Final Report

Geospatial Wetlands Impacts & Mitigation Forecasting Models

A Research Project in Support
of Operational Requirements
for the South Carolina
Department of Transportation

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30 June 2017

Technical Report Document Page

1. Report No FHWA-SC-17-05	2. Government Accession No. --- ----	3. Recipient's Catalog No. --- ----
4. Title and Subtitle Geospatial Wetlands Impacts and Mitigation Forecasting Models		5. Report Date June 30, 2017
		6. Performing Organization Code --- ----
7. Author/s Michael E. Hodgson and John Kupfer, et al.		8. Performing Organization Report No. --- ----
9. Performing Organization Name and Address Department of Geography, University of South Carolina Callcott Building, 709 Bull St. Columbia, SC 29208		10. Work Unit No. (TRAIS) --- ---- 11. Contract or Grant No. SPR No. 707
12. Sponsoring Organization Name and Address South Carolina Department of Transportation Office of Materials and Research 1406 Shop Road Columbia, SC 29201		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code USC 13540-FB11
15. Supplementary Notes Prepared in cooperation with the Federal Highway Administration		

16. Abstract

The South Carolina Department of Transportation (SCDOT) develops near (3-5 years) and long (15-20 years) range plans for road widening, alignment, bridge replacement, and new road construction. Each road/bridge project may impact wetlands or streams typically through (but not limited to) placement of fill, clearing of vegetation, installation of pipes or culverts, or excavation of the wetland/stream feature. Most wetlands and streams are protected in the United States under Federal regulations (i.e., Clean Water Act). Enforcement of this protection is through the U.S. Army Corp of Engineers (USACE) and Environmental Protection Agency (EPA). Destruction of wetlands or impacts of wetlands/streams is permitted by the USACE for road/bridge projects if the transportation project is the least environmentally damaging of all options for construction and if compensatory mitigation for impacts are greater than or equal to the associated impacts. Compensatory mitigation activities can be in the form of creation, restoration or enhancement, or preservation of a wetland/stream. There is a "credit" amount applied to each compensatory activity which is typically derived from the area of the feature, the quality of the feature, and the timing of the compensatory actions. These credits can then be utilized to offset impacts to wetlands/streams at a prescribed ratio dependent upon the impacted feature. Construction of transportation projects cannot begin until the wetland/stream impacts are known, compensatory mitigation is sufficient and obtained, and activities are approved by the USACE. These linked actions can result in a very long delay (often years or even cancelling of projects) in a transportation project until the SCDOT has an approved plan for wetland-stream compensatory mitigation. To reduce risk of delays and to better anticipate need for compensatory mitigation can only be anticipated based on the prediction of future impacts within a watershed-ecoregion. Thus, the mitigation forecasting problem has large geographic scale dimensions, with impacts at the site scale (i.e., road/bridge location), mitigation actions at the meso-scale (i.e., watershed-ecoregion) but with a very large geographic scope (i.e., the entire state of South

Carolina). This wetlands mitigation related project was initiated to assist the South Carolina Department of Transportation (SCDOT) plan for future environmental wetlands mitigation activities. A geodatabase representing the likelihood of wetlands (i.e., a wetlands likelihood layer) in South Carolina was developed after an evaluation of both digital and analog sources of wetlands data and proxies for wetlands. Using highly accuracy spatial/attribute wetlands data (referred to as the jurisdictional wetland determination) from already permitted transportation projects the accuracy of National Wetlands Inventory (NWI) and (SSURGO)-based wetlands data were evaluated. A high spatial resolution database from LiDAR-derived elevation and products, hydrography, culverts, parcel-level zoning/use, and historical maps/imagery was used to model the likelihood of wetlands and streams for the state of South Carolina. The accuracy of the final wetlands likelihood layer was 83%, a dramatic improvement from the commonly used National Wetlands Inventory data at 51% accuracy.

GIS-based road widening and bridge replacement tools were developed to model the existing and new wetland/stream impacts from the wetlands likelihood layer for each of more than 300 future transportation projects with likely unavoidable impacts. Aggregate impacts of wetlands and streams were summarized at the watershed-ecoregion scale for prediction of future mitigation needs.

A set of recommendations to the wetlands/stream impact forecasting process were made, including 1) incorporating other indicators of wetlands, such as historic maps and aerial photography, 2) maintaining an evolving wetlands likelihood layer and 3) maintaining SCDOT project layers.

17. Key Words Wetlands, modeling, LiDAR, forecast, mitigation	18. Distribution Statement No Restrictions		
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. Of Pages 63	22. Price n/a

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

Acknowledgments

While the overall project was initially designed and led by the two lead authors – Michael E Hodgson and John Kupfer – the participation by others was essential for the execution. In alphabetical order, these participants from the University of South Carolina were Karen Beidel, Peng Gao, Alex McCombs, Silvia Piovan, Geoff Schwitzgebel, Kylie Tokar, and Haiqing Xu. The South Carolina Department of Transportation participants include Tucker Creed, Russell Chandler, Sean Connolly, Chad Long, and Jeff Siceloff. From the beginning of the project, the frequent meetings and interaction of the participants created a rich learning experience in both the University and state agency's participants and fostered a strong project.

Disclaimer

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The State of South Carolina and the United States Government do not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

The work in this project was developed under contract with the SCDOT and in collaboration with SCDOT staff. The data and models, such as the wetlands likelihood layer, STIP future projects, models for road/bridge projects, evolved throughout the project. The analyses conducted in this project were based on the state of the data and models at that moment in time.   Expectations of the performance of the models and data should be based on the most recent versions of the data/models released in the spring of 2017.

Executive Summary

The South Carolina Department of Transportation (SCDOT) develops near (3-5 years) and long (15-20 years) range plans for road widening, alignment, bridge replacement, and new road construction. Each road/bridge project may impact wetlands or streams typically through (but not limited to) placement of fill, clearing of vegetation, installation of pipes or culverts, or excavation of the wetland/stream feature. Most wetlands and streams are protected in the United States under Federal regulations (i.e., Clean Water Act). Enforcement of this protection is through the U.S. Army Corp of Engineers (USACE) and Environmental Protection Agency (EPA). Destruction of wetlands or impacts of wetlands/streams is permitted by the USACE for road/bridge projects if the transportation project is the least environmentally damaging of all options for construction and if compensatory mitigation for impacts are greater than or equal to the associated impacts. Compensatory mitigation activities can be in the form of creation, restoration or enhancement, or preservation of a wetland/stream. There is a "credit" amount applied to each compensatory activity which is typically derived from the area of the feature, the quality of the feature, and the timing of the compensatory actions. These credits can then be utilized to offset impacts to wetlands/streams at a prescribed ratio dependent upon the impacted feature. Construction of transportation projects cannot begin until the wetland/stream impacts are known, compensatory mitigation is sufficient and obtained, and activities are approved by the USACE. These linked actions can result in a very long delay (often years or even cancelling of projects) in a transportation project until the SCDOT has an approved plan for wetland-stream compensatory mitigation. To reduce risk of delays and to better anticipate need for compensatory mitigation can only be anticipated based on the prediction of future impacts within a watershed-ecoregion. Thus, the mitigation forecasting problem has large geographic scale dimensions, with impacts at the site scale (i.e., road/bridge location), mitigation actions at the meso-scale (i.e., watershed-ecoregion) but with a very large geographic scope (i.e., the entire state of South Carolina). This wetlands mitigation related project was initiated to assist the South Carolina Department of Transportation (SCDOT) plan for future environmental wetlands mitigation activities.

A geodatabase representing the likelihood of wetlands (i.e., a wetlands likelihood layer) in South Carolina was developed after an evaluation of both digital and analog sources of wetlands data and proxies for wetlands. Using highly accuracy spatial/attribute wetlands data (referred to as the jurisdictional wetland determination) from already permitted transportation projects the accuracy of National Wetlands Inventory (NWI) and (SSURGO)-based wetlands data were evaluated. A high spatial resolution database from LiDAR-derived elevation and products, hydrography, culverts, parcel-level zoning/use, and historical maps/imagery was used to model the likelihood of wetlands and streams for the state of South Carolina. The accuracy of the final wetlands likelihood layer was 83%, a dramatic improvement from the commonly used National Wetlands Inventory data at 51% accuracy.

GIS-based road widening and bridge replacement tools were developed to model the existing and new wetland/stream impacts from the wetlands likelihood layer for each of more than 300 future transportation projects with likely unavoidable impacts. Aggregate impacts of wetlands and streams were summarized at the watershed-ecoregion scale for prediction of future mitigation needs.

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1. Introduction

The South Carolina Department of Transportation (SCDOT) develops near (3-5 years) and long (15-20 years) range plans for road widening, alignment, bridge replacement, and new road construction. Each road/bridge project may impact wetlands or streams typically through (but not limited to) placement of fill, clearing of vegetation, installation of pipes or culverts, or excavation of the wetland/stream feature. Most wetlands and streams are protected in the United States under Federal regulations (i.e., Clean Water Act). Enforcement of this protection is through the U.S. Army Corp of Engineers (USACE) and Environmental Protection Agency (EPA). Destruction of wetlands or impacts of wetlands/streams is permitted by the USACE for road/bridge projects if the transportation project is the least environmentally damaging of all options for construction and if compensatory mitigation for impacts are greater than or equal to the associated impacts. Compensatory mitigation activities can be in the form of creation, restoration or enhancement, or preservation of a wetland/stream. There is a “credit” amount applied to each compensatory activity which is typically derived from the area of the feature, the quality of the feature, and the timing of the compensatory actions. These credits can then be utilized to offset impacts to wetlands/streams at a prescribed ratio dependent upon the impacted feature. Construction of transportation projects cannot begin until the wetland/stream impacts are known, compensatory mitigation is sufficient and obtained, and activities are approved by the USACE. These linked actions can result in a very long delay (often years or even cancelling of projects) in a transportation project until the SCDOT has an approved plan for wetland-stream compensatory mitigation. To reduce risk of delays and to better anticipate need for compensatory mitigation can only be anticipated based on the prediction of future impacts within a watershed-ecoregion. Thus, the mitigation forecasting problem has large geographic scale dimensions, with impacts at the site scale (i.e., road/bridge location), mitigation actions at the meso-scale (i.e., watershed-ecoregion) but with a very large geographic scope (i.e., the entire state of South Carolina). This wetlands mitigation related project was initiated to assist the South Carolina Department of Transportation (SCDOT) plan for future environmental wetlands mitigation activities.

This wetlands mitigation related project was initiated to assist the South Carolina Department of Transportation (SCDOT) plan for future environmental wetlands mitigation activities. The proposed solution was to: 1) develop a geospatial database of relevant wetlands and ancillary data, 2) research the current state-level approach to wetlands mitigation efforts from a transportation planning perspective within and outside of South Carolina, 3) develop a GIS-based wetlands mitigation forecasting model, and 4) apply the developed tool to selected watersheds within South Carolina to better understand the potential impacts. In collaboration with the SCDOT faculty, staff, and students at the GISciences Research Laboratory within the Department of Geography at the University of South Carolina and Department of Historical, Geographical and Antiquity Sciences (ITALY) completed these four tasks.

Parts of the objectives were modified during the course of the project based on the new understanding of the SCDOT planning process, geographic data sources on planned projects, and evolving nature of SCDOT project planning in light of learned. For example, the focus on applying the developed tools to selected watersheds was refocused on identifying critical watersheds based on a state-wide analysis of proposed projects in the short term (STIP) and long-term.

Solutions for the prediction of transportation improvement projects require fine-grained spatial analysis with high quality (accuracy and spatial precision) geographic data. As the scope of analysis is large (state of South Carolina) the supporting database of wetlands and stream locations is complex. Thus, the problem is also one of a big-data variant with large computational demands with fine-grained spatial data. In this research we began with a national database of high spatial resolution (NWI, SSURGO) but with accuracy levels unacceptable for the forecasts. Using highly accurate spatial/attribute wetlands data (referred to as the jurisdictional wetland determination) from already permitted transportation projects the accuracy of National Wetlands Inventory (NWI) and (SSURGO)-based wetlands data was evaluated. Omission errors for the NWI and SSURGO data were 50% and 10%, respectively, with high rates of commission errors with the SSURGO data. Subsequently, a high spatial resolution database from LiDAR-derived elevation and products, hydrography, culverts, parcel-level zoning/use, and historical maps/imagery was used to model the likelihood of wetlands and streams for the state of South Carolina. The accuracy of the final wetlands likelihood layer was 90% accurate at wetland omission errors.

A wetlands likelihood model was developed to predict areas that will likely be classified as jurisdictional wetlands by the USACE. Subsequently, GIS-based road widening and bridge replacement tools were developed to model the existing and new wetland/stream impacts from the wetlands likelihood layer for each of the more than 300 future transportation projects with likely unavoidable impacts. Aggregate impacts of wetlands and streams were summarized at the watershed-ecoregion scale for prediction of future mitigation needs.

2. Work Plan

The work plan for this project was divided into four separate but closely linked tasks with a final task of writing the project report with maintenance plan. We planned on initiating the first three tasks almost simultaneously as what is learned from each task will benefit and map influence decisions in the other three tasks. The five tasks were:

1. Construction of a Statewide Geospatial Database
2. Assessment of Existing State Wetlands Mitigation Tools/Approaches
3. GIS-Based Wetlands Mitigation Forecasting Model
4. Application to Selected State Watersheds
5. Project communication and website

Execution of the project took place over three years, beginning in January 2014 and ending in December 2016 (**Figure 1**). The initial kickoff meeting took place at SCDOT offices on January 13, 2014 and the final formal meeting for the project occurred on January 27, 2017 at the University of South Carolina. We met with SCDOT tasks 32 times during the course of the project in formal meetings.

Task 1. Assessment of State Wetlands Mitigation Tools/ Approaches

Approach for Gathering Information

This task will require background research in the current (and possibly planned) approaches and geospatial tools in use by state-level transportation agencies in the United States. We will use three sources of information gathering approaches: 1) referenced literature, 2) gray-literature, and 3) personal telephone conversations. In the initial stage we will conduct a rapid survey of all states using open sources (refereed literature and web-searches) and build a matrix of all state transportation agencies and their approach (if any) for wetlands mitigation forecasting and banking. Included in this survey are the metrics (e.g., wetlands area, stream miles) used by the state. Following the rapid survey of all states we will then, with guidance from the South Carolina DOT, focus on selected states that may be appropriate examples with approaches for use in South Carolina. We will also seek to determine the role that geospatial data, their data sources, and their modeling approaches used.

Findings

The online survey of state department of transportation centers revealed that few states have a codified approach for estimating wetlands/streams impacts using a geospatial solution. Some states have somewhat of a documented approach for estimating impacts – Florida, North Carolina, Virginia, while most others do not. Many states have funded research projects on developing approaches or tools for mapping wetlands, estimating wetlands impacts, or planning for mitigation site alternatives. Determining if the state subsequently adopted the approach is considerably more difficult. What can be generalized from the review of state approaches to wetlands impact estimate methods are the sources of data used to support wetlands impact estimates rely heavily on the F&WS National Wetlands Inventory (NWI) in almost every state.

The states of Washington, Delaware, and New York have long been leaders in mapping wetlands and have been critical of the National Wetlands Inventory (NWI) focus on larger wetlands (e.g., greater than 10-acres) and avoidance of mapping agricultural wetlands. Their approaches have relied on the use of high spatial resolution data such as aerial photography (Ossinger et al., 1992) to map wetlands of at least .25-acre and larger.

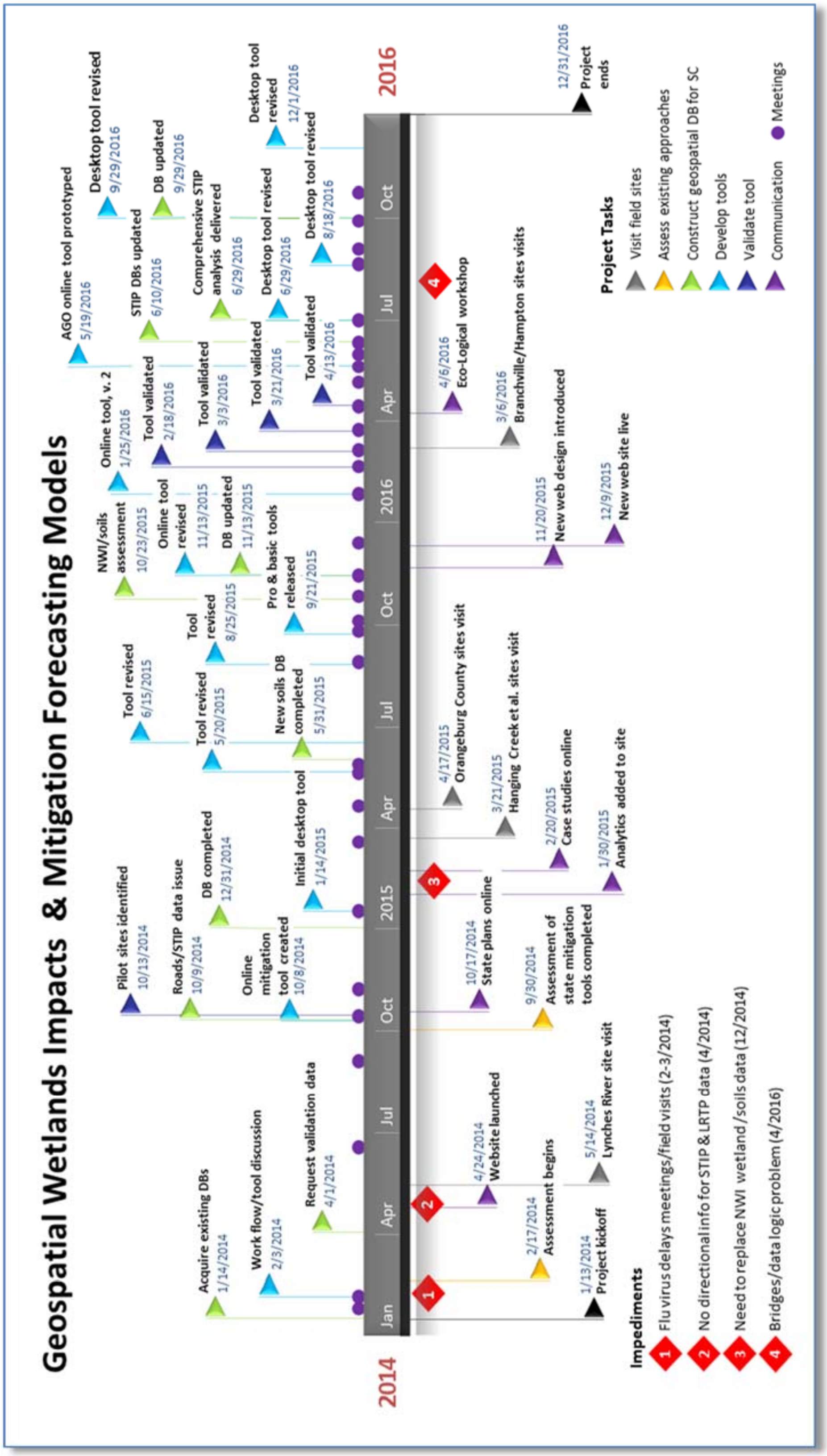


Figure 1. Activities (meetings, deliverables, and impediments) conducted during the project.

Because of the close relationship between activities in North Carolina and South Carolina we contacted SCDOT staff and their supporting contractors in an effort to better understand their geospatial modeling approaches for predicting wetlands and subsequent impacts. We had two briefings (general discussion of the problem and the example of the Kinston bypass project) of the approach and tools used by Morgan Weatherford (Project Lead) at the state of North Carolina. The NC modeling approach was primarily developed for comparing alternative solutions for the LEDPA process rather than detailed modeling for an individual alternative. The NC model for predicting wetlands is in the form of a logistic regression based on 12 terrain derivatives and soils, land use/cover. A separate model is used for riparian versus non-riparian wetland prediction. The six key terrain derivatives include ratio of slope to drainage area, elevation, stochastic depression analysis, soil type, slope_brdem (undefined variable), and reclassified slope wetlands elevation index (Wang, 2015). The NC staff estimated a traditional field investigation for the Kinston bypass alternative evaluation would cost $600,000. Preparation of the stream and wetlands GIS layers for the modeling solution was budgeted at $250,000. Thus, they believe their GIS-based modeling approach for comparing alternative bypasses saved $350,000 and 16 months of time. The findings from their project noted the deficiency in the lateral drainage influence of ditches on the water table (and subsequently wetland inundation) in the project areas. A proposed solution would involve digitizing each ditch manually by interpreting aerial imagery, incorporating SSURGO data for soils present, and ditch depth from LiDAR data. New project funding at NCDOT has provided additional support for Weatherford's team to continue research (for alternative model form as logistic and random forest smart models) on GIS-based modeling approaches for predicting wetlands to be used in comparing highway location alternatives.

Florida has an online tool, the Environmental Screening Tool, for evaluating transportation project plans and the NEPA procedure (https://etdmpub.fla-etat.org/est/). The overarching program for the tool development is the Efficient Transportation Decision Making (etdm). The tool uses fundamental geospatial layer overlays of the planned road modification on NEPA related layers – wetlands, archaeological/historical, historic buildings, and other selected datasets. Most importantly, the Florida DOT makes available the location of projects publicly in a digital map form on this site. Users can create buffers around road segments and selection layers to participate in the screening.

Virginia has a few ongoing studies to begin designing wetlands prediction models. One such study (began in 2015) is to evaluate existing remote sensing approaches for mapping wetlands by the University of Virginia and sponsored by the Virginia Center for Transportation Innovation and Research (VCTIR). A more recent study sponsored by the VCTIR is for a screening tool to identify potential wetlands over large geographic areas. Compared to the focus in the SCDOT project the Virginia tool was coarse using the NLCD and Landsat 8 30-m spatial resolution data. The developed tool uses Landsat 8 satellite imagery, elevation data, FEMA 100-yr floodplain data, SSURGO soils data, NHD stream data, NLCD, and the NWI wetlands data. Validation in a small watershed (a 17-mile corridor around a highway) demonstrates a 70% accuracy in identifying known wetlands but a 24% error in falsely identifying wetlands.

Michigan recently conducted a review of GIS-based approaches for selecting wetlands mitigation sites. The Michigan Technology Research Institute determined the key priorities for the Michigan Department of Transportation that needed to be captured in a geospatially-based wetlands mitigation site suitability tool referred to as WMSST.

Maryland's Department of Transportation has been a leader in the creation of an online tool (their name is Water Resources Registry) for evaluating wetlands mitigation sites (http://watershedresourcesregistry.com). The tools is a screening tool to allow a user to select mitigation site location based on criteria defined in an attribute table (e.g., size, type, proximity to other features). The attribution for wetland mitigation sites is created separately using an ArcGIS Model Builder tool. This Model Builder tool must be executed separately prior to use of the attribution in selection criteria. Wetlands data for use in their screening tool comes from one of two sources – the National Wetlands Inventory (NWI) data and Maryland's Department of Natural Resources (DNR). Maryland's DNR has mapped wetlands, using the NWI classes, and analyst interpreted aerial photography collected from 1998 to 1995.

Minnesota has created an online tool for examining areas that may best be restorable to a quality functioning wetland. The Minnesota tool is called the Restorable Wetland Prioritization Tool (http://www.mnwetlandrestore.org/).

The Mississippi Department of Transportation (MDOT) uses satellite imagery, aerial photographs, land use and land cover (LULC) data, existing NWI data, and digital elevation data to map wetlands. Mississippi also seven wetlands mitigation banks (http://www.mississippiswamp.org/Mitigation/banks.aspx).

The Colorado DOT incorporates NWI data and utilizes satellite imagery (Landsat 7 ETM+, Terra ASTER, and EO-1 Hyperion/ALI) and aerial photography (from the National Agriculture Imagery Program (NAIP)) for mapping wetlands.

Task 2. Construction of Statewide Geospatial Database

The primary goal for the statewide geospatial database was to develop a plan for obtaining relevant data, selection of map projection/datum/units, minimizing of coordinate precision/error (if transformed), and to the extent possible, populate the database with the best data. The initial data layers specified in the contract were all gathered and examined for their appropriateness in predicting wetlands and streams and for defining the appropriate geographic regions. As planned in the proposal, the final geospatial data structure was to be based on the ArcGIS geodatabase (either file or SQL-Server Enterprise geodatabase). The key metrics for the proposed mitigation tool were assumed to be stream length and wetlands area.

The initial list of geospatial data sources we anticipated examining were:

- Wetlands – National Wetlands Inventory (NWI) other proxies.
- NOAA C-CAP Land Cover
- HUCS – 8-digit and 10-digit
- Hydrographic Features (e.g., USGS)

- Ecoregions (e.g., level 3)
- County Boundaries
- State Boundary
- LiDAR or derived LiDAR products
- Planned transportation projects (SC-DOT)
- Provide advice on other needed geospatial data

Because of the limitations of SCDOT with an enterprise database (e.g., Oracle or SQL-Server), it was decided the geospatial database would be one or more file geodatabases using the ESRI technology. Topology was deemed not necessary for modeling the wetlands locations or streams. Topology was initially considered not important for road or transportation project designs; however, because of the later modifications of the wetlands impact tool the use of topology could help in resolving some of the issues (as will be discussed under the wetlands impact tool). For SCDOT's intended use of the wetlands impact model geospatial data outside the state was not considered necessary. Modeling stream locations based on LiDAR, or other digital elevation data (DEM) derived data within the upstream watersheds, would be important for deriving flow accumulation values.

The decisions for selecting a geospatial coordinate system, a horizontal/vertical datum, and units are a common problem with large projects involving multiple staff. The importance of defining and systematically using a datum is often overlooked and results in many problems later. The state of South Carolina has a defined map projection and units that state agencies should use. The map projection, datum, and units together represent the "South Carolina Coordinate System." Some South Carolina laws requires the use of the "South Carolina Coordinate System" as defined in the 1979 Act:

> "The South Carolina Coordinate System is a Lambert conformal projection of the North American Datum, 1983, having standard parallels at north latitudes 32° 30' and 34° 50', along which parallels the scale must be exact. The origin of coordinates is at the intersection of the meridian 81° 00' west of Greenwich and the parallel 31° 50' north latitude. This origin is given the coordinates: * = 2,000,000 feet and y = 0 feet. For the purposes of the South Carolina Coordinate System, the foot is the International Foot with one inch being exactly equal to 2.54 centimeters." (1979 Act No. 54, § 1; 1989 Act No. 32, § 1.)

As defined by the 1979 and later 1989 acts the South Carolina Coordinate System is implemented in GIS software, such as ArcGIS, and found under their projections tab:

- Projected Coordinate Systems
  - State Plane
    - NAD 1983 (Intl Feet)
    - Or "NAD_1983_StatePlane_South_Carolina_FIPS_3900_Feet_Intl"

The horizontal datum defined in public law has since been superseded by more accurate datums and the use a more recent datum is a sound idea. However, the differences between the location of point features within South Carolina using NAD83, NAD83 CORS96, NAD83 HARN, and NAD83 NSRS2007 horizontal datums are less than one meter, and generally less than a few centimeters. For the purpose of mapping wetlands and stream impacts with the available data sources the choice of one of these datums will not impact the results.

However, the choice of one of the later datums is desirable for two reasons:

1. Consistency between datasets
2. Computational Performance

Any computations within a geographic information system (as of today in 2017) require the data to be in a map projection. Moreover, the use of multiple data layers in the same analysis requires all of the layers to be in a common map projection, datum, and units. While most GIS will automatically select a common projection/datum/units to process the task, the computational effort in converting the data for the operation (even though transparent to the user) results in substantial computational time for large datasets. Thus, we recommend the selection of one, and only one, projection/datum/units for the data involved in the projection. For efficiency reasons, the selection of one of these later datums could be chosen based on the data layer that is largest and requires the greatest computational effort to reproject – such as the LiDAR data. For this reason, we recommend, for the next five years (until 2022) all geospatial data be converted and maintained using the **State Plane North American Datum of 1983 (NAD83) High Accuracy Reference Network (HARN) FIPS 3900 for South Carolina** horizontal coordinates system/datum. The vertical coordinates for the statewide LiDAR are in NAVD88 and where vertical coordinates are assigned to a GIS layer we recommend the NAVD88 vertical datum be used. The South Carolina statewide LiDAR mapping program has required the project vendors to deliver their data in South Carolina State Plane NAD83 HARN FIPS 3900 coordinate system with units in international feet.

In 2022 the National Geodetic Survey (NGS) will officially release specifications for National Spatial Reference System (NSRS) that covers both the horizontal and vertical datums. This new datum is advantageous as it combines the specifications of both the horizontal and vertical in one datum. Although not specifically required of the states by the Federal government as of now there may be funding connections that do require using the NSRS. Expect federal agencies to use the NSRS and thus, all data they provide. The differences in vertical heights in South Carolina between NAVD88 (the current national vertical datum) and the new NSRS will be between 20-cm and 50-cm. The SCDOT should be planning for converting all of their geospatial data to the new NSRS datum by 2022.

Hydrologic Unit Boundaries

The USACE requires wetland impacts and mitigation measures to be conducted within a watershed-ecoregion. The watershed scale is the 8-digit watersheds defined by the USGS. HUC-8 watershed regions were downloaded from the USGS National Hydrography Dataset (NHD).

Ecoregions

Level II ecoregions defined by the Environmental Protection Agency were downloaded by the USGS National Map. The intersection of the HUC-8 hydrologic unit boundaries and the Ecoregions represent the units of analysis for determining impacts within a critical watershed/ecoregion and the geographic units that mitigation should be conducted (**Figure 2**).

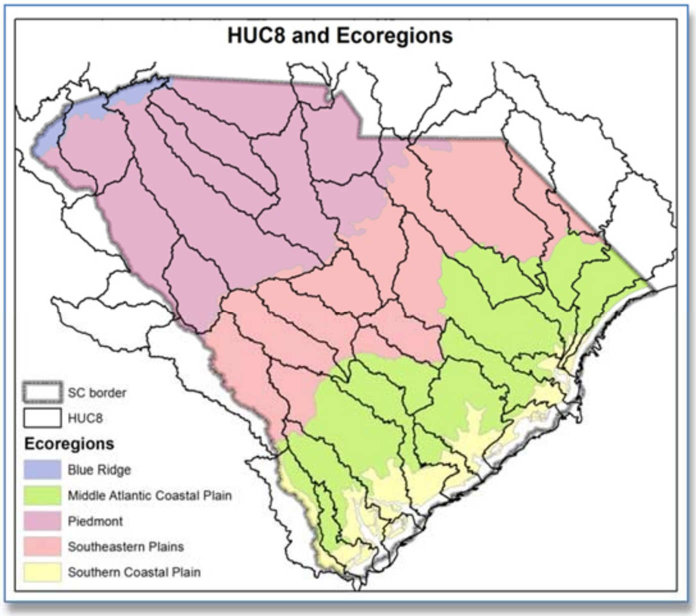


Figure 2. HUC-8 watersheds and Level III ecoregions.

USFWS National Wetlands Inventory

The U.S. Fish and Wildlife Service (USFWS) began an ambitious program of mapping the location and change in wetlands during the 1970s. The materials used for the mapping program primarily consisted of large scale aerial photography supplemented by soils maps and limited field work. These wetlands maps from USFWS are commonly referred to as the National Wetlands Inventory (NWI) maps and are regarded as the single most reliable source for mapping wetlands at fine spatial scales in a consistent manner across the United States. It is important to note that the NWI maps were not intended to be used for regulatory purposes but were designed to monitor the overall status and trends of wetlands in the United States.

The NWI (**Figure 3**) is based primarily on the Cowardin wetland classification system (Cowardin et al., 1979) and vegetative cover (height and canopy closure, or species type/mixture for specific classes) is a key indicator. Because of this, the NWI largely ignores wetlands that are under agricultural production because of the vegetative cover changes so rapidly.

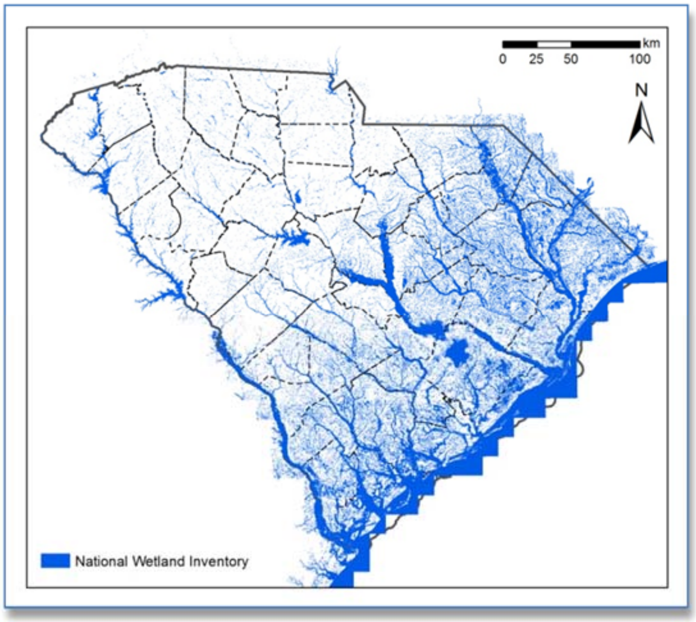


Figure 3. National Wetland Inventory.

While there are many advantages of relying on the NWI maps as a baseline data layer for the wetland impact and mitigation work a few issues will remain: 1) accuracy and 2) timelines. The NWI mapping process used a conservative approach for determining wetland areas that had a high probability of begin wetlands. For example, farmed wetlands were intentionally not mapped as the NWI process using hydrophytic vegetation as an indicator for wetland presence. Thus, omitted wetland areas are to be expected. Previous studies have examined the accuracy of the NWI maps and found them to have high commission accuracies but low omission accuracies (Kuzila et al. 1991; Stolt and Baker 1995; Kudray and Gale, 2000). The NWI maps frequently miss wetlands. In one of the few studies that used jurisdictionally defined wetlands, Stolt and Baker (1995) found the NWI data in the Blue Ridge Mountains of Virginia were 91% accurate in identifying wetlands. In the same study, the authors found less than 16% of the actual wetlands judged from field work were mapped in the NWI data. The missing wetlands were often small or heavily vegetated. Kudray and Gale (2000) confirmed that 90% of the NWI mapped wetlands in a forested landscape in northern Michigan were found to indeed be wetlands. Thus, only 10% commission errors are seen in the NWI data.

In addition, the NWI maps are created on a 7.5' quadrangle map basis for relatively small areas; thus, for a large area like a state the temporal serious of imagery used for constructing the NWI maps may span 30 years or more (**Figure 4**). A statewide coverage for South Carolina from NWI data would represent dates of imagery from 1981 to 2011. The implications for such a large span of image dates to support the interpretation and mapping of wetlands is the compiled statewide database will have varying spatial accuracy. Areas mapped with older imagery and with rapid development are likely to have undergone changes with some wetland loss. Even areas without development will have experienced wetland change from natural processes, such as the continued growth of vegetation. These changes will influence tree height and canopy closure – both metrics for determining the class of wetlands in the Cowardin system. For example, planted cypress trees may grow at an average of 1.4'/year. The growth rate of some wetland trees may average to about 1' per year (Jeff Siceloff, personal communication). The implication is, for example, palustrine scrub-shrub areas may have changed into palustrine forested wetland. Additionally, coastal wetlands can also change dramatically from invasive species, such as *Phragmites communis*. (commonly called reed grass), which can spread up to 30' per year (Klemas et al, 1974). The implications for a wetlands database of varying spatial accuracy is one single summary accuracy may not best reflect the accuracy for all areas of the state. Without an accuracy assessment with enough sample observations for all areas of the state it is difficult to estimate the spatial accuracy for each area except from proxies, such as the date of original imagery or anthropogenic development within an area.

The pragmatic question is how the NWI wetlands database can be improved to minimize omission errors and be updated to reflect current wetland conditions. Minimizing omission errors will be addressed in this report by incorporating other data sources, such as the USDA SURGO dataset and the South Carolina state land use/cover data. Additional improvements can be made by processing the raw statewide airborne LiDAR point-clouds to extract above-ground canopy characteristics and more recent aerial imagery to distinguish between certain wetland classes. Processing the raw LiDAR point-clouds is not trivial as the database sizes are large, the environmental conditions between counties varies, and the collection/processing of LiDAR for each county varies somewhat. The issues related to these ancillary data sources will be treated in the following sections of this final report.

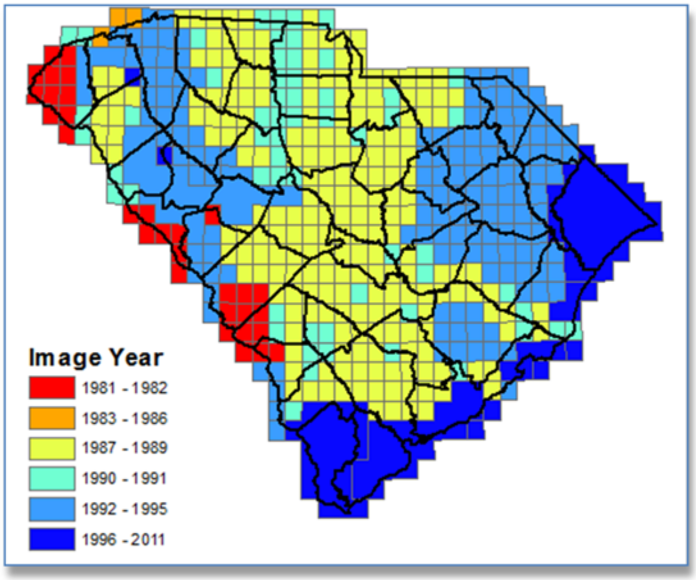


Figure 4. Image year used to create the most recent NWI maps in South Carolina.

Even though no new NWI mapping from aerial imagery has been conducted since 2011 in South Carolina the F&WS continues to make changes to the NWI database. Most recently the F&WS has integrated some of the National Hydrography Data (NDH) into the NWI database (e.g., **Figure 5**). Thus, the NWI for

South Carolina may change content from the integration of other sources. The NWI data used to build the final wetlands likelihood layer was obtained from the F&WS in March of 2016.

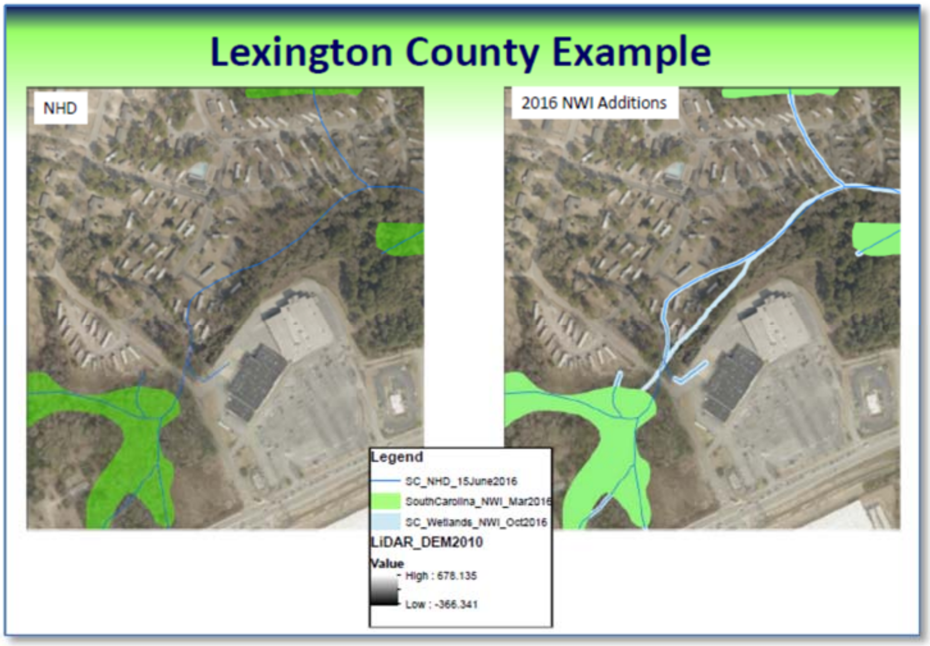


Figure 5. Example of recent changes to the NWI database, presumably from the NHD.

Hydrogeomorphic Approach for Wetlands Classification

An alternative approach to wetlands classification also used by the USACE is the hydrogeomorphic approach that began development in 1995 with guidance documents released in 2003. This approach classifies wetlands based on their function rather than strictly their vegetative characteristics. Three fundamental factors are used to characterize function: position of wetlands in the geomorphic landscape, water source, and flow/fluctuation of the water once it is in the wetland. A key difference between the Cowardin classification and the hydrogeomorphic method is the latter considers the geographic context (e.g., the placement of the location with a larger area). The HGM approach has seven major hydrogeomorphic classes: “riverine, depressions, slope, flats (organic soil and mineral soil), and fringe (estuarine and lacustrine)” (Clairain, 2002, p. 9). USACE stresses that the HGM approach is not meant to assign a value to wetland functions; such a value is dependent on the local/political context and society/economy (Clairain, 2002, p. 12). Factors that are important for defining the regional subclass are: climate, geomorphic setting, hydrodynamics, soils, vegetation, wildlife, and disturbances (natural and anthropogenic).

Of importance to this research is there is no dataset for even a single county in South Carolina where wetlands have been mapped using the HGM approach. Thus, the HGM approach, while useful for some of the credit classifications (buffer preservation and salt marsh preservation) by the USACE in South Carolina, has not been implemented to create a state or even county-wide database for use for the SCDOT. The USACE in South Carolina relies on the Cowardin classification system for credit determination except for buffer and salt marsh preservation.

USDA SURGO Data

The SSURGO database (Soil Survey Geographic database) refers to digital soils data produced and distributed by the Natural Resources Conservation Service (NRCS). This database contains information about soil collected by the NRCS over the course of a century of field surveys and observations of the soils and analyses in laboratories. The information was collected at scales ranging from 1:12,000 to 1:63,360. The USDA-NRCS order 2 soil survey maps contain polygonal delineations created from aerial photographic base maps with field surveys on maps ranging from 1:12,000 to 1:24,000 scales. The minimum mapping unit was 0.4-ha on 1:12,000 scale maps. SSURGO data are updated versions of the USDA-NRCS order 2 maps.

The accuracy of SSURGO defined hydric soils as an indicator of wetlands has few investigations (Malo, 1991; Hurt and Carlisle, 2001). Hurt and Carlisle (2001) report good consistencies while Brevik et al. (2000) reported accuracies of 63% and less.

SSURGO datasets consist of map data, tabular data, and information about how the maps and tables were created. The extent of a SSURGO dataset is a soil survey area, which may consist of a single county, multiple counties, or parts of multiple counties. Hydric soil delineation can be justified by definition, criteria, and lists. The definition for a hydric soil is a soil, “that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part” (Federal Register, 1994). The Federal Register also defined four criteria of hydric soils that takes into account specific soil taxonomy and the flood regime of a soil. It is important to note that while a soil may satisfy hydric criteria, it still only means that at most it is likely to be hydric and is dependent on *in situ* field surveys for verification. Depending on state agency resources, some lists already exist and give full detail as to soil series that are likely to be hydric. In 2015 Leslie Parker focused on evaluating the reliability of the SSURGO dataset for South Carolina for predicting wetlands locations. The SSURGO data were believed to be particularly useful for completing the large number of omitted wetland areas (as will be discussed later).

To evaluate the SSURGO dataset Parker used the USDA Soil Data Viewer and the SCDNR hydric soils criteria list. Both types of resources were used to identify potential hydric soils for all counties within the state. Specifically, the USDA Soil Data Viewer was used to generate hydric ratings for all SSURGO datasets of the state. Likewise, soil series that were denoted as hydric by the SCDNR list were queried and extracted from all SSURGO datasets. The USDA Soil Data Viewer is an add on to Arc Map that uses both the spatial and tabular data of county SSURGO data to create a new shape file with a new hydric rating field. Hydric ratings simply indicate that (USDA, 2011). Both types of resources were used to identify potential hydric soils for all counties within the state. Specifically, the USDA Soil Data Viewer was used to generate hydric ratings for all SSURGO datasets of the state. Likewise, soil series that were denoted as hydric by the SCDNR list were queried and extracted from all SSURGO datasets.

Most counties appeared to have accurately mapped hydric soils; however, some counties still drastically over/under-predicted the amount of hydric soils. These problems became apparent when observing hydric soil polygons along county lines for both soil criteria datasets. For example, a soil polygon with similar properties (or the same series) on both sides of a county boundary could be easily discerned by observing the original SSURGO shape files for both counties, but would appear dissected when hydric soils for two adjacent counties were extracted and compared. Visual examples of the various issues are given in **Figure 6**.

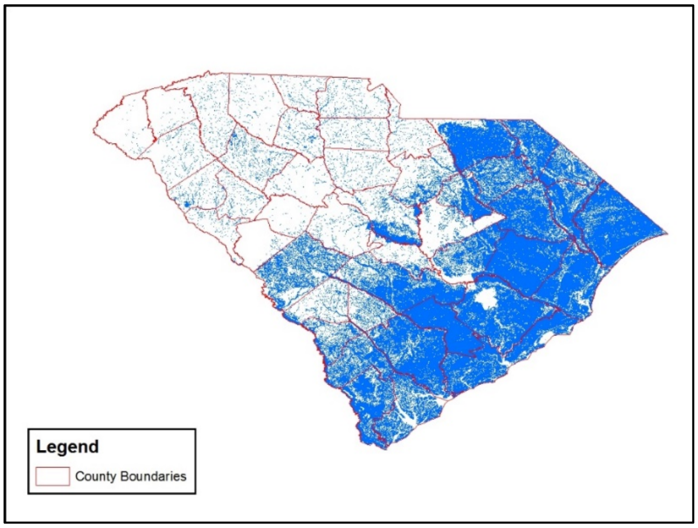


Figure 6. Map showing the hydric soils (in blue color) within the state by using the SCDNR hydric soils criteria.

Using the USDA Soil Data Viewer to represent hydric soils showed had major inconsistencies throughout the state. When observing **Figure 6**, it was evident that the same soil series for two adjacent counties were not treated the same when creating a hydric rating. Hydric ratings ranging from 0 – 100 classified polygons based on drainage types (i.e., hydric, poorly drained, moderately drained, and well drained). For a soil to be considered potentially hydric it must have received a hydric rating of 100 from the USDA Soil Data Viewer. Poorly drained soils ranged from 65 – 99 with many potentially hydric soils falling within this range. When only selecting the soils that received a hydric rating of 100, there was poor agreement between most adjacent counties in the state.

Parker used a logic to identify the SSURGO polygons that most likely represented wetlands (**Figure 7**).

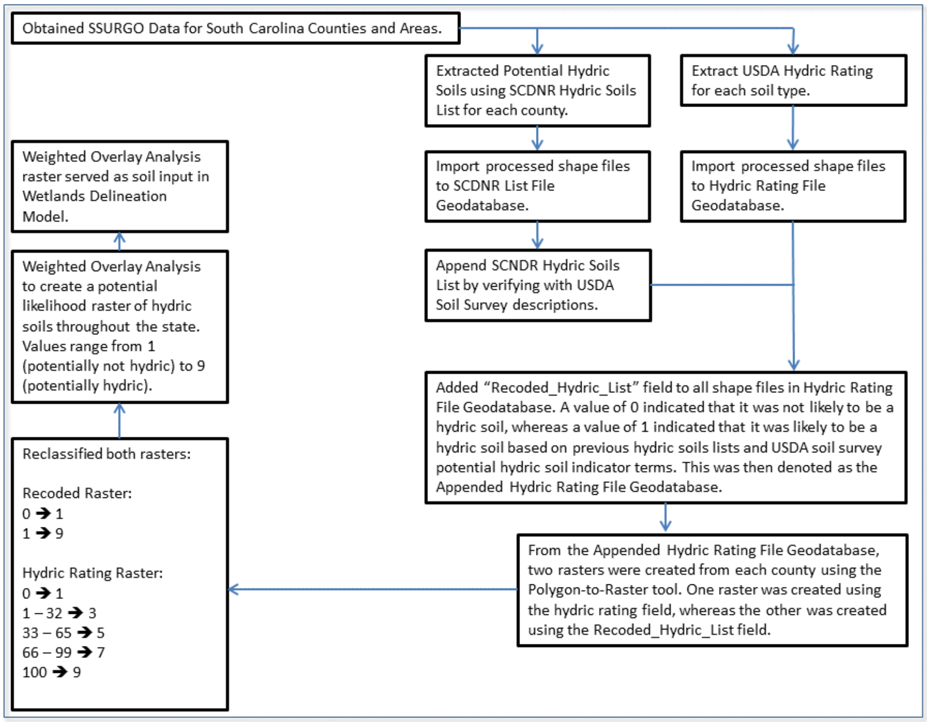


Figure 7. Logic for processing SSURGO data to rank potential wetlands.

Statewide LiDAR Data

Airborne LiDAR data of fairly high spatial resolution (e.g., 1.4 to 2.0-m post spacing) has been collected over all of South Carolina in the 2007 – 2017 period (**Figure 8**). These data are available from the South Carolina Department of Natural Resources (SCDNR) as digital elevation models (DEMs) representing the ground surface. The DEMs are products from collaborative efforts from each county, the SCDNR, and USGS (in collaboration with FEMA). For most counties the DEM was created by USGS from an ESRI Terrain data model. The DEMs at 10-ft x 10-ft spatial resolution are available are by county. Due to funding and river high water conditions over the last ten years, LiDAR data was only recently collected for Georgetown County in March of 2017 (and has not been processed for distribution as of this report). No composite DEM for the entire state existed prior to this project. The LiDAR point-cloud data is available for many, but not all counties in the state. Management of the statewide LiDAR collection and product generation was by Jim Scurry (SCDNR) and Gary Merrill (USGS) both of whom have retired as of 2016.

The statewide LiDAR collection was funded in part by DHS/FEMA for floodplain mapping purpose and thus, similar data collection requirements were used for collection and processing. Collection requirements for the vendors involved were 1.4-m nominal point spacing with a resulting 18.5-cm RMSE vertical accuracy to support 2-ft contour mapping. Point-cloud data with horizontal coordinates were delivered in the South Carolina state Plane NAD83 HARN FIPS 3900 projection/datum using international feet (see *http://www.dnr.sc.gov/GIS/lidar.html* for more details). Vertical coordinates are delivered using the national North American Vertical Datum of 1988 (NAVD88). The vertical units are generally in US survey feet while some counteis were in internaitonal feet. The differences between international and survey feet is insignificant for the elvation ranges in the state – but this only applies to the *vertical* coordinate system. The differences in units for the *horizontal* system amount to a few meters. Some changes in the collection requirements have been made during the 2007 – 2013 period but not substantial so as to influence the use of the data for SCDOT planning/mitigation purposes. Processed LiDAR point clouds were conducted by the contracted vendors but all were required to classify the LiDAR returns into ground and a few non-ground classes. The ground returns were used to create ESRI terrain and DEMs. For some counties it is important to note that several companies (e.g., Sanborn, Fugro Earthdata, PhotoScience Geospatial) flew different airplanes with different sensors, and some different collection parameters (but still meeting the statewide requirements). What the collection differences mean is that a mosaic of LiDAR data for the state will introduce some notable differences in data quality between counties. For analysis of an individual SCDOT project at full spatial resolution the differences might be notable, particularly for areas where water levels vary diurnally or seasonally. For this project on wetlands mitigation these differences are often visible as artifacts in the tiles used to create the county-county boundary areas. As long as the analyst is aware of the possible artifacts the LiDAR data are fine for analysis. For some automated analysis, such as hydroline mapping, the differences must be considered.

Individual county DEMs were obtained from the SCDNR for all counties except Jasper and Colleton counties. The Jasper and Colleton counties the raw LiDAR point-cloud dataset was obtained and DEMs at the 10’ x 10’ cell size (to match the SCDNR resolution) were created using ESRI ArcGIS and Qcoherent LP360 software. A statewide composite DEM was created by mosaicing the individual county-level DEMs. The resulting statewide DEM is approximately 63-gb in size with 145743 columns and 116124 rows in the 10’ x 10’ tesselation. For a statewide analysis using this size and resolution DEM warrants consideration of the processing time and intermediate layers created from any analysis. Warning: Planning for processing time and space for the many intermediate layers (often of the same 63-gb in size) should be planned for.

Creating a wetlands likelihood proxy from LiDAR data is a research area with little previous research. The dominant approach has been to map depressions (functionally a closed basin) from the LiDAR-derived DEM (Tang, 2014). Under the assumption the depressions are likely areas that trap water these areas would be inundated for at least some periods of the year – a first proxy for wetlands indication.

SCDNR Land Use/Cover Data

Statewide land use/cover data were originally obtained from the South Carolina Department of Natural Resources (SCDNR) over ten years ago for a project with The Nature Conservancy. These data were modified in the project with the TNC and updating to the land cover in the Pee Dee and neighboring rivers, using visual analysis of aerial photography, was conducted. The updated land use/cover data were utilized in this project to supplement the NWI data by adding additional wetlands that were mapped in the project.

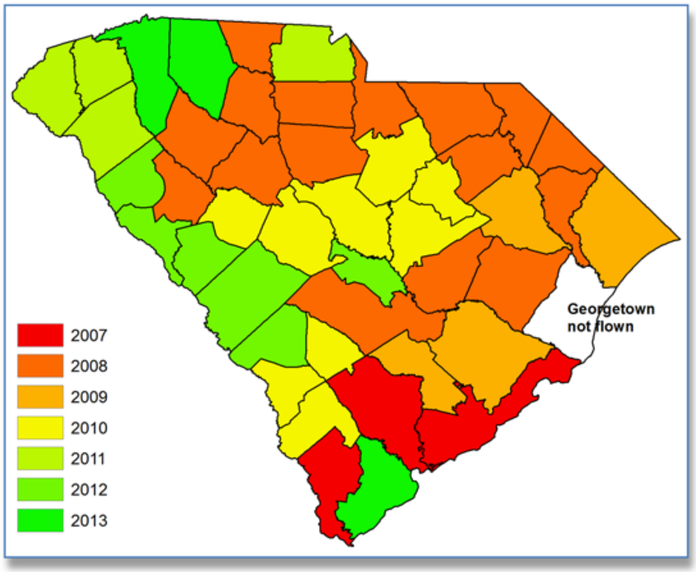


Figure 8. Image year used to create the most recent LiDAR coverage in South Carolina.

County Land Parcels as Indicators

Land parcel information can be useful for various reasons. Some of these include property size, property values, zoning or land use codes. Parcels enable a better understanding as to how a piece of property is being utilized. The implications of land use type and whether the parcel may contain a wetland can be reasonably inferred. It is easier to infer that a parcel does not contain a wetland than it is to predict the presence of one.

Cadastral data contain geographic information on the location of property parcels and characteristics of the owner (e.g., mailing address, name), the tax data, and the improvements on the parcel. Initially, the goal of implementing cadastral data, was to use it as an elimination for the wetland likelihood layer. It would be used to filter out areas where it was highly unlikely that there would be a wetland. The initial evaluation set out to include only parcels that were smaller than one acre. The inference was that most small parcels can be related to residential subdivisions. The likelihood of the neighborhood containing a wetland is small, especially with newer subdivisions, as developers many times clear cut most of the property and then develop it. This is also the case in areas that are highly developed.

The parcel assessment data was evaluated to see if there was any additional information that could be used to filter out parcels that did not contain a wetland. It turns out that there were a few useful attributes: Building values (developed property less likely to have wetlands), agricultural use (agricultural use exemptions increased likelihood of wetlands), land use codes (e.g., residential, rural, commercial) and zoning (designating permitted use on a property). Ideally, these attributes could be used to help improve the accuracy of the wetlands likelihood layer.

Four counties were used in the pilot investigation: Lexington, Beaufort, Dorchester and Berkeley counties. They generally had similar attribution of the cadastral data that included the above referenced information. Unfortunately, there was minimal consistency on a county by county basis in both the information provided and how each county actually classified their information. Parcel information is unique to each county, but how they classify and maintain their data may be different. For example, Lexington and Beaufort counties have very detailed land use information, while other counties had no land use information at all.

All parcels were grouped into three categories: Low, medium and high. These groupings varied from county to county due to the availability of the data. Land use information contributed to increasing the amount of area of the "low" ranking. This ranking implies that it is unlikely that there is a wetland contained within it.

We also tested the use of parcel data to estimate which parcels likely contained at wetland. Unfortunately, these results were not as reliable as using the low ranking values. In order to proceed down this path, more assessment information would need to be provided on a consistent basis. The final breakdown of the number of counties and the assessment data that was provided within each parcel layer:

- ***No Data*** (16 counties)
- ***Building and Land use*** (12 counties)
- ***Buildings Only*** (15 counties)
- ***Land use Only*** (3 counties)

There are 12 of 46 counties that provide both building and land use information (4 of which have been evaluated). It is recommended that these 12 counties be researched and evaluated in the same method as the four pilot areas. These counties will provide the best results to increase the accuracy of the wetlands likelihood layer. Eighteen (18) counties that have either building or land use information. These counties can also be reviewed in the same manner, however, it may be prudent to try and obtain additional assessment data from each county to ensure the best results.

Sixteen (16) counties have no assessment information and a coarse evaluation could be done solely on parcel size, however the results may not be as reliable. It is recommended that these particular counties are contacted to obtain more detailed information.

It should not be left unsaid that obtaining up-to-date, and appropriately attributed parcel data can be difficult to obtain. There are multiple ways that counties deal with the distribution of their cadastral data. Some will give it away freely, while others will charge a fee in some instances. Before trying to obtain data directly from the counties, it is recommended that SCDOT prioritize which counties would benefit from this evaluation if deciding to contact individual counties directly. It may also benefit to contact the SC Geographic Information Council to see if they can request additional information from the counties when they compile an update to their existing information.

In addition to evaluating the cadastral information, spatial queries to denote proximity of parcels to natural features such as existing wetland, rivers and various soil types will also help to improve the wetlands likelihood layer. A formal methodology for ranking various conditions will need to be created before proceeding with proximity analysis.

Historic Topographic Maps and Aerial Imagery

This section will present:

- The geo-historical approach in the study of wetlands
- The use of historic maps and photos in the analysis of wetlands
- The contribution that historic maps and photos can bring in the analysis of cultural value of wetlands.

The geo-historical analysis of the humans-environment relationship is of value to understand system dynamics and environmental changes over the time and for management and restoration of the territory. Historic maps and historic aerial photos are among the main tools in the geo-historical approach to the study of the environment and were used in this project within the study of the presence of wetlands and their evolution.

Historic maps may contain indicators of the past presence of wetlands derived from extensive field observations during the map construction. In fact, historic maps document the state of the environment over a long time period. These historic documents allow investigation of wetlands back in time where other methods cannot provide such information (e.g., historic aerial are only available since the 1930s). For example, some USGS historic maps go back in time since the 1920s (see **Figure 9**) while Robert Mill's Atlas of the State of South Carolina describe the wetland landscape at a small scale during 1825. While the USGS topographic map series are large scale documents (e.g., 1:24,000) and are a tool for a very accurate census of wetlands in the past, smaller scale maps such as those in Mill's Atlas can be useful to study the status of larger wetland areas. Although the map scales can be different, historic maps allow the construction of long diachronic sequences to investigate the trend of wetlands over time (**Figure 9**).

Although historic aerial photos provide a shorter time period of coverage (late 1930s to present), they can be considered a more objective tool for environmental and landscape analysis than historic maps since they are not a product of interpretations from analysts. Historic aerial photos are useful to help in understanding the contextual evolution in soil types (overlap in 1973 photo), vegetation, land cover and the presence of water (see **Figure 10** and **Figure 11**).

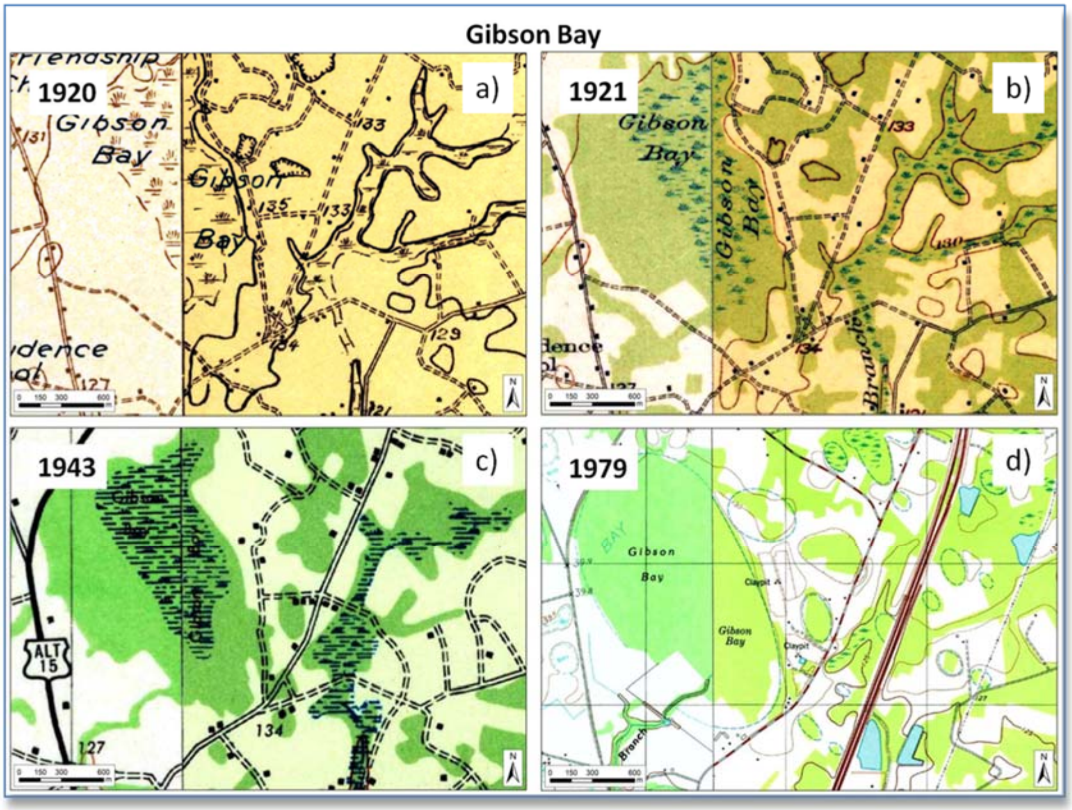


Figure 9. Example of a diachronic analysis of wetlands in Gibson Bay area (south of Santee, SC) through USGS historic maps at different year of survey and scale: a) 1920 at 1:48k, b) 1921 at 1:62.5k, c) 1943 at 1:62.5k and d) 1979 at 1:24k. In the example it is possible to notice the swamp area inside Gibson Bay (a Carolina bay) becomes smaller during the time and completely disappears on the 1979 map. To the west, the construction of the interstate I-95 in the 1960s brought the excavation of many clay pits that are now small geographically isolated wetlands.

Figure 10. Present-day imagery showing a small wetland south of Santee. Notice that this area is involved in some recent SCDOT works for the creation of a transportation connection between the "Old Number 6 Hwy" and I-95. The white rectangle shows the same area of interest for the historic aerial photos comparison in **Figure 11**.

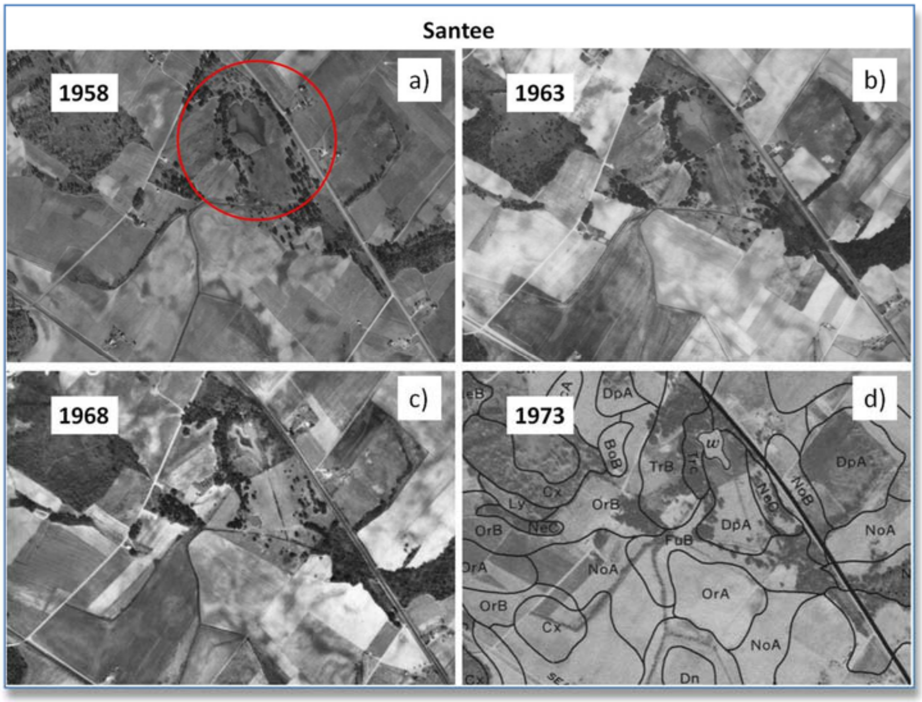


Figure 11. Diachronic comparison between four different historic aerial photos (i.e., 1958, 1963, 1968 and 1973 respectively) for an area south of Santee, SC in the white rectangle of **Figure 10**. The red circle indicates a small wetland of interest.

Stream Geospatial Data

Geospatial data for stream locations and for validation were somewhat problematic. The best available representation of stream locations for the entire state of South Carolina are from the National Hydrography Data (NHD). The NHD high resolution data were compiled from the blue lines on the 1:24,000 scale topographic maps. To the extent the topographic quad maps were compiled consistently (the process was well defined but a few topographic map sheets vary greatly in the resulting stream content) the NHD high resolution data form a seamless mosaic for the state. The NHD flowlines were extracted from the NHD data and delivered to the SCDOT in a geodatabase.

Some of the counties have developed more detailed streams, ditches, and other water-related features. Much of these data were mapped from high spatial resolution photography (0.5' x 0.5' resolution) and LiDAR data (~10' x 10' resolution). Thus, the spatial accuracy of the county created data are improved as compared to the USGS NHD data. In addition, headwater streams, which are largely missing in the NHD data were mapped by the county. However, the criteria for defining streams, ditches, and other water-related features are not consistent across the few counties that have completed their work. A statewide compilation of county data and NHD is problematic.

Combination of stream location data from multiple sources involves problems that are not present with the wetlands polygonal data. For example, the stream locations from multiple sources (e.g., NHD and a county) will always result in two locations for the same lineal location of a stream. Resolving the multiple locations of the same lines is referred to as conflation in GIScience. There are some solutions but the assumptions are too restrictive. For example the conflation logic is only appropriate when the line in two sources is well-known to represent the same stream segment. If one source contains a stream and the other source does not contain a stream the problem is exasperated.

More problematic is obtaining validation data to represent jurisdictional streams. Many attempts at acquiring such jurisdictional streams were made but were unsuccessful. Thus, it was not possible to conduct a validation phase for stream locations as was done with wetland areas. At best, we examined a few past projects for reported and predicted stream impacts. Because of these issues this project only used NHD high resolution data (i.e., the flowlines) to represent stream locations that may be impacted by a road/bridge improvement project.

Approaches for Wetlands Data Accuracy Assessment

The development of a toolset to forecast future wetlands impacts from SCDOT improvements requires 1) input data and 2) an appropriate model. The input data is in the form of existing road/bridge and associated shoulders/et and anticipated modifications for the road/bridge improvement. In South Carolina, as in most states, there are no geospatial data representing the current state of the road/bridges with shoulders. The road/bridge data maintained by the SCDOT includes road centerlines, estimated road and shoulder widths on the right/left sides. This existing geospatial data assume constant widths and precise placements of the centerlines. The geospatial data are good but the centerlines are not always in the center of the roadway and for divided highways/interstates, there is only one centerline that seldom is in the center of the combined roadways.

The modified form of the road/bridge require the greatest assumptions as the final plans are not known. Even the final pavement widths and shoulder widths are not known. For bridge replacements the road and new bridge might be offset by some unknown distance. In fact, the final location of the bridge and road modification might be decided upon to avoid wetland impacts. Thus, the combination of current road/bridge/shoulders and future modifications combine to create estimates that are likely to contain errors. The goal in this project was to develop a method that could not only estimate future wetland impacts but to also estimate the degree of uncertainty in forecasted impacts. It should be understood that the error in estimates of wetland/stream impacts for a single project may be somewhat large; however, the error in estimates for a set of projects (e.g., within a HUC-8 watershed) are expected to be more modest.

The input data for the project also includes a layer representing current wetlands and current streams. As discussed earlier these data sources were created from multiple input data layers, in large part, to obviate the substantial underestimates in wetlands areas by the NWI data. To estimate what the remaining errors are in the wetlands/stream layers were requested validation data from the SCDOT. The SCDOT did not previously create or maintain such a data source so a dataset of locations was created using different methods: 1) final project reports and impact assessments and 2) polygonal data created by the contractors or in-house SCDOT staff. We also undertook site visits to both restoration sites and pas project locations to get a better understanding of the potential problems in input wetlands/stream data and model performance.

The following sections will present field trips and validation of NWI, soils, and combined wetlands likelihood layers. While developing the final wetlands likelihood layer we examined the accuracy of the input road data, projected road/bridge improvements, and intermediate forms of the wetlands impact tool. Thus, parts of this report represent early assessments of model performance and quality of the input data. A summary at the end documents the quality of the final products.

Field Trips to Understand Data and Problems

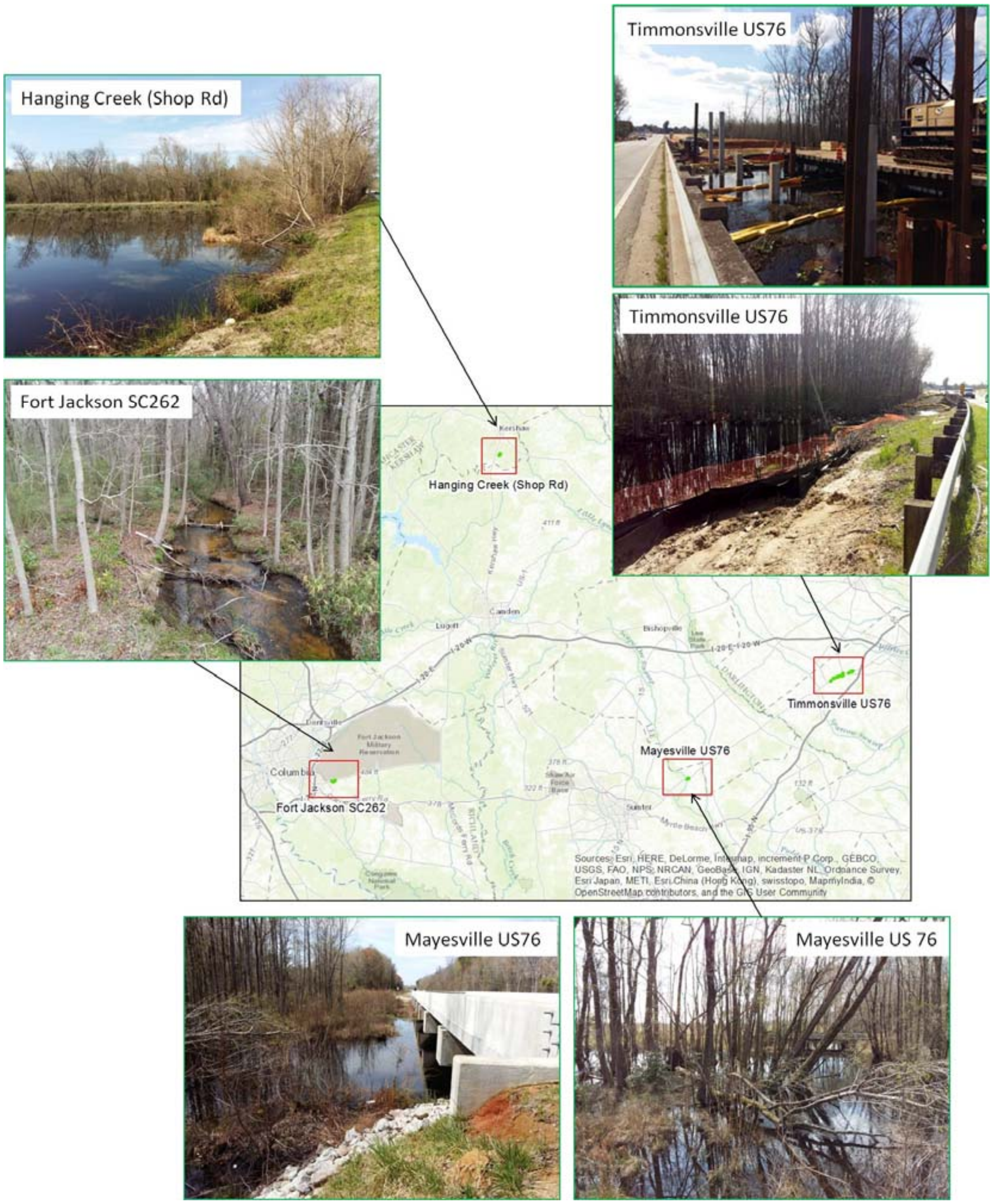
To better understand data accuracy, relationship between different layers of geographic information and their relationship with SCDOT jurisdictional wetlands, SCDOT STIP data and SCDOT survey corridors we organized and participated in several field trips. In this chapter, a short description for the four most important fieldtrips is provided.

“**Lynches River fieldtrip” (March 2014).** A site visit was taken by members of the USC and SCDOT staff to see the mitigation projects along the Lynches River and Rose Branch (a tributary to the Lynches River) in Darlington County, SC. Mitigation work was carried out in this site between August 2013 and May 2014. A total of 41,765-ft of streams were restored, enhanced, or preserved. Additionally, 429-acres of wetlands were restored, enhanced, or preserved (**Figure 12**).

Figure 12 Rose branch before and after construction of wetlands.

“Mayesville-Timmonsville fieldtrip” (March 2015). This first fieldtrip focused on some of the first SCDOT road widening or bridge replacement projects provided to study the impact of on wetlands. The major stops (**Figure 13**) included Fort Jackson SC-262 Road (bridge on Mill Creek), Hanging Creek Shop Road (ditches and bridge widening over Hanging Creek), Mayesville US-76 (new and old bridge on Scape Ore Swamp) and Timmonsville US-76 (Lake Swamp and some lateral ditches). At the time of this fieldtrip, the limits of the road construction were provided only for a very limited number of SCDOT projects (initially Hanging Creek) so the observations in the field were based only on the location of jurisdictional wetlands identified by SCDOT. The main finding of this fieldtrip were a better understanding of the quality of the NWI and the SURGO soil data in order to build the Wetland Likelihood Layer and a first approach to SCDOT structures as bridges and lateral ditches. The wetlands identified by SCDOT and USACOE field work in the apex of the road intersection were not present in either the NWI or SURGO soil data because of the spatial resolution of these data sources.

“Orangeburg-Santee fieldtrip” (April 2015). This fieldtrip focused on three main areas (**Figure 14**), located along the Five Chop Road (bridges on Four Holes Swamp between Orangeburg and Felderville), between the I-95 and the Old Number 6 Road south of Santee and in the Gibson Bay area (between Bass Road and the I-95). This fieldtrip was useful to understand the necessity to have a systematic database of polygons representing “surveyed corridors” of interest for SCDOT road projects. The surveyed corridors are buffer areas around a particular road in which jurisdictional wetlands were defined. These corridors were used later in the validation of modeled impact assessment using a base of NWI, soil data and the composite wetlands likelihood layer. Even though the Gibson Bay area was not included in any work-in-progress SCDOT projects, the visit to this site was very useful to understand some of territorial dynamics that drive the management and the evolution of wetlands both in private and public contexts. Gibson Bay (a Carolina bay about 2 km long) is located on the private property of Mr. Walter Dantzler who provided information on the evolution of the wetlands within and out of the bay since the 1960s, also in relation with the construction of the nearby I-95 (see also **Figure 9**).



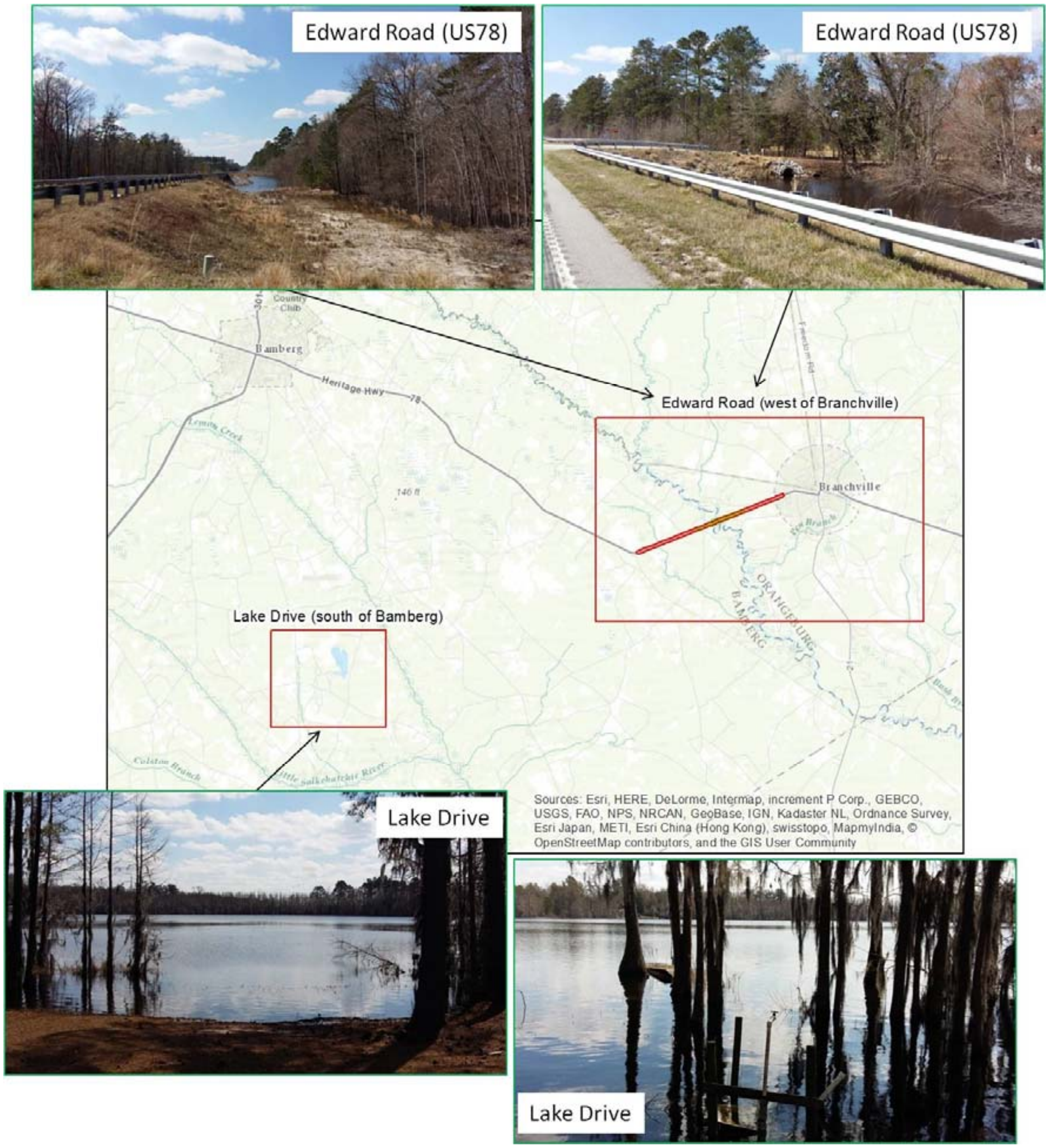
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 13. Locations of the SCDOT projects visited during the "Mayesville-Timmonsville fieldtrip" in March 2015.

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 14. Locations and in situ photos of the work projects visited during the "Orangeburg-Santee fieldtrip" in April 2015.

"Branchville fieldtrip" (March 2016). This fieldtrip focused on one of the surveyed corridors that SCDOT provided in September 2015. The corridor (see **Figure 15**) is located along the Edward Road on Edisto River, southwest of Branchville. The visit to this site helped in the validation process of NWI data and the wetlands likelihood layer on SCDOT jurisdictional wetlands inside the corridor. During the fieldtrip a small Carolina bay, in the area between Bamberg and the Little Salkehatchie River, was also visited. The bay is located in Lake Drive and appeared as a small lake, probably a former touristic fishing pond, now almost abandoned.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 15. Locations of the work projects visited during the “Branchville fieldtrip” in March 2016 and related photos.

Modeling Integrated Data Sources for Wetlands Likelihood

There are many models for combining geospatial data sources to predict a single value or in this case class – wetlands or not wetlands. The trend in geospatial science has been to use multiple geospatial layers that are differentially weighted based on their reliability and combined in a linear or sometimes non-linear form. The common methods are single models, such as multiple linear or logistic regression (). North Carolina, for instance has been experimenting with logistic regression models with over 12 input geospatial layers (many which are highly correlated) to map the confidence in wetlands (Morgan Weatherford, pers. communication; Wang, 2015). For many geospatial applications the concept is named multi-criteria analysis and the application areas are considerable – landslide mapping, drought likelihood, vulnerability of humans to hazards, desirable places to live, suitable locations for facility construction (Feizizadeh, 2013; Kar and Hodgson, 2012; Tang, 2012; Hodgson et al., 2003; Liu and Hodgson, 2013). For any specific application the challenge is to 1) select a model form (e.g., linear, non-linear, tree or rule-based) that best represents the physical process interaction in predicting the output variable (e.g., wetlands/non-wetlands), 2) select numerical weights for each variable in the model (a process called calibration). For most geospatial research studies the trend has been to select a linear/non-linear model form (mostly because it is convenient and automatic) and calibrate – with little understanding of whether the relationship between variables is appropriately represented in the model.

Models that are ill-formed (e.g., logistic, regression trees) might appear to be good predictors with the test data but perform poorly when used in real-world applications. This finding has been observed in most research applications and often seen when the geographical contexts are introduced (e.g., coastal plain, piedmont, mountainous regions). However, for regulatory purposes or even preliminary studies for regulatory applications most states rely on very simple model forms that may be explained to regulatory agencies and whose performance can be understood in different geographic contexts. The archaeological site suitability models commonly used in state agencies follow the simplistic form. For all statistical-based models, such as logistic/linear regression, discriminate analysis, a threshold value must be determined that separates the classes in the final output (e.g., wetlands versus non-wetlands in this example). Again, it is easier to establish understandable thresholds in simplistic model forms.

For this project we wanted to combine the prediction value of NWI, the recoded SSURGO soils, and land use/cover wetlands data to produce a single layer that represents high confidence in the mapped wetlands. There was also interest in producing a model that resulted in the extremes – the minimum and maximum wetland impacts expected from the road/bridge improvement projects. Estimating the minimum wetland impacts could be accomplished (at least from the WLL layer) by mapping areas where at least one input variable suggested the area was wetlands. The data we had to calibrate the model was from some 31 selected previous SCDOT projects.

For this initial project on mapping wetlands for the entire state, we decided to use a simple overlay model form combining the three input layers that are already in binary form. The logic we chose was based on a simple concept integrating NWI (the wetlands identified in NWI are highly likely to really be wetlands) with two supporting layers (**Table 1**). If one of the three layers indicates the area is wetlands then there is at least low likelihood. The NWI data (as will be shown later) has high reliability for the areas that were identified in the dataset as wetlands (although NWI misses almost 50% of other wetlands, such as those under agricultural production).

Table 1. Ranking logic for wetlands likelihood model based on three statewide data sources.

Likelihood	National Wetlands Inventory (NWI) indicates wetlands	SSURGO indicates hydric soil	SCDNR indicates wetlands
Very High	Yes	Yes	Yes
Very High	Yes	Yes	
Very High	Yes		Yes
High	Yes		
Moderately High		Yes	Yes
Low		Yes	
Low			Yes
Not Wetlands			

Validation Data

We conducted a validation on the each version of the wetlands likelihood layer to understand if the final use of the wetlands impact model would over or under-predict (or neither) in the process of estimating total impacts by watershed/ecoregion. The validation process was important in order to give us an estimate of the modeled wetlands likelihood as representative of wetlands in South Carolina.

The process of validation was applied to the following layers:

- NWI data
- Recoded Soil data (April 2015 version)
- Recoded Soil data (September 2015 version)
- NWI and SCDNR Land Use/Cover
- USC Wetlands (final version of the wetland likelihood layer) data (August 2016)

Reference Data (i.e., “truth”), represented by two different sets of jurisdictional (JD) wetlands and corridors layers, were provided by SCDOT. The initial set of SCDOT reference data (April 2015) contained polygons of wetlands but did not include polygons that were determined to be non-wetlands. Knowing where jurisdictional wetlands is important in evaluating if the developed wetlands layer also indicates these areas of jurisdictionally determined wetlands were labeled as wetlands. If the wetlands likelihood layer does not label the same jurisdictional areas as wetlands this is an omission error. However, it is also important to know where in the SCDOT project areas were areas of non-wetlands. If the wetlands likelihood layer indicates a non-wetland area is believed to be wetlands this is an error. Technically, it would be a commission error.

Subsequent reference dataset obtained from SCDOT in the summer of 2015 included polygons of both wetlands and non-wetlands. These polygons of wetlands/non-wetlands were available for the

September 2015 and August 2016 validations and helped very much in the assessment of the commission error.

Accuracy Assessment (Omission & Commission)

As shown in the right part of **Figure 16**, the validation process consists of an intersection between the wetland likelihood layer (WLL) polygons and the SCDOT corridors containing both the JD wetland polygons and the non-wetland polygons.

The areas inside the project area (or corridor) where the SCDOT polygonal data type (wetlands versus non-wetlands) disagree with the WLL polygonal data are considered errors. As noted above omissions errors are areas where the WLL polygons are labeled non-wetlands while the SCDOT data are labeled JD-wetlands. Commission errors are when the WLL polygons are labeled as wetlands while the SCDOT data are labeled non-wetlands.

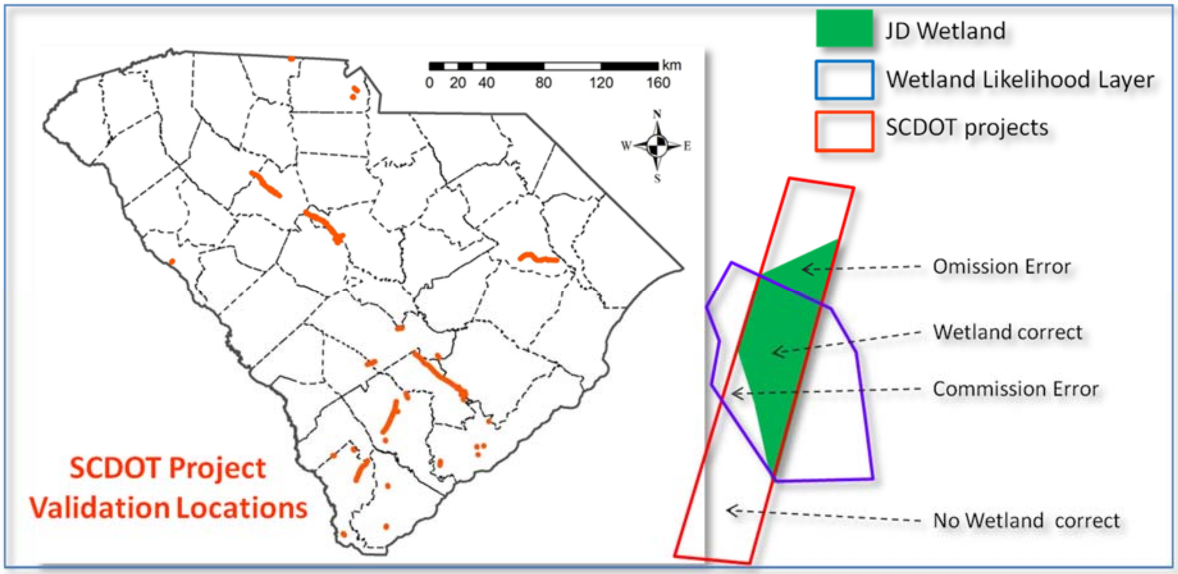
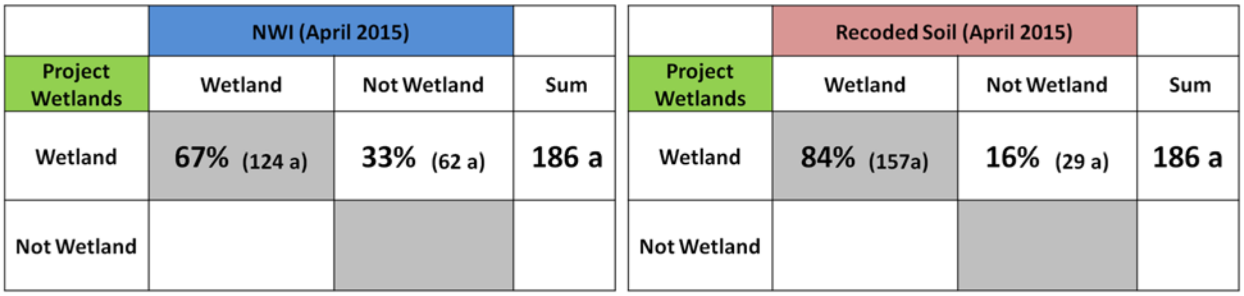


Figure 16. SCDOT Project Validation Locations for the last two validation processes (September 2015 and August 2016) and a schematic explanation for the validation process of the USC Wetland layer (wetland likelihood layer).

NWI and SURGO Soils Assessment

The tables in **Figure 17** show the results for the validation processes of April 2015 when only the JD wetlands were available for 29 previous SCDOT improvement projects containing 347 wetland polygonal areas. The NWI data are accurate 67% of the time for predicting the location of wetlands. The NWI would miss 33% of the wetlands. Using the first recoded dataset of SSURGO soils results in 84% accuracy of predicting the location of wetlands. It would seem from this initial validation that the recoded SSURGO data are superior than the NWI for locating wetlands. However, it must be realized that high accuracy in locating wetlands can be created by simply coding the entire study area as a wetland – thus, no wetland area would be missed in the mapping project.

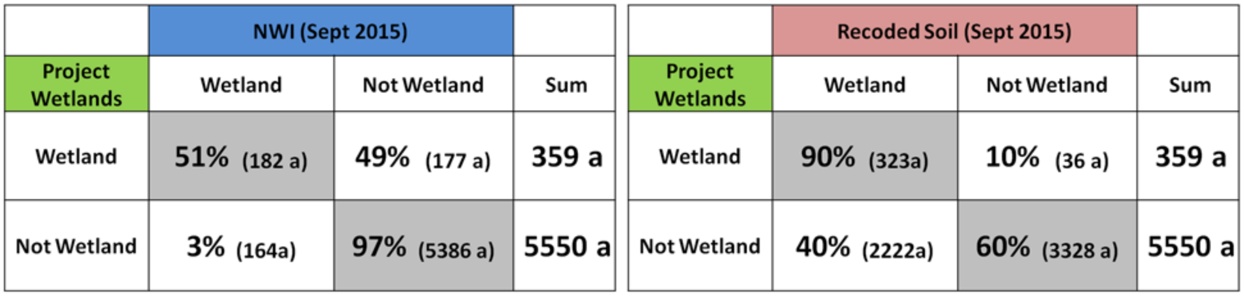
In September of 2015 we received polygonal data for SCDOT projects indicating both the JD-wetlands the non-wetland determinations. Thus, validations could be conducted to analyze both the omission and commission errors. We also received additional project locations and made an adjustment to the NWI wetlands (by removing lakes/ponds and streams as a wetland class). Additionally, improvements were made to the recoded SSURGO data. The results of the validation with the modified NWI and recoded SSURGO data are shown in (**Figure 18**). The new version of the Recoded Soil indicated very low omission errors (only 10 %) but the high omission accuracy (90%) came at the expense of relative high commission errors (40%). The omission accuracy for the NWI data were 51% while the commission error was very low (only 3%). Assuming the validation dataset is representative of all future SCDOT projects in the state, relying on the NWI data alone to forecast future wetlands impacts would likely result in a 49% underestimation of wetland area impacts.



	NWI (April 2015)		
Project Wetlands	Wetland	Not Wetland	Sum
Wetland	67% (124 a)	33% (62 a)	186 a
Not Wetland			

	Recoded Soil (April 2015)		
Project Wetlands	Wetland	Not Wetland	Sum
Wetland	84% (157a)	16% (29 a)	186 a
Not Wetland			

Figure 17. Results for 2015 validations (April), obtained first generation versions of recoded soil and project data.

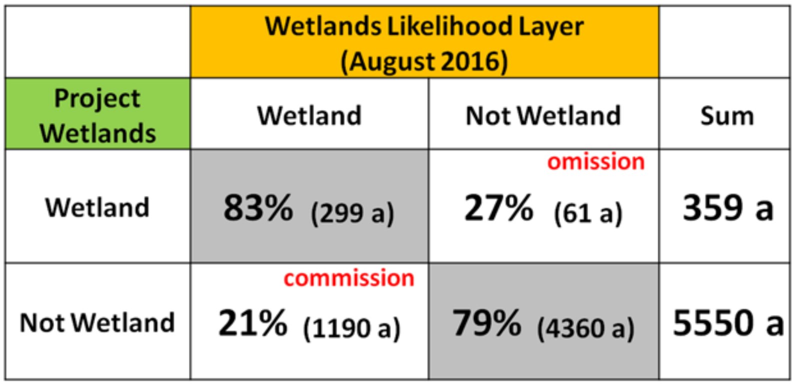


	NWI (Sept 2015)		
Project Wetlands	Wetland	Not Wetland	Sum
Wetland	51% (182 a)	49% (177 a)	359 a
Not Wetland	3% (164a)	97% (5386 a)	5550 a

	Recoded Soil (Sept 2015)		
Project Wetlands	Wetland	Not Wetland	Sum
Wetland	90% (323a)	10% (36 a)	359 a
Not Wetland	40% (2222a)	60% (3328 a)	5550 a

Figure 18. Results for 2015 validations (September), using project specific non-wetlands and revised recoded soil and project data.

The final version of the wetland likelihood layer (WLL) was created by combining the NWI data, the recoded SSURGO data, and the SCDNR land use/cover data. The WLL is distributed as an ESRI geodatabase feature class. The WLL contains separate codes for each of the three input layers and can be analyzed from the individual layers or the combination of layers (**Figure 19**). The omission error results are only 27%, very close to the commission error (21%). The most accurate balanced combination of omission and commission accuracy is using the WLL with likelihood rankings from low to very high (inclusive). Utilizing this composite WLL for predicting the location of wetlands results in an omission accuracy of 83% and a commission accuracy of 79%. Thus, the WLL will miss 27% of the JD-wetlands and commit 21% areas as wetlands when the areas are not. For summarizing a relatively large set of project areas at the HUC-8 watershed level is estimated to only slightly under-predict the total amount of impacted wetlands.



	Wetlands Likelihood Layer (August 2016)		
Project Wetlands	Wetland	Not Wetland	Sum
Wetland	83% (299 a)	omission 27% (61 a)	359 a
Not Wetland	commission 21% (1190 a)	79% (4360 a)	5550 a

Figure 19. Results for the August 2016 validation, obtained using the final version of the wetland likelihood layer.

The final WLL contains wetland areas without a wetlands class label when the area was identified by the recoded SSURGO soils data. The reason for this is the recoded SSURGO hydric soils do not have a wetland class identified by the soil scientists who conducted the original survey. For a more detailed estimate of the type of wetlands we explored methods for adding the top-level classes – forested, scrub-shrub, emergent, and non-vegetated wetlands. We developed and validated an approach for identifying wetland class labels using Horry County as the test case (where SCDOT was conducting a very large area improvement project).

In summary, assuming the validation data analysis represents future SCDOT road/bridge improvement projects, using the NWI data alone for estimating total wetlands impacts for a large set of projects will underestimate the impacts by 49%. Using the WLL from this project will underestimate total wetland impact area for a hydrologic basin by only 6%. This amount and analysis should not be misinterpreted as the confidence in predicted wetland impacts for a single project but is representative of a large set of projects, such as at the watershed level.

Assignment of Wetland Type to non-NWI Areas

The National Wetlands Inventory (NWI) data are known to exhibit low errors of commission yet have high omission errors. Mapping the omitted areas is necessary for wetland impact forecasting in long term development plans. Such mapping could be performed using non-image data (e.g., hydric soils) but will lack the wetland typology. Wetlands are dynamic features and their typological changes influence the quality of their ecological services; thus, regular monitoring wetland change is needed. The research goals in this study were 1) to use an automatic approach based on imagery, LiDAR data, and knowledge rules to assign wetland classes to palustrine wetlands under the Cowardin et al. (1979) wetland classification system, and 2) to quantify wetland class changes. Vegetation height and spectral information were extracted from airborne LiDAR (two years of data) and CIR aerial imagery (two years of data), respectively. A classification logic to monitor the palustrine wetland change in Horry County, SC was developed and validated. A total of 28,800 palustrine wetland polygons (100,402 ha) were analyzed. The results demonstrated the zonal statistics of canopy height model and NDVI can effectively (94% accurate overall and 98% accurate for palustrine forest wetland) be applied to wetland classification and change detection.

The source imagery for creating Horry County's NWI includes South Carolina Department of Natural Resources (SCDNR) 1m x 1m CIR Digital Orthophoto Quadrangles (DOQQ) and the USFWS 0.5m x 0.5m True Color Imagery. Both imagery datasets were collected in 2006. The LiDAR dataset was collected in January 2009 (leaf-off season). Historical aerial imagery is extremely useful in wetland change detection research. Google Earth historical imagery collected between 2001 and 2014 was also used as reference data. Most areas of Horry County have historical imagery collected in 2003, 2005, 2006, 2007, 2009, 2011, 2012, and 2014. In some years (2009 and 2011) imagery collected in multiple months were also available. Wetland vegetation change are easily detectable by visually studying image sequences. User-uploaded geotagged photos were also used as reference when available.

The NWI polygons and class type for the four wetlands classes (PFO, PSS, PEM and a combined non-vegetated PUB+PUS) were used as target areas to model with aerial imagery and LiDAR data. Canopy height/coverage and bottomland cover were modeled using the digital aerial imagery and airborne LIDAR data. Classification rules for wetland classification were defined originally by Cowardin et al. (1979) and incorporated by USFWS analysts. Model accuracies for predicting NWI 2006 era classification and for subsequent 2014 era classification were conducted. Changes in wetland classification between 2006 and 2014 were then investigated using ancillary and reference data. Possible misclassification of the NWI polygons in 2006 was also explored.

The boundary of each NWI wetland polygon defined the spatial extent of each true wetland. LiDAR and imagery was clipped using these NWI polygons, and then vegetation height and spectral information within each polygon was extracted and summarized for wetland classification. Vegetation height is critical information for separating subclasses in palustrine wetlands. Height information cannot be easily extracted from traditional aerial imagery unless stereo coverage is available and used photogrammetrically. However, vegetation height can be accurately extracted from airborne LiDAR point clouds.

LiDAR processing is required before extracting vegetation height information. Processing the LiDAR datasets were performed using QCoherent LP360. The first step was to generate a digital elevation model (DEM) from LiDAR ground returns. Labeling of LiDAR returns into ground/non-ground classes was performed by contractors for the state/FEMA/Horry county flood plain mapping program. The DEM is a raster layer representing the terrain's surface above mean sea level. A digital surface model (DSM) was created from LiDAR first returns. The DSM is a raster layer that includes the vegetation, buildings, bridges, and other above-ground features. In our DSM, the value of a DSM cell represents the highest elevation of all LiDAR returns in the cell. On flat unvegetated surfaces the DSM and DEM should coincide.

When vegetation is present, the first returns in a LiDAR point cloud often represent the highest vegetation feature. A canopy height model (CHM) is simply defined as the difference between a DSM and DEM (CHM = DSM - DEM). The CHM approach used in this research was as an estimation of vegetation height. The use of a small cell size results in cells that only cover a portion of a tree crown, and thus, underestimate the highest part of a tree. On the other hand, a large cell size could overestimate the tree coverage area. The decision to use a 3m x 3m cell size for all LiDAR derived raster layers was a compromise. Some advanced approaches have been developed for estimating individual tree characteristics from LiDAR point clouds (Chen and Zhu 2013; Unger et al. 2014; Fang et al. 2016). Statistical models are often used to predict individual tree height based on LiDAR observations (Yu et al. 2011; Estornell et al. 2014). However, these tree-centric approaches usually require field surveys and location-specific tuning parameters. Most importantly, knowing the height of individual trees (vs. canopy) is unnecessarily complex for wetland classification under the Cowardin et al. (1979) system. Because a broad vegetation characteristic (e.g., forest canopy) will suffice. Thus, this research used a straightforward raster based CHM to calculate vegetation coverage.

LiDAR ground point density, and the lack of ground returns over water bodies, is an indicator of the presence of open water, and could be used to help identify non-vegetated wetlands. The emitted laser pulses from a LiDAR system are typically easily absorbed by water; thus, usually very few LiDAR returns exist over open water. The point density of LiDAR returns are defined here as the number of returns per cell area. A cell with a positive frequency of LiDAR ground returns indicated non-water, while a zero frequency indicates water. If an NWI defined wetland polygon has over 70% area without LiDAR ground returns, this wetland is very likely to be a non-vegetated wetland (or PUB for Horry County).

Other studies have noted the NWI omission problems (NWI misses many wetlands) while exhibiting low commission errors and we recognize this (Kuzila et al. 1991; Stolt and Baker 1995). However, for the purposes here we only examined the locations identified in the NWI mapping program and did not search for omitted areas.

The NDVI value is a unitless ratio usually ranging from [-1.0, 1.0]:

$$\mathrm{NDVI} = \frac{Near\ infrared - Red}{Near\ infrared + Red}$$

A high value of NDVI indicates healthy, green vegetation, while a low value indicates stressed vegetation or non-vegetation. Thus, given an aerial image dataset collected under similar lightening conditions, it is possible to find a threshold NDVI value to separate healthy, green vegetation from stressed vegetation or non-vegetation. The threshold value can be found by trial-and-error under visual interpretation. In this study for example, CIR imagery was overlain on its corresponding NDVI layer. Supervised testing of numerous locations were used to determine an appropriate threshold value. The threshold value for the 2006 NDVI layer was 0.02

The CHM was reclassified into three categories: trees (6m or taller), scrub-shrubs (1m – 6m), and herbaceous vegetation (lower than 1m). The threshold height (6m) between trees and scrub-shrubs is a standard by Cowardin et al. (1979). But Cowardin et al. (1979) did not provide a recommended threshold height between scrub-shrubs and herbaceous vegetation, so in this study we used 1m as recommended by the U.S. Army Corps of Engineers (USACE 2010). The LiDAR point density layer was reclassified into two categories: water (zero returns) and non-water (non-zero returns). The two NDVI layers were reclassified into binary raster layers based on their corresponding threshold values.

For each NWI polygon an inner polygon (3m inside the original polygon) was used to minimize the 1) spatial accuracy issues of the NWI, imagery, LiDAR data and 2) overhanging trees in the slightly oblique portions of an aerial image/LiDAR scan angles. Summary statistics for each NWI inner polygon were derived: canopy height statistics (trees, scrub-shrub), point frequencies (water, non-water), and NDVI-based (vegetated, non-vegetated). From these frequencies, the areal coverage of each wetland characteristic was derived with a zonal operator. For example, if trees cover 30% or more of the total area of a wetland, then the wetland was classified as PFO wetland. If trees cover less than 30% but the total of trees and scrub-shrubs (1m-6m) cover at least 30% of the total area, then the wetland was classified as PSS wetland. The remaining wetland polygons are to be classified as either PEM or non-vegetated.

To be considered a PEM wetland, two constraints from Cowardin et al. (1979) were used to resolve fuzziness in the NDVI threshold. First, vegetation must cover at least 30% area of the wetland. Second, at least 30% area of the wetland must have LiDAR returns. The threshold for determining vegetation from non-vegetation using the NDVI from aerial imagery was not a perfect estimate for all images over Horry County. The addition of a LiDAR frequency layer was used as an additional criterion to minimize the threshold issue. After classifying the PFO, PSS, and PEM wetlands, the remaining wetlands are classified as non-vegetated wetlands.

The automated wetland classification model was applied to 28,800 palustrine wetland polygons in Horry County, SC. The classifications were performed twice, once for each of two different date combinations (Table 5). The “2006 wetland classification” used the 2009 LiDAR and 2006 aerial imagery. As noted earlier the 2006 imagery was the same imagery used by the USFWS analysts for human-derived creation of the NWI polygons. No 2006 LiDAR data were collected so the 2009 LiDAR was used to represent the canopy height characteristics for the 2006 year. We did expect, and thus examined the data for, some changes between 2006 and 2009. However, as wetlands are federally protected we expected few changes represented by wetlands removal.

The two classification results were then compared with the reference data to assess the accuracies. The accuracy assessment is based on how well the model predicted wetland classes agree with the reference wetland classes (i.e., NWI classes in 2006).

Confusion matrices (error matrices) were used to express the accuracy assessments. Producer's accuracy (PA), user's accuracy (UA), overall accuracy (OA), and Kappa coefficients were derived. This study, however, will use "disagreement" instead of the term "error", as any disagreement could be a model error, reference data errors, or an actual wetland type changes.

The confusion matrices contain the disagreements between all 28,800 palustrine wetland polygons as mapped by USFWS staff for the NWI. To analyze the causes of the disagreements, we randomly selected and investigated 435 misclassified wetland polygons. A modified stratified sample design was used with a minimum number of 20 sample sites for rare disagreement types. For each sample, visual interpretation was conducted with all available data: LiDAR, CIR aerial imagery, and Google Earth historical imagery. After the cause(s) of the disagreement was determined, a detailed code was assigned to the sample. The cause could be:

- Single: for example, incorrect reference data or wetland type change.
- Combination: for example, incorrect reference data and wetland type change.

A less common scenario where both model prediction and reference data are incorrect and thus, agree on the incorrect class, could exist. However, this scenario is assumed to be extremely rare and not considered in the accuracy assessment.

The confusion matrix (**Table 2**) show that the 2009 LiDAR + 2006 CIR imagery data combination has an overall agreement (~accuracy) of 87% (area-weighted) and a Kappa coefficient of 0.59. In other words, the 2009 LiDAR + 2006 CIR imagery combination can correctly classify 87% of all investigated palustrine wetlands in Horry County. Palustrine forested (PFO) wetlands are the dominant wetland class in the study area. Nearly 82% of all investigated wetlands are PFO wetlands. Using the 2009 LiDAR + 2006 CIR imagery data combination (a proxy of USFWS analysts' data), the PFO class exhibited the highest accuracy among all wetland classes. The Producer's Accuracy (PA) is 93% and the User's Accuracy (UA) is 94%. The model only produces 7% omission error and 6% commission error for the PFO class.

Rapid Processing of LiDAR Data

Processing the LiDAR point-cloud data for creating canopy height models (as in the wetland class labeling task) or other derivative products requires a considerable computation effort. The raw LiDAR point clouds are very large and conventional GIS software, such as ESRI Arcmap, do not have an adequate data model and processing routines for efficient work. While working to create the missing Jasper and Colleton county DEMs (the State had not created these as of project time and of the writing of this final report in June 2017) we developed a computationally efficient approach using cluster computing with open-source software.

Table 2. Area-weighted Confusion Matrix of Predicted Wetland Type for 2006

	Predicted Wetland Classes using 2009 LiDAR and 2006 Imagery (ha)						
		PFO	***PSS***	***PEM***	***Non-vegetated***	***Total***	***PA***
NWI Wetland Types (2006 imagery)	***PFO***	76,636 *93%*	3,531 *4%*	1,833 *2%*	168 *0%*	82,168 *100%*	93%
	PSS	**4,522** ***36%***	6,799 *54%*	1,068 *8%*	177 *1%*	12,565 *100%*	54%
	PEM	70 *3%*	**914** ***34%***	1,103 *41%*	**631** ***23%***	2,718 *100%*	41%
	Non-vegetated	45 *2%*	102 *3%*	42 *1%*	2,761 *94%*	2,951 *100%*	94%
	Total	81,273	11,346	4,046	3,738	100,402	
	UA	94%	60%	27%	74%		
	OA	87%					
	Kappa	0.59					

To tackle such challenges, we developed a general-purpose scalable framework coupled with a sophisticated data decomposition and parallelization strategy to efficiently handle large LiDAR data collections. The goals in this research were to develop a processing approach for large LiDAR collections utilizing 1) the native .las format (i.e., no need to restructure the data) and 2) existing and widely available LiDAR processing software (i.e., no need to write unique LiDAR processing software). The contributions of this research were 1) a tile-based spatial index to manage big LiDAR data in the scalable and fault-tolerable Hadoop distributed file system (HDFS), 2) two spatial decomposition techniques to enable efficient parallelization of different types of LiDAR processing tasks, and 3) by coupling existing LiDAR processing tools with Hadoop, a variety of LiDAR data processing tasks can be conducted in parallel in a highly scalable distributed computing environment using an online geoprocessing application. A proof-of-concept prototype is presented here to demonstrate the feasibility, performance and scalability of the proposed framework.   The resulting framework and implemented solutions permits processing of all LiDAR data in a county (e.g., Colleton County) to produce a canopy height model (CHM) in less than 5 minutes.   Importing the raw LiDAR (.las) files took an appreciable time but is human monitoring is not required.   Additional information is explained in the published article (Li, et al. 2017).

Recommendations on Geospatial Data

In the course of the project we made numerous recommendations for the SCDOT team and these recommendations are summarized at the end of this report.   Some important issues related to the geospatial use now are listed next.

Datum/Map Projection.

As defined in state law state agencies in South Carolina are expected to use the South Carolina State Plane coordinate system developed on the Lambert Conformal Conic map projection. As initially defined in law the datum (ellipsoid and its fitting to the earth) was the GRS80. The horizontal units were international feet (not survey feet). Agencies in South Carolina have utilized other datums (e.g., HARN, HARN2007) as they are developed since the law was made. The horizontal differences between these datums is less than 10cm – an insignificant amount for wetlands impact and mitigation prediction.

However, available data sources from various local and state agencies in South Carolina may use the North American Datum of 1927 (NAD27) or the North American Datum of 1983 (NAD83). The differences in X-Y coordinates for a position can be over 230'. This amount of mismatch between data sources (e.g., road centerlines, wetlands data, stream data) is excessive. This issue emerged several times in the execution of the project with diverse data sources and our recommendation is to convert and maintain all data sources to a common horizontal datum/projection, such as: ***South Carolina State Plane HARN NAD83, international feet.*** The North American Vertical Datum (**NAVD88**), the national vertical datum for the United States should be consistently used (<u>not a GPS z-value</u>!).

Remaining Challenges

Temporal Mosaic of Data Sources

The quality of the wetlands likelihood layer and the NHD-based streams data will vary across the state. There are several explanations. First, the source imagery used for creating both the NWI and topographic maps to support the streams data are from different years, with an elapsed time of some 30 years across the state. Changes to wetlands (both destructive and regrowth areas) will have occurred and are not reflected in the final WLL. The NHD streams data were created from the consistent set of 1:24,000 scale topographic maps; however, the consistency in the analyst identification of streams was not evident. And the NHD data largely omit the headwater streams. Secondly, the geography of the state varies from the coastal plain through the piedmont to the upstate. Many of the counties in South Carolina are creating their own versions of ditches/streams with different criteria for defining these features. While it is possible to merge the diverse county derived data the composition will create a very heterogenous patchwork for the quality of stream locational data in the state. Similarly, the incorporation of parcel-level land use codes is highly variable in the state and problematic to incorporate. Thus, the use of the wetlands likelihood layer and NHD streams should be conducted in the context of geographic variation in quality.

Granularity of Projects and Breadth of Study Area

A goal of obtaining highly accurate wetland impact forecasts for each and every specific road improvement project is elusive. The amount of resources required to create a wetlands likelihood layer and streams layer at fine resolution (e.g., 10' x 10') for the entire state is monumental. The state of North Carolina expended $250,000 alone in developing stream and wetland data layers at a coarser level (e.g., 20' x 20') to support the Kinston bypass study (portions of only three counties). Even developing appropriate and reliable data to represent the current road and shoulder conditions for the entire state of South Carolina would require a substantial effort. To create such a fine resolution wetlands/stream database to support individual project analysis would require substantial resources in an initial effort and continued resources to maintain the databases to support future forecasts.

Task 3. GIS-Based Impact/Mitigation Forecasting Model

The goal of the forecasting model is to 1) estimate the wetlands related loss from a planned transportation project(s) and 2) estimate the offsets needed and where the offsets may be derived (e.g., banking). The plan was to implement the model as an ArcMap model in the form of a model-builder or python implementation. The only issues experienced in the design of the desktop model was the ESRI Arcmap license level (e.g., basic versus advanced) that was available on SCDOT desktop machines.

During the course of the project we developed, modified, and redeveloped different versions of the road-widening, new road, and bridge tools for estimating impacts. Required input for the tools became increasing complex (such as the triangular approximation of bridge approaches and rip-rap) until the teams realized the input data for existing and future improvements were not specific enough to support a complex tool. In 2016 the tools were simplified to support the available input data. Also, some tool complexity (e.g., variable width of shoulders on left/right sides of road) require an ArcGIS licensing at the Advanced level. This level of ArcGIS licenses were not available by SCDOT staff.

Impact Model Design

Desktop ArcGIS Impact Model

The required input data for all tools in this package are polylines representing the centerlines for roads or bridges. Depending on the availability of attributes for the existing roads either a functional class (BASC Version) or existing road width and should widths (PRO version) are required, with some attribute fields such as the surface widths and the shoulder widths on left and right sides (**Table 3**). The tools will create buffer regions representing the combination of surface width and shoulders (i.e., the existing footprint of the roadway) based on the centerlines, and then export the buffer regions into polygonal shapefiles (**Figure 20** and **Figure 21**). After the polygonal shapefiles are created, the user can then intersect the wetlands likelihood layer or streams layer using the ***Predict Impact*** tool. The actual impacted areas will be generated and the total area/length for each specific project will be automatically created by the tool.

Table 3. Example SCDOT project data for future near term projects (STIP data).

OBJECTID	SurfWidth	ShWidRo	ShWidLo	Functional Class	Route_ID	Work_ID	Project_ID
1	24	8	8	13	US 29	Widening	US 29
2	48	12	12	13	US 29	Widening	US 29
3	48	12	12	2	US 29	Widening	US 29
4	24	8	8	2	US 29	Widening	US 29
5	26	8	8	15	S-62	Widening	College Park
6	22	4	4	15	S-62	Widening	College Park
7	46	0	0	15	S-62	Widening	College Park
8	60	0	0	15	S-62	Widening	College Park
9	50	0	0	15	S-62	Widening	College Park

In summary the process for estimating future wetland impacts for a new project are conducted in two steps:

1. **Run one of the bridge or road tools**
   - ✓ Input Data (for roads): Road location to be improved or new roads (and bridge locations)
   - ✓ Input Data (for bridges): Bridge location to be improved and existing road locations
   - ✓ Output Data: Polygonal regions representing the future road/bridge impact areas
2. **Run the single project or batch Predict Impact tool to summarize impacts**
   - ✓ Input data: wetlands likelihood layer or NHD streams
   - ✓ Output Data: Polygonal regions representing impacted wetlands and streams

In concept, the wetlands impact tools are somewhat simple from a GIS perspective. However, the concept is quite complex. The Input GIS data for future bridge projects is very sparse – the location of the bridge and current width. For example, in estimating the widened shoulders to represent the approaches for bridge improvements requires an estimate of the approach distance and roads on either side of the bridge. Developing an automated solution to identify the approaching roads is very complex when multiple are present.

The final tools delivered in November of 2016 and modified to include project specific identifiers and delivered in the spring of 2017 are:

- New Road Tool
- Widening Road Tool
- Bridge Close & Detour Tool
- Bridge Off-Alignment Tool
- Predict Impacts Tool
- Predict Impacts Tool (Batch Run)

Another unique contribution of this research was a technique to estimate the future road and shoulder widths based on the existing roadway and capacity. A lookup table approach to integrate with the wetlands impact model was developed (**Table 4**).

Table 4. Look-up table for road functional class and resulting width of road.

FClass	Functional Class	Number Lanes	Minimum Total Width (ft)	Maximum Total Width (ft)
2	Rural Four-Lane Divided Highway	4	136	179
3	Urban Four-Lane Divided Highway	4	136	179
4	Rural Six-Lane Divided Freeway	6	131	178
5	Urban Six-Lane Divided Freeway	6	131	178
6	Rural Two-Lane Arterial	2	56	103
7	Rural Two-Lane Collector	2	52	99
8	Rural Four-Lane Divided Arterial	4	128	175
9	Suburban Four-Lane Street	4	116	163
10	Urban Five-Lane Street with Shoulders	5	95	142
11	Urban Five-Lane Street with Curb and Gutter	5	79	130
12	Rural Local Road or Street with Shoulders	2	46	93
13	Urban Local Road or Street with Shoulders	2	46	93
14	Urban Local Street with Curb and Gutter	2	38	55
15	Urban Local Street with Valley Gutter	2	34	44

Specific instructions for using the tools are in the User's Guide (attachment listed in Appendix 2 in this report).

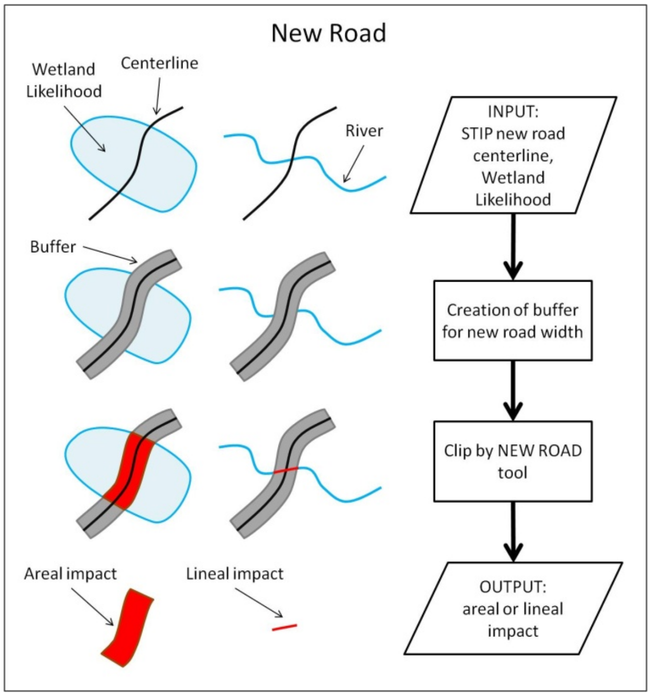


Figure 20. Diagram of the new road tool showing the intersection (estimated impacts) of the road and shoulders on existing wetlands and streams.

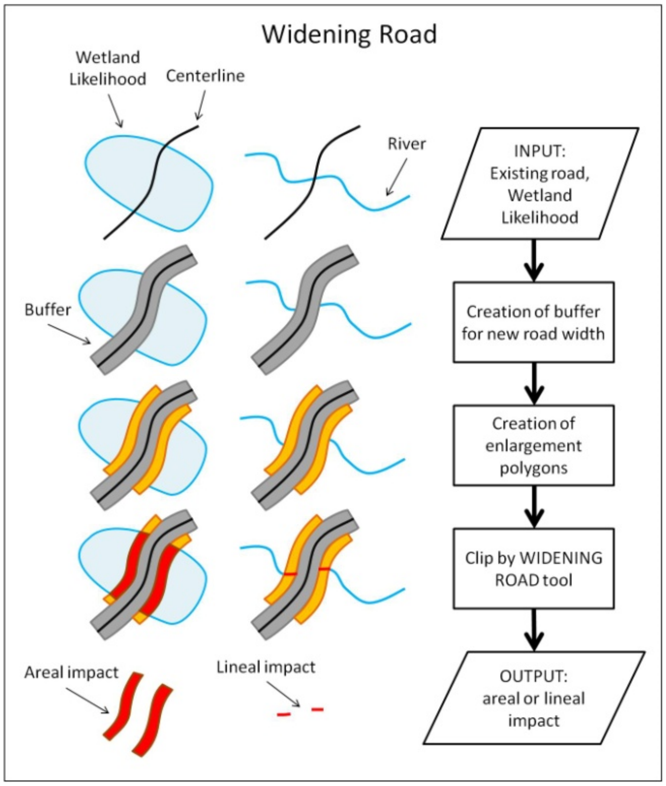


Figure 21. Diagram of the road widening tool and computation of wetland and stream impacts.

Online Impact Model

Mid-way through the execution of the project SCDOT became interested in an online tool for quickly examining possible wetlands impacts from future road projects. In part, this interest was based on preliminary work by Maryland, Florida, and a few other states in creating online tools that do not require a GIS software package. In response to this interest USC created an online tool using open-source software (in part, software developed by our PhD students Haiqing Xu). The online tool contains NWI data, elevation models, NHD stream data, and a user interface to display these data. A custom tool allows the user to draw a line or polygon, create a buffer around the line/polygon representing a potential impact area, and intersect this potential impact area with existing wetlands/streams. The tool is operational as of the writing of the final report. Examples are provided in a later section on the wetmit.org website where the tool is expressed.

Project Specific Impact Model Identifiers

In late Fall 2016 and early spring 2017, USC received a request to add project specific identifiers to the impact model results. The project specific identifiers would be used to summarize the impact in area and stream length for each SCDOT improvement project. For instance, the total wetland acres or stream feet in the project area would be identified. Technically, this addition is doable and completed on May 2, 2017. Interpretation of the results should be considered in light of the precision of the input SCDOT improvement project data, the assumptions for existing road wide and should width and road widening/movement, and the precision/accuracy of the wetland likelihood locations and stream locations. The original design of the wetlands tools were to assess wetlands impact needs on a watershed/ecosystem size area rather than an individual project area. The errors for an individual project may be, and usually are, larger than the error for a watershed/ecosystem area. Thus, interpretation of the impact results should be done with caution.

Mitigation Bank Data

Obtaining reliable information on the available credits in the South Carolina mitigation banks is also a challenge. The USACE maintains an online database of available credits through *https://ribits.usace.army.mil*. Unfortunately, the reliability of the information in the online database is suspect based on the experience of the SCDOT staff.

SCDOT generated an analysis of existing mitigation banks and utilized modeled impact data to prioritize watersheds with substantial impacts and low available credits. SCDOT utilized the available mitigation bank data from the US Army Corps of Engineers (USACE) Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS) and results of the impacts forecast model developed by USC to identify and designate critical watersheds based on mitigation credit availability and forecasted impacts.

SCDOT first downloaded all available private mitigation bank locations and service areas from RIBITS as .kml files and converted those to shapefiles. Once this was completed and all service areas were identified, SCDOT reviewed the mitigation bank credit ledgers available on RIBITS with the goal of classifying banks based on credit availability and confidence in each bank to provide credits for SCDOT impacts. During this review it became apparent that there were some issues with comparing banks since there was not a similar credit reporting from each bank. Credit availability based on readily available credits was determined to be inconsistent and therefore not viable for determining confidence. During the review it became apparent that some banks were relatively new and had a much higher amount of credits to be released than other banks which had already released most of their credits. SCDOT began to analyze the credit release potential of each bank by utilizing the “Potential Credits” and “Released Credits” data provided on RIBITS. The “Released Credits” were divided by “Potential Credits” to determine a percentage of credits remaining to be released from each bank. This allowed SCDOT to determine a relative confidence of each bank based on its ability to provide credits for future projects (**Figure 22**). SCDOT initially elected to review all credit types (preservation, restoration, enhancement, restoration/enhancement) equally. However, due to the current regulations set forth by the USACE Charleston District, no more than 50% of mitigation credits can be in the form of preservation. Restoration or enhancement credit types can be used 100% of the time. Therefore, SCDOT determined that credit potential confidence should be based on the “Potential Credits” and “Released Credits” of all restoration or enhancement type credits. SCDOT classified banks based on percentage ranges of 100%-75% (High Confidence), 75%-40% (Medium Confidence), 40%-0% (Low Confidence).

This same analysis was performed on SCDOT-only mitigation banks. However, only SCDOT’s Black River and Huspa Creek are actively servicing projects and have valid service area data. These are the only two banks depicted.

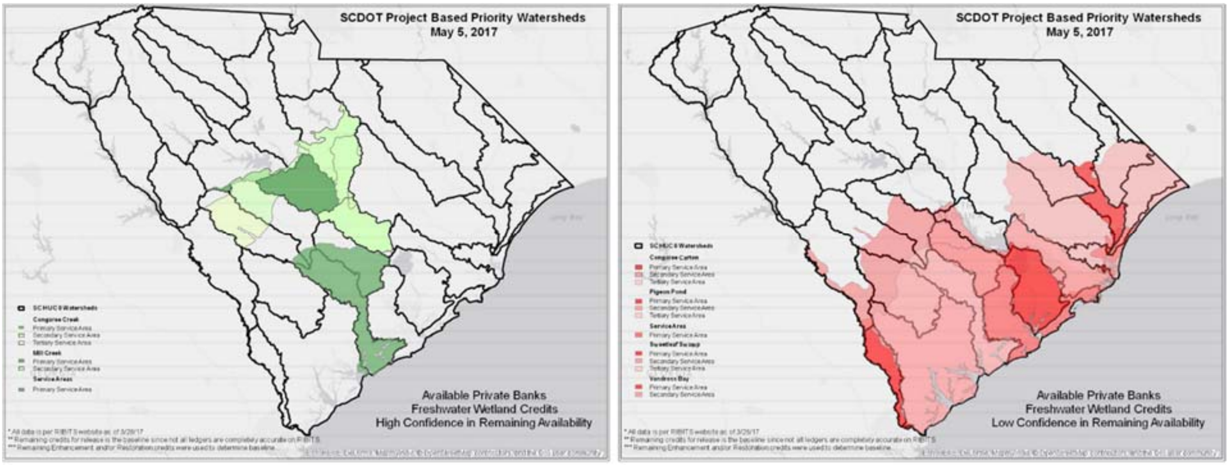


Figure 22. Confidence results in freshwater available credits in mitigation banks (analysis by SCDOT, C. Russell, 2017).

Task 4. Application of Model to Selected SCDOT Projects

The effectiveness of implementing the tool will be examined by applying it to a small number of high priority South Carolina watersheds. The Final Compensatory Mitigation Rule, approved in 2008, laid out regulations designed to improve the effectiveness of compensatory mitigation to replace lost aquatic resource functions and area, expand public participation in compensatory mitigation decision making, and increase the efficiency and predictability of the mitigation project review process. The design and implementation of the South Carolina-based tool must be consistent with these larger objectives. Therefore, based on previous research by Co-PI Kupfer aimed at identifying at-risk watersheds in conjunction with feedback from SC DOT officials, we will select a small number (*ca.* five) of watersheds and implement the tool based on projected transportation projects.

Application to STIP Data (Highway 68 and 153)

Test Case on Highways 68 and 153

In early 2016 we examined the question of whether the functional class look-up table for approximate road and shoulder widths was an appropriate representation of the future road projects. Permit data and projected impacts were examined in detail for road modifications along 153 and 68. For Hwy 68 the modeled results of wetland impacts for Hwy 68 ranged from 1.1-acres to 9.8-acres (**Table 5**). Reference data from permits indicated 8.1-acres of wetland were impacted. The greatest variance was due to the uncertainty in the existing road width/shoulder. Thus, a preferred model would have better knowledge of the current road width/shoulder (**Figure 23**). The issue here is the estimate of the current width of the road and forecast width of the road after improvements has an appreciable impacts one modeled wetland impacts. For the highway 68 example, using the jurisdictionally defined wetlands polygons (i.e., the truth), the range in modeled wetland impacts is from 1.1-acres to 9.8-acres depending on the current and future widths of the road. This range in impacts is independent of the estimated location of wetlands as the jurisdictional wetlands were used here.

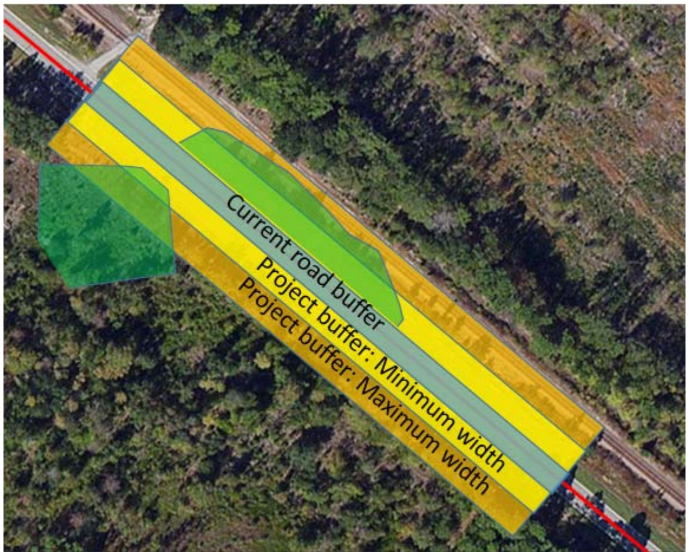
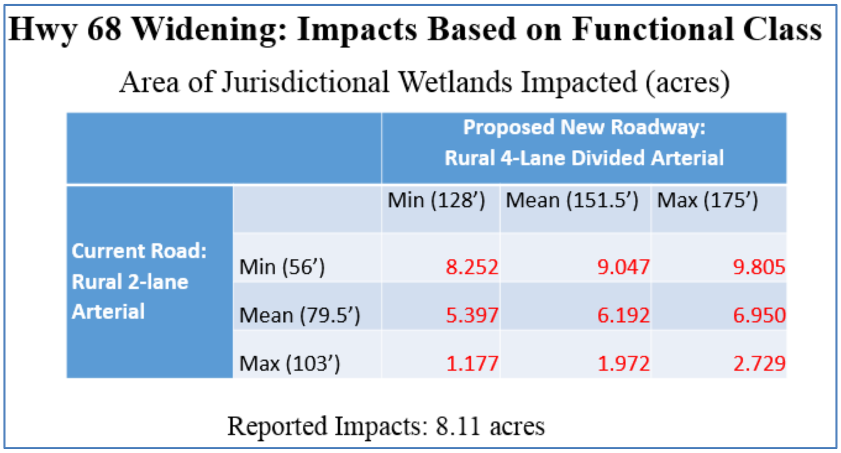


Figure 23. Modeled existing road and minimum and maximum impacts from road widening along highway 68.

Table 5. Modeled wetland impacts along highway 68 improvement



Hwy 68 Widening: Impacts Based on Functional Class

Area of Jurisdictional Wetlands Impacted (acres)

		Proposed New Roadway: Rural 4-Lane Divided Arterial		
		Min (128’)	Mean (151.5’)	Max (175’)
Current Road: Rural 2-lane Arterial	Min (56’)	8.252	9.047	9.805
	Mean (79.5’)	5.397	6.192	6.950
	Max (103’)	1.177	1.972	2.729

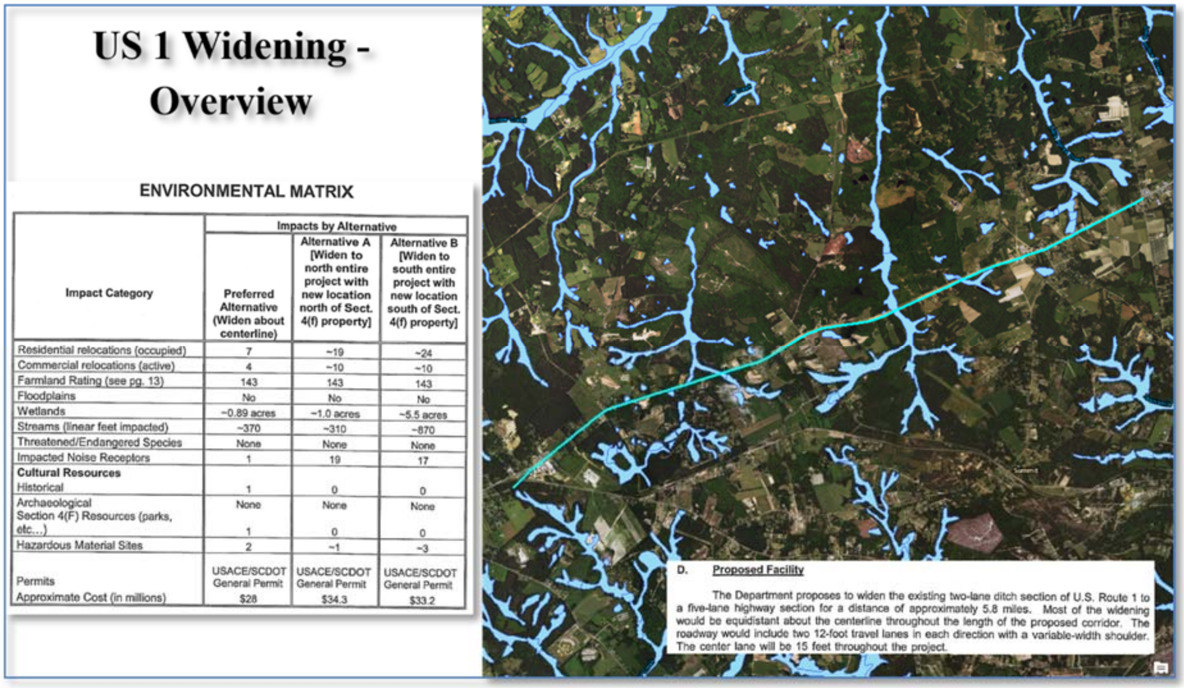
Reported Impacts: 8.11 acres

A similar analysis was conducted for the SC 153 realignment impact. This project only had documented stream impacts (1315’ of impacts). The modeling tool using the NHD high resolution data indicated only 206’ of impacts. Impacted streams were missing the modeled results due to 1) the omission of ditches alongside the roadway, and 2) the omission of headwater streams in the NHD data. There was some discussion of whether accurate data on culvert locations might help in predicting the location of missing streams.

Application to STIP Data (US Highway 1 and 17A)

Additional tests of the evolving wetlands likelihood layer and GIS-based impact model were conducted in March of 2016. Each case was compared to permitted impacts and the estimates from an environmental impact analysis (EIA). An example is from the road widening project along US Highway 1 (**Figure 24**). The current width of US Highway 1 is 42’ while the modeled projected widths vary between 95’ and 142’. The EIA analysis forecast .89 acres of impacts while the USC model and data projected 1.2 acres. The EIA analysis only used the NWI data so the lower estimate of .89 acres was expected. The actual permitted impact was 2.28 acres. Modeled stream impacts were 542’ while the actual permitted stream impacts were 569’.

Another analysis with the US 17A widening (Berkeley County) forecast 55 acres of wetland impacts. The actual permitted impacts were 3 acres. Stream impacts were modeled at 1289’ while the actual permitted impacts were 1687’. The conclusion from this analysis was the wetlands likelihood layer using the liberal estimate of hydric soil ratings was over-estimating wetlands. From this analysis and similar analysis the soil-based component of predicting wetlands was revised to a more conservative estimate of the hydric ratings – the results was a significantly improved wetlands likelihood layer.   In addition, this analysis suggested the tax parcels and land use codes might help in predicting wetlands likelihood.



US 1 Widening - Overview

ENVIRONMENTAL MATRIX

Impact Category	Impacts by Alternative		
	Preferred Alternative (Widen about centerline)	Alternative A [Widen to north entire project with new location north of Sect. 4(f) property]	Alternative B [Widen to south entire project with new location south of Sect. 4(f) property]
Residential relocations (occupied)	7	~19	~24
Commercial relocations (active)	4	~10	~10
Farmland Rating (see pg. 13)	143	143	143
Floodplains	No	No	No
Wetlands	~0.89 acres	~1.0 acres	~5.5 acres
Streams (linear feet impacted)	~370	~310	~870
Threatened/Endangered Species	None	None	None
Impacted Noise Receptors	1	19	17
Cultural Resources			
Historical	1	0	0
Archaeological	None	None	None
Section 4(F) Resources (parks, etc...)	1	0	0
Hazardous Material Sites	2	~1	~3
Permits	USACE/SCDOT General Permit	USACE/SCDOT General Permit	USACE/SCDOT General Permit
Approximate Cost (in millions)	$28	$34.3	$33.2

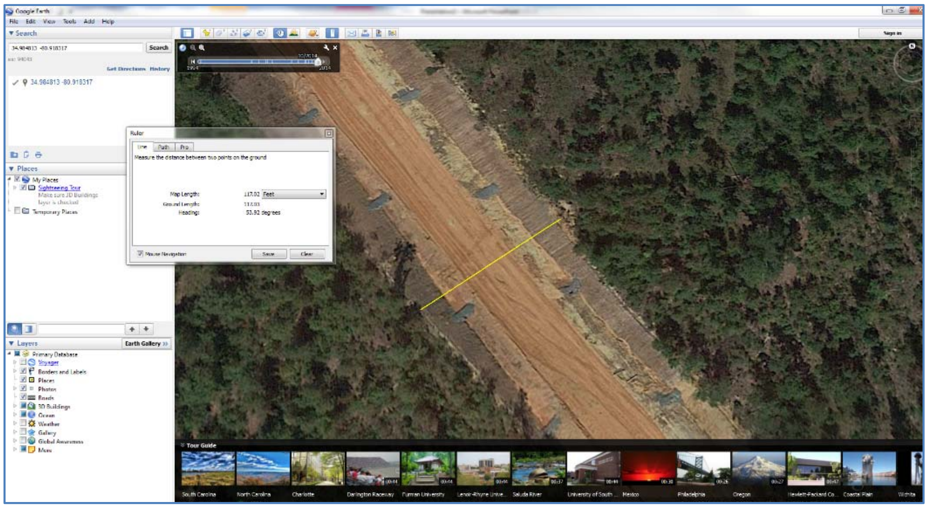
D. **Proposed Facility**

The Department proposes to widen the existing two-lane ditch section of U.S. Route 1 to a five-lane highway section for a distance of approximately 5.8 miles. Most of the widening would be equidistant about the centerline throughout the length of the proposed corridor. The roadway would include two 12-foot travel lanes in each direction with a variable-width shoulder. The center lane will be 15 feet throughout the project.

Figure 24.   Comparison of modeled results to EIA estimates and permitted wetland and stream impacts for US Highway 1 widening.

Application to STIP Data (18 projects analysis)

The wetlands impact tool with the USC wetlands layer and NHD streams were used to predict wetland impacts in a comparison with 18 past SCDOT projects. Predicted wetland impacts versus permitted wetland impacts (actual impacts) compared and statistically analyzed (using linear regression). Many of the single projects were examined to determine the disagreements in total wetland acres impacted versus permitted. Time series analysis with Google Earth imagery was used to determine the land use/cover change before, during, and after the project (**Figure 25**). Some projects were captured by the imagery during construction to show the construction impacts. The SCDOT project shapefiles were examined and some modified to correct for errors. The wetlands impact model was run using minimum, mean, and maximum widths for road improvements.



Measure the distance between two points on the ground

Map Length: 117.02 Feet

Ground Length: 117.03

Heading: 53.92 degrees

☑ Mouse Navigation

Figure 25. Use of Google Earth time series imagery to detect phases and characteristics of the road construction project.

Some projects under estimated and overestimated wetland acre (or stream) impacts. Not surprisingly, the overall total impacts were overestimated with the soils-based data. Using the soils-based data the model performed best (as a whole) using minimum widths. After correcting for land use (4 projects that were clearly in error from land use change and thus, inaccurate soils-based wetland data) a linear regression was used. Using a linear regression the predicted impacts versus actual permitted impacts resulted in an R^2 of .95 (**Figure 26**).

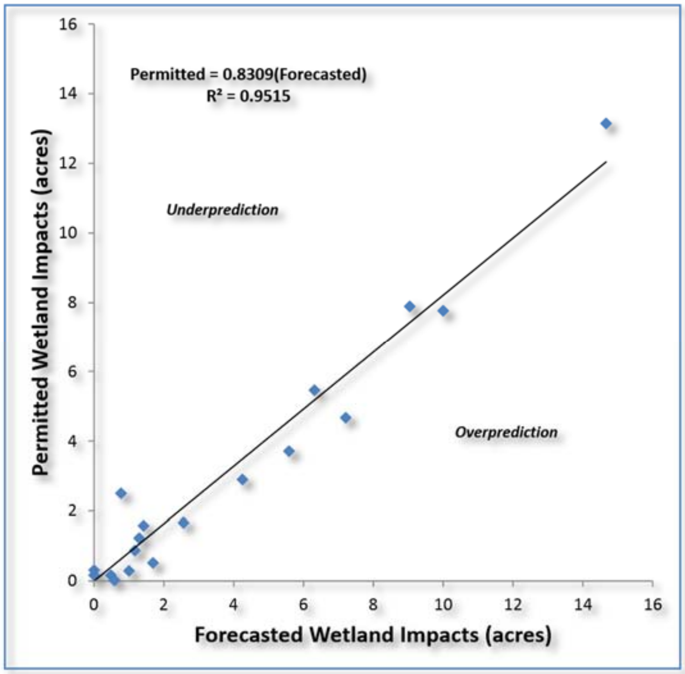


Figure 26. Comparison of predicted (using modeled and wetlands data) versus permitted impacts for 18 past projects.

Recommendations from the analysis. The road shapefiles came from an intern digitizing the project roads. In the future for STIP and LRTP projections the shapefiles would be from the SCDOT roads database (supplemented with start/stop points).

Application to STIP Data by SCDOT – Transition (2017)

The final set of software and data were delivered in the fall of 2016. The new wetlands likelihood layer incorporated the changes in the input layers learned from the analysis of SCDOT past projects, the location of jurisdictional wetlands, and visual analysis of imagery and terrain data. A few minor enhancements were made to the deliverables in the spring of 2017 and delivered to SCDOT. SCDOT staff then utilized the wetlands tools and data to predict impacts to all future STIP and LRTP projects. They then compared the estimated impacts to the wetlands bank credits to predict the critical watersheds where the wetland and stream credit needs would be low. (Note: the extension of wetland area and stream feet to credits is not straightforward but the relationship is consistent. The variations are with the quality of wetlands and streams impacted – the quality data is not contained in any data source, such as NWI, SSURGO, or other for the entire state).

Mitigation Needs Analysis

SCDOT analyzed the forecasted wetland impacts with mitigation bank credits for over 1000 future road widening and bridge projects. Projects were then assigned a mitigation confidence based on the highest confidence level of existing banks in which they were located. SCDOT viewed any projects that had a low confidence for mitigation credit availability as critical. All critical projects were then selected out and overlaid over 8-digit Hydrologic Unit Codes (HUC). Each watershed was then analyzed for impacts based on the impacts forecast. The maximum and minimum estimated impacts were averaged for each project. All projects within a watershed were averaged and summed to generate and estimated average impact for all watersheds containing projects which had a low confidence for mitigation credit availability. These watersheds were then reviewed and ranked based on impacts to wetlands and streams. Watersheds were then prioritized based on impact and impact type (**Figure 27**). If a watershed had a high number of proposed impacts to both streams and wetlands but had available mitigation for streams, it was prioritized lower than a watershed which had both stream and wetland impacts but no credit availability for either resource type.

SCDOT is currently reviewing the approximately 1000 projects run through the wetlands/stream impact model to determine if there was any overlap in data and to ensure that all projects within SCDOT’s STIP, 10 year Consolidated Plan and Load Restricted Bridge list are all accounted for. It is possible that the prioritized watersheds could change based on changes in projects, impacts, or newly approved mitigation banks. SCDOT intends to implement changes to watershed priorities based on new data as needed.

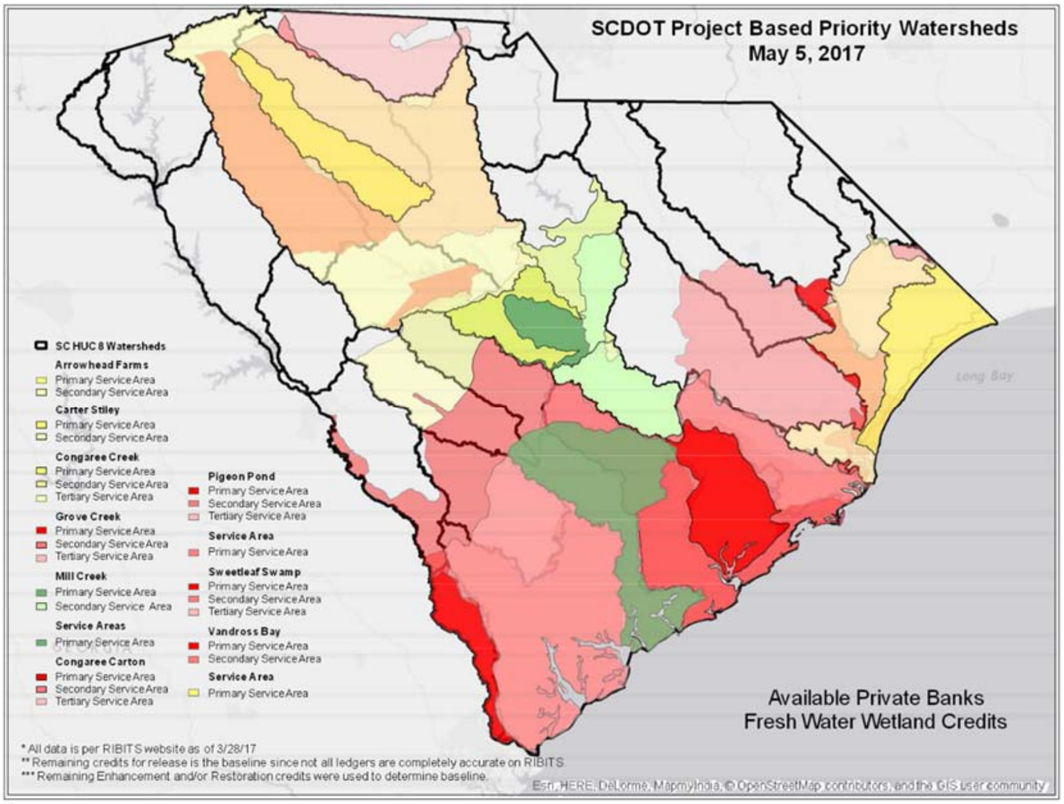


Figure 27. Integration of project wetland/stream impacts and available credits to produce a prioritized list of watersheds.

Task 5. Project Communication

The goal of this task was to both publicize the novel approaches developed in this research and share appropriate test data and/or forecasting models to others. We planned on completing this task by using traditional publication methods (reports in .pdf form or other) and Internet website communication methods. Following our device-independent design approach for other projects (e.g., prototype.respt.org, www.miat.us, and www.scarchsite.net) we designed and hosted a website (wetmit.org) for publicizing and disseminating the research and products.

The key phases of the application task were:

- Website Design (content, user experience, user interface)
- Draft website implementation (3-months)
- Initial Website Content (6-months)
- Ongoing Website Modification (6-months to 36-months)

SCDOT-USC Geography Meetings

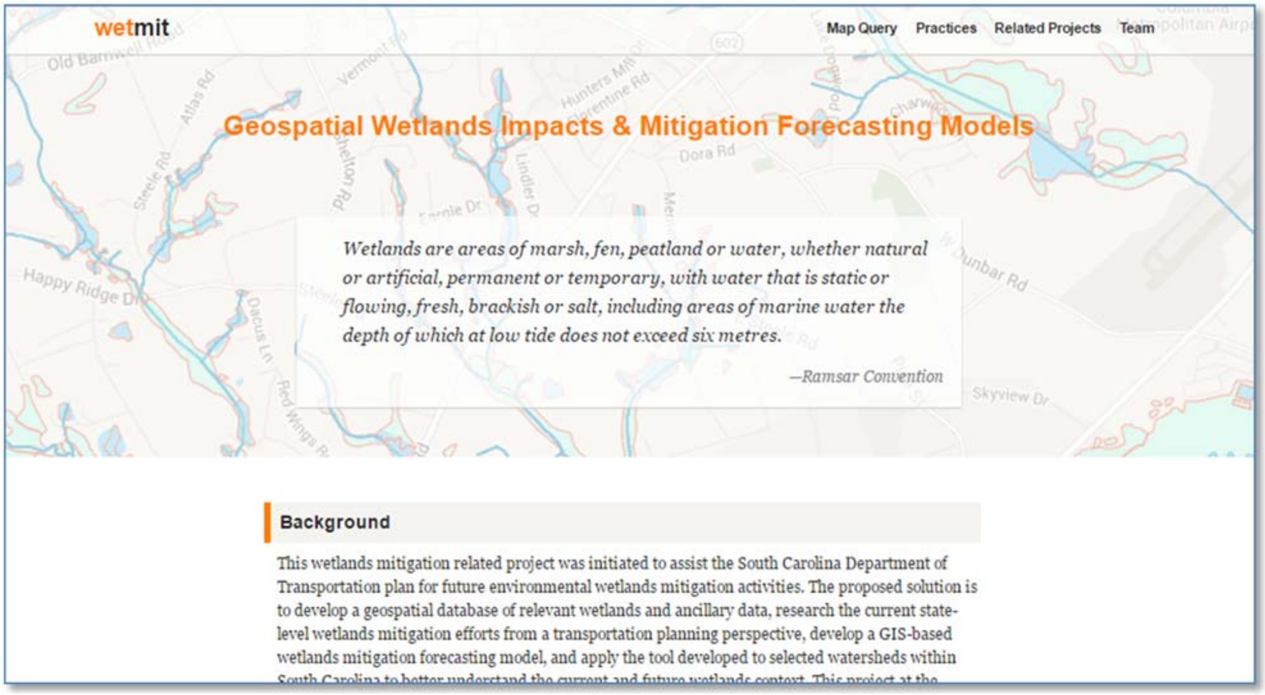
The members of the participating teams from the SC Department of Transportation and the University of South Carolina's Department of Geography met regularly during the course of the project. At least thirty official meetings were held with all members invited. Individuals would also meet informally with counterparts in the other organization when necessary to further the project. These meetings were especially useful in helping the USC team understand the operational side of SCDOT's work process.

Meeting Dates

2014: Jan 23, Feb 3, Jun 19, Aug 28, Oct 9, Oct 30
2015: Jan 19, Mar 18, Apr 22, May 20, May 27, Aug 27, Sep 23, Sep 30, Oct 23(?), Nov 13, Dec 9
2016: Jan 25, Feb 18, Mar 3, Mar 21, Apr 13, Apr 27, May 19, Jun 4, Jun 8, Jun 29, Aug 18, Aug 31, Sep 29, Oct 20
2017: Jan 27

Online wetmit.org Website

As part of the project a website, www.wetmit.org, was created (**Figure 21**). Initial pages laid out the scope of the work to be undertaken and the members of the project team. After Alexandra McCombs completed a survey of approaches that other states' transportation departments were taking toward wetlands mitigation in Fall 2014, a page summarizing those findings was published (**Figure 28 and Figure 29**). A chloropleth map provided a quick overview of approaches, while pop-up windows provided more detailed information for individual states.



Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.

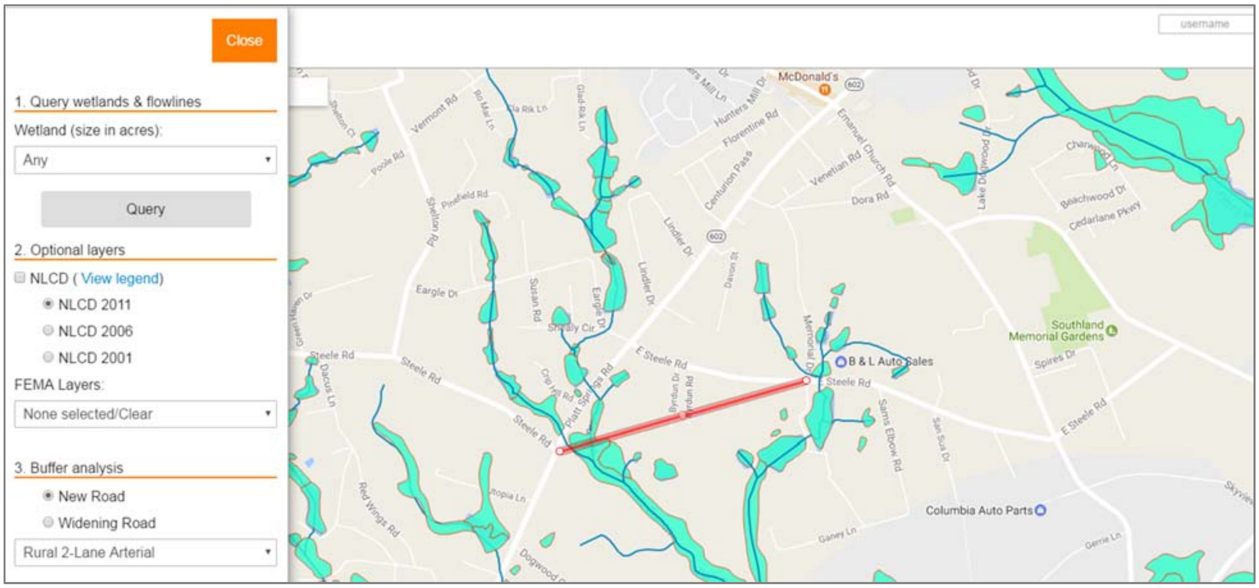
—Ramsar Convention

This wetlands mitigation related project was initiated to assist the South Carolina Department of Transportation plan for future environmental wetlands mitigation activities. The proposed solution is to develop a geospatial database of relevant wetlands and ancillary data, research the current state-level wetlands mitigation efforts from a transportation planning perspective, develop a GIS-based wetlands mitigation forecasting model, and apply the tool developed to selected watersheds within South Carolina to better understand the current and future wetlands context. This project at the

Figure 28. Main page for the www.wetmit.org web site.

Figure 29. The Related Projects page provided an overview of the approach other states were taking toward wetlands mitigation at the time the project began. Pop-up windows offered more details for individual states.

As the project progressed, it became apparent that SCDOT (and potentially other agencies) would find a tool that could identify wetlands as a preliminary step would be useful, and the online wetlands tools was developed. The online tool allowed users to draw a potential path or area on a map, specify the type of road (and the associated buffer) and query the total area of wetlands impacted by development there (**Figure 30**).

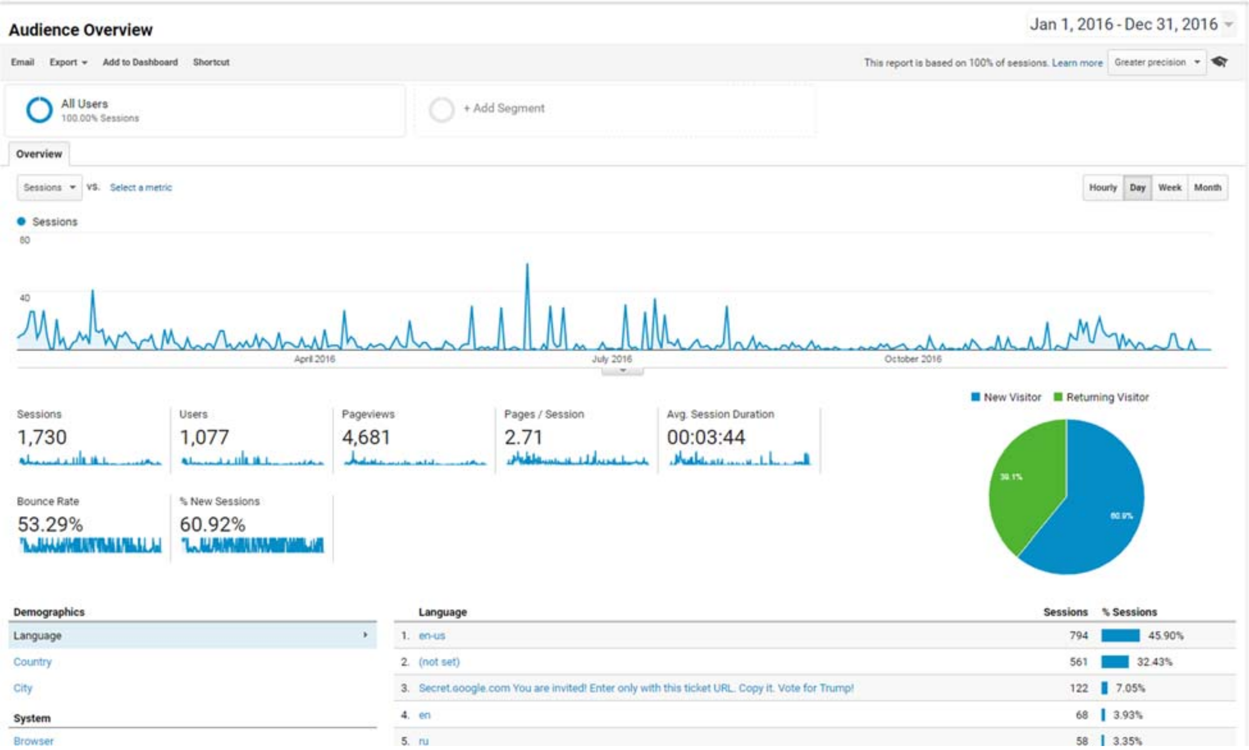


1. Query wetlands & flowlines
Wetland (size in acres): Any
2. Optional layers
☐ NLCD (View legend)
● NLCD 2011
○ NLCD 2006
○ NLCD 2001
FEMA Layers: None selected/Clear
3. Buffer analysis
● New Road
○ Widening Road
Rural 2-Lane Arterial

Figure 30. The online tool allows users to draw a path or area on the map (the orange line here) and get a quick estimate of the wetlands impact road development there would result in.

A review of usage statistics for the website during the calendar year 2016 (a year the project team was largely focused on the desktop tool and making few changes/visits to the online tool that might skew results) reveals more than 1,000 users visited the site and more than 1,700 sessions were logged (**Figure 31**).

While the largest single group of sessions originated in South Carolina (625 sessions), there was significant interest from other states and other countries (**Figure 32**).



Sessions 1,730

Users 1,077

Pageviews 4,681

Pages / Session 2.71

Avg. Session Duration 00:03:44

Bounce Rate 53.29%

% New Sessions 60.92%

Demographics

Language

Country

City

System

Browser

	Language	Sessions	% Sessions
1.	en-us	794	45.90%
2.	(not set)	561	32.43%
3.	Secret.google.com You are invited! Enter only with this ticket URL. Copy it. Vote for Trump!	122	7.05%
4.	en	68	3.93%
5.	ru	58	3.35%

Figure 31. An overview of the audience for wetmit.org, January 1, 2016–December 31, 2016.

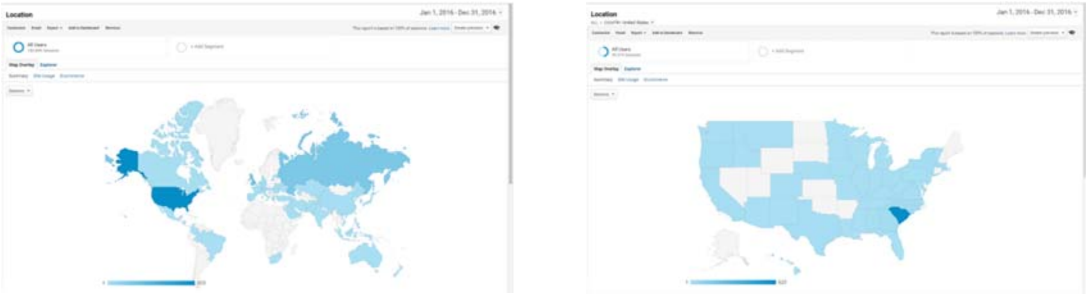


Figure 32. Origins of visitors to the wetmit website.

3. Reporting and Deliverables

Quarterly reports for the project were provided during the course of execution. These reports included completed tasks, planned tasks for the next quarter, and budgetary information (e.g., funds spent, remaining funds). Project deliverables included geospatial data, analysis of STIP/LRTIP impacts, wetland programmatic tools, and website modifications.

4. Summary Recommendations

The research in this project of the data and methods for modeling wetlands/streams likelihood and understanding of the context and process for creating/using the South Carolina Department of Transportation planning data (i.e., STIP) have resulted in several recommendations to SCDOT for their long-term plans in predicting impacts and maintaining appropriate data. We summarize the discussions from earlier in this report to the following recommendations organized under geospatial data to support wetlands or stream prediction, existing road/bridge representations, validation data to improve impact modeling efforts, and geospatial data to support mitigation efforts.

Geospatial Data Wetlands/Stream Prediction

The needs for a state agency, such as SCDOT, to use a seamless and uniformly developed geospatial data layer for the entire state at a spatial resolution/precision to support individual road improvement projects is problematic. Statewide efforts, such as land use/cover mapping by SCDNR or even national efforts such as NWI, produce near-systematic geospatial data for statewide operational use; however, these statewide data are not ideal for modeling precision-level needs of individual projects. The spatial resolution (i.e., size of the smallest mapable unit) and spatial accuracy (horizontal error in boundary/line position) for statewide or national mapping efforts is typically well-over 5-m RMSE. The best available geospatial data are and will continue to be created at the local level (generally county). Unfortunately, each county may develop their own definitions for a stream/channel or land use. Each county has a different temporal geospatial data source (e.g., aerial imagery, airborne LiDAR data) used to create their spatial layers. If SCDOT considers the spatial resolution and precision for individual project locations to be the most important element then a statewide geospatial database from each individual county mapping efforts will represent a spatial quilt. In all fairness to national or statewide efforts, all such large area projects are mosaics of geospatial data from different time periods and different analysts' efforts. Recognition of the spatial quilt when creating a seamless geospatial data layer for wetlands or streams must be considered and incorporated in the prediction of the likelihood for wetlands and streams. Assuming SCDOT will, in the future, work closely with county mapping efforts we make the following recommendations:

- **Scale of Analysis**: the tool/geospatial data are not expected to be highly accurate for a specific project. The assumption is the errors for all projects will average out for a total watershed and be good.
- Contact and review the current and projected status of each county's efforts in creating a local-resolution or comparable **stream network** based on the most recent LiDAR data, aerial imagery, and processing (human and machine) approach for deriving a connected stream network (including the culverts and covered channels invisible to airborne LiDAR collection methods. Document the **definition** of what a stream is in the county's effort.
- Systematically examine the **parcel level data** for each county and decide on a long-term maintainable approach for cross-walking the land use/cover codes from each county to a state-wide code set.
- Digital **historic aerial imagery** are available for from the USC Government Documents for many counties in South Carolina from the 1930s to the 1990s.
- Digital **historic topographic maps** are available from the USGS in the form of a web mapping service and downloadable images. The most usable form would be to download the historic images and clip the side-annotation to make the imagery more useful.
- The resulting 2017 Wetlands Likelihood Layer does contain some 27% omissions. Moreover, 339,126 (out of 2,418,118 or 14%) of the wetland polygons do not have **wetland class labels** as these locations were derived from other sources, such as hydric soils layers. The combined use of LiDAR and aerial imagery could be used to assign class labels (e.g., forest, scrub-shrub, emergent) to these unlabeled wetlands areas).
- Maintain a **geospatial dataset for validation** purposes. The ability to estimate the accuracy or over/under-prediction of wetland impacts using a model is dependent on validation data. Each SCDOT road/bridge project in the future should include a requirement by the contractor to deliver a geospatial dataset of polygons and lines for jurisdictionally defined wetland areas and streams in the project area.

Geospatial Data Representing Existing Roads/Bridges

- **Representation of Existing Road/Bridge**: SCDOT project data are based on estimates of existing road width and future widening and modeled from centerlines. Ideal STIP data would contain the current paved area and shoulders. Divided roads have one centerline for only one of the lane directions!
- **Functional Class**: a post-study should examine the reliability of using a functional class for predicting present and future road widths. (As of now it appears to be a good solution.)
- **Road Crossings**: an automated method for modeling road/bridge widening is problematic when bridge crossings are present. The baseline road data should include all known bridge crossings.
- **Software License Level**. The capabilities to develop complex tools to support SCDOT project needs were impeded by the license levels available to SCDOT staff. It is important for the SCDOT staff to have ArcGIS Advanced license levels to support all of the tools developed in the project.

Geospatial Data Representing Future Road/Bridge Projects

- **Approach for Road/Bridge.** One of the key elements in a bridge widening or road widening project is the length of the approach. Longer approaches will typically result in larger wetland impacts. To the extent possible a **min/max range in the estimated approach** by future project would be the most important modification for estimating impacts.

Geospatial Data for Mitigation Planning

- **Parcel-Level Data.** In a mitigation effort where properties are purchased or set aside in easements for the goal of restoring or creating wetlands the **parcel-level data** will be a key layer. Land will be acquired at the legal parcel level. The efforts required for creating a statewide-crosswalk between land use/cover codes will be very useful in determining the suitability for existing parcels for wetlands purposes.
- **Existing locations** of wetlands, water bodies, streams, and similar features are very useful in creating a list of candidate wetland restoration parcels. The same data that are useful for modeling the current locations of wetlands/streams will be useful in ranking the suitability of land parcels for wetlands restoration.
- **Historic aerial imagery** and **topographic maps** are very useful in determining the past land use/cover of parcels and the presence of wetlands-type soils. Unfortunately, these data are not in a digital form for automated processing and must be analyzed using visual means. The USGS has an ongoing-program for scanning/digitizing all historic USGS maps. The USC Government Documents has a programs for scanning all historic aerial imagery in South Carolina. Data from both sources (as well as some counties historic data collections) should be routinely acquired and managed in a SCDOT geospatial database.
- **Geospatial Data for Recent Events.** Some of the best opportunities in land conversion for any application occur when an event occurs. The event could be a natural disaster (e.g., recent October 2015 flooding) or industrial expansion. A systematic plan should be created for obtaining environmental event data (e.g., dam failures from DHEC) and planning data from the Development Board.

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Appendixes

Appendix 1. List of Mitigation Banks

Big Pine Tree Creek (SCDOT)
Black River (SCDOT)
Beaufort Jasper Water and Sewer Authority Primary
Broad River Wetlands
Carter Stilley Wetland and Stream Mitigation Bank Primary
Carter Stilley Wetland and Stream Mitigation Bank Secondary
Grove Creek Primary
Hunting Creek
Huspa Creek (SCDOT East and West Marsh Primary)
Pigeon Pond Primary
Sandy Fork Primary
Swallow Savannah Primary
Sweetleaf Swamp Primary
Taylors Creek Primary
Turkey Creek Primary
Turners Branch Primary
Vandross Bay Primary

Attachments

Attachment 1. Wetlands Impact Prediction Tools

The attached document is the **Users' Manual** for the wetlands impact tools developed in this project. The tools are python based tool using the ArcGIS desktop ***advanced*** license.

List of Figures

List of Tables