water monitoring and assessment techniques and promoted communication among participants through teleconferences, meetings, and Web site. Coordinated training about wetland monitoring and assessment methodologies. Provided technical support to develop coefficients of conservatism for wetland plants in the southeastern United States.

Southeast Isolated Wetlands Assessment (2007 to 2010). For this project, coordinated a team of state government and university scientists to develop methods to identify isolated wetlands in the United States and assessed their environmental significance in terms of the ecological services they provide. Managed data collected during the second phase of field data collection and provided feedback to make model improvements. Translated results to characterize the condition of isolated wetlands and the rate of destruction, modification, and conversion of isolated wetlands.

Jordyn Miller

Data Scientist

Data Scientist meeting GIS needs in water resources, national government, and the private sector.

Summary

Dr. Jordyn Miller joined Esri's Professional Services Division in 2022. Her responsibilities include consulting and technical leadership on the Advanced Analytics team and development with Esri's Arc Hydro team. She has over 10 years of experience working with hydrological data and models, and data science workflows. Dr. Miller assesses user needs, develops conceptual workflows, and coordinates with project managers and other technical staff. At Esri she specializes in Python development, but she also has experience in R. She is passionate about science communication, has delivered in-person Data Science workshops to customers, and supports a team at Esri focused on connecting our developers.

Career Highlights

- Applied a deep learning workflow to identify areas of wetland potential across the state of Tennessee.

Experience

- Esri: 2 yrs 2 months
- Total: 15 yrs

Education

- Ph.D., Earth, Atmospheric, and Planetary Studies, Purdue University, West Lafayette, IN, 2014
- BS, Mechanical Engineering, Wilkes University, Wilkes-Barre, PA, 2014

Technical Capabilities

- **3rd Party Technology:** Confluence, Jira, Jupyter Labs, Microsoft – PowerBI, Microsoft – Windows
- **ArcGIS Apps:** ArcGIS Dashboards, ArcGIS Experience Builder, ArcGIS Field Maps
- **ArcGIS Developer:** ArcGIS API for Python, ArcGIS GeoAnalytics Engine, ArcGIS Notebooks, ArcPy
- **Business Skill:** Proposal Development/Writing, Requirements Gathering & Discovery, Technical Writing
- **ArcGIS Extensions:** ArcGIS GeoAnalytics Server, ArcGIS GeoEvent Server, ArcGIS Geostatistical Analyst, ArcGIS Hub, ArcGIS Image Analyst ArcGIS Image Server, ArcGIS Notebooks, ArcGIS Spatial Analyst, ArcGIS Velocity
- **ArcGIS Products:** ArcGIS Enterprise, ArcGIS Online, ArcGIS Pro
- **Programming Languages & Frameworks:** Python, R, SQL
- **Technical Skill:** AI/ML, AutoCAD, Cartography, Data Visualization, ETL Development, Feature Extraction, Geospatial Analysis, Image Analysis, LiDAR, Remote Sensing, Solution Design, Spatial Statistics, Technical LOE Development, Technical SOW Development, UI/UX Design, Workflow Design

Selected Experience

Consultant, Data Scientist and Hydrologist, Panamá Canal Authority

Dr. Miller worked with a small team of Esri staff to establish an Advantage Program Work Plan for Autoridad del Canal de Panamá (ACP). ACP is eager to implement a geospatial strategy and incorporate cutting edge technology to aid in decision making related to canal operations and water resources. The focus areas include: establishing a scalable GIS architecture to support ACP's growth and data needs, advancing spatial analytics within the data science department as well as in the mission areas, establishing a hub for the Rio Indio project allowing the exchange of information among multiple users, developing a proof of concept for where GIS plays a role in optimized ship scheduling workflows, and developing a proof of concept for addressing real-time water resources visualization and analytics. Time frame: 2024-present

Consultant and Data Scientist, Wetland Identification Model, Skytec LLC
Dr. Miller worked with Skytec LLC on a project with the State of Tennessee and the Tennessee Wildlife Federation implementing the Wetland Identification Model (WIM) from Arc Hydro. WIM is a deep learning workflow used to identify potential wetland locations and extents in a semi-automated approach and has been identified as a candidate to support the National Wetland Inventory's goal of creating high quality, contemporary data in cost-effective ways. Her involvement was primarily in the development of 6 regional deep learning models for the state. This project provided enhanced geospatial data to the state of Tennessee, which is vital given the uncertainty regarding the jurisdictional status of wetlands, and will better guide the management of fish, wildlife, and plant habitats. Time frame: 2024

Employment History

Employer	Position Title	Position Dates
Esri	Data Scientist	2022 – Present
Booz Allen Hamilton	Data Scientist	2022
Purdue University	Graduate Researcher	2015 – 2021
Purdue University	Adjunct Instructor and Teaching Assistant	2016 – 2019
Wyman Gordon	Design Engineer/Technical Sales Intern	2014 – 2015
Wilkes University	Undergraduate Researcher	2013 – 2014
Purdue University	Undergraduate Researcher	2013
First Quality	Process Engineer Intern	2012
Wilkes University	Resident Assistant	2011 – 2014
Wilkes University	Freshman Mentor and Orientation Leader	2011 – 2014
Wilkes University	Workstudy	2010 – 2013

Continued Professional Development

Presentations

- Artificial Intelligence for Hydrologic Feature Extraction, Esri User Conference, San Diego, CA, July 2023
- COTS Deep Learning with Non-traditional Datasets: Hydrologic Use Cases, Esri Developer Summit, Palm Springs, CA, March 2024

Publications

- Miller, J. B., Frisbee, M. D., Hamilton, T. L., and Murugapiran, S. K. (2021). Recharge from glacial meltwater is critical for alpine springs and their microbiomes. Environmental Research Letters, 16(6), 064012.
- Frisbee, M.D., Meyers, Z. P., Miller, J.B., Gleason, C.L., Stewart-Maddox, N.S., Larson, E.B., ... & Frisbee, E.E. (2019). Processes leading to the re-activation of a sinkhole in buried karst and the subsequent drying of waterfalls in a small catchment in Northern Indiana, USA. Journal of Cave & Karst Studies, 81(2).

- Miller, J.B. and Frisbee, M.D. (2018). Using 3D printing to create a robust and compact peristaltic field pump: an update to the Montana Drill Pump. Groundwater Monitoring & Remediation, 38(3), 75-78.
- Miller, J.B., Frisbee, M.D., and Hamilton, T.L. (2018), Does meltwater from alpine glaciers provide mountain-block recharge? A discussion of evolving conceptual models and methodological challenges. Seminario Internacional de Modelamiento Numerico de Fluidos Aplicado a la Ingenierea (SIMFAI-2018).

GEORGE L. VAN HOUTVEN

Summary of Professional Experience

George Van Houtven, PhD, is a Senior Environmental Economist in RTI International's Center for Water Resources, with more than 30 years of experience in conducting and managing environmental policy and natural resource management research. Dr. Van Houtven specializes in economic valuation of land and water resources, ecosystem services, and environmental health benefits in support of cost-benefit and hydro-economic analyses. He regularly leads and collaborates on interdisciplinary studies linking biophysical and economic models to evaluate the economic returns on nature-based and other resource management investments. From 2016 to 2018, he served as a member of EPA's Science Advisory Board (SAB) Environmental Economics Advisory Committee.

Education

PhD, Economics, University of Maryland, College Park, MD, 1993.
BA, Economics, Johns Hopkins University, Baltimore, MD, 1985.

Selected Project Experience

Economic Value of Flood and Streamflow Forecasts (2022 to present)—*Principal Investigator*. Leading NOAA-funded project through the Cooperative Institute for Research to Operations in Hydrology (CIROH) to develop and demonstrate a value-of-information (VOI) framework for estimating the economic benefits of investments in flood and streamflow forecasts. Conducting a case study investigating the use and benefits of Spring flooding forecasts on the Mississippi River by emergency managers in St. Paul, Minnesota to avoid flood damages or unnecessary spending on protective actions.

Needs Assessment for State-level Conservation Funding in North Carolina (2020 to 2021)—*Project Leader*. For a coalition of conservation organizations, led the development of a report that reviews and summarizes the status, benefits, and opportunities for state-funded conservation in North Carolina. Compiled and analyzed budgetary data for multiple state programs, trust funds, and federal–state matching programs to assess trends, opportunities, and future needs. The report also included a detailed review and assessment of evidence regarding the current threats to natural and working lands in the state, including population growth, land development, and climate change, and the multiple benefits of conservation investments including those related to recreation, flood control, biodiversity, local economic development, water and air quality enhancement, military preparedness, and carbon sequestration.

Estimating the Benefits of Stream Water Quality Improvements in Urbanizing Watersheds (2017 to 2022)—*Co-Principal Investigator.* With funding from EPA's Science to Achieve Results (STAR) grant program, collaborated with a multidisciplinary team of researchers from North Carolina State University to develop and apply a combined expert elicitation and stated preference approach to estimate households' WTP for improvements in urban stream water quality. Oversaw the design and administration of a mail-to-internet survey that collected stated preference data from roughly 2,000 households in three North Carolina counties. Collaborated on econometric analysis to estimate households' WTP for water quality improvements and applied findings in a case study of Wake County estimating the benefits of runoff control policies.

Quantifying the Water Resource Benefits of Land Conservation in the Catawba-Wateree Watershed (2017 to 2020). *Lead Economist*. Conducted an economic analysis for the Catawba-Wateree Watershed Management Group to assess the cost-benefit tradeoffs of land conservation in the watershed. Developed measures of land conservation benefits, including reductions in streamflow variability and extremes, recreation benefits, property value impacts, and avoided drinking water treatment costs due to reduced reservoir sediment loads, as well as carbon storage and air quality benefits from maintaining tree cover. Estimated land conservation costs in each catchment based on average per-acre tax assessed values for parcels with predominantly natural land cover. Applied these metrics to demonstrate how the framework can help to assess tradeoffs and identify priority areas for land conservation.

Climate Change and North Carolina: Near-term Impacts on Society and Recommended Actions (2020)—*Project Leader*. For the Environmental Defense Fund, led the development of a report targeted to a broad audience that summarizes how climate change is expected to impact North Carolina in the near-future and what actions can be taken by state and local officials to prepare for and reduce these impacts. The report focuses on specific climate hazards, examines eight major sectors of the economy—agriculture and forestry, commercial fishing, energy, transportation, water supply, commercial/residential property, human health, and outdoor recreation—and summarizes available evidence on the projected costs of the climate hazards for these sectors. The report also examines environmental justice issues by discussing cases where climate impacts are expected to disproportionately affect vulnerable communities.

Flood Mitigation Benefits of Green Infrastructure in the Chesapeake Bay Watershed (2019 to 2020)—*Project Leader*. Coordinated interdisciplinary study to develop and demonstrate methods for quantifying and valuing the average per-acre flood mitigation benefits of selected best management practices (BMPs) in the watershed, focusing on avoided damages to downstream structures. The value estimates are designed as inputs to a larger decision support tool used by county-level decision makers to assess the cost-benefit trade-offs of different strategies for meeting pollutant reduction goals in the watershed.

Economic Valuation of the Albemarle-Pamlico Watershed's Natural Resources (2015 to 2016)—*Project Supervisor.* For the Albemarle-Pamlico National Estuary Program and the North Carolina Department of Environmental Quality, is leading a study to assess the economic value of the Albemarle-Pamlico watershed's natural resources, such as water resources, species, aquatic and terrestrial habitats, and ecosystems, by using the most up-to-date economic analytic techniques and information. Is developing and applying benefit transfer methods to assess the annual value of ecosystem service flows to market sectors (e.g., agriculture, forestry, commercial fishing) and directly to households in the watershed (e.g., via outdoor recreation and aesthetic benefits).

Selected Peer-Reviewed Publications

Van Houtven, G. (2024). Economic Value of Flood Forecasts and Early Warning Systems: A Review. *Natural Hazards Review*, 25(4), 03124002.

von Haefen, R. H., Van Houtven, G., Naumenko, A., Obenour, D. R., Miller, J. W., Kenney, M. A., Gerst, M. D., & Waters, H. (2023). Estimating the benefits of stream water quality improvements in urbanizing watersheds: An ecological production function approach. *Proceedings of the National Academy of Sciences of the United States of America*, *120*(18).

Van Houtven, G., Phelan, J., Clark, C., Sabo, R., Buckley, J. J., Thomas, Q., ... LeDuc, S. (2019, February). Nitrogen deposition and climate change effects on tree species composition and ecosystem services for a forest cohort. *Ecological Monographs*, *89*(2).

Van Houtven, G., Mansfield, C., Phaneuf, D. J., von Haefen, R., Milstead, B., Kenney, M. A., … Reckhow, K. H. (2014). Combining expert elicitation and stated preference methods to value ecosystem services from improved lake water quality. *Ecological Economics*, *99*, 40–52.

Van Houtven, G. L., Powers, J., & Pattanayak, S. K. (2007). Valuing water quality improvements using meta-analysis: Is the glass half-full or half-empty for national policy analysis? *Resource and Energy Economics, 29*(3), 206–228.

Attachment C2

North Carolina Office of Strategic Partnerships
Government Research-Partnership Opportunity

Scope of Work for Phase II - Addressing Section 3(e) of Executive Order (EO) 305

by

Resource Environmental Solutions (RES)

North Carolina Department of Environmental Quality and

North Carolina Office of Strategic Partnerships

Scope of Work for Phase II - Addressing Section 3(e) of Executive Order (EO) 305

January 21, 2025

3600 Glenwood Avenue, Suite 100
Raleigh, NC 27612

Corporate Headquarters
6575 West Loop South, Suite 300
Bellaire, TX 77401

January 21, 2025

North Carolina Department of Environmental Quality
Attn: Stephanie C. Bolyard, PhD, CPM
217 West Jones Street
1601 Mail Service Center
Raleigh, NC 27699
Email: partnerships@osbm.nc.gov, Stephanie.Bolyard@deq.nc.gov

RE: Scope of Work for Phase II - Addressing Section 3(e) of Executive Order (EO) 305

Dear Ms. Bolyard,

On behalf of HGS, LLC t/a RES Environmental Operating Company, LLC (RES) and our team, we are pleased to submit the following Scope of Work (SOW) in response to the research partnership opportunity outlined by the North Carolina Department of Environmental Quality (NCDEQ) and the North Carolina Office of Strategic Partnerships (OSP).

From the 1987 mitigation rule, the Tulloch ditching episode in 1997, to the present day, our team has been involved with wetlands in North Carolina for many decades. The North Carolina Coastal Federation and N.C. A&T will represent the entire state while RES, Ecosystem Planning & Restoration, TealWaters, and Earth Economics will develop a technically defensible study to address N.C. Executive Order (EO) 305. The team is deeply involved in North Carolina and nationally to map, classify, and value natural and working lands, including wetlands. The timing for this project is ideal due to recent advancements and expertise in machine learning that will provide a valuable and more robust wetland mapping, classification, and valuation system to the state.

The research team understands that our focus is on developing a framework to regulate wetlands in North Carolina based on the costs to the state over the next 10 years. This effort will help guide policy decisions and generate public support for wetland protection, especially peatlands, pocosins, and headwater wetlands that may lose protection within upper reaches of the watershed. We are excited about the opportunity to be involved with this project and look forward to presenting and discussing the effort outlined in this Scope of Work (SOW).

Sincerely,

Colleen Autry
Client Solutions Manager
RES
cautry@res.us | 314.580.6049

Ben Eubanks
Regional Vice President
RES
beubanks@res.us | 804.955.0330

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1.0 Executive Summary

The proposed scope of work (SOW) is a technically rigorous and urgently needed response to the challenge of protecting North Carolina's natural and working lands, particularly wetlands, in the context of recent legal and regulatory shifts. Specifically, the Sackett v. Environmental Protection Agency (EPA) Supreme Court decision and the North Carolina Farm Act of 2023 have limited federal and state wetland protections, making a comprehensive assessment imperative. This SOW outlines a project to deliver a detailed spatial inventory and valuation of these lands, providing a science-based foundation for policy and conservation decisions over the next 5-10 years.

This project is not merely a mapping exercise but rather a sophisticated integration of geospatial analysis, ecological modeling, machine learning, and economic valuation. The timing of this study is strategic due to recent advances in training data development methods and associated machine learning. The deliverable will improve classification and establish a baseline of land area and economic value for diverse working land types across North Carolina. The data, classifications, GIS mapping applications, and natural / working land valuations will provide far greater resolution and defensibility than past efforts in North Carolina due to recent developments in artificial intelligence.

This project will involve mapping and classifying wetlands by a range of parameters such as landscape position, flow regime, stream order, hydroperiod, FEMA flood zone, and surface connection obstacles, all of which are relevant to the Sackett ruling. The project leverages existing datasets like those from the North Carolina Division of Coastal Management (DCM) and National Oceanic and Atmospheric Administration's (NOAA) expanded Coastal Change Analysis Program (C-CAP), but will go beyond these through the development of training databases to more accurately quantify the resources. A machine learning model will be developed to produce more accurate Section 404 wetland mapping for the entire State, including the Coastal Plain, Sandhills, Piedmont, and Mountain regions. In addition, the Wetland Advanced Model Predictor (WetAMP) tool and the Wetland Intrinsic Potential (WIP) tool will be used to further map and classify the wetlands, especially those difficult to detect and value with traditional methods. The WIP tool has been well-tested across the U.S., Canada, and Africa and offers a comprehensive approach to wetland mapping and classification. The WetAMP tool was developed in North Carolina and is highly specialized for the state's geographic regions. The machine learning models will further tune and train based on data from North Carolina. The combination of the two models will ensure the best available science for machine learning of wetlands. This machine learning approach incorporates multi-scale remote sensing data such as topography, hydrology, and vegetation to estimate the probability of wetland presence and type across the landscape. Ground truthing and field verification will also be performed to ensure an evolving quantitative classification of all-natural and working lands in North Carolina, including wetlands.

A critical aspect of this project is its commitment to economic valuation. The project will quantify the social, environmental, resiliency, and commercial functions provided by natural and working lands. This process will involve a thorough assessment of ecosystem services provided by classified wetland types, such as flood control, water purification, carbon dioxide reduction, and wildlife habitat. The valuation will include estimating the economic impacts of wetland degradation due to recent regulatory changes. Earth Economics will apply a range of Benefit Transfer Methods (BTMs) to efficiently evaluate these impacts using a proprietary database with over 9,300 estimates of non-market economic values, which are tagged with the associated ecological, climatological, and social contexts. The methodology will incorporate point transfers and function transfers, where statistical models are applied to site-specific data to provide quantifiable values. Spatially explicit value-function transfers are a nuanced approach for assessing a broad range of economic benefits provided by wetlands, and the consequences of their loss.

To ensure practical application, the project will produce a Decision Support Tool (DST). The DST will integrate the research findings in a user-friendly GIS format to help stakeholders prioritize conservation, preservation, regulatory, and legislative actions. The project will develop a regression model to identify demographic, macroeconomic, socioeconomic, and other attributes that will drive land use changes around The Office of Management and Budget's revised delineations of Metropolitan Statistical Areas. Urban development trends will be analyzed to predict future impacts on wetlands, considering municipal growth estimates, sea level rise projections, and flood data. Rural development trends in wetlands will be predicted including projected land speculation, ditching, and drainage activities projected post-Sackett using past case studies such as the Tulloch ditching episode in 1998.

Conservation programs, policy, and legislative action represent important components of this scope of work. The project team has been involved in the development of environmental mitigation policy in North Carolina for over 30 years. In addition, we have a direct reach to over 300,000 people to generate support including conservation, preservation, restoration, program development, legislation, tax law, and legal support. We have collaborated with the State Legislature many times over the years to procure appropriations, policies, and regulations that most effectively provide funding for, and protection of environmental resources, especially wetlands.

Key deliverables include:

- A comprehensive Geographic Information Systems (GIS) database and web application featuring mapping and classification of natural and working lands, including wetlands. The application will quantify changes in working land uses along with projected annual impacts to wetlands post-Sackett and SB 582.
- Quantitative and defensible functional assessments and valuations of the economic, resilience, environmental, and social costs to the state.
- The GIS application, classification, and valuation will include an alternatives analysis dependent upon the varying potential interpretations of "surface connection" at the federal level to guide future decisions on a suitable long-term definition at the state level.
- A website and ArcGIS Story Map to communicate the project's findings to the public.
- A DST, for evidence-based decision-making, that prioritizes conservation, regulatory, and policy options proposed by the research team to mitigate Sackett's impact, including legislative documents to address identified gaps in wetland protection.
- Stakeholder meetings, public hearings, lobbying, documentaries, interviews, proposals, and workshops as needed to highlight social values, develop support, and promote funding opportunities for proposed actions including conservation, protection, regulation, recreation, education, and social justice.

This SOW acknowledges the limitations of current data and classification systems and proposes to bridge these gaps through innovative modeling techniques, remote sensing, and field verification. The team has demonstrated understanding of regulatory frameworks and has plans to engage with the regulatory community and with policy makers. The project team's blend of academic rigor and practical experience makes us uniquely positioned to navigate the complexities of this issue. The ultimate goal is to provide clear policy recommendations, prioritize conservation actions, and support the long-term ecological sustainability and resilience of North Carolina's natural and working lands. This work will set a baseline for future assessments and offer guidance for effective wetland management in the face of ongoing environmental challenges.

1.1 The Research Team

1.1.1 RES

RES is a leader in ecological restoration, specializing in climate resilience, flood control, and ecosystem recovery. With deep expertise in GIS and modeling for streams and wetlands, RES excels in the spatial, technical, and ecological aspects of environmental projects. Their extensive regulatory knowledge enhances their ability to meet complex requirements in restoration work.

A key area of RES expertise involves stream and wetland mitigation. Through extensive experience developing and managing mitigation banks, RES balances the economic and ecological values of land, conducting detailed assessments of ecosystems' health and performance. Their work ensures mitigation projects maximize ecological benefits, addressing hydrology, soil composition, vegetation, wildlife habitat, and overall ecosystem function.

In collaboration with the NCDEQ and the Flood Resiliency Blueprint, RES is studying over 13,000 Carolina bays to assess their role in flood reduction and CO_2 mitigation. This work supports the state's wetland and flood mitigation strategies and informs climate pollution reduction efforts. By examining the ecological functions and potential benefits of conserving and restoring these bays, RES utilizes GIS to prioritize areas with the greatest flood mitigation, carbon storage, water quality, and biodiversity potential.

RES also employs advanced groundwater and surface water modeling to quantify the benefits of wetland protection, enhancement, and restoration. These models assess factors like flood attenuation, CO_2 storage, and water table depth, providing crucial data for making informed land-use decisions. Through their interactive web applications and GIS tools, RES maps, evaluates, and prioritizes wetland resources across North Carolina, helping to guide conservation and restoration efforts.

RES' ability to integrate detailed spatial analysis with ecological insights has enabled them to lead a team effort to address critical questions raised by the state regarding the implications of the U.S. Supreme Court decision Sackett v. EPA, This decision may eliminate federal protection status for a significant portion of the nation's wetlands, including those in North Carolina. Furthermore, with the passage of the 2023 Farm Bill SB 582, which limits state wetland jurisdiction to be no more stringent than federal jurisdiction, there is a pressing need for research to quantify the social, economic, and environmental impacts of both decisions.

PRINCIPAL RES TEAM MEMBERS:

Colleen Autry, Client Solutions Manager

Colleen has 15 years of experience in project management, operations, ecological restoration estimating, and team leadership. Colleen holds a Bachelor of Science in Sustainability from Washington University. She is also a LEED Green Associate and Certified Arborist with a background in horticulture.

Robin Bedenbaugh, PWD, VSWD, Senior Project Manager

Robin has more than 40 years of experience in applied environmental sciences research and environmental consulting. During this time, he has worked for a highly diverse client base, including the Department of Defense, state departments of transportation, Federal Highway Administration, National Park Service, National Aeronautics and Space Administration, port authorities, United States Environmental Protection Agency, railroads, utilities (water, wastewater, electric, and gas), state agencies, localities, and confidential private clients. He has extensive experience in applied wetlands science, including wetland delineations; wetland assessments; wetland mitigation studies; wetland mitigation design and construction; permitting; and natural resources management planning projects. He has served as project manager on numerous wetland mitigation site feasibility, mitigation site design, and mitigation site monitoring projects.

Wes Newell, Senior Project Manager

Wes has 35 years of experience as a researcher, environmental scientist, and wetland specialist. Wes has experience in aquaculture, stormwater, solar/wind energy, erosion control, flood resiliency, climate change, living shorelines, dam removal, water quality, and stream and wetland restoration. He has managed over 200 employees, subcontractors, and turnkey environmental projects to successful completion. Wes served as principal investigator for mitigation planning, quantitative functional assessments, and decision support models for N.C. Global TransPark, Randleman Reservoir, North Carolina Department of Transportation (NCDOT) open-ended contracts, dam removals, and endangered species studies. Projects include EA/EIS, natural resource studies, hydraulic models, plans, permits, construction, and monitoring, including ability in soils, hydrology, vegetation, and ecosystem modeling.

Robert Hopper, PE, Project Manager

Robert is a project manager with 19 years of experience in water resource engineering and management, specializing in stormwater project planning and development. He has a strong track record of leading teams and overseeing the successful delivery of a diverse range of water resources projects across the Carolinas, Tennessee, and Georgia. His expertise encompasses the full project lifecycle, from the development of technical proposals and H&H studies to design, construction plans, permitting, and construction. Prior to his current role at RES, Robert played a key role in managing and ensuring the proper engineering and successful outcomes of various stormwater projects across the southeast for an environmental engineering firm.

1.1.2 EARTH ECONOMICS

EARTH ECONOMICS

Earth Economics is dedicated to quantifying and valuing the benefits nature provides, using a broad range of methodologies to identify, measure, and communicate these benefits for diverse clients. For decades, Earth Economics has been applying ecological economics in practical, real-world contexts to support decision-making and policy development.

Central to Earth Economics' work comprises the Ecosystem Valuation Toolkit (EVToolkit), an extensive database of over 9,300 estimates of non-market economic values provided by natural assets globally. This web-based tool helps generate timely ecosystem services valuations (ESVs) at various scales, supporting decisions that fully incorporate nature's value. It has proven instrumental in influencing federal agencies, such as FEMA, to integrate ecosystem services into their decision-making frameworks. Notably, Earth Economics has worked with FEMA since 2013, contributing to the development of FEMA's Benefit-Cost Analysis Toolkit, which now includes ecosystem services for assessing hazard mitigation solutions.

With over 25 years of experience, Earth Economics has completed more than 50 ESVs, collaborating on numerous projects that value the economic, social, and environmental impacts of ecosystem restoration and conservation. Recent projects include evaluating the economic benefits of restoring coastal forested wetlands in Louisiana and assessing the value of wetlands and peatlands throughout the state of Minnesota. That 2024 analysis for The Nature Conservancy in Minnesota estimated that avoided conversion of wetlands and peatlands statewide would generate $114 million in annual benefits, while restoring 32,000 acres would support $210 million annually in ecosystem services.

Earth Economics' expertise also includes disaster recovery assessments, such as a 2021 study for Audubon North Carolina, which estimated the benefits of wetland conservation and restoration in the Cape Fear region. The study found that the benefits of these projects—such as improving water quality, enhancing habitat, and reducing storm surge—would exceed $277 million over 35 years, with benefit-cost ratios as high as 44:1 for specific projects such as the conservation of Lea-Hutaff Island.

By combining rigorous economic analysis with a deep understanding of ecosystem services, Earth Economics provides valuable insights that help decision-makers prioritize nature-based solutions for climate resilience, disaster recovery, and long-term ecological sustainability.

PRINCIPAL EARTH ECONOMICS TEAM MEMBER:

Ken Cousins, Research Principal

Ken brings over 30 years of hands-on knowledge of regenerative practices on farms and forests with the latest research on ecosystem services to deliver innovative empirical economic analyses. He leverages a variety of geospatial and statistical methods to assess relationships between ecosystems and the communities they sustain. He studied Ecological Economics under Herman Daly and Robert Constanza at the University of Maryland, where he earned a doctorate in the Politics of Environment and Natural Resources. As Earth Economics' Research Principal, Ken coordinates the research and GIS teams.

1.1.3 TEALWATERS

TealWaters is a collaborative initiative that combines the expertise and resources of TerrainWorks Inc. (TW) and the University of Washington (UW), creating a robust platform for advancing wetland mapping, monitoring, and restoration. By merging cutting-edge science with practical applications, TealWaters leverages technology and operational models to enhance wetland ecosystem management.

TW specializes in innovative geospatial solutions for natural resource management. Their NetMap system is a sophisticated tool that simulates watershed landforms and processes, enabling the creation of virtual watersheds populated with critical data for planning and evaluation. The TW team combines scientific expertise with technology, mapping, and programming to offer powerful insights into landscape and wetland ecosystem management.

The Remote Sensing and Geospatial Analysis Laboratory (RSGAL) at UW provides advanced technology for landscape change analysis through remote sensing and geospatial tools. RSGAL specializes in multiscale landscape dynamics, supporting TealWaters' mission to monitor and quantify wetlands from local to continental scales. Utilizing high-performance computing, LiDAR, and multispectral imagery, UW researchers have developed methods to detect and assess wetlands, including hard-to-identify areas. These tools analyze wetland hydrology, vegetation, and land use changes, offering crucial insights into wetland ecosystems.

TealWaters integrates the strengths of these partners to enhance the understanding and management of wetland ecosystems, using cutting-edge technology for more effective restoration and conservation strategies.

PRINCIPAL TEALWATERS TEAM MEMBERS:

Dr. Dan Miller (TW), Geomorphologist

Dr. Miller has over 30 years of experience as a geomorphologist, developing computer-based simulations to bring new insights to our understanding of the dynamic interactions that create the environments documented by field observations. He has applied these efforts to a broad range of resource-management issues, starting with M2 Environmental Services, established in 1990 with his wife Lynne, and continuing to the present. Dr. Miller worked with the nonprofit Earth Systems

Institute, cofounded with Lee Benda in 1997, which continued through 2014. He was co-founder of TerrainWorks, Inc., also with Lee Benda, in 2014. He has a BS in physics (University of Nebraska, 1979), an MS in geology (University of Hawaii, 1987), and a PhD in geomorphology (University of Washington, 1993).

Dr. Meghan Halabisky (UW), Remote Sensing Ecologist/Research Scientist/Senior Science Advisor

Dr. Halabisky is a remote sensing ecologist, a research scientist at UW, the Senior Science Advisor for Digital Earth Africa, and co-founder of TealWaters. Her research focuses on developing remote sensing tools to understand wetlands' roles and responses in changing environments. With extensive experience connecting research with policymakers and practitioners, she ensures Earth Observation products are actionable and impactful. Dr. Halabisky holds a concurrent MS/MPA from UW's Evans School of Public Policy and a PhD in landscape ecology. She has published over 30 peer-reviewed papers and led multiple large-scale projects. She is an active member of several national and international initiatives, including the NASA Carbon Monitoring System Science Team (where she chairs the WetCarbon Working Group), the Committee on Earth Observation Satellites Aquatic Carbon Roadmap Writing Team, the Project Advisory Board for the ESA World Ecosystem Extent Dynamics project, the U.S.-based Wetland Function Working Group, and the Inland Wetland GHG Inventory Workgroup.

1.1.4 North Carolina Coastal Federation (NCCF)

North Carolina Coastal Federation
Working Together for a Healthy Coast

Since 1982, the NCCF has been dedicated to the protection and restoration of the North Carolina Coastal Plain, an area particularly vulnerable to wetland losses due to the impacts of the *Sackett v. EPA* decision and the passage of SB 582. NCCF plays a pivotal role in connecting coastal communities with a broad network of traditional and nontraditional organizations, government agencies, and businesses. With 16,000 supporters and a direct outreach to nearly 300,000 individuals annually, the NCCF is a key leader in public relations and policy support aimed at addressing wetland impacts.

The NCCF's long-standing commitment to social, resilience, economic, and environmental benefits—especially related to wetland conservation policies—has earned it a strong reputation in the region. They actively support funding initiatives and harness expansive public support to enhance conservation efforts. With over 40 years of experience, the NCCF will play a central role in providing regulatory, legislative, and public advocacy to mitigate the potential negative effects of the recent decisions on wetlands and coastal ecosystems.

PRINCIPAL NCCF MEMBERS:

Todd Miller, Senior Advisor

Todd is the founder and former executive director of the NCCF. A native of coastal North Carolina, Todd found his passion for coastal protection in 1982, aiming to keep the coast a great place to live, work, and play. Starting as a one-man (and a dog) operation in the back room of his house, Todd grew the Federation over the next 42 years by forming partnerships and rallying volunteers, expanding it to three offices and a staff of more than three dozen, covering the entire North Carolina coast. A graduate of the University of North Carolina at Chapel Hill, where he earned both undergraduate and master's degrees, Todd was selected in 2013 by the Faculty Council and the Board of Trustees to receive UNC Chapel Hill's Distinguished Alumnus Award. This honorary degree recognizes a select group of alumni for outstanding contributions to society. In August 2024, Todd received North Carolina's highest civilian honor, the Order of the Long Leaf Pine, from Governor Roy Cooper. This award is given to individuals who have made significant contributions to the state and their communities through exemplary service and exceptional accomplishments. Todd was also honored with the "Hero of the Seas" award by the Peter Benchley Ocean Awards in 2015. In addition to numerous other awards, recognitions, and volunteer board assignments, he is a founding board member of Restore America's Estuaries and currently serves on the Board of Visitors for the UNC Institute for the Environment. Todd also served for decades on the Leadership Committee for the Albemarle-Pamlico National Estuary Partnership before stepping down as Executive Director of the NCCF on January 31, 2024. He now provides strategic advice and program assistance to the organization.

Bree Charron, PE, Water Quality Director

Bree, a Manteo native, joined the NCCF staff in 2016 as a Coastal Specialist in the Ocean office. She holds a Master of Science in biological and agricultural engineering and a Bachelor of Science in environmental science and wetland assessment from North Carolina State University. In 2021, Bree successfully attained her Professional Engineer license and now manages the survey, design, and construction oversight of the Federation's water quality projects, including stormwater retrofits and large-scale wetland restoration. As Water Quality Program Director, Bree oversees the Federation's mission to improve water quality and reduce flooding from the first stages of planning through implementation.

Kerri Allen, Coastal Management Program Director

As Coastal Advocate, Kerri represents the NCCF's stance on key issues and works to represent the coast at local, state, and federal levels to ensure that actions are taken to safeguard North Carolina's water quality, coastal environment, and economy. A registered lobbyist, Kerri leads the NCCF's Advocacy and Policy initiatives and works to seek laws, rules, appropriations, policies and permit decisions that are aligned with the Federation's goals and benchmarks. Since joining the Federation in 2018, she has worked with stakeholders up and down the coast to build public and decision-maker support for achieving the NCCF's objectives. A North Carolina native, Kerri holds a master's degree in coastal geology and undergraduate degrees in geosciences, environmental studies, and geospatial technologies from the University of North Carolina Wilmington.

Alyson Flynn, Coastal Advocate and Environmental Economist

Alyson joined the NCCF in early 2022 as a Coastal Advocate and Environmental Economist. Her work focuses on advancing sustainable policies that support the protection and restoration of our coast. As an economist, her work applies tools from benefit-cost analysis and non-market valuation to quantify restoration objectives and evaluate the benefits of ecosystem services to promote and strengthen responsible coastal management. Alyson holds a Master of Science in Applied and Natural Resource Economics from East Carolina University and a Bachelor of Science in Economics from the University of North Carolina at Wilmington. In 2014 she achieved PhD candidacy from East Carolina University, where her research examined the economic implications associated with coastal management decisions in Dare County.

1.1.5 Ecosystem Planning & Restoration (EPR)

EPR

EPR specializes in the evaluation and restoration of ecosystem planning and restoration with a focus on stream and wetlands services. They have assessed, modeled, designed, and constructed numerous stream and wetland restoration projects throughout North Carolina.

EPR's data science team specializes in utilizing machine learning and GIS technologies to model/map wetlands and conduct geospatial analyses of streams in North Carolina. They leverage advanced machine learning algorithms, often beyond typical software capabilities, cloud computing, and have developed extensive data pipelines to support their modeling efforts. By incorporating various data sources and types, EPR has built web applications for deploying machine learning models, including public-facing tools for viewing large datasets, and applications for the EPA. In coordination with the EPA, EPR helped develop the Streamflow Duration Assessment Methods (SDAMs) for the Great Plains and Eastern regions of the US. Their background with the SDAMs project will be beneficial to any jurisdictional hydrography modeling and mapping.

Through collaboration with NCDOT, EPR has been mapping and identifying wetlands through applied machine learning as part of a NCDOT program of modeling wetlands developed over the past 10 years. They have expertise in the modeling process and what data are needed to produce a satisfactory model. Their discussions and contacts with the U.S. Army Corps of Engineers (USACE) on the modeling process are crucial assets from a policy perspective.

EPR's engineering team has deep expertise in flood resilience hydrologic modeling in North Carolina, and their environmental staff possesses considerable experience in soils, vegetation, and wetland delineations. In collaboration with the North Carolina Division of Mitigation Services, EPR has undertaken a pioneering flood resiliency project in the Stoney Creek watershed, focusing on nature-based solutions like constructed wetlands, floodplain enhancements, and riparian buffer restoration. They are developing hydrologic models to assess and predict the effectiveness of these solutions in reducing flood impacts, offering tools that provide rapid, cost-effective predictions without complex modeling efforts. EPR's proficiency in modeling wetlands' role in flood resilience positions them to scale this analysis and evaluate the broader impacts of wetland loss on flood resiliency across the state.

PRINCIPAL EPR TEAM MEMBERS:

Will Saulnier, Department Head, Data Science

Will is a senior level data scientist with 10 years of experience working in data science, geospatial analysis, and application development. He has expertise in Python and R programming languages, designing, developing, and deploying machine learning algorithms, geospatial analyses in multiple GIS platforms, custom web-based application development using the Shiny framework, as well as automating data wrangling, analysis, summary, and reports. Some of his past projects include utilizing machine learning to predict wetlands in North Carolina, large data set compilation and analysis, custom dashboard development, environmental and social impact assessments, stream and wetland delineation analysis, GIS tool development, and wetland mitigation tract searches. He holds a bachelor's and master's degree in forestry from Virginia Tech.

Dr. Beth Allen, Environmental Scientist

Dr. Allen has specialized research experience in watershed hydrology and water quality characterization. Her doctoral research explored and developed a suite of monitoring, modeling, and data analysis techniques to identify temporal patterns and drivers of stream hydrology and water quality at the annual, seasonal, and event scales. She has worked on a variety of projects, including paired watershed studies in upland and coastal watersheds across the United States to determine the impacts of land use change and implementation of management and restoration practices. Her skill set includes data wrangling and automation of analytical methods and reporting, intensive high-resolution time series analysis, and watershed and statistical modeling. She is proficient in R and Python programming languages, geospatial analyses, multiple GIS platforms, watershed delineations, and has modeling experience using SWAT, GWLF-E, HEC-HMS, HEC-RAS, and DRAINMOD.

Tami Norton, PE, Senior Water Resources Engineer

Tami has over 25 years of varied stream restoration, stormwater design, hydrology and hydraulic modeling, and watershed master planning experience for projects throughout the United States as a Water Resources Engineer. She has served as project manager and design engineer for numerous holistic capital and maintenance projects in central and north Texas. Tami has unique training and expertise in nature-based solutions for flood mitigation, stream stability, and stormwater best management practices. She served as the project manager for the Cibolo Creek Holistic Master Plan under previous employment with the San Antonio River Authority during the initial community engagement phase and scoping considerations based on stakeholder input. Tami currently provides hydrologic and hydraulic modeling support, training, and technical expertise for EPR projects and staff.

Mark Mickley, Senior Environmental Manager

Mark has more than 20 years of experience performing natural resources investigations for public and private sector clients in the Southeast. With extensive knowledge of natural resources management, Mark has prepared technical reports and natural resources sections for numerous environmental documents. His expertise consists of stream and wetland delineation, GPS and GIS analysis, endangered species surveys, impact calculations, stream assessment and classification, stream mitigation activities including existing and reference reach surveys and monitoring, and Clean Water Act (CWA) permitting.

1.1.6 North Carolina Agricultural and Technical State University (N.C. A&T)

NORTH CAROLINA AGRICULTURAL AND TECHNICAL STATE UNIVERSITY

N.C. A&T, an 1890 land-grant minority-serving institution with a strong Cooperative Extension Service, is uniquely positioned to assess and address the environmental justice implications of wetland protection loss. N.C. A&T is focusing on the crucial role of wetlands in mitigating environmental challenges and promoting environmental justice, especially for marginalized communities. These communities, historically underrepresented and underserved, are often on the frontline of exposure to environmental and climate hazards.

This scope of work outlines a plan to study these impacts, delineate mitigation strategies, engage stakeholders, and empower affected communities. N.C. A&T's proposed project will use a combination of remote sensing, GIS, modeling, counterfactual AI, and community surveys to develop a decision-support framework that connects wetlands' role in addressing issues such as flooding, drought, and pollution, and the implications on the socio-economic wellbeing of marginalized communities in wetland watersheds.

PRINCIPAL N.C. A&T TEAM MEMBERS:

Dr. Abubakarr Mansaray, Research Assistant Professor

Dr. Mansaray is an experienced researcher and educator with a demonstrated history of working in the higher education industry and the private sector. He primarily advances water systems management using expertise in Environmental Chemistry, Remote Sensing, GIS, Modeling, and Climate Change. He is a strong research professional with a PhD focused on Water Resources Science and Management from Oklahoma State University.

Dr. Godfrey Uzochukwu, PhD, Senior Professor

Dr. Uzochukwu is an expert in Environmental Justice. He teaches interdisciplinary courses in environmental sciences and waste management sustainability. Research areas include soil and mineral properties for better land use, uses of natural resources data, assessment and evaluation of environmental technologies, interdisciplinary and multidisciplinary environmental/geological processes, and ecology.

Dr. Manoj K. Jha, Professor and Chair, Architectural, and Environmental Engineering

Dr. Jha is an expert in Watershed Modeling. His research and teaching interests are in the fields of water resources and environmental engineering. He has developed and applied various field-to-watershed scale models to extend the boundaries of our knowledge and understand the impacts of land use and climate change on hydrology, water availability, and water quality.

Dr. Niroj Aryal, Associate Professor and Chair

Dr. Aryal is an expert in the fate and transport of emerging contaminants. He has a bachelor's in agricultural engineering from Tribhuvan University in Nepal, a postgraduate diploma in environmental education and sustainable development from Kathmandu University in Nepal, a master’s in biosystems engineering from Michigan State University, and a doctorate in biosystems engineering and environmental engineering from Michigan State. After earning his doctorate in 2015, he worked as a post-doctoral researcher in hydrology and water quality at the USDA's Delta Water Management Research Unit. He has published several research papers in reputable journals and presented at national and international conferences.

2.0 Scope of Services

2.1 Project Management and Administration

RES will serve as the lead for all project management, reporting, and administrative tasks associated with the project. RES' Senior Project Manager will oversee all aspects of the project, serve as the primary liaison to DEQ, and ensure that this innovative project achieves the goals and objectives envisioned by EO 305. RES senior staff have served as project managers and lead investigators on numerous large-scale projects in North Carolina such as the first open-ended NCDOT contract for Section 404 mitigation and the Conservation Plan and Detailed Mitigation Plans for the North Carolina Global TransPark (NCGTP), the largest state-funded project in history at that time.

The project has been subdivided into four phases for adaptive management and funding purposes: 1) Spatial Data, Training data, and Attributes Development; 2) Models, Mapping, and Classification; 3) Functional Evaluation and Impact Analyses; and 4) Conservation, Policy, and Legislative Support. The draft schedule and cost by phase are outlined in ***Sections 3.0 and 4.0***. If the estimated cost, proposed timeline, or phasing approach does not meet the needs of this request for services, we look forward to meeting to present additional options for the project. Currently, we have estimated 24 months to complete all technical and economic analyses, including the GIS application and related documentation. The final milestone, which involves conservation, policy, and public support components of the project, includes up to an additional 4 months to August 2027, depending upon the results of the technical phase and requirements from DEQ (24 months total).

Project management and administrative tasks include the following:

- Project Initiation
    - Project kick-off meeting(s).
    - Stakeholder Engagement Plan.
    - QA/QC Plan.
    - Stakeholder meeting(s).
    - Finalize the scope of work and detailed schedule with milestones.
- Scheduling and Timeline
    - Track progress and ensure timely completion of tasks.
    - Adjust schedule and resources as needed to account for delays and changes.
- Budget Management
    - Monitor and track expenses regularly to ensure the project stays within budget.
    - Plan for contingencies and unexpected costs.
- Resource Allocation
    - Ensure proper allocation of materials and resources to meet the project demands.
    - Manage resource capacity, and assign appropriate staff, tools, and technologies for each task.
- Risk Management
    - Identify potential risks to the project, including delays, budget overruns, and scope migration.
    - Develop risk mitigation strategies and contingency plans.
    - Monitor risk factors and adjust as necessary.
    - Manage expectations and resolve conflicts as they arise.
- Communication and Collaboration
    - Conduct monthly status meetings with project owners to review progress, address challenges and align on next steps.
    - Establish clear communication channels among team members.
    - Ensure transparency and encourage open collaboration.
- Documentation, Reporting, and Deliverables
    - Maintain thorough documentation of project processes, decisions, and changes.
    - Track and document milestones, deliverables, and results.
    - Prepare regular status reports for stakeholders.

- Develop, maintain, distribute, and publish the GIS application, decision support tool, and related deliverables.
- Quality Assurance
  - Implement processes for reviewing and ensuring quality of deliverables.
  - Conduct periodic audits to verify accuracy and compliance with standards.
  - Ensure the project meets research objectives and stakeholder expectations.
- Project Evaluation and Closure
  - Conduct a post-project evaluation to assess outcomes, lessons learned, and performance against goals.
  - Finalize and architect project deliverables and documentation for future reference.
  - Hold a project debrief with stakeholders to discuss successes, challenges, and improvement areas.
- Owner / Stakeholder Meetings
  - Organize and facilitate regular meetings with the owner as needed to review progress and deliverables.
  - Hold periodic meetings with additional stakeholders as needed
  - Hold public meetings to present results and recommendations

2.2 Spatial Data, Training Data, and Attributes Development

This section details the approach to model development for this project, which includes the creation of a robust spatial database, incorporating a wide range of existing datasets, and developing new training attributes and data points to accurately analyze the impact of the Sackett decision and the North Carolina Farm Act of 2023. The project will leverage the spatial data, training data, and GIS to establish models (***Section 2.3***) that quantify changes in social, resilience, environmental, and economic functions and benefits over the next 10+ years throughout all working lands in North Carolina.

2.2.1 Existing Spatial Databases and Attributes

This supporting task involves the process of integrating existing and available data and remote sensing sources into a comprehensive GIS database that will be used as a baseline for the project's modeling efforts. The project will draw on a multitude of existing sources to build a comprehensive database of natural and working lands in North Carolina. An inventory of existing data layers that will be incorporated into the GIS is included in ***Appendix A***. Some of these existing data layers have already been compiled and analyzed in the GIS Web Application (App) prepared during our DMS Carolina bay flood resiliency study. Many of these existing layers and data sets will require improvement, refinement, and training to provide more accurate mapping, classification, modeling, and valuation results. A summary of a few of the more important existing databases and limitations follows.

HYDROGRAPHY – STREAMS AND DRAINAGEWAYS

Existing stream mapping and classification will be imported from several sources including the NCDOT Advancing Transportation through Linkages, Automation, and Screening (ATLAS) program. The statewide elevation-derived hydrography resource, called ATLAS Hydrography will provide the base map for jurisdictional stream origin from LiDAR-derived Digital Elevation Models (DEMs) and modeled stream origin data. Additional existing datasets such as the National Hydrography Dataset (NHD) will also be incorporated as needed. The ATLAS and NHD may require improvements to more accurately portray connectivity, potential Sackett impacts, and environmental attributes such as nitrogen/phosphorous loading, buffers, flow attenuation, and related economic benefits (i.e. water quality, flood mitigation, etc.)

Ephemeral drainageways and drainage paths above jurisdictional intermittent/perennial stream endpoints will be trained and refined as described in ***Section 2.2.2*** (Training Databases and Attributes) to further connect headwater wetlands to downstream resources (i.e. hyporheic zones, pond dams, roads, etc.). These headwater wetlands are typically surficial expressions of the groundwater table without clearly demarcated surface connections, but provide surface connections during storm flows, especially in the Piedmont and Mountain physiographic regions.

WETLAND MAPPING AND CLASSIFICATION

Spatially accurate maps of wetlands are the necessary foundation on which to layer advanced data and analyses required for this scope of work. In many regions of North Carolina, wetland inventories are inaccurate with high errors of omission (missed wetlands) — especially for small, vegetated, or forested wetlands. The best existing U.S. wetlands inventory, the National Wetlands Inventory (NWI), is the only comprehensive wetland inventory for North Carolina. The NWI was created with hand-drawn maps from aerial photographs that, now converted to digital form, are spatially misaligned in ways that disallow systematic correction and combination with other datasets (e.g. streamlines). The NWI, a standard tool that provides useful location information, is being updated and will be incorporated into our analysis and mapping efforts. However, it represents an older generation of technology and does not contain the necessary information for a project of this scope, specifically, it misses many wetlands, it cannot be combined with other datasets for Sackett ruling scenario analysis, and it does not address wetland functions. More broadly, wetland inventories and analyses developed largely in isolation from that of rivers, floodplains, lakes, and groundwater, without convergence across the hydrologic cycle cannot answer the questions of wetland function and require being able to connect wetland locations with attributed hydrography datasets. Existing tools do not reflect the reality in nature that all waters are connected.

To date, Earth Economics has relied on the NWI and other land cover datasets to identify ecosystem types and portions of the NWI classification for economic analyses and portions of the NWI classification system will be carried forward in this database for functional and impact analyses. However, to maximize benefits related to EO 305, the NWI mapping will be replaced through the application of the merged WetAMP tool and the WIP Tool as described in ***Section 2.3.3***.

Existing wetland data from the North Carolina DCM will be used as a key dataset for the coastal region, as this data is more accurate than the NWI in this area. DCM wetland data includes information on wetland type and hydrogeomorphic (HGM) classifications for 40 coastal counties. This coastal wetland data layer will be improved through training and machine learning (***Section 2.3.3***).

LIDAR – TOPOGRAPHIC BASE MAPPING

Existing Light Detection and Ranging (LiDAR) data will be used to generate high-resolution DEMs. This data will be used to support landscape classification, hydrologic modeling, and wetland identification through the merger of the WetAMP and WIP tools. This SOW does not include additional training databases or models to improve the existing LiDAR database for North Carolina.

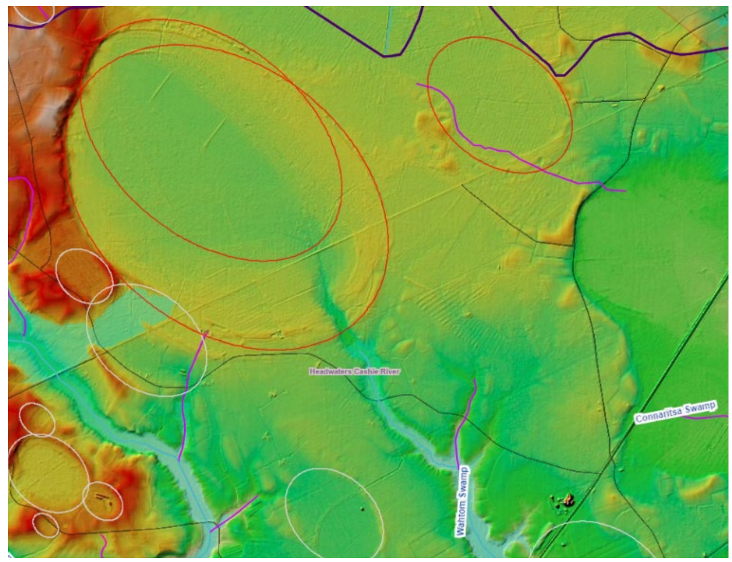

Figure 1. LiDAR Image of Large Carolina Bay Wetland in Upper Cashie River Watershed

RIVER BASINS - HYDROLOGIC UNITS

Spatial and statistical data on river basins and hydrologic units will be included to quantify potential working land impacts on upstream-downstream dynamics by watershed at any scale. Focusing on hydrologic units will allow assessment of economic impacts including water quality, environmental justice, and other functions by Hydrologic Unit Code (HUC 6, 8, 10, 12, etc).

PHYSIOGRAPHIC PROVINCES/FALL LINES

The project will incorporate data on the physiographic provinces (Coastal Plain, Sandhills, Piedmont, Foothills, and Mountains) and fall lines to account for the different ecological and hydrological characteristics of each region, as wetland types and hydrologic attributes vary widely across the State.

LAND COVER TYPES

The NOAA Office for Coastal Management's C-CAP is scheduled to be expanded to produce a Level 2 (20-class) land use / land cover interpretation for the entire State (NC-CAP). We plan to utilize this mapping and classification with some modifications to existing developed cover types for economic growth models and valuations. We understand that the NC-CAP statewide 1-meter product will be available in early 2025 and no additional training data or feature development are currently proposed in this SOW. Existing Peatland, pocosin, Carolina bay, coastal wetland/sea marsh corridor, and mountain bog layers will also be incorporated into the land cover database. If NC-CAP is unavailable, National Land Cover Dataset (NLCD) mapping and classification may be used with some limitations.

FLOODING DATA

FEMA flood zone data will be included to assess the flood risk and flood resiliency functions of potentially impacted wetlands. Data will be integrated for varying flood return intervals for valuations and impact analyses. Flooding data from the NC Emergency Management and associated hot spots will be used to identify areas and valuations particularly vulnerable to flooding. Additional historic flood data such as the FEMA National Risk Index will be added to this database for model training purposes.

OTHER EXISTING LAYERS

The project will utilize other existing data layers including those outlined in ***Appendix A***, as appropriate for the analysis.

2.2.2 Training Databases and Attributes

Training data, features, and attributes that will be measured and collected to improve the existing datasets and for use in machine learning algorithms and models scoped in ***Section 2.3***. Training data will include the collection and processing of the following attributes.

HYDROGRAPHY – DEM DERIVED HEADWATER DELINEATION

For consistency, we will rely to the extent possible on the existing ATLAS dataset to maintain consistency with other state efforts. The ATLAS dataset will be improved upstream of the intermittent/perennial stream classification to more accurately delineate ephemeral channels and drainageways that affect wetlands and working lands in the upper watershed and along interstream divides. In part, the "drainageway" addition will serve to legally defend the surface connection of all wetlands in North Carolina, including surface connection during certain storm/flood events. Extending the hydrography into the upper watershed will also provide information related to functions such as nutrient loading to lakes, streams, and estuaries. In the Piedmont and Mountains, this dataset will "connect" isolated headwater wetlands within the upper reaches of the valley. In the Coastal Plain, this dataset will connect peatlands and Carolina Bays during certain storm events and along trained artificial ditches and canals. The "drainageway" training process will be applied to one or more HUC 8s within each physiographic region, tested, verified, and then expanded to the entire state.

MITIGATION/RESTORATION SITES

Data on existing wetland, stream, nutrient, buffer, and species mitigation/restoration sites throughout the state will be incorporated from available sources including the USACE, NCDEQ, and the NCDOT.

STREAM PERMIT DATA/DELINEATIONS

Section 401 Water Quality intermittent/perennial stream delineations and data form attributes will be incorporated into to the hydrography and wetland mapping data to further train the wetland and hydrography models.

DESKTOP DELINEATED WETLANDS

GIS analysis will be conducted to correct additional wetland datasets such as the USFWS, NWI, and the North Carolina DCM Wetlands. The additional corrected wetland features will be added to the NCDOT training dataset to train the machine learning wetland models.

NCDOT TRAINING DATA

Previously collected field delineations of Section 404 wetlands from NCDOT will be used to update and retrain the WetAMP model.

PAST FLOOD DATA

Past flood data will be processed and imported into the GIS app and models to more accurately quantify and portray the flood risk associated with deregulation and the flood resiliency functions potentially lost within these wetlands.

ENVIRONMENTAL IMPACT STATEMENT/ENVIRONMENTAL ASSESSMENT DATA

Data from Environmental Impact Statements (EIS) and Environmental Assessments (EA) will be used to refine the mapping/classification, develop the urban/rural expansion models, and quantify the economic valuations.

URBAN AND RURAL DEVELOPMENT HISTORICAL TREND DATA

Development trend data will be reposited from historical aerial imagery, census data, and additional resources to train the regional development model and urban/rural development expansion simulators as described in the next section. The training data will calibrate development trends and refine vulnerability assessments needed to identify areas at risk of wetland loss.

CO2 / FIRE REDUCTION ATTRIBUTES:

Training features related to climate resiliency, carbon dioxide (CO2) sequestration, and fire reduction will be incorporated into the models and GIS app, especially for organic soil landscapes such as pocosins, peatlands, and Carolina Bays. Many of these attributes have already been incorporated into the Carolina Bay Flood Resiliency Study being developed for DEQ. Data related to carbon sequestration, fire reduction, weir inventory, storage capacity, drainage density, and groundwater models will be used. The attributes will be utilized in economic valuations such as carbon (tons) emitted and other important wetland functions lost due to deregulation. Training attributes include the following.

Weir inventory: The location, dimensions, and related hydraulic information for weirs within peatlands will be digitized or imported from available sources, including the North Carolina Wildlife Resources Commission (WRC) and The Nature Conservancy (TNC).

Groundwater Data: Groundwater gauge data, drainage density classifications, storage capacity, and available groundwater models will be incorporated into the machine learning model to quantify carbon, flood, biodiversity, and economic costs to the state related to deregulation.

Other environmental feature data related to peatlands and Carolina bays will be reposited including TNC's biodiversity ranking to further value the ecosystems and portray imminent losses due to Sackett and especially SB 582.

FIELD VERIFICATION AND GROUND TRUTHING

Training data will be verified as needed to increase accuracy and decrease error rates in the mapping products. On-the-ground and remote sensing (drone) methods will be used for in-situ documentation.

2.3 Models, Mapping, and Classification

The project will use the collected data to simulate and calibrate models, specifically the WetAMP tool, which will allow the team to map wetlands even where they may have been previously difficult to detect. The model results will be used to address the goals of the overall project.

This section is crucial for establishing a scientifically rigorous and defensible approach to assessing the impacts of the Sackett decision on North Carolina's wetlands. The integration of existing data with newly developed attributes, combined with advanced modeling techniques and field verification, will ensure that the project's outputs are both accurate and relevant to decision-making.

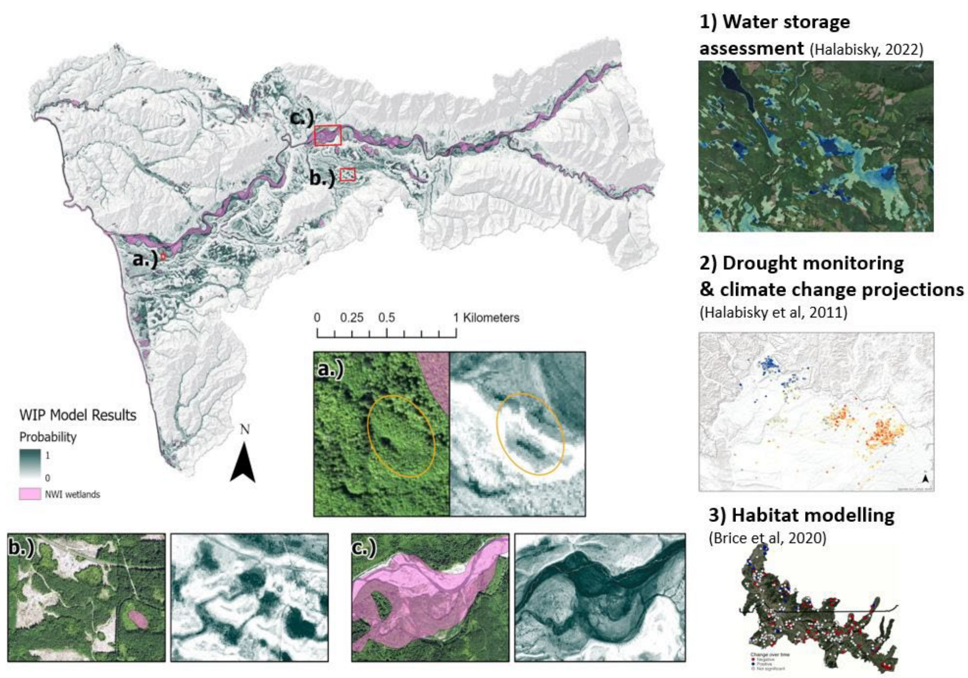

Figure 2. WIP Tool Example

This framework will set the stage for a comprehensive and scientifically rigorous assessment of the impacts of the Sackett decision on wetlands in North Carolina and will help to inform the development of targeted strategies for wetland protection and restoration. In addition, a base-line assessment of all natural and working lands in North Carolina will be established for future analyses.

2.3.1 Hydrogeomorphic (HGM) Landscape Classification

A land classification will be developed that subdivides the landscape into map units based primarily on a HGM classification system. A separate landscape classification will be developed for each major ecoregion including the Coastal Plain, Sandhills, Piedmont, and Mountain provinces. The classification will provide a mechanism to predict potential wetland, stream, and drainageway impacts based on various Sackett interpretations. In addition, the classification will provide additional subdivisions for the environmental and economic impact models and assessments described below. The classification will provide a GIS-based layer that subdivides the landscape into physiographic landscape units such as the following example.

1) Mineral soil interstream divide/ridge (precipitation driven, vertical groundwater flow)
2) Organic soil Interstream divide/ridge (precipitation driven, peatland/pocosin)
3) Carolina bay (variable)

4) Intermediate slope (radial groundwater flow, proximal to drainageways)
5) Riparian slope (sub-radial groundwater flow, proximal to ephemeral channels)
6) Secondary floodplain/terrace (lateral groundwater flow, proximal to intermittent streams)
7) Primary floodplain (perennial stream)
8) Riparian buffer (for Nutrient Sensitive Waters [NSW] impact analyses)

Although the land classification will adopt certain characteristics of the HGM approach, the methodology will utilize a Landscape Ecosystem Classification (LEC) approach to capture features required for various Sackett interpretations. LEC was developed at N.C. State University and Clemson University over the last several decades. LEC was developed primarily to optimize agroforestry management and other working land practices within mapped regions of North and South Carolina. LEC is based on the inter-relationship between soil, vegetation, and landform to map forested natural and working land types. The model has been applied within various Coastal Plain, Piedmont, and Mountain locations throughout the southeastern U.S. LEC will be applied using available remote sensing cover data, Natural Resource Conservation Service (NRCS) soil surveys, and LiDAR interpretations for the landform discriminant variable. The graphic below shows a conceptual application of LEC within the Piedmont that will be used to assess various potential surface connection scenarios and impacts. LEC map units will be overlain on the wetland mapping to predict/quantify the wetland types that may no longer be protected. This process will include mapped peatland and Carolina bay types in the Coastal Plain for climate resiliency and C02 reduction analyses as described below. In addition, riparian buffers as defined for Nutrient Sensitive Waters in North Carolina will also be mapped and classified for nitrogen and phosphorous impact analyses.

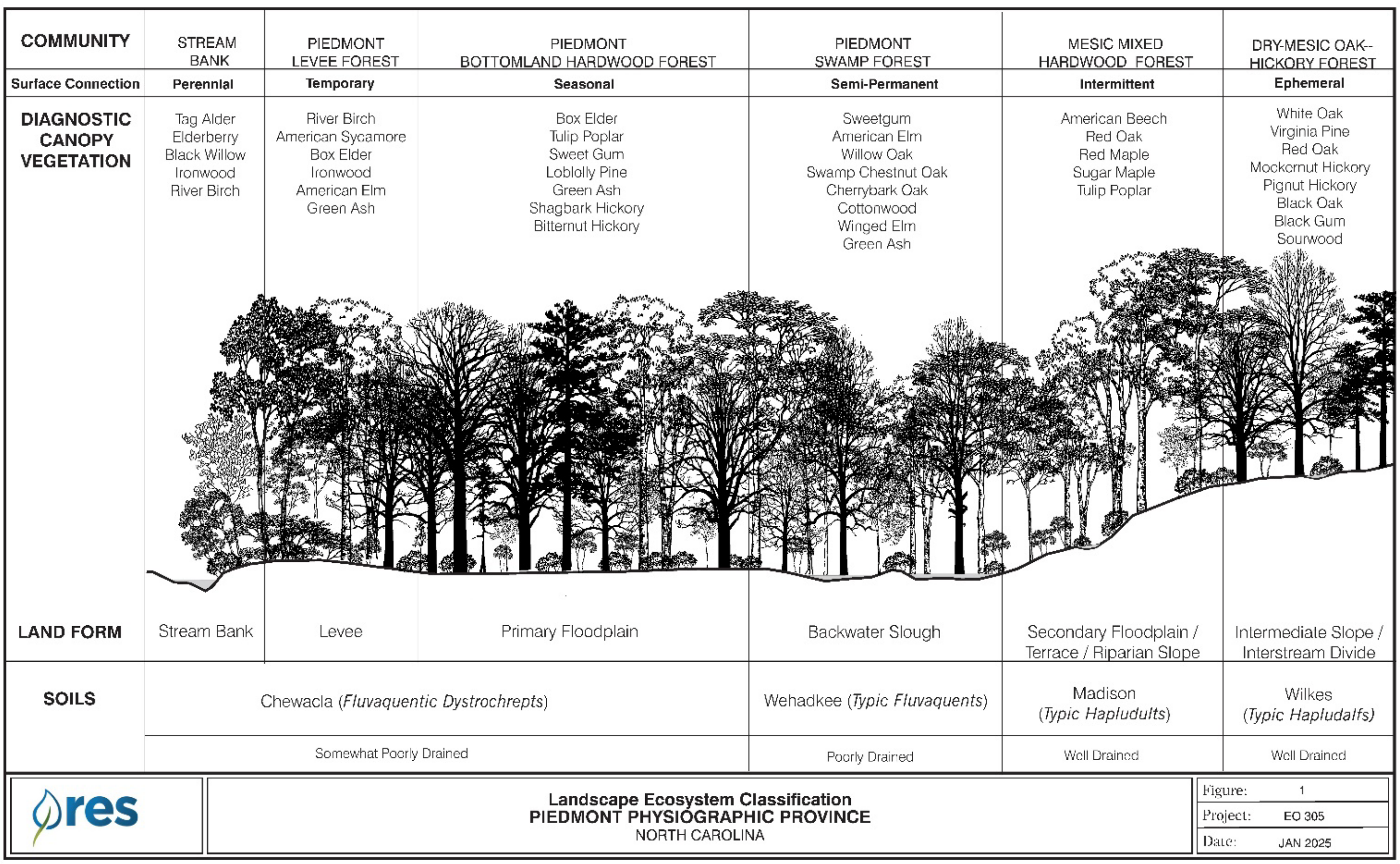

Figure 3. Landscape Ecosystem Classification Example

2.3.2 Regional Development Projection Model

The regional development model will serve to predict urban and rural development patterns based upon model parameters such as historic data, economic trends, population growth, transportation needs, and related infrastructure. The model will utilize regression and trend analyses for HUC 8s using dasymetric population mapping to predict annual changes in land cover for all natural and working lands, including drainageways, streams, and wetlands. The model will focus upon a 10-year time frame under this SOW but will be designed to allow for more long-term calibration and assessments moving forward.

The model will quantify the area of potential impacts to natural and working lands, including wetlands through GIS-based simulators (sliders) that graphically depict the loss of potentially unprotected wetlands based on a range of selected Sackett interpretations. The simulators will sum acreage by working land type converted to different land uses as the annual slider and Sackett definition are changed in the GIS web application. This information and training data will subsequently be imported into the models, studies, and impact analyses described below. In addition, the visual simulator and working land impact estimator will provide the foundation for conservation, policy, and legislative decisions (***Section 2.5***) such as the following.

1) Identify priority land areas for conservation.
2) Identify optimal interpretations of "surface connection" in the GIS App to balance economic and environmental goals at the state level.
3) Identify land areas that may require legislative/policy support to provide optimal social justice such as green space, recreation opportunities, local agriculture, forestry, and related services.

URBAN EXPANSION SIMULATOR

For urban and transportation-related development, the model will predict growth patterns and land conversion demand based on available training variables such as historic population growth, past land conversion patterns, gross domestic product (GDP) rates, population/industry composition, occupation dynamics, median household income, median house value, labor force participation/unemployment data, composition, recession patterns, and related information. The urban model results will translate industry, infrastructure, and population growth to land area needed to accommodate growth following typical patterns. Results will be interpreted and mapped concentrically from the central point of each census block and extrapolated as linear cones along major transportation corridors based on available data and model results.

RURAL LAND CONVERSION SIMULATOR

The Sackett rule and SB 582 will likely induce significant land speculation and rapid ditching activities within rural and remote wetland areas throughout North Carolina and especially within the Coastal Plain region. Indeed, the Tulloch Rule Invalidation of 1998 created a land speculation frenzy that can be used, in part, to model projected wetland impacts based on various Sackett interpretations. Past Tulloch data along with historic conversion rates and suburban development patterns will be used to map cones of potential drainage and eventual expansion into unregulated wetland areas. The following graphic depicts an area of North Carolina that represents an existing wetland adjacent to expanding suburban areas that will likely lose protection under most Sackett interpretations and will be within the mapped cone of potential drainage and eventual loss in the GIS App. Interfaces like this will likely be ditched immediately upon perceived deregulation based on activities that occurred in the immediate wake of the Tulloch Ditching episode of 1998. Drainage network, tree plantation, and cropland conversion rates on uplands over the last 50 years will also be extrapolated to wetland areas modeled as losing protection.

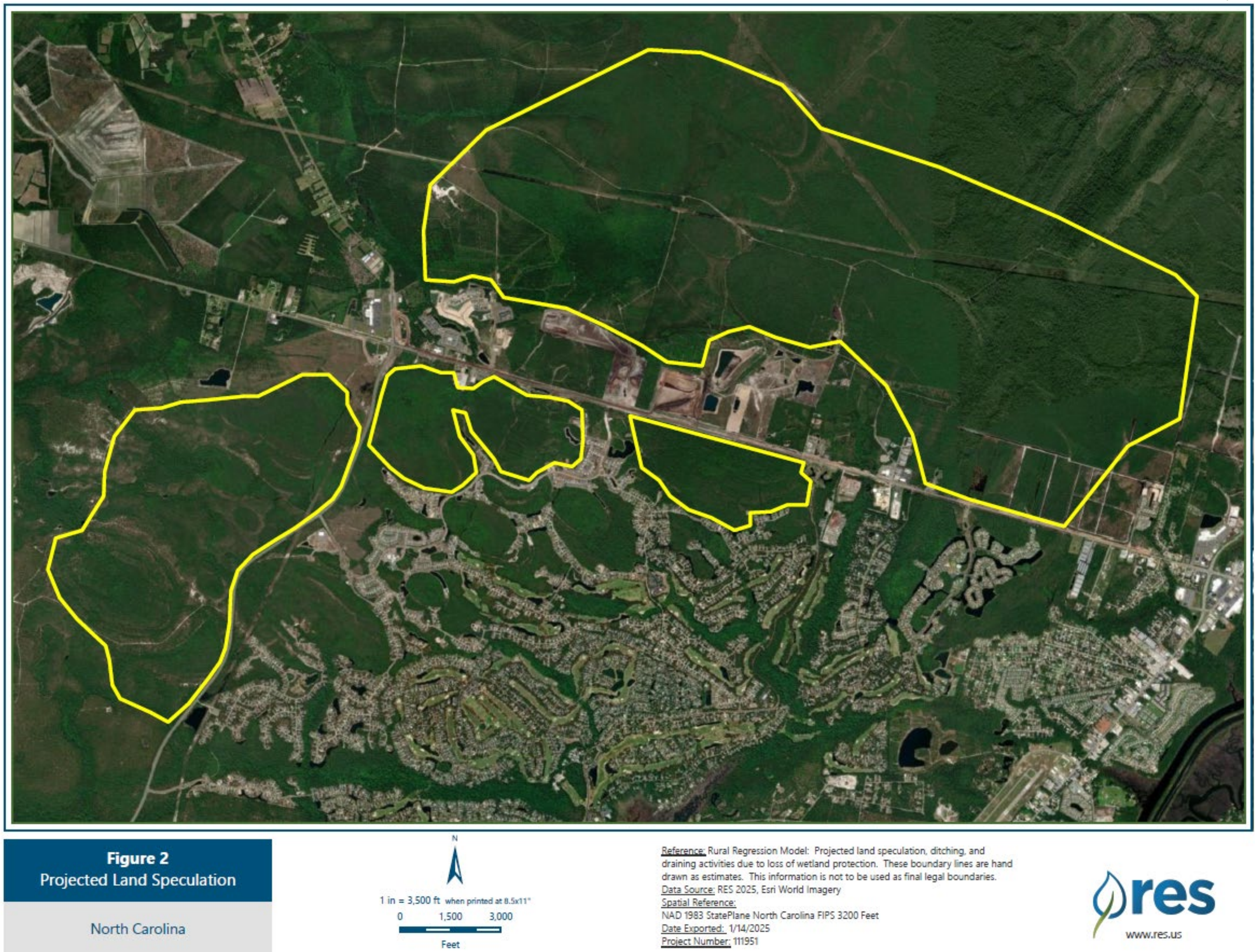

Figure 4. Projected Land Speculation

2.3.3 WETLAND AND HYDROGRAPHY MODELING

WETLAND ADVANCED MODEL PREDICTOR (WETAMP)

Overview

The WetAMP tool was developed by EPR in collaboration with NCDOT to predict the spatial representation of wetlands in North Carolina. The WetAMP tool is built off a previous random forest model developed by NCDOT (Wang et al., 2015). WetAMP currently uses a machine learning gradient-boosted algorithm (XGBoost) to predict the probability of a specific location being a wetland. The WetAMP tool is a complete framework written in Python that involves data preprocessing, feature extraction, training database construction, model training and optimizing, model prediction, probability sensitivity analysis, and geospatial post-processing.

EPR in collaboration with TealWaters, will refine the WetAMP tool to ensure the best machine learning model is utilized for predicting wetlands. TealWaters, the developer of the WIP tool, will serve in an advisory role to advise EPR on training data creation techniques, machine learning approaches with spatial data, and post-processing methodologies. Both EPR and TealWaters have extensive experience in wetland modeling and their partnership will provide substantial gains in modeling efficacy.

Figure 5. Finalized Vector Wetland Layer Created by WetAMP Tool (Blue Polygons are Predicted Wetlands)

The modeling process will involve curating old and new training data to create a robust training dataset used to train the models, assembling geospatially located features that the model will use to predict wetland occurrences, training and testing multiple machine learning model types, finalizing models for each homogeneous geographic region, optimizing the models for maximum performance, predicting wetland occurrences for the entire state of North Carolina with the various final production models, and finally, post-processing the predicted wetlands into the final deliverable formats.

Training Data

The models will be trained on field and desktop-delineated wetlands and non-wetlands. The training data sourced from the NCDOT field delineations will remain the possession of the NCDOT and not be made publicly available. Any training data manually created by EPR will belong to the RES team and be made available as necessary.

Outside wetland data sources will be used to create additional training data for the machine learning models. These data sources could include but are not limited to, the USFWS, NWI, and the North Carolina Division of Coastal Management Wetlands. The outside data will be vetted through a GIS process to ensure the accuracy of the wetlands is consistent with field delineations. Outside wetland data sources used for training will be compared to imagery and DEMs derived from the most recent and highest definition LiDAR data, stochastic depressions modeled with a GIS toolset, topographic wetness index, and hydric soils to ensure that identified wetland boundaries are accurate. After the manual dataset has been delineated, it will be added to the NCDOT field-delineated training data to train the machine learning models.

The final training dataset will be split into two data sets used to train and test the models. Following tested machine learning methods, 80% of the training data will be used to train the model, and a reserved 20% of the initial training dataset will be set aside for testing. The test dataset will not be seen by the models during training but will be used to verify their performance.

Model Features

Model features used to help the model predict the occurrence of wetlands will include DEMs derived from LiDAR and terrain derivatives, best land cover, Sentinel-2 spectral bands and derivatives, and Soil Survey Geographic Database (SSURGO) soils. ***Table 1*** provides a summary of currently identified features to potentially include in the model, but it is not a final list of features to be used in the production model.

Table 1. Current Model Features to be Used in a Machine Learning Model to Predict Wetlands in the Landscape

Model Feature	Description
Slope	Steepness of the terrain
Ratio of slope drainage area	Slope of each cell divided by the contributing drainage area
Aspect	Direction the terrain faces, which influences sunlight exposure and moisture retention
Curvature	Convexity or concavity of the surface
Plan curvature	Curvature on horizontal (x) direction
Smooth curvature	Mean curvature value for a neighborhood of 5X5
Profile curvature	Curvature on vertical (y) direction
Elevation deviation from max	Ratio of cell elevation compared to max elevation within a designated neighborhood size
Elevation deviation from mean	Difference between elevation of each grid cell and the mean elevation of the centering local neighborhood
Topographic Wetness Index (TWI)	Index that combines slope and upstream drainage area to model potential water accumulation zones
Depth to Water (DTW)	Index that is related to soil moisture and that helps to identify low-lying areas
Stochastic depression analysis	Probability of each cell from a raw DEM belonging to a depression
Breached stochastic depression analysis	Probability of each cell from a breached DEM belonging to a depression
Sobel filter	Edge detection
NLCD	National land cover database land cover classes
Hydric soils	Binary input where SSURGO soils identified as hydric are 1 and non-hydric soils are 0
Sentinel-2 spectral bands and derivatives	R, G, B, near-infrared, short-wave infrared, normalized difference vegetation index, normalized difference water index

For a selected test watershed, TealWaters will run the WIP tool, an open-source machine learning model that predicts the intrinsic potential of an area to support wetlands. By applying the WIP tool to this watershed, we aim to evaluate additional variables and identify potential improvements that could enhance the WetAMP model. Since the WetAMP and WIP models share similar workflows—such as input variable creation, feature testing, and the use of machine learning—integrating variables from the WIP model into WetAMP is a straightforward process.

The WIP tool includes over 30 different variables derived from LiDAR, remote sensing imagery (NAIP, Sentinel-2), and ancillary data. Many of the data variables within WIP are already incorporated in the WetAMP model. However, the WIP has several additional variables, including multiscale terrain metrics, such as curvature, depression index, and slope, which have shown to improve wetland mapping (Halabisky et al. 2023). These variables are crucial for capturing the diverse geomorphic characteristics of wetlands, particularly small, forested depressions and vegetated peatlands, which are often missed in traditional wetland inventories. Multiscale analysis allows these metrics to reflect topographic patterns at varying spatial resolutions, which has been shown to significantly improve mapping accuracy compared to single-scale approaches (e.g., curvature alone),

By incorporating these new variables and systematically comparing the performance of the baseline model, we aim to create the most robust model possible for wetland identification. This iterative testing process will focus on improving the accuracy and performance of the WetAMP model by leveraging insights and variables derived from the WIP tool. The newest available feature datasets will be compiled before training the models and making model predictions. The updated feature datasets ensure the wetland mapping is as indicative of current conditions as possible.

Model Training

Several machine-learning model types will be tested for efficacy in modeling wetlands, such as gradient-boosted models (XGBoost), random forests, support vector machines, and neural networks with deep learning. EPR will utilize a gradient-boosted algorithm (XGBoost) based on experience and performance. Neural networks are better suited for unstructured data such as images or text. In addition to gradient-boosted models' superior performance with structured data, the algorithms can be used in parallel processing and distributed across a Graphic Processor Unit (GPU). The use of the GPU will drastically reduce the training and prediction times for the final model. The model will be trained and implemented on an advanced virtual machine in the cloud that is tailored to machine learning applications. The use of the virtual machine in the cloud will help speed up the training and prediction phases of the modeling efforts, allowing our Team to meet the project schedule demands.

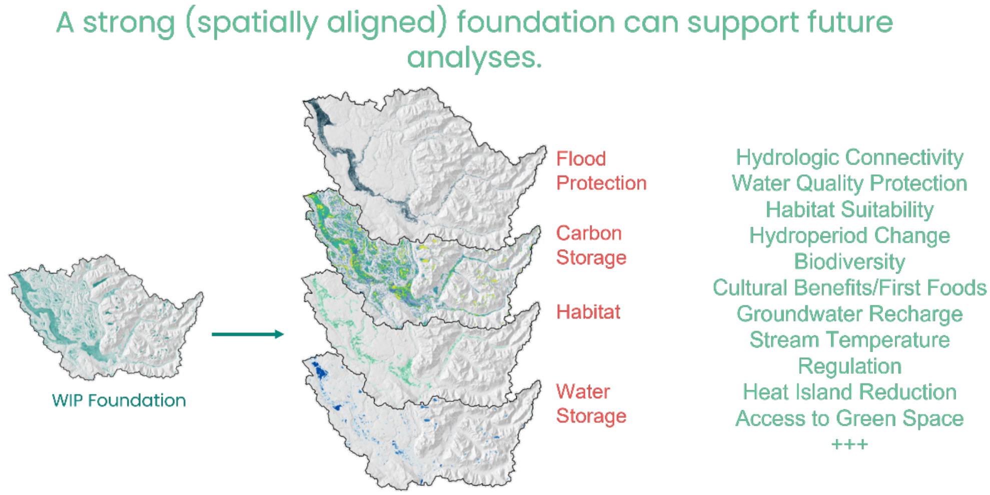

Figure 6. Example of WIP Tool for Modeling Wetland Functions

EPR and TealWaters will run a prototyping exercise on one watershed or county within each physiographic region. The prototyping exercise will be run with the WetAMP features and then again with the WIP features. Running both models and comparing the model input features will help the researchers define a set of features that best predict wetlands.

After a final set of models are chosen to move forward for production, EPR will tune hyperparameters using different methods to ensure the highest level of performance is achieved for each geographically specific model.

Geographical Regions

It is expected that multiple machine learning models will be implemented in production to predict the wetlands across North Carolina. Given the complexities and differences between regions of the state, EPR will initially test developing models for each EPA Level III Ecoregion. If enough training data are available in each Level IV Ecoregions, EPR will create models at the finer geographic scale.

Model Predictions

Model predictions will be completed on a county scale using a virtual machine in the cloud to boost computational performance and speed. The enormous spatial datasets are computationally demanding, and the virtual machine will speed up both the model predictions and any post-processing. The model will predict for each grid cell, a probability from 0 to 1 of whether that grid cell is a wetland. Based on previous sensitivity analysis, EPR will assign a threshold probability for each county that will be used to create a binary (0 = non-wetland, 1 = wetland) raster. After all North Carolina counties are predicted, EPR will use post-processing techniques to improve model metrics and predictions and create a vectorized final deliverable.

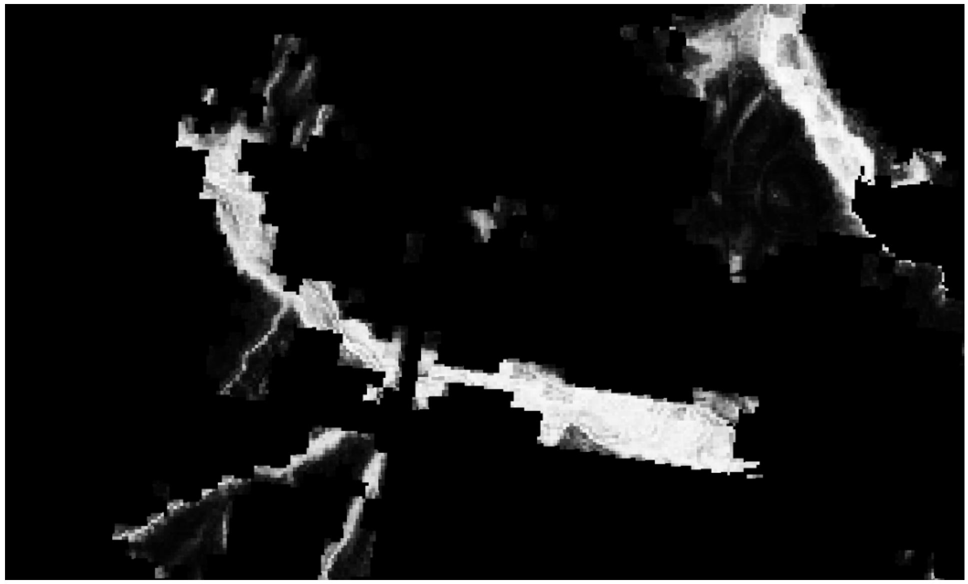

Figure 7. Rasterized Probability Output from the WetAMP Tool (Each Cell is Assigned a Probability [0-1] of being a Wetland with White being more Indicative of a Wetland

Wetland Classification

The perceived value of a wetland is determined by the ecological, geomorphic, and social functions it provides. The specific functions of a wetland and how they manifest depend on its unique characteristics and the surrounding landscape context. Classification systems group wetlands by specific functional and/or landscape-context characteristics relevant to measures of wetland value.

The only statewide wetland classification system that exists for North Carolina is the NWI Cowardin classification. While the Cowardin classification is widely used, it does not offer the detail often needed to capture the processes of wetland functions. The Cowardin system is used for economic valuation because it provides a standardized framework for identifying and categorizing wetlands based on their ecological attributes. The standardized framework allows Earth Economics to link wetland types to general ecosystem services—such as water filtration, flood mitigation, or habitat provision—and assign economic values to these service based on scientific literature. For example, a wetland classified as "Palustrine emergent" under Cowardin can be associated with specific benefits like water storage or biodiversity support, which are then monetized based on existing valuation data.

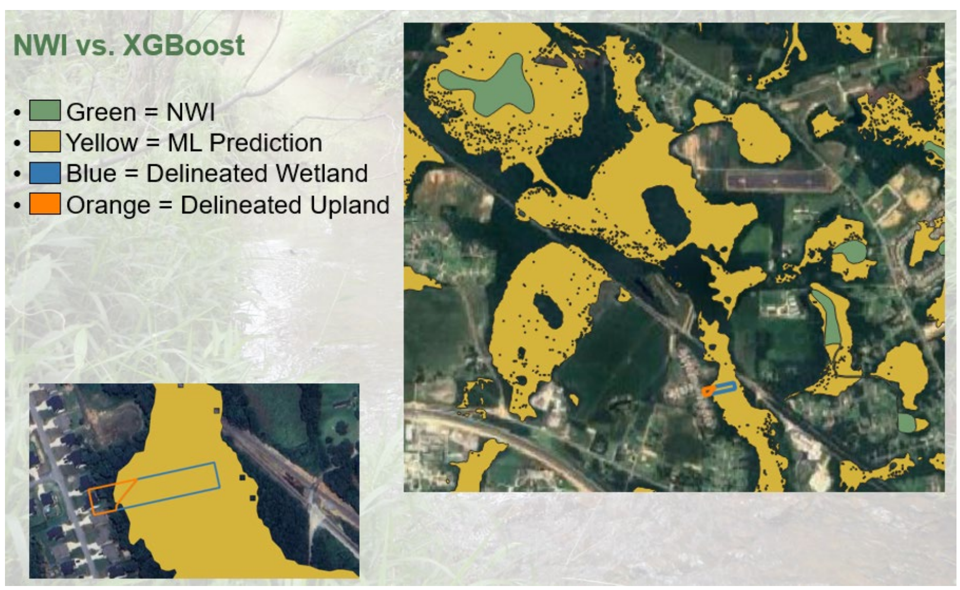

Figure 8. Demonstrating that the NWI Underestimates Wetlands and that the WetAMP Tool Can Identify Wetlands Missed by NWI

However, the Cowardin system is less appropriate for understanding wetland function because it is not designed to capture the detailed processes that drive wetland ecosystem services. The system focuses on descriptive classifications rather than on dynamic attributes like:

- Hydrological connectivity (e.g., flow paths, water retention, and storage dynamics).
- Carbon cycling (e.g., soil organic carbon storage or methane emissions).
- Nutrient processing (e.g., nitrogen and phosphorus cycling).
- Flood attenuation (e.g., volume of water retained during storm events).

These functional attributes often require additional classification systems, such as the HGM approach, or advanced spatial and hydrological analyses that go beyond the Cowardin framework. Without this functional detail, the Cowardin system can oversimplify or miss key ecological processes critical for evaluating how wetlands perform in a specific landscape or under changing conditions.

We will utilize existing wetland classification systems, such as the hydrogeomorphic classification developed by the North Carolina Division of Coastal Management. More specifically, we will coordinate efforts across the team and stakeholders to identify wetland attributes to better enable wetland characterization and evaluation, particularly for determination of how each wetland is affected by the Sackett ruling. We bring a variety of data analysis tools to aid in this effort.

The spatial template for these analyses is provided by the stream-channel hydrography. This hydrography must be derived based on flow paths interpreted from a DEM so that each point in the landscape, i.e., each DEM grid cell, can be referenced in terms of the channel that it drains to. With determination of these flow paths, we can trace the flux of water and water-carried material throughout a landscape, thus determining hydrological connectivity point to point. To accurately trace these flow paths in the context of the channel network, the channels in the GIS stream layer must be accurately located on DEM-based flow paths. These traced channels must also extend sufficiently far upstream to accurately identify headwater connections to the channel network. Headwater channels, despite their small size, compose a large portion of the total channel length, potentially even the majority, and therefore exert an oversized role in basin hydrology.

The NCDOT ATLAS hydrographic dataset provides precisely such a DEM-traced channel network. This dataset will be the starting point for spatial analyses, with additions or modifications performed if the need for such is identified.

The channel network provides the reference for determining landform type and landform hydrogeomorphic function. Valley-floor landforms are mapped in terms of their elevation and location relative to traced channel centerlines and channel edges. Valley-floor locations can be characterized in terms of elevation and distance measured relative to the elevation and size of the valley-traversing channels. The topography, soils, and land cover along flow paths show how hillslope locations are connected to the channel network, enabling the classification of hillslopes into pertinent landform types (e.g., geomorphons, Jasiewicz and Stepinski, 2013).

This spatial template enables the mapping of process-based connections across entire landscapes. We then need to determine what connections to map. For wetlands, we can look at:

- Landscape position: upslope, downslope, and adjacent landforms, depending on the landform classification system used. These may be geomorphic definitions (e.g, floodplain, convergent footslope, divergent midslope, fan, as delineated using geomorphons (Jasiewicz and Stepinski, 2013), based on the HGM landform classification described in ***Section 2.3.1*** above, or aligned with a specific wetland classification system (estuarine, lacustrine, palustrine).
- Flow paths and Inflowing drainageways: how large they are, their flow regime, characteristics of their drainage areas (topography, landforms, soils, land cover, runoff, and erosion potential), flood discharge at various recurrence intervals.
- Outflowing channels: flow duration, where they drain.
- For wetlands without mapped surface-channel connections, the type of channel it drains to, the flow distance to that channel, and the potential for inundation during floods (e.g., recurrence interval for flooding).
- Wetland surface area and volume.
- Contributing area to a wetland and characteristics of that contributing area.

With the ability to measure these attributes, we can then implement a variety of wetland classification schemes, such as the Landscape position, Landform, Water flow path, and Waterbody (LLWW) type (Tiner, 2014). Importantly, we pick and choose attributes and model applications to customize classifications for specific needs and localities, such as the HGM-based classification developed for Minnesota (Ulrich et al., 2019).

Note that a key aspect of this analysis toolset is the attribution of channels and wetlands in terms of the upstream and adjacent contributing areas and characteristics of those contributing areas. This information needs to be added to existing hydrography. It is calculated at the spatial grain of the DEM but can then be aggregated over any required length scale.

Our classification process will be used to attribute the wetland polygons derived from the WetAMP model. This classification will support several additional analyses including: 1) Scenarios modeling and understanding the potential loss of wetland functions within individual projects or watersheds; and 2) Sackett classification scenario modeling. In addition, the detailed attribution of the hydrography and development of several additional data layers sets up the possibility of explicitly modeling individual wetland functions such as quantifying wetland carbon storage (Stewart et al.,2024).

Advisory Services

EPR will provide advisory services to TealWaters on wetland classification. Their experience with wetland delineation and restoration, machine learning algorithms, geospatial analyses, and common GIS operations make them suitable to assist in classifying the wetlands after they have been mapped.

Classification Datasets

EPR will create and provide GIS datasets that aid in identifying a wetland's landscape position. These datasets could include, but are not limited to, multiscale elevation percentile, relative topographic position, curvature, max branch length, elevation deviation over multiple scales to identify localized topographic position, and more regional-based topographic position. The datasets will be created on a county-by-county basis to minimize the size of individual datasets. Final deliverables include a file geodatabase of raster and vector files for each county for each data type selected by the team. The datasets will be created early in the wetland mapping process so that after the wetland mapping is completed, there is no delay in assisting the team with the wetland-type classification process.

HEADWATERS MAPPING TOOL

Hydrography Overview

EPR will utilize their experience in watershed delineation, geospatial analyses, programming, automation techniques, and extensive knowledge of GIS hydrography-based toolsets to assist TerrainWorks in analyzing, interpreting, developing, and improving existing hydrography datasets for North Carolina.

Existing Datasets

EPR will curate existing hydrography datasets such as the National Hydrography Dataset Plus High Resolution and the NCDEQ hydrography dataset to make comparisons. The team will review streamlines to ensure accuracy in the landscape and the team will also investigate whether the datasets make accurate streamflow duration (ephemeral, intermittent, perennial) calls on the stream segments. Accuracy of existing datasets will be interpreted based on team-supplied field-delineated streamflow duration calls. After thorough investigation and testing, the team will decide if the existing datasets are suitable for integration into the research process.

Hydrography Modeling

Channel attributes needed for landform and wetland classification will be calculated using the current stream layer (NCDOT ATLAS) and LiDAR DEMs together with other spatial data sources assembled for this project (e.g., land cover). If modifications to the stream layer are needed, such as upstream extension of drainageway flowlines, these will be based on US Geological Survey specifications for the 3DHP program and incorporated into the existing stream layer. If additional hydrography modeling is required to determine streamflow duration breaks or other stream attributes, EPR will assist TerrainWorks with the development of Python code, model creation and implementation, and data processing.

2.3.4 Field Verification, Ground Truthing, and Calibration

The training data and model results will be verified to the extent practicable through field verification and ground truthing. Ground truthing will be performed to validate features and attributes predicted based on the training data and model results within the test watersheds. Both manual and remote sensing (drone) methods will be employed. Field verification is crucial to developing an accurate portrayal of hydrography, wetlands, working lands, and a defensible quantitative assessment of the impact and cost to the state.

2.4 Functional Valuation and Impact Analyses

This section focuses on the economic valuation of natural and working lands and the analysis of potential costs to the state due to changes in wetland protections. It will draw from the data gathered and models developed in previous sections to provide a comprehensive assessment of the economic consequences associated with the Sackett v. EPA ruling and the North Carolina Farm Act of 2023. Land cover types will each be assigned the environmental, social, resilience, and economic values identified in this project and related studies. This will be accomplished by leveraging Earth Economics' EVToolkit and BTM.

2.4.1 Ecosystem Valuation Toolkit and Benefits Transfer Methods

The EVToolkit includes an extensive database of non-market economic value estimates and models that facilitate valuations of a broad suite of ecosystem goods and services. This database will be used to provide context and comparable values for different types of ecosystems and the services they provide. Use of a range of BTM approaches enables the rapid assessment of social, environmental, and economic impacts of wetland degradation by applying values to similar locations using project data and peer-reviewed valuation studies. This multi-faceted valuation approach will consider:

- Environmental benefits such as water quality, carbon sequestration, and habitat provision.
- Social impacts such as recreation, cultural values, and public health.
- Resilience factors such as flood protection, storm surge mitigation, and climate change adaptation.
- Direct economic benefits such as timber production, agriculture, and tourism. Where necessary, the team will conduct literature reviews to address gaps that limit the ability to estimate the value provided by the state's ecosystems. Some ecosystem services are studied more than others; accordingly, reviews will prioritize services known to provide higher value in other geographical contexts. The project will also use data from mitigation and restoration sites to help inform and validate the classification and valuation of each land type.
- Geospatial data including field verification, NWI, C-CAP, and NC OneMap will contribute to the valuations.

NATURAL CAPITAL, ECOSYSTEM FUNCTION, AND ECOSYSTEM SERVICES RELATIONSHIP

Natural capital comprises minerals, energy, plants, animals, ecosystems, climatic processes, nutrient cycles, water, and other natural structures and systems found on Earth that provide a flow of natural goods and services. Natural capital is the foundation of all human societies, yet this critical value is frequently overlooked. Natural capital provides the foundation for all human societies, yet this critical value is frequently overlooked. Interactions between natural capital features give rise to ecosystem functions, many of which produce flows of ecosystem services that support human well-being (***Figure 3***).

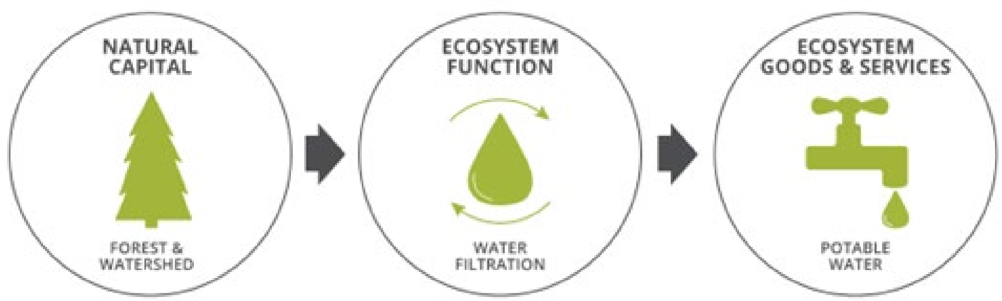

Figure 9. Natural Capital, Ecosystem Function, and Ecosystem Goods and Services

Healthy landscapes support thriving communities and economies as ecosystem services provide resources and critical processes to support industry and improve quality of life. There are multiple frameworks categorizing ecosystem services such as the Millennium Ecosystem Assessment framework (MEA) (Alcamo et al., 2003), The Economics of Ecosystems and Biodiversity framework (TEEB) (De Groot et al., 2010), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services framework (IPBES, 2017), and the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2018). The number of distinct services recognized varies widely; for instance, CICES includes 90, while the MEA and TEEB frameworks each name 21 distinct ecosystem services. Earth Economics' preferred framework is a fusion of MEA and TEEB approach, and is similarly focused on 21 ecosystem services (***Table 2***).

- **Provisioning services** are tangible resources for human use, such as foods, water storage, energy, fuel, forage, fiber, and minerals. These are often packaged and sold as market goods, although market prices may not reflect their full value.

- **Regulating services** maintain and provide buffers for natural processes, including the long-term terrestrial storage of carbon; local and regional climate regulation; water capture, conveyance and supply; water quality; soil creation and retention; disaster risk reduction (e.g. flood control); pollination; and regulation of pest species and disease.
- **Supporting services** provide critical habitat and refugia for plants, animals, and other species throughout their lifecycles.
- **Cultural services** support social, cultural, or spiritual needs, such as education; aesthetic beauty; spiritual and cultural heritage; and recreational and touristic experiences.

Table 2. Definitions of Ecosystem Services

Services	Example Benefits
Provisioning	**Materials and/or energy outputs, often sold via markets**[1]
Energy, Raw Materials	Fuel, fiber, fertilizer, minerals, and energy
Food	Livestock, crops, fish, wild game
Medicinal Resources	Traditional medicines, pharmaceuticals, assay organisms
Ornamental Resources	Clothing, jewelry, handicrafts, decoration
Water Storage	Usable surface or groundwater, stored reliably
Regulating	**Ecosystem functions that influence critical ecosystem processes**
Air Quality	Ability to create and maintain clean, breathable air
Biological Control	Disease, pest and weed control
Climate Stability	Ability to support a stable climate at global and local levels
Disaster Risk Reduction	Ability to prevent or mitigate flood, wildfire, drought, and other natural disasters
Pollination, Seed Dispersal	Dispersal of genetic material via wind, insects, birds, etc.
Soil Formation	Soil creation for agricultural and/or ecosystem integrity
Soil Quality	Soil quality improvement due to decomposition and pollutant removal
Soil Retention	Ability to retain arable land, slope stability, and coastal integrity
Water Quality	Water quality improvement due to decomposition and pollutant removal
Water Supply	Ability to provide natural irrigation, drainage, and other water flows
Navigation	Maintaining necessary water depth and passage for recreational and commercial vessels
Supporting	**Habitat, nursery, refugia**
Habitat	Ability to sustain species and maintain genetic and biological diversity
Information	**Non-material benefits**
Aesthetic Information	Sensory enjoyment and appreciation of natural features
Cultural Value	Use of nature in art, symbols, architecture, or for religious or spiritual purposes
Science and Education	Use of natural systems for education and scientific research
Recreation and Tourism	Hiking, boating, travel, camping, and more

[1] It should be noted that market prices may—or may not—reflect the full value of an ecosystem good or service. Since ecosystem services valuation typically focuses on externalities (i.e. nonmarket value), greater emphasis is placed on the concept of surplus—differences between a person's willingness to pay (or accept) and the actual costs they incur. Thus, *producer surplus* (market prices minus direct costs) is often preferred over the market value of crops or livestock. Similar emphases often emerge when estimating *consumer surplus* of recreation (willingness to pay minus travel costs).

SPATIAL APPROACH TO ECOSYSTEM SERVICES VALUATION

Identifying Land Cover Types and Contexts

To develop broad-based estimates of the value of ecosystem services produced across diverse landscapes, the range and extent of all land cover types (e.g. riparian wetlands, estuarine wetlands) across a study area must first be identified, as well as a variety of contextual factors known to affect economic value (e.g. proximity to urban areas). This project will rely on land cover data from multiple sources, including existing remote sensing data such as the NLCD, the C-CAP, the NHD, and the NWI. Since the latter is considered to generally underestimate the extent of wetlands, those features will be modeled by the project team using the NWI framework and multiple calibration datasets.

There are challenges to integrating data sources of varying spatial and categorical resolution. The C-CAP dataset offers the highest spatial resolution (1 meter), but currently only reports tree canopy, surface waters, and impervious surfaces (more extensive land cover reporting is planned, but not yet available). The NLCD is the most extensive land cover dataset available, reporting the extent of 15 land cover types at 30-meter resolution for the continental U.S. every year since 1985. The NWI reports the extent of eight wetland categories at 30-meter resolution for the continental U.S. as well, but there are several known issues with those data, including underestimation of wetland extent. The National Hydrology Dataset includes a wide range of spatial data, including point, line, and areal features, as well as supporting tabular data.

A comprehensive understanding of the types and extents and land cover across North Carolina is critical to multiple project tasks, from wetland modeling to ecosystem services valuation. Ideally, such an understanding would maximize the available spatial and categorical resolution, prioritizing higher spatial-resolution footprints where those overlap with lower spatial-resolution features, and maximizing categorical resolution based on the intersection of multiple data sources. The greater categorical resolution of the NLCD and NWI provide a starting point for literature reviews of the value of ecosystem services produced throughout North Carolina, but modeling the value of those benefits will require precise estimates of the extent of each land cover type. For non-wetland land covers, Earth Economics will be responsible for developing guidelines for determining land cover classes where spatial datasets disagree on the extent and/or type of land cover. These guidelines will be incorporated with wetland maps (modeled by partners) to produce the best-available map of land cover types and their extents throughout North Carolina. The guidelines will be further characterized by contextual attributes (see Benefit Transfer Methods below) known to influence the value of ecosystem goods and services.

BENEFIT TRANSFER METHODS (BTM)

Estimating the Value of Ecosystem Goods and Services

While many ecosystem goods and services categorized as provisioning services are traded in markets, others are not—these are referred to as non-market benefits. Over the past several decades, economic science has developed multiple methods for estimating the value of such benefits. These methods can be broadly categorized into revealed preferences (e.g. travel costs, replacement costs, avoided costs) and stated preferences (e.g. willingness to pay, willingness to accept). Since the time and resources necessary to conduct primary research of a new location are often prohibitive, a common approach is to apply BTMs, which generalize value estimated at a primary study site to other similar sites. Broadly defined as "…the use of existing data or information in settings other than for what it was originally collected," (Richardson et al., 2015) BTM is frequently used to indirectly estimate the value of ecological goods or services. A common application of BTM is property appraisal, by which the value of off-market properties is estimated by comparing recent sale prices of nearby properties sharing similar features. Simply put, BTM is an efficient means of estimating value in a timely way—given the variety of ecosystem services produced by most land cover types, BTM is often the only pragmatic way of estimating the broad value of ecosystem services for a given project site.

FUNCTION TRANSFER

Proper application of BTM ensures that relevant conditions and contexts are similar across both primary and "transfer" sites. There are multiple approaches to BTM, depending on the available data and supporting literature. The simplest form is known as "point transfer," by which the estimated value of a given ecosystem service produced by a given land cover type at a primary study site is converted to a unit value (e.g. $/acre/year), then scaled by the extent of that land cover type at the transfer site. These estimates are further refined by distinguishing between similar land covers in different contexts (e.g. rural vs urban), as these are known to influence the value of ecosystem services. Another approach is to apply statistical models reported in the literature, substituting local measures of the explanatory variables for those in the original studies. This is known as "function transfer," and is known to generally produce estimates with greater accuracy than point transfer approaches.

Meta-analyses, in which the contextual factors reported by multiple primary studies are analyzed for their influence on value, can be especially useful for understanding the influence of various contextual factors. Meta-analyses are common to health research. There are several advantages to basing function transfers on meta-analyses:

- Since meta-analytic value functions are estimated from multiple studies, they can control for greater variation in the characteristics of ecosystems, beneficiaries, and methodological differences across primary studies.
- This approach allows us to develop models that are more generalizable than what can be obtained from a single study, because we are using information drawn from multiple contexts.
- More generalized models can fill literature gaps, inferring value at transfer sites based on contextual factors reported across multiple studies.
- Research has shown that function transfer using meta-analyses produce smaller errors than point transfer approaches (Kaul et al., 2013).
- Using function transfer to estimate the value of ecosystem services is recommended by federal agencies, especially where those functions are based on meta-analyses (OMB, 2023).

Where function models include contextual variables known to vary throughout the study area (e.g. relative scarcity of relevant land covers, population affected), they can be applied to each landscape feature in isolation. That is, it is possible to develop unique per-acre and total value estimates for each contiguous wetland tract or forest (sharing relevant contextual features) across a study area. For instance, a model that includes the extent of nearby land cover types will generally produce higher per-acre estimates where the land cover type in question is relatively scarce, in contrast to areas where it is more common. The same is often true when scale is a factor—larger contiguous landscape features will tend to have smaller per-acre estimates than smaller features. Where available, such geographically explicit function transfers can produce estimates that vary by location, to better reflect local factors known to influence the value of ecosystem services. In this study, landscape features will be identified as single-part features recorded in ArcGIS. Geographically explicit value-function models will be given preference over more general function models, which will be preferred over point-value transfers, which will be applied only in instances where more robust BTM approaches are not available.

Over more than two decades, Earth Economics has accumulated an extensive library of ecosystem services valuation studies. These have been transcribed into the EVToolkit, a continually expanding database that currently includes over 9,300 value estimates and valuation models. Each estimate has been tagged with as many as 200 attributes, including original study site location and characteristics (e.g. proximity to urban areas, climate), methodology and sampling approaches, valuation type (e.g. revealed or stated preferences) etc. Where feasible, each estimate has been "regularized" into a unit value (e.g. $/acre/year, $/household/year). Most of the studies in the database have been published in peer-reviewed academic journals, yet each transcription undergoes an additional internal peer review to ensure that each estimate has been properly transcribed and that the underlying methodology conforms with contemporary best practices.

To develop an initial assessment of the literature relevant to North Carolinian contexts, Earth Economics analysts first identified the North Carolina land covers reported in the latest versions of the NLCD and NWI. These were used to identify estimates based on similar land cover types and context in the EVToolkit, prioritizing studies that included at least one primary study site within North Carolina, then those conducted in neighboring states (Virginia, South Carolina, Tennessee, Georgia), and finally, national or global meta-analyses (see ***Table 3***). These estimates have been identified as point transfers (P) and function transfers (F). To identify gaps, we also queried the EVToolkit for studies of ecosystem services produced by each land cover type globally (identified in grey). Higher-value ecosystem services have been flagged for additional transcriptions (T), provided studies appropriate for transfer to North Carolina contexts are available in scholarly literature. Additional ecosystem services may be considered, following consultation with partners and the client.

Table 3. Ecosystem Valuation Estimates in EVToolkit as of December 2024

	Ecosystem Service (general)	Ecosystem Service (specific)	Barren, rock, sand, clay	Cultivated, crops	Cultivated, pastures	Forests, deciduous	Forests, evergreen	Forests, mixed	Grasses	Scrub, shrub	Water, estuaries	Water, lakes	Water, open (general)	Water, open (seagrass)	Water, rivers	Wetlands, general	Wetlands, herbaceous	Wetlands, woody	Wetlands, peat
Provisioning	Energy, Raw Materials	Animal products																	
		Energy											T			F			
		Mineral products																	
		Plant products																	
		Other														F			
	Food	Crops																	
		Fish														F			
		Forage							P	P									
		Game														F			
		Livestock																	
		Other																	
	Medicinal Resources	Pharmaceuticals						T											
	Ornamental Resources	Decorations, handicrafts																	
		Other																	
	Water Storage	Groundwater														T			
		Surface water											T			F			
		Other						T										P	
Regulating	Air Quality	Oxygen production																	
		Pollutant removal						P	P				T		T				
	Biological Control	Pest control																	
		Weed control																	
		Other																	
	Climate Stability	GHG sequestration		T		P	P	P						T				P	
		GHG storage		T		P	P	P						T					
		Temperature regulation																	
Regulating	Disaster Risk Reduction	Flood						T								F			
		Storm buffering												T					
		Wildfire						T											
		Other																P	
	Navigation	Navigable waters																	
	Pollination, Seed Dispersal	Pollination																	
		Other																	
Regulating	Soil Formation	Mineralization																	
		Sediment transfer																	
		Soil biota																	
	Soil Quality	Soil fertility																	
		Other																	
	Soil Retention	Erosion control		T	T									T					
	Water Capture, Conveyance, Supply	Groundwater recharge																	
		Hydrological flow																	
		Natural irrigation																	
		Runoff reduction																	
		Other				P	P	P					T						
Regulating	Water Quality	Dissolved oxygen																	
		Contaminant removal				P	P			T		F	T			F	P	P	
		Salinity regulation																P	
		Waste treatment																	
		Other																	
S =	Habitat	Biodiversity																	

	Ecosystem Service (general)	Ecosystem Service (specific)	Barren, rock, sand, clay	Cultivated, crops	Cultivated, pastures	Forests, deciduous	Forests, evergreen	Forests, mixed	Grasses	Scrub, shrub	Water, estuaries	Water, lakes	Water, open (general)	Water, open (seagrass)	Water, rivers	Wetlands, general	Wetlands, herbaceous	Wetlands, woody	Wetlands, peat
		Habitat, general					P					F		T		F			
		Net primary production																	
		Nursery, refugia												T					
		Other																	
Information	Aesthetic Information	Real estate value						P					T						
Information	Aesthetic Information	Other						P											
Information	Cultural Value	Amenity value										F				F			
Information	Cultural Value	Conservation, restoration		P					P				T						
Information	Cultural Value	Social fabric																	
Information	Cultural Value	Spiritual value										F							
Information	Cultural Value	Other																	
Information	Recreation, Tourism	Beachcombing												T					
Information	Recreation, Tourism	Camping										F							
Information	Recreation, Tourism	Ecotourism																	
Information	Recreation, Tourism	Fishing, freshwater										F				F			
Information	Recreation, Tourism	Fishing, saltwater														F			
Information	Recreation, Tourism	Foraging																	
Information	Recreation, Tourism	General recreation	P						P			F	T	T		F			
Information	Recreation, Tourism	Hiking, walking																	
Information	Recreation, Tourism	Hunting, big game																	

	Ecosystem Service (general)	Ecosystem Service (specific)	Barren, rock, sand, clay	Cultivated, crops	Cultivated, pastures	Forests, deciduous	Forests, evergreen	Forests, mixed	Grasses	Scrub, shrub	Water, estuaries	Water, lakes	Water, open (general)	Water, open (seagrass)	Water, rivers	Wetlands, general	Wetlands, herbaceous	Wetlands, woody	Wetlands, peat
Information	Recreation, Tourism	Hunting, birds																	
Information	Recreation, Tourism	Hunting, general														F			
Information	Recreation, Tourism	Motorboating										F							
Information	Recreation, Tourism	Mountain biking																	
Information	Recreation, Tourism	Nature study, centers																	
Information	Recreation, Tourism	Off-road vehicles																	
Information	Recreation, Tourism	Paddle sports																	
Information	Recreation, Tourism	Sightseeing										F							
Information	Recreation, Tourism	Swimming										F							
Information	Recreation, Tourism	Wildlife watching																	
Information	Recreation, Tourism	Other											T						
Information	Science, Education	Education																	
Information	Science, Education	Genetic resources																	
Information	Science, Education	Science																	

Key

(shaded)	Ecosystem services *with* observed value for a land cover type, globally, and included in EVToolkit
P	Value for ecosystem service-land cover combination in EVToolkit suitable for **point transfer** to the study area*
F	Value for ecosystem service-land cover combination in EVToolkit suitable for **function transfer** to the study area
T	Higher value ecosystem services *with* observed value for a land cover type, globally, and flagged for **transcription** to the study area context
	Ecosystem services *without* observed value for a land cover type, globally, in EVToolkit

*Query includes values from North Carolina, Virginia, West Virginia, South Carolina and Georgia. The values outside of North Carolina fall under the same climate group (C- Temperate/ Mesothermal) and climate type (Cfa- Temperate Hot Summer Without Dry Season and Csc- Temperate Cold Dry Summer).

LAND COVER CHANGE FRAMEWORK

The Effects of Land cover Change on Ecosystem Services

Since not all land cover types (ecosystems) produce the same services at the same levels, land cover changes usually affect the net value of ecosystem services. In other words, land cover change usually leads to trade-offs, as one or more ecosystem functions (and associated services) are diminished or increased. By comparing net differences in the estimated nonmarket value before and after land cover change, we may better understand the full benefits and costs of converting one land cover or land use to another, especially as applied to the context of wetlands under the Sackett ruling.

Below (***Table 4***) is a simplified framework to illustrate how trade-offs in (nonmarket) ecosystem services can be systematically assessed. The green cells represent the baseline unit value (e.g. $/acre/year) produced by land cover type. Other cells reflect the net gains or losses of converting one land cover type to another, subtracting the unit value of the initial land cover type from the unit value of the land cover displacing it (e.g. converting wetlands to cropland is calculated as W-C). These net unit-value differences are then scaled by the extent of the associated land cover changes throughout the study area. While the total net differences across the full study area could also be calculated based simply on pre- and post-land cover extents, this framework can identify those land cover transformations leading to the greatest gains or losses.

Table 4. A Simplified Land Cover Change Framework (per-acre values)

From / To	Crops (C)	Developed (D)	Grasses (G)	Wetlands (W)
Crops (C)	**C**	D-C	G-C	W-C
Developed (D)	C-D	**D**	G-D	W-D
Grasses (G)	C-G	D-G	**G**	W-G
Wetlands (W)	C-W	D-W	G-W	**W**

Costs (and avoided costs) to the State of North Carolina

Often, avoided or replacement cost estimates may be identified through the ecosystem services valuations; such methods are common to multiple studies in the EVToolkit. However, increasing the certainty of the estimated costs of infrastructure, industries, and water quality affected by wetland loss or degradation to governments in North Carolina will require a thorough literature review (see Adusumilli, 2015; Sun & Carson, 2020; and Costanza et al, 2008 for examples). A brief review of the published literature reveals that more focused studies appear to be available (***Table 5***). It should be noted that these are preliminary numbers—it is quite likely that some articles have been included because they reference research by scholars working at one of North Carolina's colleges or universities, rather than because a study was conducted within the state.

Table 5. Search Results for Articles Published Since 2018

Term 1	Term 2	Google Scholar	Science.gov
North Carolina	"disaster" AND "ecosystem service!" AND "cost!"	559	67
	"flooding" AND "ecosystem service!" AND "cost!"	982	120
	"ecosystem service!" AND ("avoided cost!" OR "replacement cost!")	112	245

FEMA's Hazus Flood Model is commonly used to map the damages from riverine and coastal flooding but does not include so-called "nuisance" flooding associated with poor drainage during and following high-precipitation events. However, the model provides standardized data to estimate risk and project the parcel-level damages associated with flooding and hurricanes, including physical damage to buildings and infrastructure, losses to businesses and local economies, social impacts such as displaced households and shelter requirements, and cost-effectiveness of mitigation strategies, such as elevating structures in a floodplain. Uses include anticipating the possible scope of necessary emergency responses; supporting recovery and reconstruction planning; and mitigating flood impacts. A Level 1 analysis incorporates baseline hazard, inventory, and damage information without additional data needs. It can estimate the direct economic and social losses associated with general building stock and essential facilities, including transportation and utility infrastructure. A Level 1 analysis could be conducted for the entire state of North Carolina, as well as for regions within the state. It should be noted that a Level 1 analysis is appropriate for preliminary evaluation and to better understand mitigation needs. Improving the precision and accuracy of the estimates would require a Level 2 or 3 analysis, which would require substantial local data on buildings, construction costs, and economic linkages.

- Using the flood risk and flood resilience information collected and analyzed, the changes in floodplains created by wetland degradation will be mapped and any properties and infrastructure now at risk will be identified. Economic loss caused by flooding will be estimated by using tools created by FEMA's Hazus Program. The economic impact analysis will also consider the avoided or replacement costs of wetlands. This involves determining where the state is responsible for providing services currently generated by wetlands and which wetlands the state has a responsibility to maintain or restore if damaged. Projected costs will be estimated for ongoing and projected wetland loss over the next 5 and 10 years. This analysis will be based on data reflecting human encroachment, climate change, sea-level rise, and municipal growth projections. RES will use a regression model to identify drivers of land use changes around Metropolitan Statistical Areas.
- The $/acre/year values of North Carolina wetlands calculated earlier will be applied to the total acreage of lost wetlands, as well as applying comparable tools like the Virginia Institute of Marine Science's Wetland Condition Assessment Tool (WetCAT), which can model wetland functions lost due to degradation. The team will develop a methodology to link the value of ecosystem services to wetland integrity.

2.4.2 Economic Contribution Analysis

This study proposes to analyze the economic contribution effects of the Sackett ruling on North Carolina's shellfish and recreational hunting industries. IMPLAN, the industry-standard economic contribution analysis platform, records regional cross-industry economic linkages, allowing us to model the "ripple effects." Initial spending produces additional spending in connected industries, as they purchase goods and services, and pay wages and taxes. Initial expenditures (also known as "direct impacts") such as spending on hunting have indirect impacts (e.g. shifts in demand) and induced impacts (e.g. shifts in household spending). To the degree that industries supporting the primary sector (e.g. shellfishing, hunting) are local, the resulting total economic contribution of that initial spending can be considerably greater—this is known as the "multiplier effect." Results from the contribution analysis will be reported as shifts in overall economic activity (expressed as "total output"), value-added, employment, wages, and state tax revenues.

The research questions we aim to answer with a contribution analysis include:

1) How might Sackett be expected to influence the economic output, employment, and income levels in North Carolina's shellfish industry?
2) What are the potential impacts of Sackett on recreational hunting, including equipment sales, tourism, and licensing revenues?

SHELLFISH

Wetlands are known to be efficient at removing excess nutrients (e.g. nitrogen, phosphorus) from surface and groundwater (Richardson et al 2011; Humphrey et al 2014). Poor water quality can lead to the closure of shellfish harvesting to protect public health, potentially destabilizing struggling shellfish growers and wild harvesters. In a 2017 survey, 50 percent of shellfish growers reported making no profit or losing money but still considered the future of their business more optimistically than wild harvesters. Both growers and harvesters agreed that coastal development is the biggest concern for the industry (Stemle and Condon, 2018).

The 2023 Aquaculture Census (National Agriculture Statistics Service) estimated $1.53 million in direct mollusk sales in North Carolina, but a SeaGrant report from the same year found that North Carolina's shellfish industry contributed $31 million to the state economy, half from farmed oysters (Edwards, 2023). Should models suggest that shellfish beds could be at increased risk of closure due to poor water quality (owing to upland conversion of wetlands), Earth Economics could conduct an economic contribution analysis of the losses associated with each additional annual closure day, including changes in direct output, employment, wages, and tax revenues. We may derive daily revenue loss estimates from the literature, or by interviews with local growers, harvesters, and/or local fisheries experts during stakeholder engagement.

OUTDOOR RECREATION

Fish and wildlife wetland habitat drives considerable recreational spending in North Carolina as well as state revenues in the form of fishing and hunting licenses ($41 million in 2022, according to the US Census Bureau). There are several challenges to estimating the potential impacts of Sackett on wetland-dependent recreation, including the limited availability of fishing and hunting on private lands. The NCCF's stakeholder survey is a valuable resource, but will need to be supplemented with stakeholder interviews, including hunters and fishers, agency staff, and relevant conservation organizations (e.g. Ducks Unlimited). Should interviewees express reasonable concern about substantial impacts to hunting and recreational fishing, Earth Economics will conduct an economic contribution analysis to estimate the anticipated losses to economic output, employment, wages, and tax revenues. Recreationist spending per acre could be scaled by the extent of at-risk wetland habitat to estimate potential direct expenditure losses, which would be entered into IMPLAN to produce broader contribution estimates, such as foregone economic activity, employment, wages, and tax revenues.

Overwintering waterfowl rely heavily on wetlands for feeding (Strader & Stinson, 2005), with each acre contributing to the quantity of waterfowl that can be supported. This quanity can be estimated by calculating Duck Use Energy Days (DEDs), or the energy needed to support one average-sized duck for one day. DED estimates are based on yield estimates and True Metabolizable Energy (TME), each of which varies by food source (see ***Table 6*** for examples). To the degree that Sackett is projected to convert wetlands to other land uses, it is reasonable to expect this to also impact the number of waterfowl feeding within the state, if not the total number of waterfowl regionally.

Table 6. Example Habitat Carrying Capacity for Waterfowl (LMVJV-WWG 2015)

Habitat / Crop	Food (lbs/acre)	TME (kcal/gram)	DEDs/acre
Soybeans (harvested)	54	2.65	36
Bottomland hardwood forests	103	2.76	250
Moist soil wetlands	103	2.47	1,686

Dividing the net DED change associated wetland conversion by the number of ducks allowed per hunter, per day, would allow us to estimate the number of hunting days affected. By combining this with average daily expenditures per hunter, IMPLAN could be used to estimate changes to the total economic contribution of waterfowl hunting, as affected by wetland conversion, post-Sackett.

2.4.3 Wetland Functional Valuation

Wetland functions will be developed for each classified wetland type in the Coastal Plain, Sand Hills, Piedmont, and Mountains. The classified types and the functional evaluation methods borrow from the hydrogeomorphic (HGM) approach developed by Dr. Brinson at East Carolina University (Brinson 1993a and 1993b) and applications such as the Minnesota Simplified HGM method. This HGM approach classifies wetlands by geomorphic setting, dominant water source, and the primary direction of water movement which are related to "surface connection". The grouping allows for the development of a benefit / value profile and assessment for each wetland class. However, the classification will be adapted by WIP and LEC to depict the Sackett boundary conditions potentially defined by the federal courts. In addition, the classification will identify several alternative surface connection definitions that will reduce costs to the state. For the federal definition and each state alternative, the cost to the state due to deregulation will be analyzed both financially and qualitatively for wetland functions and functional attributes such as the following.

Table 7. Wetland Functions and Functional Attributes

#	Function	Potential Cost Due to Deregulation
1.0	**Flood Mitigation**	Changes in the 100-year floodplain within developed lands created by upstream wetland degradation and conversion. Infrastructure damage and losses due to increased flooding from accelerated surface runoff. Loss of water storage capacity and buffer storage during large storm events. Loss of stormwater detention and evapotranspiration within riparian buffer zones: (In-lieu fee (ILF) = $1 - $6 per square foot.
1.1	Dynamic Surface Water Storage	
1.2	Long-Term Surface Water Storage	
1.3	Subsurface Water Storage	
1.4	Moderation of Groundwater Discharge	
1.5	Energy Dissipation	
1.6	Infrastructure Protection	
1.7	Forested Riparian Buffers within Flood Zones	
2.0	**Water Quality Mitigation**	
2.1	Nutrient and Element Retention and Recycling	
2.2	Nitrogen Import and Sequestration	Increased nitrogen delivered to Nutrient Sensitive Waters (NSW) due to wetland degradation and losses (ILF = $12 - $150 per pound.
2.3	Carbon Import and Sequestration	CO2 Reduction costs.
2.4	Phosphorus Import and Sequestration	Increased Phosphorus delivered to Nutrient Sensitive Waters (NSW) due to wetland degradation and losses (ILF = $181 - $630 per pound.
2.5	Removal of Pollutants, Elements, and Compounds	Includes mitigation costs to the state for compounds such as PFAS, distillates, metals, and contaminants in wastewater discharge and urban runoff
2.6	Sediment Retention	Increased sedimentation and water supply impacts due to wetland degradation and losses.
3.0	**Catastrophic Fire Suppression**	Speculative and accelerated drainage ditching and drying in de-regulated wetlands including pine flatwood systems. Projected additional infrastructure losses based on climate trends. Cost for wetland restoration and fire prevention post catastrophic fire event (ILF = $77,000 - $758,000 per credit acre).
3.1	Subsurface Water Storage	
3.2	Long Term Surface Water Storage	
3.3	Moderation of Groundwater Discharge	
4.0	**Climate Mitigation**	Speculative and accelerated drainage ditching and drying in de-regulated wetlands including pocosins, peatlands, and Carolina Bays. Projected additional infrastructure losses based on climate trends.
4.1	Organic Carbon Redox and Retention	
4.2	Organic Carbon Redox and Accumulation	
4.3	Catastrophic Fire Prevention	

#	Function	Potential Cost Due to Deregulation
4.4	Characteristic Organic Soil Wetland Hydroperiod	
5.0	**Ecological Benefits**	Loss of biodiversity, wildlife, and natural habitat will be valued by wetland class under the federal definition and the state alternatives analysis.
5.1	Maintain Characteristic Plant Communities	
5.2	Maintain Characteristic Detrital Biomass	
5.3	Maintain Spatial Structure of Habitat	
5.4	Maintain Diagnostic / Keystone Species	
5.5	Maintain Interspersion and Connectivity among Wetland Classes and Ecotonal Corridors	
5.6	Presence of Rare, Threatened, and Endangered Species	
6.0	**Commercial Functions**	Loss of commercial functions will be valued by wetland class under the federal definition and the state alternatives analysis. Shellfish Closures, commercial fisheries impact, tourism, and recreational fishery losses will be quantified.
6.1	Hunting	
6.2	Fishing, Fisheries, and Aquaculture	
6.3	Forestry, Timber, and Forest Floor Products	
6.4	Water Supply - Groundwater and Aquifer Recharge	
6.5	Biomedical Research and Technology Development	
6.6	Carbon, Nitrogen, and Phosphorous Mitigation	
6.7	Pollutant and Contaminant Removal	
6.8	Eco-Tourism	
6.9	Revenue for Local Businesses	
7.0	**Social Functions**	As described below, the team includes several of the most qualified institutions in the state to develop support and portray potential costs associated with losses in social functions including the NCCF and N.C. A&T University.
7.1	Research and Education	
7.2	Recreational Hunting and Fishing	
7.3	Natural Areas and Gamelands	
7.4	Outdoor Recreation	
7.5	Cultural Heritage	
7.6	Marginalized Community Support	

2.4.4 Social Assessment and Valuation

The NCCF and our partners in the Piedmont and Mountain provinces will utilize our outreach network to develop a series of interviews and questionnaires with stake holders who are directly or indirectly reliant on natural and working lands. This will include commercial fishermen, hunting guides, restaurant owners in tourist towns, hotels, etc., many which are part of the almost 300,000 direct reaches of the Federation and our partners. We will work with these stakeholder groups to gather a survey of social or cultural relationships to wetlands and working lands. These qualitative responses will be combined with the economic analyses to produce a story that communicates the intrinsic value of these potentially lost wetland classes. The valuation will help to identify the most cost-effective wetland definition for North Carolina based on the alternatives analysis and independent of the federal courts.

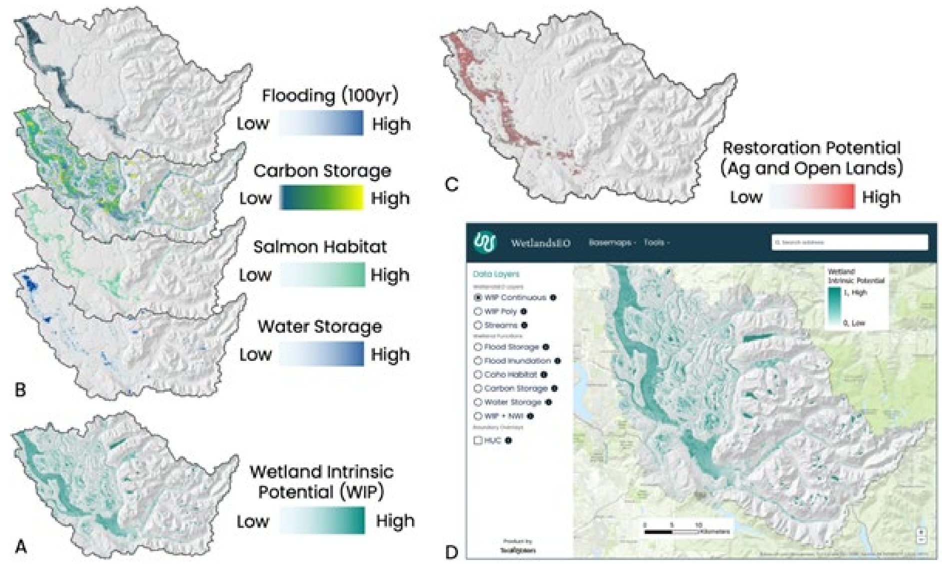

Figure 10. Wetland Functions can be Built on Top of the WIP Tool

N.C. A&T will provide further research and development with a specialized focus upon marginalized communities. N.C. A&T will further increase our presence and support with the Piedmont and Mountains regions of North Carolina. N.C. A&T will focus on social impact research and tool development for each alternative wetland definition, with a special emphasis on community and stakeholder engagement through workshops, advocacy meetings, strategy development, and related activities. The wetland mapping and classification data will be overlain with socio-economic data to identify affected communities such as small farmers, more isolated communities, and affected poor urban populations. N.C. A&T will develop participatory research and social surveys within these potentially impacted groups to collect personal stories and community narratives about the benefits of these specific wetlands, including important functions such as flood protection, water quality, and cultural significance. The effort will use remote sensing and GIS-based change detection, historical literature, and local knowledge to document historical socioeconomic impacts related to these wetlands. Priority areas will be identified and strategies developed for wetland restoration or conservation to strengthen community resilience within the identified areas. N.C. A&T will conduct educational workshops and adaptation planning sessions with small farmers, impacted communities, and stakeholders to ensure findings are actionable and community-driven. We will provide training on low-cost monitoring tools, GIS applications, and citizen science platforms to empower communities to monitor wetlands and advocate for policy changes.

2.4.5 Summary of Economic Valuation and Impacts Analysis

The economic, ecosystem, and social valuation, trade-off analysis, literature review, and Hazus Flood Model analysis will provide a comprehensive summary of the state economic impacts based on land cover changes for potential federal and state wetland definitions.

The economic analysis team will conduct a comprehensive statewide assessment that synthesizes and scales the developed wetland valuations into a systemic economic framework for North Carolina. This analysis will aggregate and extrapolate current wetland values to develop state-level economic indicators, with particular emphasis on understanding the cumulative impacts across watersheds, economic sectors, and communities. Using existing wetland mapping and valuation data, analysts will quantify the aggregate economic consequences of wetland protections lost between 2022-2023 through an integrated analysis combining flood risk modeling using Hazus or similar platforms, infrastructure vulnerability assessments, and evaluation of cascading economic impacts across sectors. The team will then develop forward-looking cost projections for 5- and 10-year scenarios, incorporating climate change impacts, development pressures, and system-wide vulnerabilities to estimate the full economic burden of continued wetland loss at a state scale. These projections will account for both direct costs like infrastructure damage and indirect costs from lost ecosystem services, with particular attention to cross-jurisdictional and cumulative effects. The analysis will examine how various policy mechanisms could influence these system-wide economic outcomes, including analysis of state-level fiscal impacts, economic resilience benefits, and multiplier effects across sectors. Throughout the analysis, the team will maintain close coordination with state agencies and facilitate structured engagement with regional economic development entities and sector representatives to validate assumptions about systemic impacts. Final deliverables will include a comprehensive state-level economic impact assessment that synthesizes watershed, sectoral, and regional effects into cohesive findings about the total economic value and vulnerability of North Carolina's wetland systems. These findings will directly inform a subsequent phase of policy development, where recommendations for regulatory and legislative approaches will be formulated based on the economic evidence gathered. This phased approach ensures that policy recommendations are grounded in an understanding of the full scale and scope of wetland-related economic impacts to the state.

2.5 Conservation, Policy, and Legislative Support

RES and EPR staff, the Federation, and our active team members have been involved in development of environmental mitigation policy in North Carolina for over 30 years. Activities include conservation, preservation, mitigation, program development, legislation, tax law, and legal support. We have attended Lobby Day and collaborated with the State Legislature many times over the years to procure appropriations, policy, and regulations that most effectively provide funding for, and protection of environmental resources, especially wetlands. Among many economic drivers, we have been involved with the wastewater treatment industry state-wide and have a clear understanding of development impacts to water quality (Nitrogen and Phosphorus loading) which is closely aligned with costs to the state when wetland functions are lost within the watershed. The team proposes to provide conservation, policy, and legislative support using a combination of marketing materials, public outreach, intergovernmental lobbying, program development, and wetland funding procurement.

The 2023 North Carolina Farm Act (Senate Bill 582) revises the state's definition of "wetlands" to align with federal law, specifically the Clean Water Act (WOTUS), excluding wetlands like prior converted cropland. This temporary definition, effective until the state adopts a permanent rule, reflects the federal definition of wetlands as waters of the U.S. However, the Sackett v. EPA decision limits the scope of what qualifies as WOTUS, creating uncertainty about whether some wetlands no longer qualify as "waters of the state" under North Carolina law.

In particular, isolated wetlands such as pocosins or freshwater swamps, which may only connect to surface waters via groundwater, could lose all protections, as they do not meet the surface connection criteria set by the Sackett decision. The state's regulations on isolated wetlands may no longer apply and as of July 2023; the Division of Water Resources (DWR) is not enforcing non-jurisdictional isolated wetland permits and is awaiting further federal guidance.

The definition and protections for coastal wetlands will remain intact due to the Coastal Area Management Act (CAMA), which protects wetlands in 20 eastern counties of North Carolina. CAMA provides protections for coastal wetlands and the contiguous land around them, which may remain unaffected by the 2023 Farm Act, despite the changes brought by the Sackett decision. This means coastal wetlands may continue to benefit from state water quality protections and may remain shielded from the broader regulatory shifts.

The regulatory definition of coastal wetlands is currently limited to ten plant species and the area subject to regular or occasional flooding by tides. The definition includes wind tides that reach the marsh area through natural or artificial watercourses but does not include storm tides. The conservation, policy, and legislative tasks within this scope of work will specifically address the option to extend this CAMA interpretation for "coastal" wetlands to hurricane and tropical storm tidally influenced areas if practicable.

North Carolina may still apply protections for unique wetlands as the 2023 Farm Act did not directly address this authority. The Environmental Management Commission (EMC) has the authority to designate certain wetlands as unique wetlands due to their ecological importance, such as wetlands essential for endangered species habitat, climate, or flood resilience. These wetlands, regardless of size, require compensatory mitigation for any impacts, ensuring they are preserved within the same watershed whenever possible. The conservation, policy, and legislative tasks within this scope of work are designed to quantify the importance of wetland classification types and the continuing need for avoidance, minimization, and ultimately compensatory mitigation for unavoidable impacts.

While stream protection was not specifically altered by the 2023 Farm Act, North Carolina's riparian buffer programs offer protections for streams and their surrounding areas, though their application varies by location. These buffer programs exist in multiple river basins across the state, such as the Neuse River estuary, Tar-Pamlico estuary, Catawba basin, Falls Lake, Randleman Reservoir, and Jordan Lake watersheds. Specific activity limitations exist for each program, with some delegated to local governments for enforcement. This project will highlight the functional benefit of riparian buffers including threatened headwater wetlands along ephemeral streams and stormwater drainageways within the upper watershed.

The 2023 Farm Act has created uncertainty regarding the inclusion of headwater wetlands in the state's stream and wetland mitigation programs, including North Carolina DMS. Previously included, these wetlands may no longer be protected or require compensatory mitigation, depending on how Sackett is interpreted and how the 2023 Farm Act is implemented by state agencies like DWR and the EMC. The project team is deeply involved in compensatory mitigation programs and has designed this study to address the economic impact of deregulation on no-net loss policies for the state. By highlighting the importance of these wetlands potentially losing protection, policy support will include justification for continuing to require compensatory mitigation within these wetland classes.

This scope of work will include direct engagement with legislators and government agencies as needed to promote policies that best serve the state to facilitate legislation and state regulations that conserve natural and working lands, and allocate resources to conservation, protection, and compensatory mitigation within vulnerable communities and wetland ecosystems. The products generated by the working group and larger stakeholder group may include executive actions, legislative solutions, the potential for local ordinances, and an analysis of the intersection of insurance with wetlands deregulation and flood resilience. The working group will include legal counsel experienced in environmental and conservation law who will assist in lobbying, drafting proposed legislation, and any legal action while evaluating existing and proposed statutes. As the stakeholder group identifies specific amendments to law or regulation that would benefit the above stated goals, RES will lobby for legislative or executive branch action. Additionally, we have the capabilities to interact with legislators and executive branch agency staff to further educate and persuade them on the necessity of enacting further measures related to the conservation of natural and working lands, as well as soliciting support from outside groups who share the same common goals.

2.5.1 Political Climate

Since 2011, North Carolina's political landscape has seen reduced environmental protections in favor of development. While watershed programs (e.g., Neuse River, Tar-Pamlico, Jordan Lake) remain in place, the legislature has implemented policy changes like stream buffer exemptions and stormwater restrictions. These changes have been influenced by the EMC, which is politically appointed, often with shifting party control in the state.

The political dynamics have resulted in state regulatory decisions being more conservative. Even after the 2024 elections, the implications of the Sackett decision and the 2023 Farm Act will continue to be a focal point. These regulatory changes could weaken protections for wetlands that were previously safeguarded and require compensatory mitigation, including their ecological functions like floodwater mitigation and stormwater filtration.

Moving forward, administrative functions must determine the full extent of regulatory changes. The USACE is reviewing the Sackett decision and has paused jurisdictional determinations. Meanwhile, DWR continues processing certifications submitted before the 2023 Farm Act and will adjust isolated wetland rules as the state adopts new definitions. These regulatory shifts could reduce or eliminate compensatory mitigation for wetlands outside WOTUS jurisdiction, reducing the funding previously available to off-set development, land speculation, and drainage projects in potentially deregulated wetlands.

2.5.2 Decision Support Tool

A Decision Support Tool (DST) will be developed to defend proposed actions based on threat of loss, cost savings, and functional benefits to the state. The DST will be closely linked to the GIS application to especially prioritize wetlands and working lands that are simulated to be impacted over the next 10 years. The DST will, in part, be modeled after the FEMA Community Mitigation DST to help communities and decision-makers analyze, prioritize, and defend mitigation investments. In addition, The DST will be applied within each of the activities below to promote public and government support for proposed actions.

2.5.3 Marketing Materials

The Project Team will create an array of communications products around the proposed actions that will target multiple audiences. These products are aimed at simplifying the overarching goal to help decision makers understand the issue at hand. Marketing materials will publicize potential for wetland losses and the value of conserving natural and working land, with a special focus on threatened wetlands. Material may include websites/web pages, brochures, documentaries, newscasts and articles along with material for distribution and presentation at public hearings, lobbying events, and related activities.

2.5.4 Public Outreach and Stakeholder Engagement

Since Sackett and SB 582, the NCCF has been working with partners across the state to strategize how best to protect these vulnerable ecosystems. With additional support through this project's scope, the Federation along with our partners will further those efforts into a more formalized working group tasked with formulating a variety of pathways to enhance wetland protections. The Federation will lead a subgroup focused on coastal wetlands and a partner organization will lead a subgroup focused on wetlands in the piedmont and mountains. The working group will report to the NC NWL Stakeholder Group, which the Federation sits on. This Stakeholder Group will meet to prioritize policy and legislative approaches and to review deliverables created by this team.

N.C. A&T will continue to work with and expand upon communities and stakeholders engaged during the social assessment and valuation studies. The public support phase will focus upon more vulnerable communities impacted by policy decisions to generate support conclusions and recommendations from the study. Surveys, personal stories, and community narratives will be published, broadcast, and distributed to generate support for programs and policies selected by DEQ and OSP for implementation.

RES / EPR will hold public hearings and workshops as needed. We will work with the environmental mitigation organizations, water resource associations, and other 501C3s to generate support for proposed actions.

The NCCF will lead public engagement to develop an understanding of the value of NWL and the implications of losing protection of these resources. The Federation will partner with working group members to create a unified education and outreach suite of materials based on the results of this study that can be used for multiple audiences. Proposed audiences include K-12 students, HOAs, homebuilders, engineers, realtors, municipal county government officials, and more. The Federation will mobilize its extensive network of over 16,000 supporters and direct reach to almost 300,000 people to distribute and present these concepts. The Federation will oversee partners in other regions of the state to ensure the targeted messaging is made statewide. In addition, The Federation will also utilize its extensive media network through traditional news media, social media, and our award-winning daily environmental news service Coastal Review to inform the public.

2.5.5 Intergovernmental Lobbying, Proposed Policy, and Legislation

This scope of work will include direct engagement with legislators and government agencies as needed to promote policies that best serve the state, facilitate legislation and state regulations that conserve natural and working lands, and allocate resources to conservation and protection within vulnerable communities and ecosystems. The products produced by the working group and larger stakeholder group may include executive actions, legislative solutions, the potential for local ordinances, and an analysis of the intersection of insurance with wetlands deregulation and flood resilience. The project team will include legal counsel experienced in environmental and conservation law who will assist in lobbying, drafting proposed legislation, and any legal action while evaluating existing and proposed statutes. As the stakeholder group identifies specific amendments to law or regulations that would serve EO 305, lobbyists will pursue appropriate legislative or executive branch action as needed. We will interact with legislators and executive branch agency staff to further educate and persuade them on the necessity of enacting specific measures related to the conservation and funding of natural and working lands, including wetlands. In addition, this intergovernmental effort will include soliciting support and interaction from outside groups who share the same common goals.

2.5.6 Conservation Program Development and Funding Support

The NCCF and NCA&T University, along with their partners, will develop conservation and funding support programs. The Federation will work with environmental partners to pursue conservation funding for vulnerable tracts of land identified in the GIS application and DST. In addition, NCA&T will work with other academic institutions and support groups including funding pursuit for identified wetlands and working lands that upon loss, will have a direct impact on the public, including marginalized communities.

3.0 Project Deliverables and Schedule

3.1 Deliverables

Since the scope of this work will likely change over the next month, a detailed outline of deliverables and schedule will be developed after further negotiation, presentations, and contract award. We look forward to the opportunity to present components of this proposed project and work with the DEQ team to finalize the project scope, deliverables, programs, and schedule as needed. Project deliverables will include work items such as the following.

1) Monthly progress memos and presentations
2) Stakeholder and public meetings
3) Model, classification, mapping, and functional assessment results
4) GIS applications and story maps
5) Decision support tool
6) Proposed policy and legislation documents
7) Webpage
8) Video documentary
9) Workshops and lobbying events

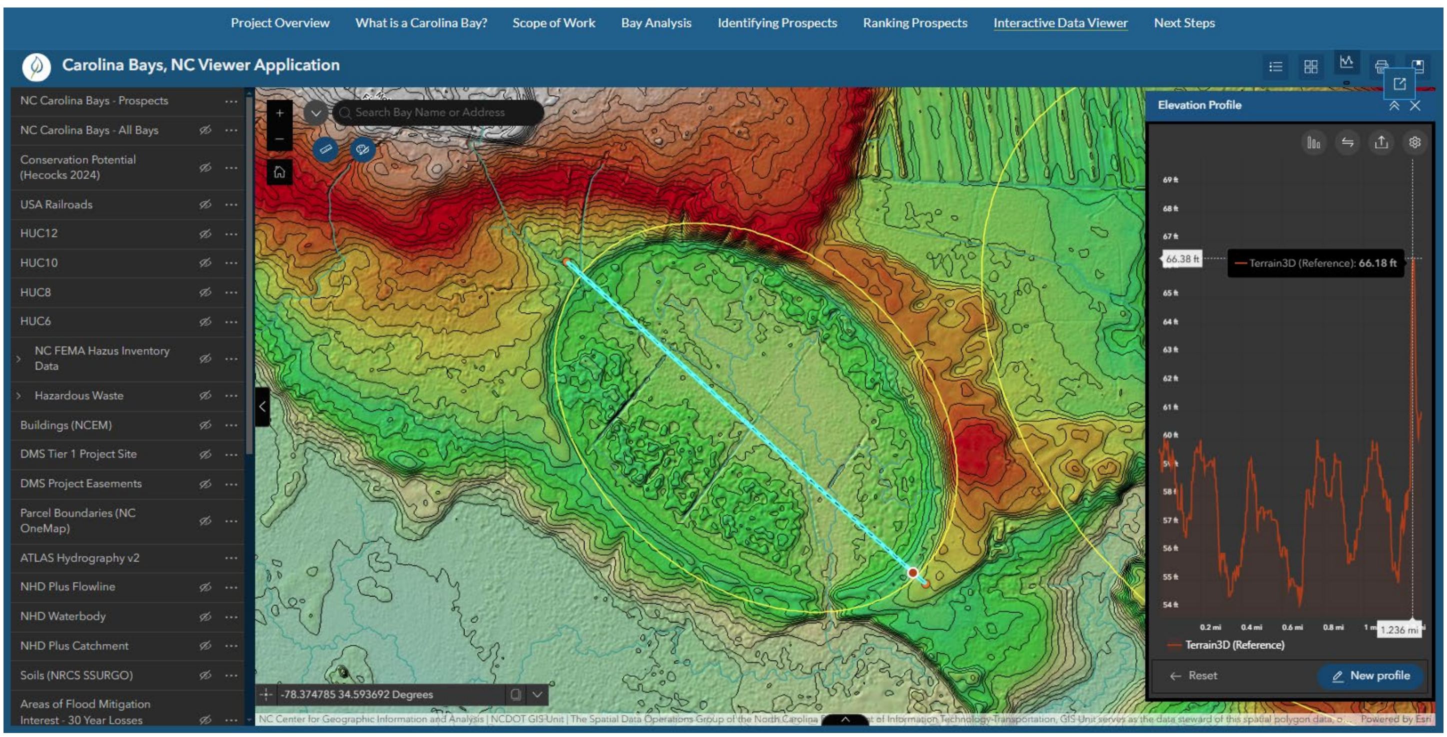

Figure 11. Flood Resiliency Storymap Example

3.2 Schedule

Table 8. Schedule

Section Number and Title	Duration	Start	Finish
2.1: Project Initiation	**25 days**	**3/31/2025**	**5/2/2025**
Project kickoff meeting	1 day	3/31/2025	3/31/2025
Project Charter, Stakeholder Engagement Plan, and QAQC Plan (Deliverable)	4 days	4/1/2025	4/4/2025
Stakeholder meetings	20 days	4/7/2025	5/2/2025
Finalize Scope of Work and Schedule	20 days	4/7/2025	5/2/2025
2.2: Spatial Data, Training Data, and Attributes Development	**80 days**	**5/5/2025**	**8/22/2025**
Existing Spatial Databases and Attributes	20 days	5/5/2025	5/30/2025
Training Databases and Attributes	80 days	5/5/2025	8/22/2025
2.3: Models, Mapping, and Classification	**240 days**	**6/2/2025**	**5/1/2026**
HGM Land Mapping and Classification	100 days	6/2/2025	10/17/2025
Regional Development Projection Model	100 days	6/2/2025	10/17/2025
WetAMP Wetland Mapping Tool	100 days	8/25/2025	1/9/2026
Headwaters Mapping Tool	100 days	8/25/2025	1/9/2026
WIP Wetland Mapping and Classification	100 days	8/25/2025	1/9/2026
Natural and Working Land Mapping and Classification (Uplands)	100 days	8/25/2025	1/9/2026
Field Verification, Ground Truthing, and Calibration	80 days	1/12/2026	5/1/2026
2.4: Functional Valuation and Impact Analyses	**160 days**	**1/12/2026**	**8/21/2026**
Benefit Transfer Method	80 days	1/12/2026	5/1/2026
Ecosystem Valuation Toolkit	80 days	5/4/2026	8/21/2026
Ecosystem Servies Assessment	80 days	1/12/2026	5/1/2026
Wetland Functional Assessment	80 days	1/12/2026	5/1/2026
Social Assessment	80 days	1/12/2026	5/1/2026
2.5: Conservation, Policy, and Legislative Support	**120 days**	**8/24/2026**	**2/5/2027**
Stakeholder Involvement and Public Outreach	120 days	8/24/2026	2/5/2027
Conservation and Community Land Prioritization	120 days	8/24/2026	2/5/2027
Proposed Programs, Policies, and Legislation	120 days	8/24/2026	2/5/2027
3.0: Project Deliverables	**160 days**	**8/24/2026**	**4/2/2027**
GIS Application and Web Story Map	60 days	8/24/2026	11/13/2026
Decision Support Tool	60 days	8/24/2026	11/13/2026
Comprehensive Final Report	40 days	2/8/2027	4/2/2027
Workshops and Lobbying Events	40 days	2/8/2027	4/2/2027

3.3 Milestones

This project will be iterative; therefore, we have not outlined the major tasks as milestones in the technical SOW. Each stage of the project will be performed iteratively on smaller hydrologic units and once acceptable to DEQ, we will expand the training, classification, mapping, and valuation to the entire state. As such, proposed milestones may include the following.

1) **Final Approved Scope of Work and Schedule**: Upon DEQ review of the final SOW following project kick-off meetings, the Stakeholder Engagement Plan, and stakeholder meetings.
2) **Publication of Existing Attributes Data:** The GIS web application and Story Map will be published to set the foundation for team collaboration and project tracking. The web app and Story Map will be updated iteratively as Milestones 3, 4, and 5 are completed.
3) **HUC-Specific Test Model:** The training process and model calibration will be applied to one or more HUCs within each physiographic region, tested, and verified prior to expanding to the entire state. This milestone would include an interim test model report for the individual HUCs, GIS app/Story Map Update, and presentation to DEQ for review, comments, and approval.
4) **State-Wide Classification, Mapping, and Valuation:** The calibrated models will be applied to the entire state and the final report, GIS application, and Story Map approved by DEQ.
5) **Conservation, Policy, and Legislative Support:** Involves conservation, policy, and legislative support products as outlined in ***Section 2.5.***

We look forward to meeting to discuss project deliverables, phasing, potential milestones, and cost breakdowns in more detail.

4.0 Project Cost

The following table provides a breakdown of project cost by major task.

Table 9. Project Cost

Section	Task	Estimated Cost
1.0	Project Management	$352,698
2.1	Project Initiation	$39,639
2.2	Spatial Data, Training Data, and Attributes	$333,664
2.3	Models, Mapping, and Classification	$2,830,973
2.4	Functional Valuation and Impact Analyses	$700,014
2.5	Conservation, Policy, and Legislative Support	$442,487
3.0	Final Project Deliverables	$162,302
	TOTAL	**$4,861,777**

Appendix I: Summary of Existing Spatial and Statistical Datasets

Table 10. Spatial and Statistical Attributes to be Incorporated into the Model

GIS DATASET	SOURCE/Publisher	ATTRIBUTES/USE
Natural and Working Lands	Nicholas Institute for Environmental Policy Solutions	Land classification
C-CAP (when updated)	NOAA/ Coastal Change Analysis Program (C-CAP)	Environmental planning, conservation and tracking urbanization and habitat changes in coastal regions (to be expanded)
Census Data	US Census Bureau	Socio-economic data, population, housing, economic characteristics, mapping, analysis, spatial planning
FEMA Flood Zone Data	FEMA National Flood Hazard Layer (NFHL), Community Rating System (CRS)	Flood zones, base flood elevations, coastal floodplain data, flood hazard boundary maps (FHBMs)
Landsat	USGS/NASA -30m per pixel	Satellite imagery for analyzing land cover, land use, vegetation, urban growth & environmental changes
Multiple water quality datasets	NCDEQ, EPA	Water quality
National Land Cover Dataset (NLCD)	US Geological Survey MLRC	Land Cover Data (2019)
National Wetlands Inventory (NWI)	USFWS *only comprehensive statewide mapping effort in North Carolina	Wetlands, deepwater habitat, aquatic resources
Natural Heritage Element Occurrences	NC Natural Heritage Program (NHP)	Ecological data, land use that impacts biodiversity and habitat
NC DCM wetlands	NCDEQ NC Division of Coastal Management *most accurate and comprehensive source of wetland mapping in North Carolina	Wetland boundaries, wetland types & classifications, human activities, wetland restoration & mitigation
NC Digital Elevation models (DEMs) and terrain derivatives	USGS, NOAA, NASA, LiDAR, NGA	Slope, aspect, hillshade, contours, watershed and flow
NCDOT Machine learning wetlands	NCDOT	Wetlands
NCDWR hydrology map	NCDEQ DWR	Surface water classifications, HUC, Hydrological
NCOneMap	Various layers	Data collection authority
NOAA Sea Level Rise Viewer	NOAA	High-resolution sea level rise maps, coastal flood risk data, storm surge, land elevation model, vulnerability assessments
Sentinel-2	ESA Copernicus Earth Observation Program, high spatial resolution 10-60m)	Land use & Land cover, Land monitoring, agriculture, forestry, WQ, disaster management and climate studies
SSURGO soils	Soil Survey Geographic Database by Natural Resources Conservation Service (NRCS)	Soil properties, classifications, texture, drainage, slope, organic content, land use, ag, hydrologic modeling, environmental impact assessments
USACE jurisdictional determination points	USACE, NWI, NHD	Wetland, lakes, rivers
USGS NHD National Hydrography Dataset	USGS	Streams, rivers, lakes

Appendix II: Acronyms

Table 11. Acronyms

Acronym	Name
BTM	Benefit Transfer Methods
CAMA	Coastal Area Management Act
C-CAP	Coastal Change Analysis Program
CWA	Clean Water Act
DCM	Division of Coastal Management
DEDs	Duck Use Energy Days
DEMs	Digital Elevation Models
DST	Decision Support Tool
DWR	Division of Water Resources
EMC	Environmental Management Commission
EO	Executive Order
EPA	Environmental Protection Agency
EPR	Ecosystem Planning & Restoration
ESVs	Ecosystem Services Valuations
EVToolkit	Ecosystem Valuation Toolkit
GIS	Geographic Information Systems
GPU	Graphic Processor Unit
HGM	Hydrogeomorphic
LEC	Landscape Ecosystem Classification
LiDAR	Light Detection and Ranging
N.C. A&T	North Carolina Agricultural and Technical State University
NCCF	North Carolina Coastal Federation
NCDEQ	North Carolina Department of Environmental Quality
NCDOT	North Carolina Department of Transportation
NCGTP	North Carolina Global TransPark
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
NWI	National Wetlands Inventory
OSP	Office of Strategic Partnerships
RSGAL	Remote Sensing and Geospatial Analysis Laboratory
SOW	Scope of Work
SSURGO	Soil Survey Geographic Database
TNC	The Nature Conservancy
TW	TerrainWorks Inc.
USACE	U.S. Army Corps of Engineers
UW	University of Washington
WetAMP	Wetland Advanced Model Predictor
WIP	Wetland Intrinsic Potential
WRC	Wildlife Resources Commission

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