Subject: **Remote Sensing the Geographical Extents of Wetlands in the Piedmont**

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Abstract:

Through time, wetlands have been of a large interest for a variety of reasons and their extents have long been a problematic question. Wetland boundaries exist in an ever-changing continuum along a soil wetness gradient. Researchers have been trying to remotely sense the bounds of these wetlands but for today's technology many of these methods are simply outdated. This project proposes modern methods for a remote sensing model using the best publicly available data for the region. In this project, a 2021 ortoimagery of the North Carolina Piedmont is used and a 2014 "QL2" lidar derived digital elevation model are used. The two methods utilized in this study are a supervised classification and a topographic wetness index. These two methods are compared against each other along with several controls.

The study used the well-established National Wetland Inventory from the US Fish and Wildlife Service as a control dataset and a ground truth wetland delineation. The comparison resulted in a topographic wetness index that predicted 128% of the total area captured in the ground truth data set. Both the topographic wetness index and the supervised classification were found to be more accurate than the National Wetland Inventory. The results of this study show a reproducible method for creating planning level wetland boundaries for piedmont ecoregion of North Carolina.

Introduction:

The remote sensing of wetland habitats has long been of interest in the United States for reasons such as wildlife value, water quality interests and general land conservation. The history of wetland identification can largely be divided into a Pre-Regulatory Period (1849 – 1977) and the Post-Regulatory Period (1977 – current) (Lee Davis, et al, 2009). Beginning in the Pre-Regulatory period mapping efforts purposes could vary greatly and standards and procedures on the detail necessary were not yet established. While science is often scene as a definitive and objective definitions of wetlands have also varied greatly over history. Wetlands are not clearly distinct, rather, they are dynamic features that fall somewhere along an every-changing moisture gradient, making a subjective line at time (Lee Davis, et al, 2009). The subjectivity of the actual delineation has also been influenced by societal and political concerns, perceptions, knowledge and scientific definition have changed over time based on societal needs, experience and increased knowledge (Lee Davis, et al, 2009).

The first large effort in the United States to remotely sense wetland habitats was in 1906 by the Department of Agriculture (Fretwell et al., 1996). This first attempt focused on identifying farmable lands, attempting to exclude wetlands since they posed a practical farming problem for the farmers. The law that encouraged this larger wetland mapping effort by the Department of Agriculture was the Swamp Land Act of 1849, encouraging states to identify lands that were too wet for cultivation (Lee Davis, et al, 2009). Later efforts were began by the Fish and Wildlife Service in 1954 with a special interest in conservation of wetlands as habitat for a declining waterfowl population (Fretwell et al., 1996). The effort by the Fish and Wildlife Service later became known as the National Wetland Inventory and was likely the largest effort to map wetland habitat to that date. Once the late 1980's had arrived The Emergency Wetlands Resources Act of 1986 defined the responsibility of wetland inventories as a task to be completed by the Fish and Wildlife Service (Fretwell et al., 1996). This new legislation moved the efforts to a new speed with the Fish and Wildlife Service producing 50,800 maps covering 88 percent of the conterminous United States. These maps were largely produced using Stereoscopic color-infrared photographs and black and white United States Geological Survey Maps, photo interpretations were made based on the patterns shown between these two maps (Fretwell et al., 1996). These maps were later digitized and in some cases have been updated to a more modern standard.

The Post-Regulatory Period includes 1977 to current time, this period is marked being beyond the passing of the Clean Water Act that required impacts to wetlands be accounted for. This era has been dominated by the ground truth field delineation of wetland features by qualified biologists. The investigators are examining the sites by the three criteria set forth by the United States Army Corps of Engineers, these three criteria include hydrophytic vegetation, wetland hydrology and hydric soils (Environmental Laboratory., 1987). The presence of the three criteria on a site deem it a wetland feature setting a unified way to delineate wetlands across the country. The subgroups of wetlands and other habitats is also defined as palustrine habitats with either forested, shrub / scrub or herbaceous vegetation regimes (U.S. Fish and Wildlife Service, 1979). Having these classifications that are often referred to as the Cowardian Classification System allows for a specific grouping that the wetlands can be put into, and we can better understand how the unique habitats work. The post regulatory period also includes the National Environmental Policy Act of 1970 that requires federal actions include consistency with all federal laws including the Clean Water Act, this greatly increased the number of wetlands necessary for mapping.

Beyond the regulatory needs for wetland mapping there are vast ecological benefits to wetlands that vary from wildlife habitat to carbon sinks in the efforts for avoiding mass climate change. Some researchers consider wetland to be a strong weapon in the fight against climate change. Wetlands are areas that provide an aquatic and terrestrial habitat interface. They are considered to be very important to biodiversity and provide a strong carbon sink (Mahdianpari et al., 2019). Wetlands are cited as the most valuable parts of our landscape in ecosystem services, and were ranked considerably more valuable than lake, rivers, forests or grasslands; only coastal wetlands rank higher than inland freshwater wetlands (Mitsch et al., 2015). The argument for wetlands as a defense against climate change is also clearly shown in research. A study in Mexico showed that flooding conditions allow accumulating significant amounts of carbon, human actives can alter the carbon stock held by these wetlands (Hernandez et al., 2015).

This particular study takes place in North Carolina, a state with a large amount of wetlands throughout its boundaries, shown in figure 1. In fact, the wetlands of North Carolina are diverse and widely distributed, about 5.7 million acres or 17 percent of the state is covered by wetlands (Dahl, 1990). These wetlands provide habitat for a variety of rare and endangered species including carnivorous plants uniquely in the wild of North Carolina, such as Venus flytraps (*Dionaea muscipula*) (Micheal P. Schafale, Alan S. Weakley, 1990). The North Carolina wetlands have a particular importance to survival of endemic populations such as Venus flytraps in the wild.

The accurate remote sensing of wetlands is a critical advancement for efficient planning and avoidance of wetland features. Historically lengthy and costly field delineations were completed by trained field biologists. The biologists document the three wetland criteria, hydrology, vegetation and hydric soils, which can result in a large amount of paperwork. These investigations are as accurate as handheld global positioning devices, with an industry standard of sub meter accuracy being developed. Creating boundaries using remote sensing methods creates a more repeatable product that can be used with consistency for scientific and regulatory end users.

This study is using remote sensing methods to delineate the geographic bounds of wetlands in the piedmont of North Carolina. These methods incorporate state of the art imagery within ArcGIS Pro software with the overall purpose of creating a reliable wetland boundary that accurately reflects the shape and size of the features. This new study uses data processing with ArcGIS Pro Software and recently released 2021 Orthoimagery of the North Carolina piedmont. Comparing the remotely sensed wetland boundaries to traditional field delineations and the National Wetland Inventory (NWI) created by the U.S. Fish and Wildlife Service. The NWI dataset is available nationwide. This NWI dataset is often considered a strong starting point in project planning.

Problem Statement and Objective:

The goal of this project is to accurately model wetlands by showing their geographic extents. The project uses updated technologies and aims to provide a reproducible method that can be extrapolated across the piedmont ecoregion.

Problem Statement:

Can modern remote sensing methods streamline wetland avoidance in planning processes?

Study Area:

The study area for this project is Durham County, NC. A previous study on wetland modeling in NC have taken place in Lenoir County focusing on the Kinston Bypass (Wang, et al., 2015). This study is extremely important because it provides a strong local example, albeit in the coastal plane. Durham County is 298 square miles with largely urban, residential, and agricultural land uses located in the central piedmont region of North Carolina. The Durham County study area is located in the Triasic basin the EPA level IV ecoregion identified in Figure 2. Rocks in the Durham sub-basin are of interbedded shale, sandstone, and siltstone, typically red, reddish brown, or maroon but locally gray or black. Conglomerate, dolomite, lacustrine black mudstone, and coal are also present. In many places, the sedimentary rocks are interbedded with basalt flows or have been intruded by diabase dikes and sills (Venkatakrishnan et al., 2022). The underlying geology of the region is important as it does have impacts on groundwater storage and infiltration, affecting the groundwater terrestrial interface that the wetland ecosystem often represents. A map showing the counties outline is shown in the Figure 1 a map showing the project study area location within the county is shown in figure 2.

Data:

The main datasets for this project are the imagery and a digital elevation model (DEM).

This imagery focuses on the eastern portion of North Carolina. The imagery was collected in 2021 by flying the eastern piedmont of North Carolina the program has a pixel resolution of 6 inches(NCDOT, NCDIT, n.d.). The DEM is derived from a “QL2” LiDAR set collected in the coastal counties of NC. The LiDAR was collected between January 30 and March 13 of 2014 with a nominal post spacing of 0.7 meters or better. All data was collected during leaf off conditions and coastal counties were collected at low tide conditions (*North Carolina Statewide Lidar DEM 2014 Phase 2 | InPort*, 2021). All the data is processed in ArcGIS Pro, utilizing the spatial analysis package when needed.

Methods:

During the analysis portion of the capstone project two analysis will be applied to the data sets. This project will involve using a supervised classification on the imagery and a topographic wetness index on the DEM. The results of both analyses are compared for all coincident locations that we would consider to have a high likelihood for wetlands. Figure 4 shows a flow chart for the proposed workflow.

Topographic Wetness Index:

The topographic dataset is analyzed by completing a total wetness index. This analysis was performed in ArcGIS Pro. The index is used in part to help understand soil moisture and also to detail hydrologic flow. The TWI has also been found by researchers to predict observed patterns of saturated areas (Sørensen et al., 2006). A topographic wetness index (TWI) takes in to account slope, flow direction, and flow accumulation (Hird et al., 2017). This study uses a high quality QL2 DEM, which is promising since researchers have noted that there is noticeable increase in the reliability of TWI analysis with high quality DEM (Rull, 2016).

The formal equation for TWI proposed for this study is below.

TWI= $\ln(\alpha/\tan\beta)$

Where α is the upslope contributing area per unit contour, and $\tan\beta$ is the local topographic gradient. Higher TWI values indicate greater potential soil-water storage (Bian et al., 2021; Hird et al., 2017)

The steps to complete a TWI in ArcGIS Pro are listed below.

Step for TWI

Input DEM - Fill DEM – Flow Direction – Flow Accumulation – Slope in Degree – Radians of slopes = (Slope in degree * 1.570796)/90 – Tan Slope = con (Slope > 0, tan(Slope), 0.001) – Flow accumulation scaled = (Flow Accumulation +1) *Cell Size – TWI = Ln(Flow Accumulation Scaled / Tan Slope

Imagery Classification:

The analysis of the aerial collected imagery was completed using a supervised classification. This method was chosen to insure a solid repeatable methodology. Many researchers have had a strong success rate these classifications, researchers in Texas claimed a accuracy of 83.3% to 100% (Guo et al., 2017). The training data used for the classification is a small wetland delineation in a City of Durham Park this data was collected in 2018 by trained wetland biologists. Having a strong training data set is critical to having a successful supervised classification. A separate study on the wetlands of Canada showed that the automated classification models have a higher accuracy in many cases than user defined boundaries (Amani et al., 2019). Additionally, using ground truth wetlands from previous delineations has been done before with success in predicting the outcomes of other wetland areas. The North Carolina Department of Transportation issued thirteen delineations projects to a modeling team to predict the occurrences of wetlands along a transportation corridor in Lenoir County NC (Wang, et al, 2015).

Results

The two data sets were compared against the National Wetland Inventory (NWI) dataset. This dataset was chosen as the baseline because it is wildly accessible. The datasets were also compared to the ground truth wetland delineations within the study area. The NWI dataset can give us a general idea did the wetland identify areas that have previously been remotely sensed to be wetlands, the ground truth data helps us understand that site specific accuracy of the model itself. Both comparisons are made to ground truth project study area. The shape and size of the polygons derived from this study area shown in figures 5 and 6.

The analysis resulted in two separate wetland lines which compared against the two constants. The acreage of the NWI wetlands was a total of 14.79 acres, the ground truth wetlands was 25.76 acres, supervised classification resulted in 17 acres of wetlands, and the TWI analysis resulted in 33.05 acres of wetlands. For the NWI comparison, the total area predicted by the TWI analysis was 223% of the total acreage that the NWI study found, resulting in a difference of 123%. The supervised classification resulted in 115% of the total acreage of the total acreage that the NWI study found, resulting in a difference of 15%. For the ground truth comparison, the TWI analysis predicted 128% of the amount of acreage that the ground truth study found, resulting in a difference of 28%. The supervised classification resulted in 66% of the amount of acreage that the ground truth study found, resulting in a difference of 34%. The area comparisons are displayed as maps in figures 7 and 8, the comparisons are also shown in a table format with the context of total acreage in figure 9.

Discussion

There is a clear difference between the two control data sets used the NWI and ground truth data were very different in morphology and extent. As stated in the introduction the history of NWI is based on an outdated analysis of wetlands that is prone to errors when viewed at this scale. The ground truth data is a much more accurate control. While the most accurate prediction between the two models and the two controls was the supervised classification at a 15% total area difference or 85% total area correctly predicted when compared against the NWI dataset we will discount this data since the NWI is a less reliable control. The initial NWI surveys were done by interpreting aerial images of the time, so it is not overly surprising that it would align somewhat with a supervised image classification.

When interpreting the two predictive models with respect to the general morphology and extent the eastern edge of the ground truth wetland is very interesting. Both methods seemed to depict the eastern edge somewhat actually and the outer most bounds of the wetlands appear somewhat accurate. The TWI analysis seems to preserve the outer edge the best throughout the study area but seems to struggle in overpredicting wetlands also. The supervised classification method seems to struggle with interior features and underestimated the amount of ground truth wetland.

Of the reviewed literature the study that was most similar in objective was created by Wang et al, studying the wetlands along transportation corridors. In this related study the researchers incorporated a more advanced logistic regression and a random forest classification. The logistic regression incorporated things such as slope, aspect, and soil types. The random forest classification had the lowest total error rate between the two methods. This study used a comparison data set of ground truth wetland delineations (Wang, et al, 2015).

A separate piece of research reviewed for this project revealed a similar phenomenon that appears in the TWI analysis in this project shown in figure 5. In this study our data showed some streaking and lines in the TWI this also occurred in at least one other piece of research. The patterns indicate that the TWI input variables do not explain wetland occurrence under particular conditions found within these patch-like portions (Hird et al., 2017). While these streak-like areas are concerning they do not necessarily undermine the validity of the methodology. There can be issues with DEMs over water features where line streaking can occur. The methodology may create a more refined TWI final product with a low water DEM used, with that noted it is also very difficult to get a variety of high resolution seasonally dependent DEMs.

The research question for this project was “Can modern remote sensing methods streamline wetland avoidance in planning processes?”. The results showed a variation between the two methods attempted but they did show a method that may be appropriate for a planning level document. The TWI over predicted the ground truth wetlands by 28%, the total area was correctly predicted by 72%, resulting in a somewhat buffer of the on-site wetlands. This could be used with an avoidance and minimization mindset to avoid the areas that the model predicts. Researchers, scientists, and planners can use a model like this for preliminary design input to avoid areas that have a higher likelihood to be wetlands. This process is not yet to the point where it could replace a ground truth wetland delineation, more research would be needed to reach that point.

A potential constraint with this and all studies that have regulatory end points is gaining agency approval. While using a model such as this may add efficacies for developers and generate more reliable data layers for recourse agencies its practical applications are limited without approval from the regulatory agencies. To gain by in from the various agencies more research is needed to show efficiencies in a wide variety of ecological situations. Once a strong research base is established a strong case could be made to agencies that this is now a accepted method in research of remotely sensing wetland areas including regulatory end users.

Conclusion:

In conclusion the TWI wetland analysis does seem appropriate for a planning level environmental assessment. The TWI analysis correctly predicted 128% of the total wetlands on the site, this overestimation could be seen as a benefit. This level analysis could have value in studies related to the National Environmental Policy Act (NEPA) where least impactful alternatives are determined. In some NEPA studies a full ground truth wetland delineation is not a requirement and a remote sensing effort may still satisfy the analysis standards. Over estimating wetlands for a project in the planning stages could be valuable insuring that designs do not have a great chance of impacting wetlands. For permitting projects under the Clean Water Act a full wetland delineation would be required to ensure that the impacts for the wetlands are properly depicted. More studies would be needed to refine the wetland modeling effort to a level that would be appropriate for permitting.

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Data Accessibility Statement: This paper has been made publicly available on the https://mkm1671.github.io/. The author welcomes any interest, questions, or opportunities for improvement with the project.

Citations:

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FIGURES

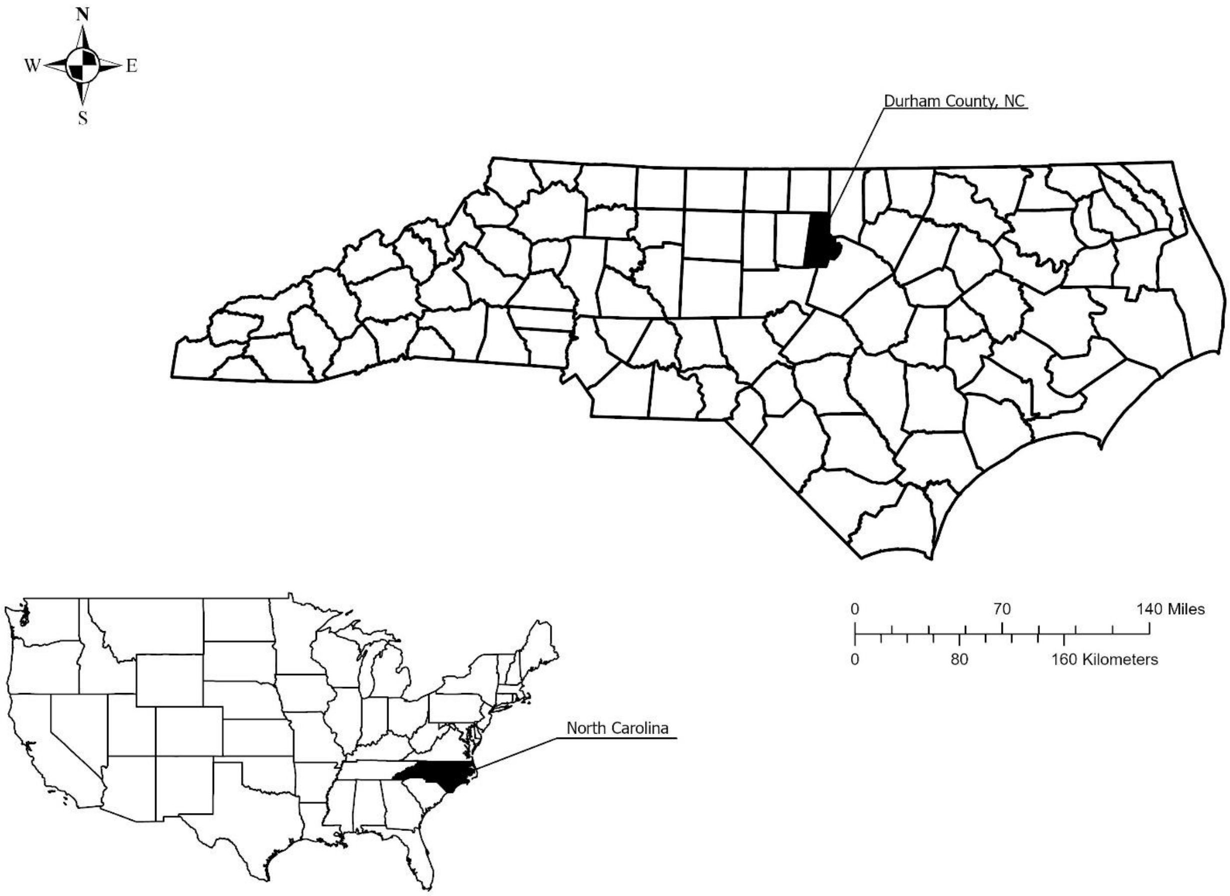

Figure 1 (Provides the context for the site evaluation for as a general location map)

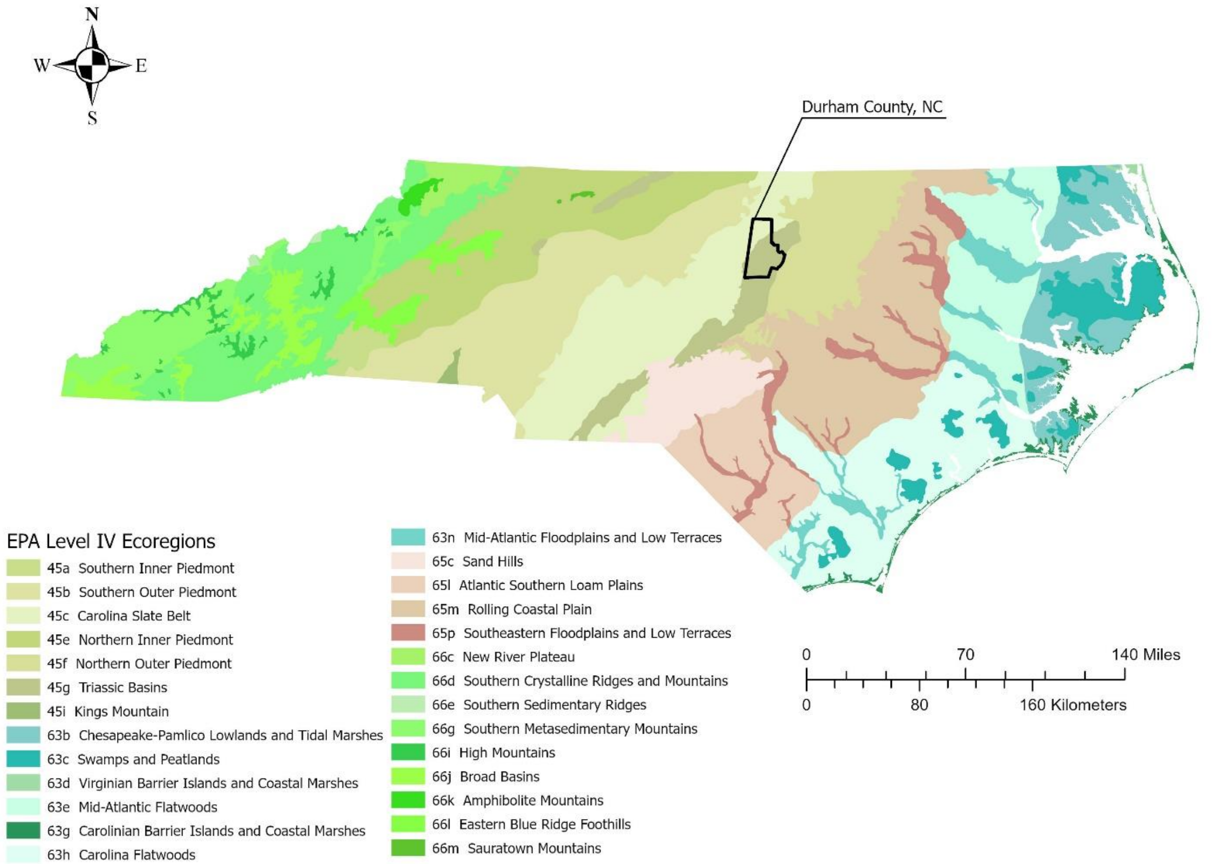

Figure 2 (Provides the context for target county within the EPA Level IV Ecoregions. Durham County is located with both the Triassic Basin and the Carolina Slate Belt)

Figure 3 (Provides the context for the study area within the bounds of the county)

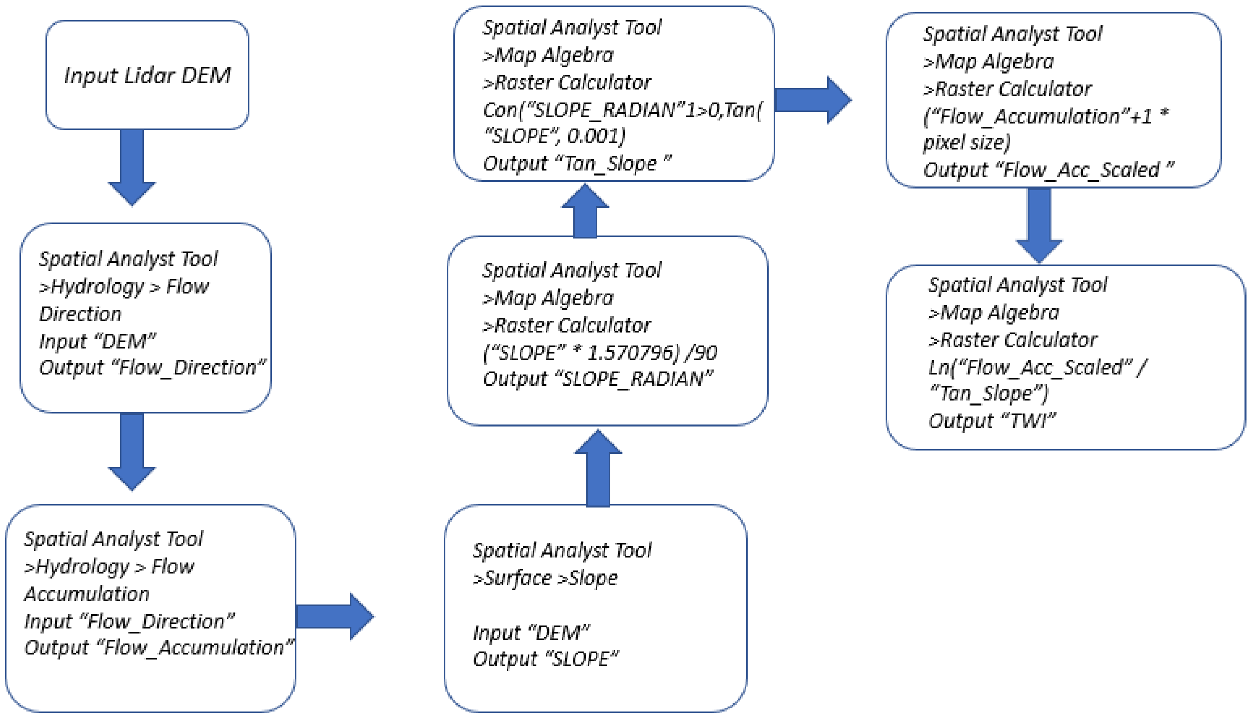

Figure 4 (A detailed flow chart of the TWI Methodology in ArcGIS Pro.)

Figure 5 (Results of the Wetland Boundaries from the TWI Methodology.)

Figure 6 (Results of the Wetland Boundaries from the Supervised Classification Methodology.)

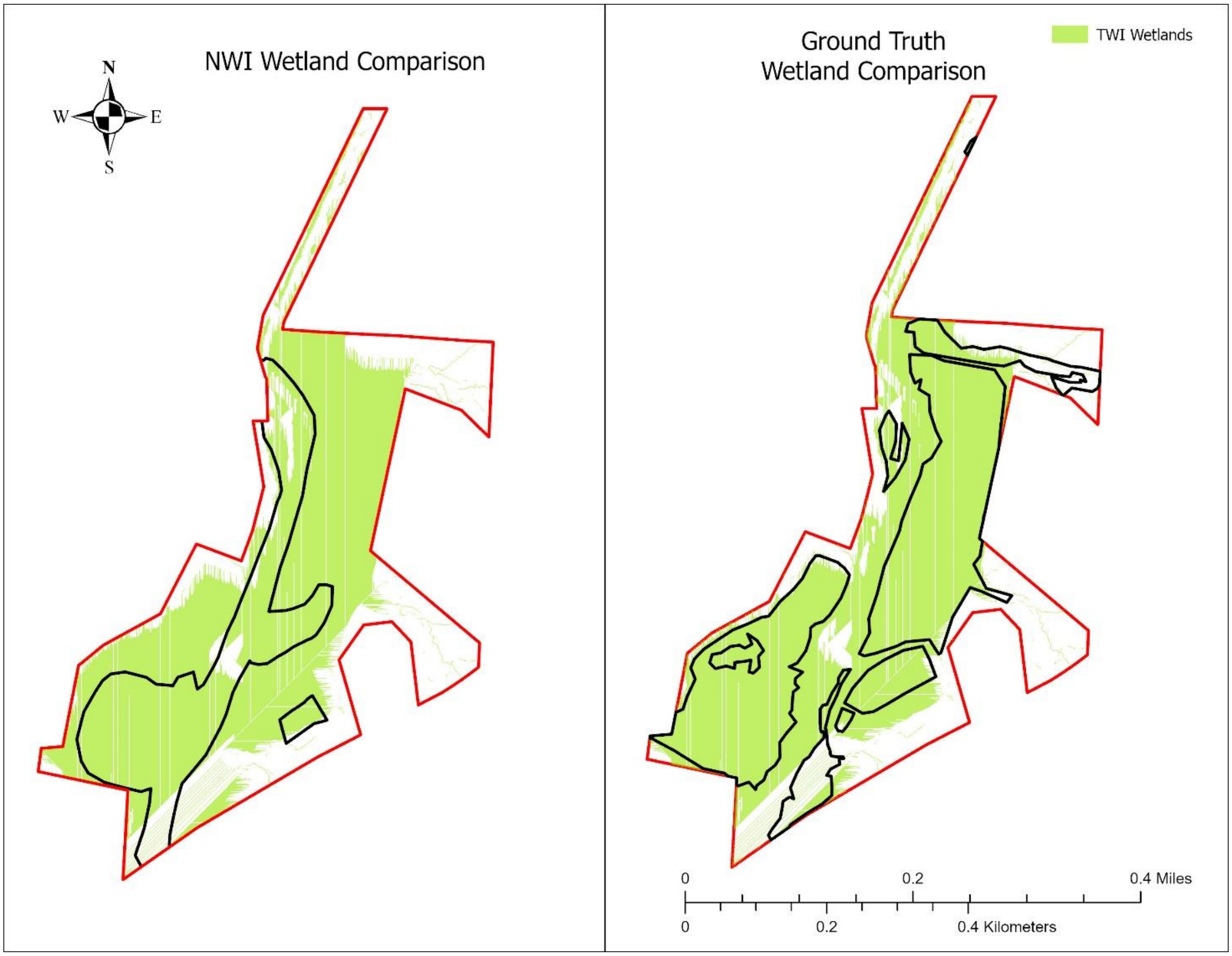

Figure 7 (Comparison against controls of the Wetland Boundaries from the TWI Methodology. On the left is a comparison of the NWI boundary in black. On the right is a comparison of the ground truth wetland delineation in black)

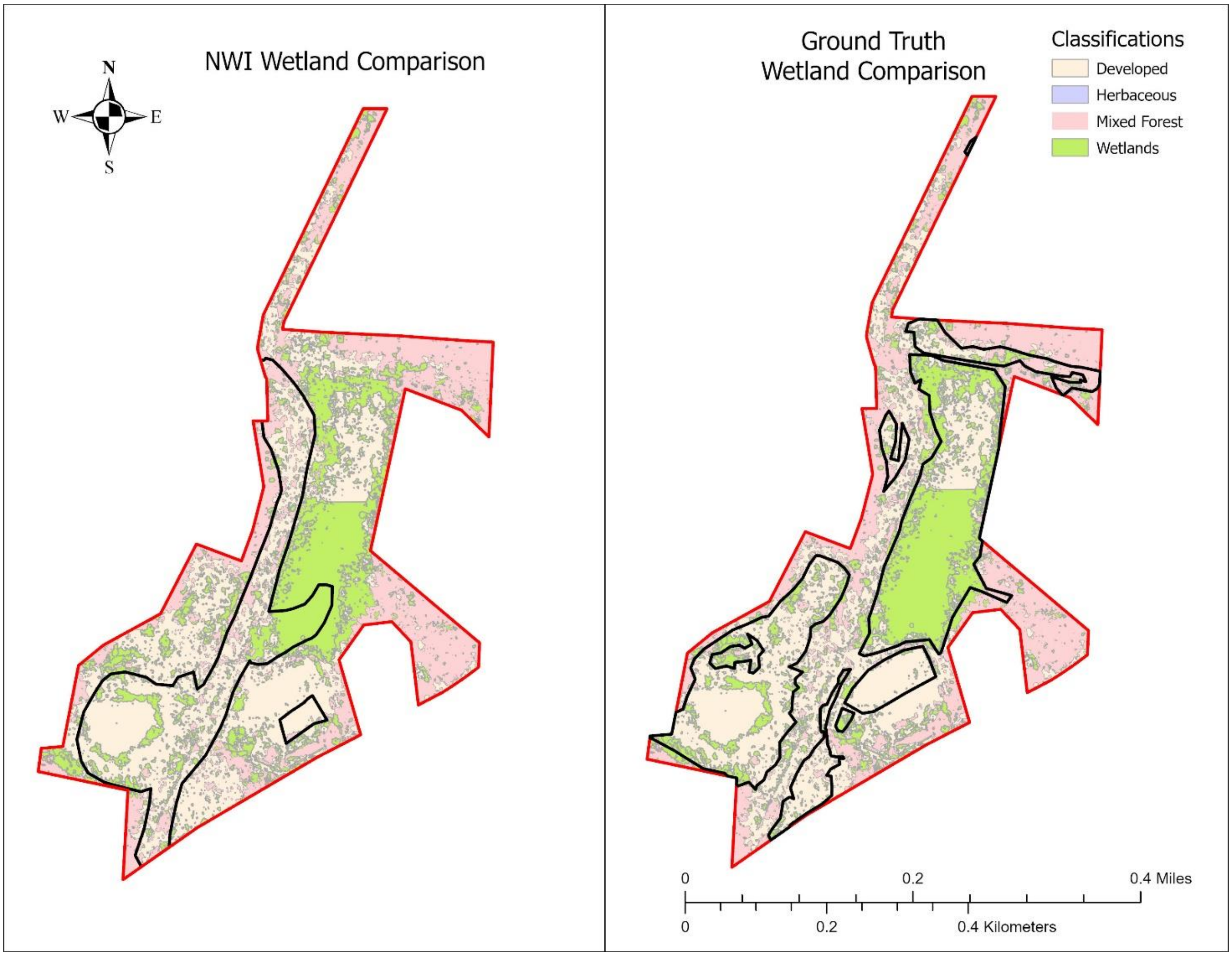

Figure 8 (Comparison against controls of the Wetland Boundaries from the Supervised Classification Methodology. On the left is a comparison of the NWI boundary in black. On the right is a comparison of the ground truth wetland delineation in black)

	Area in Acres
NWI Wetlands	14.79
Ground Truth Wetlands	25.76
Supervised Classification Wetlands	8.69
TWI Wetlands	33.05

	Percent of NWI
Ground Truth Wetlands	174%
Supervised Classification Wetlands	59%
TWI Wetlands	223%

	Percent of Ground Truth
NWI Wetlands	57%
Supervised Classification Wetlands	34%
TWI Wetlands	128%

Figure 9 (Table comparison of total area identified by the methodologies and the controls. The top table shows total acres for all methods, The middle table shows each method as a percentage of the NWI dataset. The bottom table shows each method as a percentage of the Ground Truth dataset)