A GIS MODEL FOR POTENTIAL RIPARIAN WETLAND RESTORATION SITES IN THE WAYNE NATIONAL FOREST

A thesis presented to
the faculty of
the College of Arts and Sciences of Ohio University

In partial fulfillment
of the requirements for the degree
Master of Arts

Doug A. Gibson
June 2006
This thesis entitled
A GIS MODEL FOR POTENTIAL RIPARIAN WETLAND RESTORATION SITES IN
THE WAYNE NATIONAL FOREST

by
DOUG A. GIBSON

has been approved for
the Department of Geography
and the College of Arts and Sciences by

Jeffery S. Ueland
Assistant Professor of Geography

Benjamin M. Ogles
Dean, College of Arts and Sciences
The GIS model in this study is a wetland restoration model for the Athens Unit of the Wayne National Forest. It uses secondary GIS data to identify and prioritize potential restoration sites with a restoration category value derived from the criteria present. The first objective of the study is to create and visually validate the performance of the model. The second objective is to determine the efficiency of the model method to preliminarily identify potential restoration sites with a comparison to the traditional identification method. Only 39.1% of the sample sites are classified correctly in the field with a visual sampling of criteria present. An improvement to the model’s restoration categories results in 68.1% of the sites being classified correctly. This results in a stronger performing wetland restoration model that is a more efficient wetland restoration tool. There are other modifications to improve the model’s performance.

Approved:

Jeffery S. Ueland
Assistant Professor of Geography
Acknowledgments

I want to acknowledge and thank a number of individuals who have made my educational experience at Ohio University a successful and enjoyable experience. I would not be where I am at now without all the guidance and assistance I received.

I want to thank God first of all for giving me the strength and perseverance to finish this Master’s program. He has made shaped me into a better person throughout the past two years.

I want to thank my wife, Jenn, for her incredible love and support during these past four years of school. It has been tough at times, but I knew that I could count on her to get me through it. I could not have done it without her encouragement and belief in me.

I want to thank Dr. Ueland for his continued guidance and assistance on this thesis project. He spent more time and effort than necessary to develop the project and thesis document and I truly appreciate that.

I want to thank Dr. Buckley and Dr. Dyer for their assistance throughout this project also. Their comments and suggestions were of great help in the preparation of this model’s and document’s development.

I want to thank Mr. Burk and Mr. Lowery in the GIS Department at Wayne National Forest for three summers of employment and assistance while earning my Master’s Degree. It was a great learning experience that I will always appreciate.
Table of Contents

Abstract ............................................................................................................................... 3
Acknowledgments ............................................................................................................... 4
List of Tables ...................................................................................................................... 6
List of Figures ..................................................................................................................... 7
Chapter 1. Introduction ....................................................................................................... 8
  1.1 Introduction ............................................................................................................... 8
  1.2 Project Background ................................................................................................. 11
  1.3 Study Area .............................................................................................................. 14
  1.4 Thesis Structure ...................................................................................................... 17
Chapter 2. Literature Review ............................................................................................ 19
Chapter 3. Model Creation and Validation ....................................................................... 27
  3.1 Model Introduction ................................................................................................. 27
  3.2: Data ......................................................................................................................... 27
  3.3 Creation of Site Criteria Layers .............................................................................. 28
  3.4 Identification of Potential Wetland Restoration Sites ............................................. 31
  3.5 Model Output Results ............................................................................................. 33
  3.6 Field Validation ...................................................................................................... 35
  3.7 Accuracy Assessment Results ................................................................................ 38
Chapter 4. Methods Comparison ...................................................................................... 49
  4.1 Method .................................................................................................................... 49
  4.2 Results ..................................................................................................................... 49
Chapter 5. Discussion ....................................................................................................... 52
Literature Cited: ................................................................................................................ 64
Appendix A. Series of potential wetland restoration maps ................................................. 69
Appendix B: Riparian area and poor soil indicators .......................................................... 85
Appendix C: Accuracy assessment checklist ..................................................................... 86
List of Tables

Table                                                                 | Page  
---                                                                  |------
3.1: Descriptive statistics of model’s aggregated output           | 34    
3.2: Descriptive statistics of model’s potential restoration categories | 34    
3.3: Count of potential restoration category values in field validation | 36    
3.4: Error Matrix of WNF wetland model                              | 39    
3.5: Error matrix of WNF wetland model with accuracy evaluations   | 41    
3.6: Error matrix with single Moderate category                     | 43    
3.7: Error matrix with accuracy evaluations with single Moderate category | 44    
3.8: Descriptive stats of restoration categories with new riparian layer | 46    
3.9: Error matrix of new riparian model                             | 47    
3.10: Error matrix of new riparian model with single Moderate category | 47    
5.1: Existing wetlands in model’s final sites                      | 59    
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1: Location map of Wayne National Forest</td>
<td>10</td>
</tr>
<tr>
<td>1.2: Detail map of Athens Unit, the study area</td>
<td>16</td>
</tr>
<tr>
<td>5.1: Digitized hydric soils in Ohio</td>
<td>55</td>
</tr>
<tr>
<td>5.2: Open water in existing wetland at one sample site</td>
<td>61</td>
</tr>
<tr>
<td>5.3: Vegetated areas in existing wetland at one sample site</td>
<td>61</td>
</tr>
<tr>
<td>5.4: Standing water area at one sample site</td>
<td>62</td>
</tr>
<tr>
<td>A.1: Index map of individual wetland restoration maps</td>
<td>69</td>
</tr>
<tr>
<td>A.2: Map 1: Potential sites in northeastern Vinton County</td>
<td>70</td>
</tr>
<tr>
<td>A.3: Map 2: Potential sites in southeastern Hocking County</td>
<td>71</td>
</tr>
<tr>
<td>A.4: Map 3: Potential sites in southeastern Hocking County</td>
<td>72</td>
</tr>
<tr>
<td>A.5: Map 4: Potential sites in eastern Hocking County</td>
<td>73</td>
</tr>
<tr>
<td>A.6: Map 5: Potential sites in northeastern Hocking County</td>
<td>74</td>
</tr>
<tr>
<td>A.7: Map 6: Potential sites in southwestern Perry County</td>
<td>75</td>
</tr>
<tr>
<td>A.8: Map 7: Potential sites in southern Perry County</td>
<td>76</td>
</tr>
<tr>
<td>A.9: Map 8: Potential sites in southern Perry County</td>
<td>77</td>
</tr>
<tr>
<td>A.10: Map 9: Potential sites in eastern Perry County</td>
<td>78</td>
</tr>
<tr>
<td>A.11: Map 10: Potential sites in southeastern Perry County</td>
<td>79</td>
</tr>
<tr>
<td>A.12: Map 11: Potential sites in western Morgan County</td>
<td>80</td>
</tr>
<tr>
<td>A.13: Map 12: Potential sites in northern Athens County</td>
<td>81</td>
</tr>
<tr>
<td>A.14: Map 13: Potential sites in northern Athens County</td>
<td>82</td>
</tr>
<tr>
<td>A.15: Map 14: Potential sites in northwestern Athens County</td>
<td>83</td>
</tr>
<tr>
<td>A.16: Map 15: Potential sites in northwestern Athens County</td>
<td>84</td>
</tr>
</tbody>
</table>
Chapter 1. Introduction

1.1 Introduction

Wetland restoration is defined as “a rehabilitation of a drained or degraded wetland where the soils, hydrology, vegetative community, and biological habitat are returned to the natural condition to the extent practicable” (Natural Resources Conservation Service, 1998, 1). The last four words of the definition reveal an important fact about wetland restoration. It is not always possible to fully restore a wetland to its previous extent or functionality. Sometimes the impact is simply too great to overcome. There are a number of sources that disturb and destroy wetlands, including human disruptions, wildlife activities, and farming (Middleton, 1999).

Many of Ohio’s original and expansive wetlands, including the Great Black Swamp in northwest Ohio, have been greatly reduced by agricultural drainage. Originally it was 120 miles long and 40 miles wide, but is presently located only in scattered patches on small farms (Baker and Micacchion, 1999). A document on the history of Perrysburg, Ohio states that “beginning in the 1840’s, it took several generations of determined farmers to drain it (Historic Perrysburg, Inc., 2006, 1)” and make it the area of prime farmland it is today. The Great Black Swamp has been reduced to only 5% of its original size (Andreas and Knoop, 1992). The Great Black Swamp loss accounts for approximately 63% of Ohio’s wetland loss, which totals approximately 4,500,000 acres as of 1994 (Baker and Micacchion, 1999). Drastic losses of wetland acreage such as this have not gone unnoticed by concerned individuals and organizations. The Wayne National Forest (WNF) has seen similar wetland reductions, which has spurred wetland restoration actions.

There is an ongoing movement to protect and restore wetlands within the United States. The U.S. Forest Service (USFS) is one governmental organization that continually works to protect and restore land that has been purchased from private individuals. This includes land originally purchased by the USFS to protect watersheds of navigable streams (Wayne National Forest: Legislative History, 2006). The protection of watersheds includes wetlands due to their biological importance and primary spatial
location in riparian, or streamside areas. Wetland restoration is presently an important topic in the environmental discussion of both federal and state governments. Many policies focusing on wetland conservation and restoration have been adopted since 1993. This has resulted in significant additions to wetland preserves, wilderness areas, and refuges to protect wetlands and their resources. Private organizations are also working with governmental agencies throughout the U.S. on restoration and mitigation projects (Fish and Wildlife Service, 2006). Identifying potential restoration sites requires valuable time and money to be spent by governmental agencies. Given the diminishing budgets for this activity, this process should be as efficient as possible. Today’s computer technology and programs, such as a Geographic Information System (GIS), can make the process more efficient for governmental organizations, including WNF.

The WNF consists of two separate districts, the Athens District and Ironton District. The Athens District contains two individual units, the Athens Unit and Marietta Unit, whereas the Ironton District only contains the Ironton Unit. The Marietta Unit is located along the southeast border of Ohio and the Athens Unit is located west of the Marietta Unit (Figure 1.1). The aim of this study is to create a GIS model, hereafter called the WNF wetland model, which will assist in prioritizing preliminary sites for riparian wetland restoration in the Athens Unit of the WNF. It identifies a preliminary list of potential restoration sites that satisfy one or more criteria, which may or may not contain degraded wetlands. This study focuses on two main questions: Is the WNF wetland model accurate for the Athens Unit? This question is answered through the creation and field validation of the prioritized WNF wetland model. Is the WNF wetland model more efficient than the traditional method employed to identify preliminary restoration sites for detailed fieldwork? This question is answered by comparing the time length of the analysis process to generate preliminary output of potential restoration sites in both methods.
The methods for this study are derived from a pilot project developed for the Marietta Unit of the WNF. The pilot project utilized field observations as a means to identify critical features of wetland delineation and assess the applicability of the GIS analysis on a small number of selected sites. Overall, the GIS model performed well in this capacity. The model correctly predicted the criteria present for a potential wetland area as indicated through the GIS analysis at four out of five sites. The field observation at one site also revealed the presence of a previously restored wetland. The field observations supported the results of the GIS model for the Marietta Unit. The pilot project was completed to determine efficiency and accuracy of potential site identification in the GIS environment. Wetland restoration in WNF is a priority when time and budgets are allocated, which means the process should be efficient as possible. WNF is also open to wetland mitigation projects, which involves creating a new wetland to replace a destroyed one. The WNF wetland model identifies the location of potential restoration sites that satisfy one or more of the restoration criteria, which can be
cataloged for future reference (Ewing, 2006). This current study will expand and apply this technique and criteria layers on a more comprehensive scale within the Athens Unit of the WNF. The objective is to determine if the same technique and criteria layers are accurate for a geographically separate area of the WNF. The results can be significantly beneficial to the planning and wetland restoration process in WNF.

1.2 Project Background

Wetland definitions are numerous and seemingly ad hoc in their criteria. They are often based on individual or group perspectives, the transitional nature of wetlands between wet and dry areas, and other unique attributes. The individual perspective refers to the idea that a wetland will be defined differently based on experience or profession. It is difficult to find a definition that strictly applies to every wetland type. Kent (2001) provides a wetland definition within the context of this study that incorporates three essential parameters: surface water presence, hydric soils, and hydrophytic vegetation. A “wetland is defined as land having the water table, at, near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation, and various kinds of biological activity which are adapted to the wet environment” (Kent, 2001, 5). The transitional nature of wetlands between water systems and dry, upland areas leads to a number of ecological services and biological functions. Hammer (1992) identifies six categories of wetland functions: biological life support, hydrologic modification, water quality changes, erosion protection, open space and aesthetics, and geochemical storage. All common wetland functions identified by Kent (2001), including aquatic and wildlife habitat, flood flow alteration, groundwater recharge, recreation, soil stabilization, and more, are grouped into these six categories. The variety of wetland functions is illustrative of the spatial and ecological importance of these delicate systems. Just as there is a diversity of wetland functions, there is also a diversity of wetland types throughout the U.S.

The Ohio Wetland Inventory (OWI) identifies six classes of wetlands located in Ohio. These classes include open water, forested wetlands (mature woods with hydric soils), shallow marsh (emergent vegetation in water three feet or less), shrub/scrub
wetland (emergent woody vegetation in water three feet or less), wet meadow (wet grass areas in water less than six inches on hydric soils), and farmed wetland (wet meadow in agricultural areas on hydric soils). As of 1999, there were 942,156 wetland acres in Ohio that accounted for 3.57% of the state’s total acres. Of that total, 13,072 wetland acres were located inside Athens, Hocking, Perry, and Vinton counties (1.40%). These four counties are located within the Athens Unit of WNF, the study area for this project. Open water (7,618 acres) and forested wetlands (2,186 acres) were the two largest wetland types in the counties. Wet meadows covered the least area with a total of 68 acres. The southeastern and northeastern areas of Ohio contained the smallest amount of existing wetland acreage in the state, but they also had the greatest area for restoration as of 1999 (Baker and Micacchion, 1999).

Wetland restoration is used to re-establish a degraded wetland to its natural condition to the extent possible. This involves trying to restore the essential parameters, or criteria, that exist in a naturally occurring wetland, including surface water presence, hydric soils, and hydrophytic vegetation (Natural Resources Conservation Service, 1998). Tammi (2001) defines hydric soil as soil that is saturated or flooded for extended periods during the growing season to develop anaerobic, or depleted oxygen, conditions. This means that oxygen is removed from the upper layer of soil due to extended saturation. Hydrophytic vegetation is vegetation that survives hydric soil conditions due to adaptation to the low oxygen levels. Rushes, sedges, and cattails are common examples of hydrophytic vegetation that occur in wetland areas. The restoration process and plant species present are heavily influenced by the amount of human involvement used in the restoration process. Middleton (1999) identifies two wetland restoration theories most often applied throughout the United States today: Self-Design and Design.

The Self-Design Theory views environmental conditions as the primary determinant of the vegetation type and restoration process in the area. Wetland restoration and revegetation is left to nature and is a result of the ecological processes that occur in the area. The Design Theory introduces significantly more human involvement into the restoration process. The restoration process and revegetation species used in the
replanting process are carefully selected in the planning stages of the restoration process. That knowledge is recognized as the dominant factor in the revegetation success of the project (Middleton, 1999). The WNF applies the Design Theory in many wetland restoration projects, including the Cadmus wetland restoration project in the Ironton Unit. A decision memo from the Ironton Ranger District of the WNF states that after the construction of the dam, it is to be reseeded with native or noninvasive plant species (Chrismer, 2004). The decision of which restoration theory to apply by governmental organizations cannot be made without governmental legislation to authorize restoration.

The focus of wetland policymaking in the U.S. Congress has continually shifted since the late 18th century. Agricultural committees dominated the legislative discussion in policymaking from 1789 to 1945. Wetland protection was second, third, or fourth to agricultural success and other activities in the United States during this period (Tzoumis, 1998). Wetlands were viewed as wastelands and unnecessary landscape features to be drained or filled. They stood in the way of agricultural success, population growth, and better transportation networks (Dahl and Allord, 1997). After 1945, environmental issues moved to the forefront of policymaking. Wetland protection received slightly more attention during this time. Many interests and issues, in the form of recreation, environmental protection, and economics, have competed with wetland protection for attention since 1966. Wetland protection slowly gained more attention and favor from 1966 to 1977, after which it dominated policymaking as never before (Tzoumis, 1998). Gaddie and Regens (2000) identify the Federal Water Pollution Control Act of 1972 (FWPCA) as the first step in eventual wetland protection. It was the first piece of legislation to protect and/or restore the health of the nation’s waterways. The years following 1997 have been the boom years of policymaking for wetland protection and restoration (Tzoumis, 1998). There have been a number of laws passed by Congress to conserve, protect, and restore wetlands since 1977. There are two significant wetland laws: The 1977 Clean Water Act (CWA), an amendment to the FWPCA, and the 1985 Food Security Act (Gaddie and Regens, 2000 and Fish and Wildlife Service, 2006).
The mission of the FWPCA is “to restore and maintain the chemical, physical, and biological integrity of the nation’s waters” (Gaddie and Regens 2000, 28). This is done by enforcing standards on discharges into the waters of the United States. However, the FWPCA does not specifically include wetlands as waterways. The basis for wetland protection is found in Section 404 of the 1977 CWA, which states that the Environmental Protection Agency (EPA) can regulate any discharge into the waters of the United States. The term wetland is not used in the legislation but judicial decisions have expanded the definition of waters of the United States to include wetlands (Gaddie and Regens 2000, 28-29). The 1985 Food Security Bill and later amendments strive to reverse the economic decline of American farms while at the same time protecting wetlands. Additionally, they all include provisions to stop the drainage of wetlands. Federal farm program benefits are denied to farmers who have drained wetlands since 1985. Farmers can regain benefits lost to inadvertent wetland conversion if those wetlands are restored (NOAA Coastal Service Center, 2006). Wetland protection is also encouraged by the Farm Security and Rural Investment Act of 2002 (Farm Bill) and its voluntary Wetlands Reserve Program (WRP). In the WRP, landowners receive financial and technical assistance to restore and enhance wetlands. The landowners voluntarily retire land from agricultural use through either a conservation easement or cost-share restoration agreement. The landowners still retain ownership of the land through both types of agreements (Natural Resources Conservation Service, 2004). The focus on wetland protection in wetland policymaking since 1977 has decreased the rate of wetland loss in the U.S. by 80% during the 1990’s (Fish and Wildlife Service, 2006). The invaluable functions performed by riparian wetlands juxtaposed against agricultural, recreational, and developmental initiatives ensure that wetland conservation will remain a key environmental issue.

1.3 Study Area

The WNF is Ohio’s only national forest and is administered by the U.S. Department of Agriculture (USDA). It is named after General Anthony Wayne, a soldier in the Continental Army and Legion of the United States. It currently occupies 236,500
acres of ground within Southern Ohio. The Weeks Law of 1911 gave the federal
government the authority to establish national forests by purchasing lands to protect the
watersheds of navigable streams. However, the acquisition was not that simple. The
individual states had to give authority to the federal government to purchase the land
(Wayne National Forest: Legislative History, 2006). This was the beginning of a period
of conservation by the United States government that continues today. Almost
25,000,000 acres of land added to the USFS since the passage of The Weeks Law (United
States Department of Agriculture, 2005). It took almost twenty-five years after the
passage of the Weeks Law for the USFS to focus its conservation effort on Ohio.

The first tracts of land that became WNF were purchased from private landowners
in 1935. A majority of the tracts in the original purchase contained a large number of
abandoned farms and tax delinquent holdings from the Great Depression. They were
heavily farmed, mined, and abused by both industries and individuals. The goal of the
USFS was, and still is, to restore the degraded lands for healthy watersheds, natural
resources, wildlife habitat, and recreation opportunities. In 1939, approximately 20% of
the purchased land required re-planting by the USFS. Pines were the only species
planted because the eroded land could not support hardwoods, or deciduous trees. In
1949, the headquarters for the land was moved from Columbus, Ohio to Bedford, Indiana
(Wayne National Forest: National Forest, 2006). Then in 1951, the five units were
combined with the Indiana Purchase Unit into a single National Forest unit, the Wayne-
Hoosier National Forest. In 1993, the WNF separated from the Hoosier National Forest
with the establishment of a Forest Supervisor’s Office in Athens, Ohio (Wayne National
Forest: Legislative History, 2006). WNF has a unique land-holding pattern due to its
location in the topologically diverse area of Southeast Ohio.

WNF contains a unique checkerboard pattern of ownership within the forest
boundary of all three Units. Patterns of large and contiguous Forest Service ownership
are nonexistent due to the scattered and intermingled areas of private, state, and federal
ownership throughout the WNF. The Athens Unit, the study area, is located in the
southeastern Ohio counties of Athens, Hocking, Morgan, Perry, Vinton, and Washington
(Figure 1.2). This area is the most heavily forested area of Ohio and the least productive agriculturally. The topography of the area is not conducive to large-scale farming operations found in northwestern Ohio. The Athens Unit of WNF is characterized by degradation from one significant land use activity: coal mining (Wayne National Forest: National Forest. 2006).

Figure 1.2: Detail map of Athens Unit, the study area

The Hocking River and some of its tributaries, such as Monday Creek and Sunday Creek, run through the study area and have been heavily impacted. Abandoned mine openings, rubbish piles, seepage locations, etc., are located throughout the study area and contribute acid mine drainage (AMD) to the area’s watersheds. AMD is the result of polluted water with high iron pyrite levels seeping from abandoned mining operations into nearby water systems. AMD causes stretches of some streams to become biologically dead and unsafe for fishing or swimming because sulfuric acid is introduced.
in large quantities (Horan, 1999). The Office of Surface Mining of the ODNR identifies southeast Ohio as one of the most AMD polluted streams in the U.S. Monday Creek ranks third among the most severely AMD damaged streams in the U.S. as of 2001 (Monday Creek Restoration Project, 2001). Wetlands adjacent to AMD-impacted streams are wetlands that have a strong potential to need restored. The WNF wetland model will identify those areas if they contain one or more of the restoration criteria.

1.4 Thesis Structure

The WNF wetland model is a tool to identify potential wetland restoration sites and improve the restoration process in the Athens Unit. Chapter 2 contains a literature review on the applications of GIS in landscape restoration, riparian restoration, and wetland research. A hierarchy is established for the GIS applications at the larger-scale level of riparian area restoration down to the smaller-scale level of wetland research. The wetland research focuses on the application of GIS in wetland prediction, wetland identification, and wetland restoration. The Chagrin River Watershed Partners, Inc. (2001) and White and Fennessy (2005) discuss wetland restoration models developed in Ohio. They contribute invaluable information to the WNF wetland model.

Chapter 3 focuses on the first question of this study, the reliability of the WNF wetland model. The two-stage process for the creation of the model is discussed first. The result of the validation process, which addresses the accuracy of the model, follows. The performance of the WNF wetland model is evaluated in the accuracy assessment. The chapter concludes with modifications to the model and corresponding accuracy assessments. Chapter 4 focuses on the second objective of this study, the comparison of methods for determining potential wetland restoration sites. The efficiency of the WNF wetland model is compared against the efficiency of the traditional method of determining potential sites. The process with the shortest analysis time will be considered the more efficient method. Chapter 5 discusses the potential impact of the WNF wetland model by re-examining the two research questions and their answers. The position of the WNF wetland model in the literature review’s hierarchy is also addressed. Other potential applications of the WNF wetland model are included in this final chapter.
The chapter concludes with a review of suggested improvements to the WNF wetland model to improve its performance.
Chapter 2. Literature Review

GIS can be used on large- to small-scale levels of environmental research to store and quickly process large amounts of spatial data. This literature review discusses a number of environmental research projects that apply GIS on larger- to smaller-scales based on extent of landscape studied. The larger-scale application discusses a riparian restoration application and the smaller-scale applications discuss multiple wetland research applications within riparian areas. The WNF wetland model study fits into the small-scale level of wetland research. It provides a potential tool to make the wetland restoration more efficient and focuses on a single riparian area feature. This study is most relevant to today’s governmental desire to restore wetlands in the face of reduced budgets, in which efficiency is a necessity. The successful riparian area restoration project lays the foundation for the smaller-scale wetland research applications that follow.

Russell et al. (1997) employ a modeling process in the GIS environment to identify sites for riparian restoration or preservation based on hydrology and land-use in southern California. The riparian definition in the project refers to the area’s ability to support streamside wetland functions. Flood attenuation and species habitat are the primary hydrologic factors identified as most appropriate for riparian restoration. Flood attenuation is derived using an index of wetness potential from U.S. Geological Survey (USGS) 30-meter Digital Elevation Models (DEMs). The wetness potential is determined through calculating the flow of water that would potentially accumulate from water movement downslope at all DEM pixels within the watershed. Essentially it is the potential for saturation by water runoff at each pixel. The species habitat is derived from a land use/land cover classification of a Landsat Thematic Mapper (TM) satellite image of the San Luis Rey River Watershed. The pixels in the study area are classified into seven broad land use categories: urban, agriculture, scrub, trees, bare/herbaceous, riparian, and water. All the land use classes, except riparian, are determined using the remote sensing principal of spectral signatures, which is how an object reflects light. The riparian classification is based solely on a distance from stream features, within 210
meters (7 pixels). The spectral signatures of riparian plants and upland plants, which are plants outside riparian area, are too similar to distinguish. The two data layers are overlaid together to identify and prioritize sites for riparian restoration or preservation. Prioritization of sites is based on wetness values (low, medium, and high) and distance to existing riparian land use (cottonwood, sycamores, and willow trees). Restoration sites are identified as having medium to high wetness values and agriculture or barren land use. Preservation sites are identified as having medium to high wetness values and existing riparian or tree cover. The riparian model provides many benefits to the riparian restoration process. The modeling process is a starting point for the restoration process and “an initial step in the site selection process that can guide more detailed, field-based assessments” (Russell et al., 1997, 65). It quantifies the number of acres prioritized as high, medium, or low for both preservation and restoration. It provides invaluable evidence that restoration areas can be ranked by criteria and quantified in the GIS environment. It lays the foundation for successful small-scale level applications that focus on a single riparian area feature, like wetlands. Successful GIS based analyses have been performed in the small-scale level of wetland research.

The application of GIS in wetland research falls onto the small-scale level of environmental research because of the focus on individual features within riparian areas. Research projects on wetland identification, change analysis, and restoration models using GIS provide the necessary background information and literary justification for this study. They all have different objectives and methods, but the common thread is their application inside the GIS environment to study wetlands. They all take advantage of GIS being able to efficiently and effectively analyze large amounts of spatial data quickly. Wetland identification in the GIS environment is addressed first in the following paragraphs.

Lyon and Adkins (1995) developed a wetland prediction model for the flats of the St. Clair River in Michigan. It incorporates GIS and remotely sensed data from 1974 and 1985 to identify wetland locations and then estimate change for the eleven-year time period. Digitized land cover and wetland data from 1979 were combined with soils and
elevation/water depth data from 1985 to develop a wetland prediction model. The land use data from a satellite image were classified into eight classes and a wetland map of the area showing six wetland types was digitized into the GIS system to develop the model. A soils map showing the two dominant soil types of the area was digitized into the GIS system to develop the model. The prediction model used a linear equation to combine the data layers and a constant error term to produce a predicted wetland type. It was determined through data reference that the model “was found to be fairly accurate” (Lyon and Adkins, 1995, 57). The prediction model demonstrates the ability of a GIS to assist in identifying wetland locations and their location change using secondary data. It serves as an example of successful integration of GIS and wetland research. It also provides a process structure, development and overlay of criteria layers, which serve as a framework for other projects. Wetland identification utilizing GIS has a far-reaching impact beyond the Midwest and occurs at larger scales.

Tiner (2003) describes a project undertaken by the U.S. Fish and Wildlife Service (USFWS) to predict the extent of geographically isolated wetlands across the continental U.S. and Alaska. Isolated wetlands are wetlands that have no apparent surface water connection to permanent water bodies and are surrounded by dry land. National Wetland Inventory (NWI) digital data, digital line graphs (DLGs) for hydrology, and digital raster graphs (DRGs) for roads are used in combination to identify isolated wetlands. Two different stream buffer distances, twenty and forty meters, are used to link the NWI and DLG spatial data and completely identify the riparian area to the fullest extent. Buffer distances are used because the two different data sources have the potential to contain differences in spatial accuracy. All wetlands within twenty meters of the stream are designated as connected to the stream for this project. The forty-meter buffer is to ensure that wetlands not connected (when they really are) to the stream feature due to spatial inaccuracies in the dataset are captured in the riparian area location. The GIS analysis undergoes a series of several steps to apply the riparian buffers, identify potential isolated wetlands between twenty- and forty-meters and greater than forty-meters of streams, and compare results to the DRG of roads to ensure isolation and uncover road fragmentation
of wetlands. Three scenarios are developed to present a range of estimates for the location of isolated wetlands based on the level of interpretation. This is another project that illustrates the successful use of a GIS and secondary data to identify existing wetland locations. The GIS data used and process followed is different, but it is a successful GIS-based project. Two successful wetland identification projects provide a valid argument for the extension of this project into wetland restoration site identification. The GIS environment is also able to assist researchers in measuring the performance of existing wetlands in terms of ecological and biological functionality.

Cedfeldt et al. (2000) have developed an automated wetland assessment methodology using GIS to identify functionally significant wetlands in the state of Vermont. Three wetland functions are used to designate a wetland as functionally significant: flood flow alteration, surface water quality improvement, and wildlife habitat. A Landsat TM image, Digital Elevation Model (DEM), and secondary GIS data of surface water, soils, roads, landfills, and dams are used with the ARC/INFO GRID module to develop three wetland grids containing wetlands likely to perform each of the wetland functions. The three function grids are overlaid together to identify which wetlands are functionally significant, which is a direct result of the criteria present. A functionally significant wetland performs all three functions. The present focus on restoring wetlands has resulted in GIS models being developed to efficiently identify potential restoration or mitigation sites.

Van Lonkhuyzen et al. (2004) have developed a spatial modeling approach using GIS to identify suitable locations for wetland mitigation sites at the Argonne National Laboratory-East in Illinois. There are six main variables for the model: hydrology, soils, historic condition, vegetation cover, adjacent vegetation and land use. A suitability index, from 0-1, was developed for all the criteria and a raster layer of the values produced for each model variable. Weights were also assigned to the variables to represent relative importance in determining the suitability of a site. The GIS is used to calculate the overall suitability of each cell on the basis of the suitability scores and weights for each variable. The most suitable mitigation cells have the highest overall
suitability scores, which is a direct result of the suitability of each variable present. The best areas are located in topographically low areas adjacent to streams with predominately herbaceous vegetation. The mitigation model serves as a screening tool to identify sites for further consideration and detailed fieldwork. It uses secondary GIS data in a raster grid format to identify potential sites in a data overlay process. Wetland mitigation models are similar to wetland restoration models in that they both primarily use wetland indicators to identify potential sites. Successful wetland restoration models have been developed for Ohio and North Carolina.

The Potential Wetland Restoration and Enhancement site mapping procedure is a GIS-based procedure used by the North Carolina Division of Coastal Management (NCDCM) to locate potential wetland restoration sites. It is one of four procedures that are part of the NCDCM’s Wetland Conservation Plan. Four GIS criteria layers are used to identify restoration and enhancement sites: wetland type data from NWI, NRCS soil data, land use/land cover from three separate coverages with different temporal references, and hydrography from DLGs. Potential sites are given one of nine wetland disturbance classes and an enhancement or restoration designation before they are classified for potential restoration. The disturbance class reflects the historical impact to a site based on the land cover and hydrography data, such as stream modification, flow type, and cleared forest and grass areas. The enhancement or restoration designation is determined using the disturbance class. Enhancement sites contain a ditched, not cleared, impounded, and managed pine disturbance class. Restoration sites contain the other disturbance classes: drained and not cleared, excavated or filled, and drained, not cleared. Field verification of the procedure was completed on 212 sites in Craven, Carteret, and Jones counties with the assistance of a Global Positioning System (GPS) to locate the sites. There are 90% of the sites correctly identified as restoration or enhancement sites in the mapping procedure. The mapping procedure was then expanded into the rest of North Carolina’s coastal counties and seventeen Inner Coastal Plain Counties after the original procedure was found accurate (Williams, 2002). This wetland restoration is not the only successful model for North Carolina.
Earth Tech, Incorporated developed a GIS model to identify potential restoration sites in the Piedmont Region of the Cape Fear River Basin, North Carolina with secondary GIS data. There are five criteria used to identify potential restoration sites; hydric soil, land use indicating degradation, five acres or larger size, no previous wetland identification, and sole ownership on parcel. The degraded land use, which is agriculture, is selected from the land use shapefile and hydric soils are selected from the soil layer. The two polygons are then intersected and polygons greater than five acres are extracted from the layer of agricultural land use and hydric soil. The NWI layer is overlaid on the greater than five-acre sites to check if site was previously identified as a wetland.

Following the GIS analysis, field surveys are performed on the sites to see which ones are not physically and feasibly possible for restoration. Physically unfeasible sites are sites that require significant grading and excavating or contain no evidence of saturation or flooding (Stephens, 2006). Successful wetland restoration models like this one give strong guidance to how other wetland models should be structured. Wetland restoration models have been successfully applied in the Midwest state of Ohio.

The Chagrin River Watershed Partners, Inc. (2001) has performed a survey of wetland and stream restoration sites using a GIS in the Chagrin River Watershed of northeast Ohio. The project is the first step in the Chagrin River Watershed Partners, Incorporated effort to catalog individual or multiple parcels containing wetland and stream restoration and mitigation sites. The existing wetlands in the study area are identified using digital data and the watersheds are categorized based on their potential to contain wetlands. There are four secondary GIS datasets used to identify wetlands: OWI and NWI wetland layers, hydric soils, and DEM low spots. Then potential wetland mitigation sites are identified for the Chagrin River Watershed using the secondary data as criteria. The criteria used to identify a potential site are hydric soil, low slope (4% or less), no development, sufficient acreage, and adjacent to holdings of public or non-profit conservation organizations. The site criteria are overlaid together in the study area to generate an output of sites that meet all criteria and those that do not. This is an Ohio wetland restoration model that gives strong guidance in identifying potential wetland
restoration sites. This Chagrin River Watershed project is not the only wetland restoration project that has been successfully completed for Northeast Ohio.

White and Fennessy (2005) have described a watershed level site-suitability GIS model to assess the potential for wetland restoration in the Cuyahoga River watershed in Northeast Ohio. Restoration criteria were developed to identify and rank potential sites, which include hydric soils, land use, topography, stream order, a saturation index derived from a DEM, and a biological use attainment. The criteria were divided into constraints and factors for the model. The two constraints, land use and hydric soils, were used to generate the potential sites. All land uses except urban, water, or transportation are included as constraints. The remaining factors; topography, stream order, saturation index, and biological use attainment, were used to rank the sites based on the potential to contribute to the water resource integrity. A multi-criteria evaluation technique called linear-weighted summation was used to numerically indicate restoration potential. A base model with five restoration potential values, low to high, was developed first. Lastly, three other models were produced by assigning different weight values to the project’s factors. The models reflect the influence of different priorities for the restoration process. All of the wetland identification, restoration and mitigation projects discussed in this chapter have several things in common.

All of the wetland projects use secondary GIS data and a similar process framework to identify a preliminary list of potential wetland restoration or mitigation sites. The projects serve as the initial step in the site-selection process for restoration or mitigation sites. They provide an output of potential sites that require more detailed fieldwork to decide on restoration or mitigation value. The data are organized and prepared for each project in the GIS environment. The data are then overlaid together to identify potential sites with the criteria present. The secondary data is also used in a couple of the projects to prioritize potential sites for fieldwork. All of the projects use one, two, or three criteria layers that are recognized wetland parameters: low slope, hydric soils, and riparian area location (hydrology). The importance of a potential site to support a wetland, restored or constructed, is reflected in the criteria used. Williams
(2002) has 90% of its sites classified with the correct restoration or preservation category using a combination of wetland parameters for the model’s criteria. The restoration models in North Carolina and Ohio also use existing wetland data to determine if potential sites were previously identified as wetlands or not. This also serves as a prioritization system for potential sites, where impacted wetland areas have the highest priority for restoration. The WNF wetland model has many common threads to the projects in the literature review.

This literature review established a hierarchy of larger- to smaller-scale riparian and wetland research applications of GIS. The WNF wetland model is a smaller-scale wetland research application that strives to identify a preliminary output of potential wetland restoration sites for more detailed fieldwork. It is an initial step in the restoration process that can serve as an invaluable planning tool. It employs the same process framework, overlaying of secondary GIS data in GIS environment. The WNF wetland model shares a similar regional geographic setting with two of the wetland projects, Ohio. The WNF wetland model is located in the southeast portion of the state while the other two are located in northeast Ohio. The WNF wetland model uses two of the same criteria to identify potential sites in North Carolina and Ohio: low slope and riparian area location. It also uses the criteria layers to prioritize potential sites with a potential restoration category. This is a representation of the criteria present at each potential site.

The WNF wetland model also uses a soils criteria layer, but with a different twist from the other models. The other models use hydric soil to help identify sites, which is very poorly drained and poorly drained soil. The WNF wetland model uses hydric soil with an additional drainage class: somewhat poorly drained soil. This is a result of this project repeating the methods and criteria used in the pilot project for the Marietta Unit. It was determined that somewhat poorly drained soil be included to take advantage of its potential to pond surface water for shorter periods of time, which is potentially considered a seasonal wetland. It is not a recognized hydric soil drainage class, but cannot be excluded because of pilot projects methods and criteria.
Chapter 3. Model Creation and Validation

3.1 Model Introduction

The GIS model presented in this project consists of two stages. The first stage involves the creation of the individual criteria shapefiles using secondary GIS elevation, soil and floodplain data from the USGS, Natural Resources Conservation Service (NRCS) and Ohio Department of Natural Resources (ODNR). The three criteria defined as necessary components for potential wetland restoration sites in this study are low slope, poorly drained soil, and riparian areas. These criteria were first defined in the planning stage for the pilot project in the Marietta Unit. This project applies the same restoration criteria to determine if the pilot project’s model is reliable for the Athens Unit. The second stage of the analysis involves the identification of potential restoration sites by overlaying the shapefiles together and determining a potential restoration category value for each site.

3.2: Data

The elevation data are obtained from the USGS Seamless Data Distribution System (SDDS) on the World Wide Web. The 1/3 Arc Second National Elevation Dataset (NED) provides national elevation data in a raster grid format with a spatial resolution of 10-meters. This level of resolution allows for efficient analysis over larger areas, like the Athens Unit, without diminishing the complexity found at local scales. The Athens Unit’s uneven topography of higher elevations and lower floodplain areas makes the 10-meter resolution a valid choice (United States Geological Survey, 2004). Cedfeldt et al. (2000) and Russell et al. (1997) use 30-meter DEMs to obtain elevation and drainage related data for successful larger-scale riparian restoration projects. The choice of a finer resolution DEM for the WNF wetland model greatly improves the potential for a successful model application by more accurately calculating slope. Finer resolution DEM’s contain smaller grids, which correspond to the grid value being assigned to a smaller ground area. A smaller pixel is a more accurate representation of the ground surface located in that area.
The soils data are obtained from the Soil Survey Geographic database (SSURGO), which is located in the on-line Soil Data Mart of the NRCS. The database is the most detailed level of soil mapping available from the NRCS and duplicates the original soil maps completed by the agency at the county level. The database contains polygons of different soil types and a large number of soil attribute tables at the state and county level that cover a wide variety of soil attributes. The scale of the data ranges from 1:12,000 to 1:63,360, which are large to moderate scale data. The NRCS indicates that these data are intended for users from county planners to landowners, which indicates large-scale to small-scale use (Natural Resources Conservation Service, 2006).

The riparian data are obtained from the ODNR Geographic Information Management Systems (GIMS), which is a collection of spatial data managed by the ODNR. The riparian layer is comprised of 100-year flood hazard area coverage for major streams, like the Hocking River, and their major tributaries. This is a representation of the 100-year floodplain boundary found on Federal Emergency Management Agency National Flood Insurance Maps. They are scanned, rectified with road centerline files, and digitized at a scale of 1:24,000. This results in a positional accuracy of plus or minus 40 feet for its cartographic control (GIMS Policy and Planning Committee, 2004). The riparian area coverage is a digital representation of the areas that have a high probability of flooding at least once every hundred years. Portions of the area will flood more frequently than other portions of the area. The significantly smaller stream tributaries are not included in this representation of the riparian area.

3.3 Creation of Site Criteria Layers

The three criteria shapefiles are developed independently and tailored for this wetland restoration model. There are the same criteria layers used in the previously mentioned pilot project. Their reliability will be tested for the Athens Unit in this project. The low slope shapefile is originally collected as a raster DEM, which is a different data format than the other layers. The other two criteria layers are collected as vector GIS layers. There is an extra field added to all three criteria layers to indicate the presence of the criteria at potential sites. This field is ultimately used as a means to calculate a
potential restoration category of a potential site with the criteria present after the potential sites are identified.

Low slope is a key criterion for the restoration of wetlands in this study. An area must be flat enough to pond water on a semi-permanent or permanent basis. The low slope layer is developed using a 10-meter DEM for the study area. A percent slope calculation is performed on the elevation data using a GIS surface analysis tool. This calculation results in a new raster grid of slope values that identifies the slope of a cell based on surrounding cells. However, this layer cannot be joined with the other layers while it is in the raster format. The raster grid of slope percentage is converted to a feature layer of individual polygons with the same slope value. Then the areas below 3% slope in the percent slope shapefile are selected and exported to a new shapefile. The new shapefile is clipped using the Athens Unit boundary so that areas outside the study area are eliminated from the layer. A new criteria field is added to the attribute table of the new shapefile and a ‘Yes’ entered for all records.

Poorly drained soil is also a key criterion for the restoration of wetlands in this study. A poorly drained soils layer is developed using soils information from the SSURGO database. The database provides the current version of soil data for the soil survey area of choice: county or state. The spatial and tabular soil data is obtained in a Microsoft Access 2002 template database for all the counties within the Athens Unit. This database is tailored so that only Ohio versions, not national, of reports are used for the soil polygons. The soils database contains information regarding drainage class for the soil survey area in a separate attribute table titled component. The drainage class attribute table is used to identify three soil polygon types for this project, which are very poorly drained soils, poorly drained soils, and somewhat poorly drained soils. These drainage class designations correspond to the time length that water remains at, or near ground surface and corresponding soil wetness. Tammi (2001) states that surface water remains throughout much of the year in very poorly drained soils and that somewhat poorly drained soils are wet for extended periods during the year. Very poorly drained and poorly drained soils are considered hydric soils, “assuming the soils have not been
drained” (Tammi, 2001, 40). Tiner (2003) also states that hydric soils usually consist of very poorly and poorly drained soils with a water table within one foot of the ground surface for two weeks or more during the growing season. The soil polygons are connected to the component attribute table so that multiple components, or pieces, of each soil unit can all be analyzed. This is done through setting up a related, not joined, connection between the spatial and tabular layer. The soil polygons with the related very poorly drained, poorly drained, and somewhat poorly drained soil drainage classes are selected and exported to a new shapefile. The somewhat poorly drained class is not a recognized hydric soil, but is included because it was used in the pilot project’s model. This project strives to repeat the same process of the pilot project with the same criteria layers to determine its accuracy for a separate area. The new shapefile is clipped using the Athens Unit boundary to eliminate the areas outside the study area. Finally, a new criteria field is created in the attribute table and a ‘Yes’ is entered for all records.

The riparian area is developed using the 100-year flood hazard area data from the ODNR GIMS. The justification for using the 100-year floodplain for the riparian area is found in a NRCS technical paper on riparian areas. Montgomery (1996) states there are presently no standard definitions or distances for a riparian area due to its transitional position between water bodies and upland areas. The NRCS recognizes floodplains as one example of a riparian area, which is used for this model. The riparian layer represents the presence of surface water hydrology, which is one important criterion for wetland presence. The 100-year floodplain is the widest possible extent for annual flooding, which means that there are areas inside the boundary that will flood very infrequently. The low slope and poorly drained soil criteria assist in identifying the areas that receive surface water through flooding and slope runoff most frequently. The 100-year flood hazard layer is downloaded separately for all counties within the Athens Unit boundary as interchange files and converted to coverages. The individual coverages are converted into shapefiles with the export process and then joined together to make a single 100-year floodplain shapefile. The shapefile is clipped using the Athens Unit
boundary to eliminate areas outside the study area. A new criteria field is added to the clipped shapefile and a ‘Yes’ entered for all records.

3.4 Identification of Potential Wetland Restoration Sites

The second stage of the model involves combining the three criteria shapefiles to identify potential restoration sites and calculating the restoration category for each from criteria present. Potential restoration sites for the WNF wetland model are identified by overlaying the three criteria shapefiles together using the Union tool. The Union tool is a geoprocessing tool that combines two or more shapefiles together while keeping the attribute tables of each shapefile. This allows the three criteria shapefiles to keep the ‘Yes’ for the criteria field as it relates to each layer. If a site meets all three criteria, there is a ‘Yes’ in all three of the criteria fields, which are LowSlope, PoorSoil, and Riparian. If a site only meets two of the three, then there is a ‘Yes’ in the corresponding criteria fields and a blank field for the criteria that is not met. The principal is the same for a site that only meets one of the three criteria. The three criteria field records are used together to calculate the value of a newly created field for the restoration category. The new field contains the potential restoration category value for each site. The values are calculated and any areas that do not contain a potential wetland restoration category are eliminated. These include areas with the low slope criterion only present. The model output consists of the following potential restoration category values after the low slope only areas are eliminated from the output:

- **High**: Riparian area, Poorly drained soils, and Low slope
- **Moderate 1**: Riparian area, Poorly drained soil
- **Moderate 2**: Riparian area, Low slope
- **Moderate 3**: Poorly drained soil, Low slope
- **Low 1**: Poorly drained soils
- **Low 2**: Riparian area
Bottomland restoration opportunities vary in quality within the study area due to the criteria or criterion located at each site. This potential restoration category value serves as a ranking, or prioritization system for the potential sites through the criteria present. Areas classified as High are optimal restoration sites because they meet all three criteria, which correspond to the best opportunity for successful restoration, if they contain degraded wetlands. They should be targeted first in the wetland restoration process. The potential restoration value decreases from the Moderate 1 to the Low 2 restoration category, as certain criteria combinations are less desirable for wetland restoration. The combination in the Moderate 1 category is the best combination for the moderate categories. The poorly drained soil criterion in Moderate 1 should pond surface water in the riparian area longer than other moderate areas. This allows wetland conditions to persist longer and hydric soils to develop. Poorly drained soils are the best single criterion because of the previous reason, potential for hydric soils to develop.

There is no site restoration category for the low slope criteria only for this project. There are two reasons for excluding this criterion. First, low slope only also identifies flat areas that are located on higher elevations outside the riparian area boundary, like hilltops. Lack of consistent surface water presence through flooding and hillside runoff for wetlands is a problem at higher elevations. The wetland is unable to persist long enough to provide the necessary functions and the necessary criteria will often not exist. Second, the riparian layer can also identify flat areas that are located in stream bottoms. Creating a low slope area can duplicate the riparian area in the analysis process. The initial model output identifies all potential restoration sites within the study area, regardless of ownership and size. However the potential sites of interest for this project are located only on National Forest property.

The second stage concludes by identifying those sites that are located on WNF property and greater than one quarter of an acre in size. Ewing (2006), the WNF Biologist, provides the one-quarter of an acre minimum size that WNF is interested in. This project is ultimately for WNF use and a copy of the results will be given to the WNF Biologist at its completion. The model’s output reflects the WNF’s desire for wetland
restoration or preservation in its boundaries. The identification is done by first joining the potential sites shapefile and the Athens Unit shapefile containing surface ownership data together with the Identity tool. The Identity tool is a geoprocessing tool that combines the portion of two shapefiles that overlap into a new shapefile while keeping all boundaries and attribute tables of the two shapefiles. The selection tool is used to select the sites with a surface ownership of USA and export them as a new shapefile. There are some adjacent polygons that have the same potential restoration category value in the shapefile of WNF sites only. These sites are joined together in a two-step process. First, the Dissolve tool is used to join polygons by the potential restoration category value, which results in six new multipart features. Second, an editing tool that explodes multipart features is used to break the six features into their individual polygons. The acreage for each site is then calculated within ArcMap so that one quarter of an acre and larger sites can be selected and exported. The one quarter of an acre size is primarily to eliminate the model output areas that are extremely small slivers and polygons slightly above zero acres, like an area 0.00001 acres in size.

3.5 Model Output Results

The WNF wetland model identifies a large number of potential wetland restoration sites for the Athens Unit. The sites are located in stream bottomlands of the Hocking River and its tributaries, both small and large. The study area is primarily composed of rolling hills and narrow stream valleys, with the latter containing the potential restoration sites. This spatial location results in the potential sites predominately exhibiting a long and narrow shape within riparian areas. Appendix A contains a series of maps for the WNF wetland model’s output of potential wetland restoration sites. The maps are organized on a county-by-county basis within the study area.

The minimum, maximum, and average size, in acres, of potential restoration sites is a reflection of their spatial location (Table 3.1). The maximum size of a restoration site is quite large, 98 acres, but large sites are predominately uncommon. The relatively small average size of a potential restoration site illustrates the dominance of smaller
restoration sites. The total acreage of potential sites appears significant, until it is compared with the total acreage of the study area. The Athens Unit contains 75,321 acres of property in Southeast Ohio. Potential wetland restoration sites occupy a very small percentage of the study area (5%). The strength of the WNF wetland model is its ability to prioritize the potential restoration sites based on a potential restoration category value.

<table>
<thead>
<tr>
<th>Model</th>
<th>Total Sites</th>
<th>Minimum Size</th>
<th>Maximum Size</th>
<th>Average Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1113</td>
<td>0.25 acres</td>
<td>98 acres</td>
<td>3 acres</td>
</tr>
</tbody>
</table>

Table 3.1: Descriptive statistics of model’s aggregated output

There are a few significant results from the WNF wetland model in reference to the potential restoration category value of potential sites (Table 3.2). The High restoration category value contains the least acreage, which equals 5% of the model’s total. This is expectedly small because it is the optimal category with all three criteria present. Potential restoration sites with two or one criteria present are more prevalent because they are not as exclusive in their requirements. There are 467 more Moderate than High category sites in the WNF wetland model. The Moderate category sites become important because there are a lot fewer High category sites when the two are compared. The two Low categories contain the most acreage and largest average size. The Low 1 category accounts for 52% of the model’s total acreage while the Low 2 restoration category value accounts for 17% of the model’s total acreage.

<table>
<thead>
<tr>
<th></th>
<th>Total Sites</th>
<th>Minimum Size</th>
<th>Maximum Size</th>
<th>Average Size</th>
<th>Total Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>124</td>
<td>0.25</td>
<td>12.56</td>
<td>1.57</td>
<td>194.68</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>100</td>
<td>0.25</td>
<td>19.34</td>
<td>2.73</td>
<td>272.62</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>189</td>
<td>0.25</td>
<td>24.66</td>
<td>1.77</td>
<td>335.39</td>
</tr>
<tr>
<td>Moderate 3</td>
<td>302</td>
<td>0.25</td>
<td>13.32</td>
<td>1</td>
<td>302.13</td>
</tr>
<tr>
<td>Low 1</td>
<td>251</td>
<td>0.25</td>
<td>78.85</td>
<td>7.5</td>
<td>1881.49</td>
</tr>
<tr>
<td>Low 2</td>
<td>147</td>
<td>0.26</td>
<td>97.97</td>
<td>4.27</td>
<td>627.86</td>
</tr>
</tbody>
</table>

Table 3.2: Descriptive statistics of model’s potential restoration categories
3.6 Field Validation

The wetland restoration project described by Stephens (2006) applies a minimum size criterion of five acres to designate wetland restoration sites available for field validation. A minimum size selection of five acres for this field validation is added to the model’s final output for two reasons. First, the number of sites available for the field validation is reduced for the short available time period. Second, the larger size of sites are easier for accurately performing field validation with a transect line and soil sample inside site boundary. A minimum size of five acres is applied to the model output by using the selection command with a constraint of greater than or equal to five acres. The validation process uses a soil sample point along a 100-meter transect line to assess the accuracy of the model with visual observations for the criteria. A single transect line is established within potential sites that are under ten acres and two transect lines within potential sites over ten acres. A single transect line and soil sample point is considered a sample site for the field validation and assessment process.

Campbell (2002) describes a sampling strategy, simple random sampling, for determining sample sites for accuracy assessments of remotely sensed imagery in the field of remote sensing. It is described as “probably the most powerful sampling strategy available” (Campbell, 2002, 375) and ensures that some level of bias is removed with any site having the potential of being identified as a sample site. However, the WNF wetland model identifies a large number of potential restoration sites over five acres, 158 to be exact. It is not feasible to perform an accuracy assessment on this many points for the short validation time length available. The amount of sample sites needs reduced even more for this field validation and resulting accuracy assessment.

Field validation is not needed on all six potential restoration category values due to the hierarchy involved in the model outputs. The most complex and desirable sites for the restoration process contain the High and three Moderate potential restoration categories. These sites contain all three and two of three criteria, respectively. If the
model is accurate for predicting the criteria present at these restoration categories, then it is logical that it is accurate for the Low potential restoration categories also.

The purpose of the field validation is to test the model’s accuracy for the potential restoration category value at the potential restoration sites. This is done through sampling for criteria present and determining the field-based potential restoration category value. This valued is compared to the WNF wetland model’s restoration category at the same site in the accuracy assessment. It is imperative that the field validation be as unbiased as possible in relation to knowledge of the restoration category at sample sites. This eliminates the possibility of making a sample site fit the model’s restoration category value. The bias is eliminated by creating a copy of WNF sites five acres and larger with High and Moderate restoration category values with no restoration category value or criteria fields contained in the shapefile. There are expectedly less potential sites available for field validation at the High category and more within the Moderate categories (Table 3.3). There are thirty-seven potential restoration sites available for field validation, which is used to calculate the percent of total in the table.

<table>
<thead>
<tr>
<th></th>
<th>Count</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>7</td>
<td>18.9</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>14</td>
<td>37.8</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>11</td>
<td>29.7</td>
</tr>
<tr>
<td>Moderate 3</td>
<td>5</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Table 3.3: Count of potential restoration category values in field validation

Potential restoration sites for field validation are located using a GPS unit loaded with the ArcPad mapping program. The ArcPad program allows the GPS unit to work with the shapefiles for potential sites. The GPS unit is used to navigate to a location inside a potential restoration site to begin the validation process. Visual observations for low slope and riparian area indicators are taken while walking along the transect line (Appendix B). Hydrologic indicators of flooding or ponding, such as flood debris, watermarks, trees with fluted trunks or shallow roots, hydrophytic vegetation, and
standing water, are evidence of riparian area location that are searched for. The field validation for the poorly drained soil criterion takes place using a different method.

Soil samples with Munsell soil chart readings and visual observations are the tools used to analyze the poorly drained soil criterion at a sample location along the transect line. A random number less than 100 is used to designate the location for the soil sample along each line. The soil sample location and transect line is the sample site within each validated restoration site. A soil sample is taken using a soil probe with a Munsell reading taken at eight inches to analyze the poorly drained soil criterion. The Munsell reading consists of soil color followed by a hue, value, and chroma reading. The presence or non-presence of the poorly drained soil criterion is determined from the combination of the Munsell reading and ground surface observation at the soil sample site and along the transect line. This is because somewhat poorly drained soils do not have the gleyed color and low Munsell reading that are characteristic of hydric soils (poorly drained and very poorly drained soils). Visual observations of standing water, water or sediment stained leaves, and a mucky ground surface are evidence that may be used to designate a site as poorly drained even if Munsell reading indicates otherwise.

The location of each soil sample site is recorded using the GPS unit and attributes entered for observed restoration potential category, Munsell reading, soil color, site notes, etc. A checklist for the criteria layers is used to record the results of the visual observations and Munsell soil readings (Appendix C). There are fifty sample sites in the field validation because thirteen of the thirty-seven potential sites for the field validation are over ten acres and require two sample sites each. The observed potential restoration category value for each sample site is recorded in the checklist.

After field validation, the soil sample location shapefile is downloaded from the GPS unit and brought into the GIS environment. The model’s output of potential sites with High to Moderate potential restoration categories over five acres are spatially joined to the sample points shapefile to create a new sample point shapefile. This new point file has both the potential restoration category identified by the model and the observed potential restoration category derived from the field validation. The two restoration
categories are manually compared to determine if the WNF wetland model performs well in identifying criteria present. Accuracy assessment principles and measurements from the field of remote sensing are used to quantitatively evaluate the performance of the WNF wetland model. Although this is not a remote sensing study, this method of accuracy assessment will provide a baseline by which to better understand the accuracy of the data and model used for decision-making.

3.7 Accuracy Assessment Results

The field validation for the fifty sites was completed from the beginning of February to the beginning of March. There was no input of existing water features in developing the WNF wetland model, which presented a slight problem for the accuracy assessment. Three of the sample sites were excluded from the accuracy assessment of the model after field validation was complete. One of the potential restoration sites identified for field validation is the entire portion of Burr Oak Lake that is located on WNF property. It is over ten acres in size, which results in two sample sites being excluded in the accuracy assessment. The remaining sample site is excluded because the field validation was unintentionally completed on only one site that was over ten acres. Two sample sites were required, but one was excluded without recognition. Thus, the accuracy assessment for the WNF wetland model occurs on forty-seven sample sites, which is three less than anticipated.

Campbell (2002) provides a number of ways to evaluate the accuracy of a classified map in remote sensing. One accuracy assessment method evaluates a classified map developed by an analyst by comparing it with a reference, or known, map of the same area on a pixel-by-pixel basis. This method of accuracy assessment is known as site-specific accuracy because two maps are being compared at the same locations. The accuracy assessment for the WNF wetland model uses site-specific accuracy on the potential restoration sites to evaluate the accuracy of the model. This method is applicable because it uses the same principle of assessment found in remote sensing. It compares field observed potential restoration categories with a reference potential restoration categories at the same sample sites. The model’s output serves as the
reference map for the accuracy assessment. The accuracy assessment is best understood visually with an error matrix of the classification process. An error matrix visually represents the comparison between the observed and model potential restoration category values that takes place in this accuracy assessment. The matrix provides a visual representation of the classification process. The number of correctly and incorrectly labeled classes is shown in a grid format.

The greatest amount of field misclassification in the model’s potential restoration categories occurs within the Moderate 1, Moderate 3, and High categories (Table 3.4). Seven of the High category sample sites are misclassified, all eighteen of the Moderate 1 category field sample sites are misclassified, and all five of the Moderate 3 category sample sites are misclassified. The majority of the sample sites misclassified in the Moderate 1 and 3 categories are misclassified into the Moderate 2 category, seventeen out of twenty-four sites (71%). This means that one of the criteria indicated as present is not in the model and should be replaced with the criterion indicated as not present. Four of these sites are classified into the High category, which means that a single criterion is not indicated as present. The Low 2 and None categories are included because of the field validation results. One sample site visually contained the Low 2 category’s criterion and two more sample sites contained the criterion not found in the model’s output, low slope. There are some remote sensing accuracy measurements that can be calculated to evaluate the error matrix of the WNF wetland model more thoroughly.

Table 3.4: Error Matrix of WNF wetland model

<table>
<thead>
<tr>
<th>Field Validation</th>
<th>High</th>
<th>Moderate 1</th>
<th>Moderate 2</th>
<th>Moderate 3</th>
<th>Low 2</th>
<th>None</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>2</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Moderate 3</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Low 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>6</td>
<td>0</td>
<td>38</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>
The simplest measure of accuracy that can be calculated from the error matrix is percentage correct. It is the proportion of sites classified correctly in the field. Percentage correct is also known as observed correct and is the sum of the diagonal entries divided by the total number of sample sites. The diagonal rows in the error matrix are the pixels classified correctly and the nondiagonal rows are the pixels classified incorrectly. The WNF wetland model has a percentage, or observed, correct value of 31.9%. There are only fifteen sites classified correctly, while there are thirty-two sites classified incorrectly. There are four more measurements that are also used to fully evaluate the classification or misclassification that exists in this error matrix of the WNF wetland model.

The producer’s accuracy (PA%) provides the percentage of each category classified correctly in field (Table 3.5). The error is assessed using the WNF wetland model as the base. This value is 100% for a category classified entirely correct in the field, which means that higher is better. The Moderate 2 category is classified 100% correct, while three of the other categories are primarily classified incorrectly in the field. The High category, 12.5% is slightly better than the other two categories, all 0%. The PA% is not available for the Low 2 and None categories because they are not in the categories designated for field validation. The field validation uses only sites with High to Moderate 3 categories, but field observations classify a few sites with the Low 2 and None categories. The consumer’s accuracy (CA%) provides an indicator to the reliability of the field-based observations. It provides a percentage for how much of each category actually corresponds to that same value on the ground. This value is 100% also for maps with a perfect correspondence between classified and reference image. A low percentage indicates that a lot of the sites classified as a certain category are really other potential restoration category values in the model. The Moderate 2 category has the best CA% for the model at 36.8%, which is significantly lower than 100%. As Table 5 indicates, there are a significant number of sample sites classified as Moderate 2 in the field. However, the comparison to the model reveals that a large proportion of the sites are actually
another category. The High category has the next highest CA% at 16.7%, while the Low 2 category value has 0%. The Moderate 1 and 3 categories have no possible CA% because there were no sites classified with those values in field observations. The last two error percentages evaluate the accuracy of the sites in the field classification.

<table>
<thead>
<tr>
<th>Model Output</th>
<th>High</th>
<th>Mod. 1</th>
<th>Mod. 2</th>
<th>Mod. 3</th>
<th>Low 2</th>
<th>None</th>
<th>Totals</th>
<th>PA%</th>
<th>EO%</th>
<th>EC%</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>12.5</td>
<td>87.5</td>
<td>83.3</td>
</tr>
<tr>
<td>Mod. 1</td>
<td>2</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>100</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Mod. 2</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>100</td>
<td>85.7</td>
<td>n/a</td>
</tr>
<tr>
<td>Mod. 3</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>100</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Low 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>100</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>100</td>
</tr>
<tr>
<td>Totals</td>
<td>6</td>
<td>0</td>
<td>38</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA%</td>
<td>16.7</td>
<td>n/a</td>
<td>36.8</td>
<td>n/a</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.5: Error matrix of WNF wetland model with accuracy evaluations

The error of omission (EO%) indicates the percentage of each category not correctly classified in the classification process. Essentially, it is the percentage of the category omitted from the classified map. The lower the EO% is the better. This means that the majority of sites in the category are classified correctly. Three of the categories have a very high EO%, which is an indicator of significant misclassification in those categories. The Moderate 1 and 3 categories have a 100 EO%, which means that all of the sites are misclassified in the field. Only the Moderate 2 value has the desired 0 EO%, which indicates that no sites were omitted and all are classified correctly. The EO% cannot be calculated for the Low 2 and None categories because they are not included in the field validation process. The error of commission (EC%) indicates the percentage for each category on the reference map incorrectly assigned to other categories on the classified map. The High and Moderate 2 categories have the highest EC%’s, over 50%, in the classified map because they are they only two categories assigned in the field validation. The Low 2 and None categories both have a 100 EC% because they are all incorrectly classified during the field validation. The High category has the next highest
percentage of almost 84%. The EC% cannot be calculated for the Moderate 1 and 3 categories because they are not used in the field classification and cannot be incorrectly assigned to other categories.

The majority of misclassification in the field validation of the model’s potential restoration categories occurs within the Moderate categories. Seventeen of the thirty-two misclassified sample sites with the Moderate 2 category are classified with the Moderate 3 and Moderate 1 categories in the model. This is the result of both incorrectly identifying the wrong criterion as present and not identifying the right one. At fifteen of the seventeen sites, poorly drained soil was incorrectly identified as riparian area in the field. All the criteria layers used are difficult to visually identify in the field, primarily low slope and poorly drained soil. The poorly drained soil layer contains both hydric and non-hydric soils, which have very different visual characteristics. The indicators for somewhat poorly drained soil are very similar to riparian area indicators: standing surface water, buttressed trunks, shallow roots, and wetland drainage patterns (ditches). The first method to improve the WNF wetland model’s performance lies within the potential restoration categories themselves. The large-scale criteria data may not be appropriate for calculating the multiple Moderate categories within the WNF wetland model based on field observations. The WNF wetland model may perform stronger if the Moderate 1, 2, and 3 categories are combined into a single Moderate category. It does not address the significant problem of the poorly drained soil criterion layer being incorrectly identified as riparian area in the field. This method essentially waters down the misclassification issue within the model, but may improve its performance. This hypothesis was tested using the same accuracy assessment measurements on a second wetland restoration model with a single Moderate category. The new single Moderate category simply states that there are two of the three restoration criteria present.

The diagonal row in the new error matrix reveals that thirty-two out of forty seven sites are classified correctly in the second accuracy assessment (Table 3.6). The same sample sites from the field validation are used in this new accuracy assessment. The percent correct value for the classified map using the single Moderate category is 68.1%.
Thirty-one out of thirty-nine sample sites are correctly identified with a single Moderate category in the field. This new percentage correct value is significantly better with a single Moderate category, 29% to be exact. The PA%, CA%, E0%, and EC% were also calculated again for the second accuracy assessment.

<table>
<thead>
<tr>
<th>Field Validation</th>
<th>High</th>
<th>Moderate</th>
<th>Low 2</th>
<th>None</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Moderate</td>
<td>5</td>
<td>31</td>
<td>2</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td>Low 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>6</td>
<td>38</td>
<td>2</td>
<td>1</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 3.6: Error matrix with single Moderate category

The PA% is significantly different for all the categories in the field validation. The Moderate category has the most accurate classification at 80% while the High category is dramatically lower at nearly 13% (Table 3.7). The PA% cannot be calculated for the Low 2 and None categories because they are not included for field validation, but were used to classify sites in the field based on criterion present. The highest and lowest CA% occurs in the Moderate and High categories, respectively. The Moderate category is the category that shows the strongest reliability in field classification. The High category has the weakest reliability in field classification. The poorly drained soil criterion is incorrectly left out at all six of the misclassified High category sites. The prevalent misclassification within the High category is significant because it is the most important category in terms of restoration success. Again, the poorly drained soil does not result in correct field identification of the potential restoration category at the majority of sample sites. The Low 2 and None categories have no reliable prediction because the categories are not included for field validation. These measurements are an improvement from the first accuracy assessment.
The highest EO% is found in the High category and the lowest in the Moderate category. The High category has the highest number of sites misclassified in the field observations while the Moderate category has the lowest number of sites misclassified. The field classification is significantly better for the single Moderate category. The High category, the most optimal restoration site, still shows the same 87.5% value as the first accuracy assessment. The highest EC% of the High and Moderate categories is found within the High category also. The EC% refers to the percentage of sites in the model output classified with the incorrect restoration category. Seven out of eight High category sites on the reference map are incorrectly assigned to the Moderate category. The Moderate category contains a significantly smaller EC% because the vast majority of its sites, thirty-one out of thirty-nine, are correctly classified in the field. The improvement made to the WNF wetland model in combining all Moderate categories significantly improves the accuracy assessment and model’s performance. It results in more sites being classified correctly with the appropriate restoration category value in the field validation. There is one final modification made to the WNF wetland model to improve its performance even more, which is borrowed from the earlier pilot project.

The WNF wetland model’s riparian layer is a 100-year flood boundary found on flood insurance maps. The areas inside the boundary will flood at least once every hundred years, which means that the flooding occurrences vary greatly inside the boundary. There will be some areas that flood only once in 100 years and other areas that may flood once a year during the winter and spring. This means that some areas
indicated as containing the riparian area criterion may not exhibit characteristics of a riparian area. This occurs in three of the sample sites during the field validation of the WNF wetland model. They are located on higher elevations where there are no riparian area indicators identified, which results in the incorrect omission of that criterion. The pilot project that this study is based on uses a different riparian area layer from the NRCS. It uses a riparian area layer defined as being flooded for an extended period of time during the year. The soils Microsoft Access database mentioned earlier contains an attribute file in the component table that indicates the frequency of flooding events for all twelve months, including none, occasionally, and frequently. The soil polygons with a frequently and occasionally flooding designation are selected for the riparian area indicator. This is a more reliable indicator of surface water presence in an area. The WNF wetland model was run again with this new riparian layer to evaluate its performance and compare it with the original riparian layer.

This new model gives a different view of the wetland restoration potential that exists in the Athens Unit of the WNF. It identifies a smaller number of potential wetland restoration sites, 1,040 sites (Table 3.8). There are seventy-three less potential wetland restoration sites with the new riparian layer. This reduction in total sites is offset by the change to potential sites within the restoration categories. There are 148 more sites within the four High and Moderate categories. There are also significantly more potential wetland restoration acres within these categories, 1770 to be exact. As previously stated, the criteria combinations within restoration categories are considered the best for wetland restoration success. There are potentially more optimal wetland restoration opportunities within the WNF when using the new riparian layer. There are 120 sites that are available for field validation, which is significantly more than the thirty-seven in the original WNF wetland model. This has the potential to help future field validation because it provides more samples and a better chance to achieve the desired performance level. The same sample sites are used in the accuracy assessment of this new model. The accuracy assessments are performed using three Moderate categories and a single Moderate category, as with the original WNF wetland model.
<table>
<thead>
<tr>
<th></th>
<th>Total Sites</th>
<th>Average Size</th>
<th>Total Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>302</td>
<td>1.22</td>
<td>369.65</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>78</td>
<td>1.62</td>
<td>126.64</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>263</td>
<td>1.74</td>
<td>458.27</td>
</tr>
<tr>
<td>Moderate 3</td>
<td>220</td>
<td>8.73</td>
<td>1920.5</td>
</tr>
<tr>
<td>Low 1</td>
<td>48</td>
<td>5.75</td>
<td>276.14</td>
</tr>
<tr>
<td>Low 2</td>
<td>129</td>
<td>9.91</td>
<td>1279.63</td>
</tr>
</tbody>
</table>

Table 3.8: Descriptive stats of restoration categories with new riparian layer

There are only thirteen of forty-four sample sites classified with the correct restoration category using multiple Moderate categories in the new model, which equals 29.5% correct (Table 3.9). This is a slightly weaker performance than the original WNF wetland model at the same level, which had 31.9% classified correctly. Again, the misclassification occurs most frequently within the three Moderate categories. It appears that even with the new riparian criterion, the data do not support classification into such fine categories. The accuracy assessment for this new model was also performed again using a single Moderate category. There are thirty of forty-four sample sites classified with the correct restoration category, which equals 68.2% (Table 3.10). The model’s performance increases significantly using the single Moderate category, which also occurs in the original WNF wetland model. It is interesting to note that the performance levels are very similar for the models using either riparian area criteria layers. The assumption that the second riparian area criterion layer, developed from flooding information, would be more reliable is wrong. There is only a minimal increase in the model’s performance when the pilot project’s riparian area layer is used with a single Moderate category, approximately 0.1%. However, this assumption was also tested with the somewhat poorly drained soil layer included in the model’s poorly drained soil criterion. As the accuracy assessment demonstrates, two out of the three restoration criteria for the WNF wetland model are reliable enough to use in the wetland restoration process.
The low slope and riparian area criteria layers are reliable criteria layers for this project. The WNF wetland model’s Moderate 2 categories, with low slope and riparian area, are all correctly classified in the field validation. The Moderate 1 and 3 categories, with riparian area and one of the other criteria layers each, are all classified with the wrong restoration category in the field. The repeated exclusion of the poorly drained soil layer in the field validation of the WNF wetland model’s restoration categories is a significant problem. It causes misclassification of the restoration category at the vast majority of the sample sites. The merging of the three Moderate restoration categories significantly lessens the impact of the exclusion and increases the WNF wetland model’s performance. This does not completely solve the poorly drained soil exclusion problem. There are six out of seven High category sites still misclassified with the incorrect
restoration category, due to poorly drained soil exclusion. This is a problem that needs addressed in future wetland restoration models because High category sites are optimal restoration sites. Poorly drained and very poorly drained soils (hydric soils) are wetland parameters that need to be included in restoration projects, as demonstrated in the literature review.

A potential improvement to the poorly drained soil exclusion problem in the WNF wetland model is to remove the soils criterion. The restoration category without poorly drained soil, Moderate 2, in the WNF wetland model is the most reliable. All of the Moderate 2 category sites were classified correctly in the field. However this would remove an important wetland parameter from the restoration process. The right type of soil, hydric soil, is important to the sustainability of wetlands. The poorly drained soil layer needs replaced by another restoration criterion that is similar in nature. The substitution variable has to portray a similar aspect, which is soil wetness. The literature review suggests two variables that could be substituted for soils in this model for future applications: potential wetness value or saturation index (Russell et al., 1997 and White and Fennessy, 2005). These are both DEM derived values that identify soil saturation, or wetness, at a given point from topographical data. Very poorly drained and poorly drained soils, hydric soils, will have the highest wetness values or saturation indices. The potential wetness value measures the predicted soil saturation by excess surface water runoff on surrounding slopes from higher areas (Russell et al., 1997). This projects study area is located in the topographically diverse area of southern Ohio. The potential wetland restoration sites identified by the WNF wetland model are typically located at downslope areas from an adjacent hill or hills. The wetness value would be very applicable to wetland restoration models in southern Ohio, including the WNF wetland model. The saturation index is very similar to the wetness value. It uses a DEM and slope values to estimate the saturation index of a location based on surface water flow to that location (White and Fennessy, 2005). These two variables provide a potentially reliable alternative to the poorly drained soil criteria layer in the WNF wetland model that could improve its performance even more.
Chapter 4. Methods Comparison

4.1 Method

The WNF wetland model method is a new method of determining preliminary potential restoration sites within the Athens Unit of the WNF. It serves as the first step in the wetland restoration process to guide in-depth field analysis. It uses the capabilities of a GIS to process and store criteria information quickly for the Athens Unit of the WNF. The model method has the potential to be applied to the Ironton Unit of the WNF and other National Forests also. The previous method of determining preliminary potential restoration sites involves WNF employees spending two periods of time in the field with limited knowledge of criteria present to analyze potential sites. Comparison of the time length involved in the process of developing restoration criteria and identifying preliminary list of potential restoration sites is best for determining which process is more efficient. The method that has the shorter analysis time for determining preliminary list of potential restoration sites is the most efficient for this comparison.

4.2 Results

The time length involved in developing this GIS model for preliminary potential wetland restoration sites is a short time period of two days. Each stage in the model’s development takes a day to complete with some time reserved for complications. It takes approximately three hours to download the three criteria layers from their appropriate data sources on the World Wide Web. The low slope criterion is downloaded in one raster grid for the Athens Unit. The poorly drained soil and riparian criteria is downloaded individually for each county within the Athens Unit. The riparian area criterion is also converted from an interchange file to a coverage on a county by county basis. The development of the criteria layers for model input takes approximately three hours to complete. This involves selecting the soil units designated as poorly drained, converting the riparian area coverages to shapefiles, and performing a slope calculation on the 10 m DEM, converting it to a vector file, selecting 3% and less areas, and exporting those areas to a new shapefile. Each of the criteria layers are also clipped to the Athens Unit boundary and a new criteria field added. The second stage of the
process, the model development, takes approximately four hours. The three criteria layers are joined together and the potential restoration category for each potential site is calculated. The sites are joined with the Athens Unit to include ownership information, acreage is calculated, sites with WNF ownership are exported to a new layer, adjacent sites with same restoration category are joined, and sites greater than five acres are exported to a new shapefile. This entire process encompasses a two-day period, with the end result being a map of potential restoration sites by potential restoration category. The traditional method that WNF employees apply is very different, in structure and time length, to the model method.

The traditional method takes a longer time period of approximately three weeks to develop a preliminary list of potential restoration sites. A team of WNF employees first goes into stream bottomlands on forest property with only a paper copy of the most recent soil survey record for those areas. The soil survey record is used to locate the bottomlands that contain the appropriate soils, which are poorly drained, for potential restoration sites. A site inventory is performed on those appropriate sites to identify any drainage tiles, determine slope of area, vegetation type, negative impact, standing water, existing wetlands, etc. The site inventory is used primarily to identify the potential wetland restoration sites based on all required criteria. The location of poorly drained soil areas in bottomlands and corresponding site inventory takes approximately three weeks for a large area, like the Athens Unit. The next step of the process involves using the site inventory notes to identify those locations that are ideal for wetland restoration. The same employees who performed the site inventory meet together in the office to make this selection. A week for this stage is typical because of other meetings and commitments that the employees must take care of also. The total length of time to generate a list of potential wetland restoration sites is approximately a month using the traditional method. The efficiency of a method or process is best measured using the time length involved, so that a quantitative measure can be determined.

The efficiency involves identifying preliminary potential wetland restoration sites independent of any detailed field analysis to identify prime areas. The time to develop
and run the WNF wetland model is compared with the time length to finish the site inventory in the traditional method. The WNF wetland model method is a more efficient method to identify potential wetland restoration sites. It takes significantly less time in the analysis process than the traditional method, approximately two and a half weeks less. The model method has five other benefits to employees: 1) no trips to the field are needed to help identify preliminary list of potential restoration sites, 2) all the restoration criteria are applied at the beginning of the process to eliminate the limited knowledge about potential sites before site inventory, 3) only one person performs the analysis before any site inventories are performed, 4) it is more efficient to analyze large areas, like a Forest Unit or entire National Forest, using this method, and 5) the output of the model is a shapefile, which can be stored in a GIS data library and referenced at any future date. The greater efficiency and benefits that the GIS model method provides makes it an invaluable tool for the WNF, or any National Forest, to apply in their wetland restoration process.
Chapter 5. Discussion

Wetland restoration is an on-going practice throughout the U.S., including the WNF. Wetlands perform important biological and ecological functions, which make their presence in the landscape a necessity. The GIS environment is able to store and quickly analyze spatial data for large-scale wetland restoration applications. The literature review for this study discussed applications of GIS in the field of riparian and wetland research. A hierarchy was established that discussed a larger-scale riparian restoration application down to smaller-scale wetland research applications, in which the WNF wetland model is located.

The NCDCM Wetland Restoration and Enhancement Mapping Procedure described by Williams (2002) is slightly more complex. It uses an additional disturbance class designation for potential restoration sites. A land use layer and other secondary GIS data is used to generate the disturbance class for the model. The field validation and corresponding accuracy assessment indicate that 90% of its sites were correctly classified in the field as enhancement or restoration. The Earth Tech, Inc. restoration model described by Stephens (2006) is a very similar wetland restoration model. It follows a similar process, overlaying secondary GIS data to identify potential sites. There was no indication of any accuracy assessment of the model described in the document. However, it was mentioned that field validation was used to inventory potential sites and eliminate undesirable areas. There were ten potential sites recommended for wetland restoration as a result of the project. It can be considered a reliable model because potential sites were recommended for restoration at the end of the project. The Cuyahoga River Watershed model described by White and Fennessy (2005) is a more complex wetland restoration model. It used weighting values and a multi-criteria evaluation technique to identify and prioritize potential restoration sites. There was no indication of any model validation and accuracy assessment in the project. It successfully identifies and prioritizes potential wetland restoration sites. The identification and prioritization of potential wetland restoration sites with secondary data is the common thread that links these models with the WNF wetland model. The three wetland restoration models


discussed in the previous paragraph and the WNF wetland model all successfully identify potential wetland restoration sites. All four of the wetland restoration models employ the same process framework: overlaying of secondary GIS data to identify potential wetland restoration sites. They are all “an initial step in the site selection process that can guide more detailed, field-based assessments” (Russell et al, 1997, 65).

The WNF wetland model falls into the narrow focus of wetland research. It provides a reliable wetland restoration model for Southeast Ohio, specifically the WNF. This study is significant for two reasons. First, it is the first GIS-based wetland restoration model for the Athens Unit of the WNF. The WNF has historically relied on the traditional field-based method described earlier to identify potential wetland restoration sites. The results of this study and the earlier pilot project indicate the potential of the WNF wetland model to be an effective planning tool. It should be employed in future WNF wetland restoration projects. Second, the literature review did not reveal any other wetland restoration or identification models for the Appalachian area of the U.S. It appears that this area is lacking in the application of GIS to wetland restoration, conservation, or preservation. This study is the first GIS application to the Appalachian area of Ohio. It is also an indication of the potential to employ GIS in WNF’s southern Ohio wetland restoration effort.

The goal of this study is to develop a wetland restoration model for the Athens Unit of the WNF. This study strives to answer the following two questions. Is the WNF wetland model accurate for the Athens Unit of the WNF so as to be a more effective planning tool? Is the WNF wetland model method more efficient than the traditional method for identifying potential wetland restoration sites? The following paragraphs discuss the potential of the WNF wetland model based on the answers to the study’s research questions.

Field validation and the remote sensing principle of accuracy assessment are used to evaluate the performance of the model. The field validation of the unmodified WNF wetland model results in fifteen out of forty-seven sample sites being assigned the correct potential restoration category, which is 31.9%. The WNF wetland model performs the
strongest in the Moderate 2 category, which has a PA% of 100. This indicates that all of
the Moderate 2 sites are classified correctly in the field. This category contains two
restoration criteria: low slope and riparian area location. However, none of the Moderate
1 or Moderate 3 sites and the majority of High sites are classified correctly. These
restoration categories all have the poorly drained soil criterion layer in combination with
one or both of the other restoration criteria. They are all given other restoration category
values, predominately the Moderate 2 category, as the poorly drained soil layer is
incorrectly excluded in the field. These findings indicate the principal source for the
model’s weak performance, the poorly drained soil layer. The layer puts hydric and non-
hydric soils together to identify potential wetland restoration sites. Hydric soils have a
very different geographical location than non-hydric soils in Ohio.

The WNF wetland model somewhat uses a hydric soil criterion, but also includes
a somewhat poorly drained soil layer. The somewhat poorly drained layer needs
removed from the poorly drained soil criteria layer, as it is not a recognized hydric soil.
It does not fit within the focus of wetland restoration, which is to restore the essential
parameters to the extent possible. It is predominately brown in color, like drier and
better-drained soils. It is also visually hard to identify in the field because it does not
exhibit hydric soil characteristics. Hydric soils predominately exhibit a grayish or bluish
colored soil that is also very wet due to a high water table. Baker and Micacchion (1999)
identify the geographic location for hydric and non-hydric soils in Ohio counties (Figure
5.1). Northern and western Ohio contains the largest concentration of hydric soils and
non-hydric soils with hydric inclusions in the state. This area of Ohio is also the
glaciated area of the state where past ice movements left rich and agriculturally prime dirt
with remaining wetlands in scoured areas. It is no coincidence that northern Ohio also
contained the largest early wetlands in the state, with the Great Black Swamp and Lake
Erie Marshes to name a few. Southern Ohio, specifically southeast Ohio, is dominated
by non-hydric soils within the study area of this project. The very small areas of non-
hydric soils with hydric inclusions are limited to locations along the Hocking River and
its tributaries in Athens and Hocking counties. There is no digital hydric soils data for the
rest of the counties in the Athens Unit. However reports generated in the NRCS Soil Data Mart for Morgan, Perry, and Vinton counties on hydric soils indicate that hydric soils occupy only a small part of the map units in the counties. The acreage of WNF property in the Athens Unit is also very small in these three counties, which limits the amount of hydric soil that may be found on WNF property in the Athens Unit. This makes use of hydric soil as a restoration criterion for this area unrealistic.

![Figure 5.1: Digitized hydric soils in Ohio (ODNR Analysis Program)](image)

There is another modification that is applied to the WNF wetland model to improve its performance. A review of the scale for the criteria layers involved in the model development reveals that the data are primarily large-scale. The soils data range
from 1:12000 to 1:63360 and the riparian layer is a 1:24000. They are datasets that are ideal for performing analyses over larger areas. However, the accuracy may be lost when going down to the small-scale level of one hundred meter areas within individual sites. The largest amount of misclassification of categories was within the three Moderate categories. This suggests that it may not be appropriate to use multiple Moderate categories with large-scale data for the model. This hypothesis was tested by re-running the model with a single Moderate category. The same sample sites are used in the second accuracy assessment because the objective was to determine if the new category improved the field validation results. This modification greatly increased the model’s performance, by 36.2%. The observed correct percentage of the WNF wetland model with a single Moderate category increased to 68.1%. The WNF wetland model became significantly more reliable with a single Moderate category, although it just covered up the misclassification of the sites with the poorly drained soil criteria. This allows the WNF wetland model to be applied in the wetland restoration process now.

Visual indicators of standing surface water, plant modifications, and water-stained plants must be used to identify somewhat poorly drained soil. These indicators are also riparian area indicators, which leads to uncertainty in the classification process. There is consistent misclassification in the High restoration category in the WNF wetland model. The majority of the category’s sites were labeled as a Moderate 2 category when using multiple Moderate categories. The poorly drained soil layer was indicated as being missing due to uncertainty of the criterion in the field. As the NCDCM restoration model demonstrates, there is no uncertainty in the field when using recognized hydric soils. Removing the somewhat poorly drained class from the WNF wetland model’s soil layer will reduce the number of potential sites due to the low amount of hydric soil within the study area. The remaining ones would be better suited for wetland restoration with the use of hydric soil only. Adding a degraded land use criteria layer at the same time has the potential to increase the reliability of the WNF wetland model even more. It would also shift the focus of this model to only impacted wetlands in need of restoration. Two of the previously described wetland restoration models employ a degraded land use layer.
The NCDCM restoration model has 90% of its sites identified correctly in the field using the criterion in combination with the hydric soil. The performance of the WNF wetland model may be even stronger with the addition of these two criteria. An effective wetland restoration model uses criteria that are appropriate for locating impacted wetland areas, which is demonstrated in the literature review. The performance of the WNF wetland model with a single Moderate category is closest to the NCDCM restoration model. Both of the models have over 50% of their potential sites identified correctly in the field. The three models described in the previous paragraph employ two additional criteria that the WNF wetland model lacks: hydric soil and degraded land use. The addition of these two criteria to the WNF wetland model has the potential to improve its reliability and make it a truer restoration model.

The second research question compares the efficiency of the WNF wetland model method to the traditional method in identifying potential restoration sites. The traditional process uses two separate analyses in the office and field to identify potential sites, which takes about three weeks. The WNF wetland model method uses one single analysis in the office to generate an output of potential wetland restoration sites, which takes about two days. The model method is a more efficient method when comparing the analysis time involved in each method. This faster analysis time is not the only reason it is considered more efficient. The previous discussion on the comparison of the WNF model method and the traditional WNF method indicated five other reasons for this. For example, a GIS model has the ability to be saved and exported in a format that keeps the process intact and allows other data to be substituted. An accurate model saved in this format can be sent to the Ironton Unit of the WNF or even another National Forest. The appropriate low slope, poorly drained soil, and riparian area data can be substituted for the Athens Unit data and the analysis ran to identify potential wetland restoration sites at another location. This was not possible using the traditional wetland restoration site identification process. A model method, like this one, establishes a standardized process that can be repeated for any spatial location with the appropriate data. A reliable model would be an invaluable asset to the wetland restoration process and the employees of the
WNF. This project provides a wetland restoration model that can be used in the wetland restoration process of the Athens Unit to identify potential restoration sites. The majority of sample sites in the field validation were given the correct restoration category when using a single Moderate category. The suggested improvements to the model have the potential to make it the most effective tool and method for future wetland restoration opportunities in the Athens Unit of the WNF and other topographically similar areas.

One potential application of the WNF wetland model involves using it to perform an impact analysis of potential wetland restoration sites. As previously stated, the Athens Unit has been degraded due to agriculture and surface mining activities. The locations of the impacted areas can be obtained using both GPS technology and secondary GIS data sources. The 1992 NLCD contains different agricultural land classes, such as row crops, vineyards, pasture fields, etc., and the ODNR has some secondary data on surface mining locations. WNF employees have the ability to use GPS units to record the spatial location of surface mining impacts, including open portals, coal piles, and water seepage points. These data layers, or impact layers, can be used to identify what potential restoration sites are truly in need of restoration. The impact layers can be compared with the potential restoration sites to determine the sites that have been impacted and may be degraded. This serves as another prioritization method for potential restoration sites, which is based on the need for restoration. The potential restoration sites that have been impacted can be targeted first in the restoration process. This information can be kept in a digital database for reference any time money is allocated for wetland restoration in the Athens Unit of the WNF. The restoration criteria used in this study indicate another potential application for the WNF wetland model outside of original intent.

The criteria layers used in the WNF wetland model are all recognized wetland parameters. There is no degraded land use used as a criteria layer, which means that the model has the potential to identify existing wetlands also. As previously stated, wetlands are ecologically important features that need to be protected. Secondary GIS data on existing wetlands can be overlaid on the potential sites identified by the WNF wetland model in an existing wetland analysis. The existing wetlands that overlay potential
wetland restoration sites can be targeted for field validation. Then any existing wetlands on those sites can be recorded and protected from future impacts. The OWI wetland layer is an example of secondary wetland data that can be used in this type of analysis. There is one considerable problem with using secondary wetland data, which involves the temporal resolution. The OWI wetland layer has a temporal reference of 1992. The data are too old to get a truly accurate representation of the existing wetlands but it can guide in an exploratory manner. This exploratory data analysis was completed on the WNF wetland model’s final output to get relationship between restoration criteria used and existing wetlands.

An acres field is added to the OWI wetland layer for the Athens Unit and its value calculated. There are 304 wetlands that intersect the WNF wetland model’s final output of sites ¼ of an acre and greater in size. However there is no indication of how much of the existing wetland overlaps at each of the final restoration sites. The existing wetlands and model’s final output is combined together using the Union tool. Then areas with both a restoration category and OWI wetland code are selected and made their own layer. These are final sites that overlap existing wetlands in the Athens Unit, in which the acreage field is recalculated for the newly created wetlands. Some wetlands are cut at final site borders in this process. There are 549 existing wetlands contained within the model’s final sites, for a total of 131 acres (Table 5.1).

<table>
<thead>
<tr>
<th></th>
<th>Wetland sites</th>
<th>% Total Sites</th>
<th>Acres</th>
<th>% Total Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>57</td>
<td>10</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>58</td>
<td>11</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>91</td>
<td>17</td>
<td>34</td>
<td>26</td>
</tr>
<tr>
<td>Moderate 3</td>
<td>93</td>
<td>17</td>
<td>17</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 5.1: Existing wetlands in model’s final sites

Fieldwork by WNF employees is potentially the best method to gain existing wetland data with the best temporal resolution. It is a longer process than a GIS analysis, but it will reveal the most recent wetlands and ones too small for images to pick up. The
High and Moderate categories are the most reliable for restoration success, which means that they will be most optimal for wetland existence with criteria used. Employees can use the model to identify location of High and Moderate sites of designated size to search for existing wetlands to protect. The field validation completed for this study is a perfect example of this. It reveals the presence of a large, existing wetland approximately thirteen acres on a potential restoration site. It contains both open water areas and shallow vegetated areas (Figures 5.2 and 5.3). The field validation also reveals the presence of shallow, standing water areas at six other sample sites. The standing water ranges in size from 1.5 x 17.5 meter ditches to 40 x 150 meter areas (Figure 5.4). These areas are not represented in the secondary data of the OWI. Multiple WNF departments, such as recreation and biology, can use the model to ensure that wetlands and their important ecological functions are both preserved and restored in the Athens Unit. Detailed field analysis on the High and Moderate categories can be performed by WNF employees to search for existing wetlands. The quantitative evaluation of the WNF wetland model’s performance illustrates a very important conclusion about its reliability as a planning tool.
Figure 5.2: Open water in existing wetland at one sample site (2/18/2006 by author)

Figure 5.3: Vegetated areas in existing wetland at one sample site (2/18/2006 by author)
The primary goal of this study is to develop an accurate wetland restoration model for the Athens Unit of the WNF. A reliable model is an invaluable planning tool for the wetland restoration process. The WNF wetland model successfully identifies and prioritizes potential restoration sites using restoration category values. There is a single High and multiple Moderate and Low categories in the original model due to the multiple criteria combinations available at potential sites. The field validation and corresponding accuracy assessment revealed that the WNF wetland model performs the strongest with a single Moderate category. Approximately 70% of the validated sites are correctly identified with the correct restoration category in the field using a single Moderate category. The same percentage was reached using two different riparian area criteria layers, which was unexpected. It appears that the large-scale data does not support classification into such fine categories. There was an interesting result when using this study’s pilot project restoration criteria. It presented a different view of the study area’s wetland restoration potential. It identified slightly more sites and significantly more potential acreage in the High and Moderate categories. The WNF wetland model would be more realistic using this riparian area criteria layer because it is a more reliable
indicator of surface water presence than the 100-year flood hazard area originally used. The WNF wetland model is an effective and reliable wetland restoration model with either riparian area criteria, but could potentially be even more reliable with one more modification.

The WNF wetland model uses the somewhat poorly drained soil layer in its soil criterion, which is not a recognized hydric soil. Somewhat poorly drained soils do not exhibit the same characteristics as hydric soils, which leads to uncertainty in the field. There is consistent misclassification of the High category sites in the WNF wetland model, regardless of which riparian area layer is used. Five or six out of the seven sites should have been classified as High, but are classified as Moderate 2. The poorly drained soil layer was left out as an observed criteria layer due to uncertainty in the field. As the NCDCM model indicates, there is no uncertainty with using only hydric soil with other restoration criteria. It performs extremely well in its field validation, with 90% classified correctly. The WNF wetland model has the chance to reach the same performance level with the addition of the hydric soil layer. Two of the other wetland restoration models used hydric soils in combination with other criteria to successfully identify potential restoration sites. However, the WNF wetland model is not a failure and useless planning tool for the employees of WNF. It correctly identifies the restoration category at 68.1% of the sample sites with a modification of a single Moderate category. It is the first successful GIS wetland restoration model for the Athens Unit of the WNF, which can be applied in any national forest with the substitution of appropriate data. It can be added to the list of successful wetland restoration models described in the literature review of this document, which does not include an application to southern Ohio. It can be an even better and more reliable wetland restoration model with the addition of the hydric soil criteria layer in combination with a single Moderate category.
Literature Cited:


United States Department of Agriculture. 2005. 100 years of conservation for the greatest good.


Appendix A. Series of potential wetland restoration maps

Figure A.1: Index map of individual wetland restoration maps

Legend

- Political
  - County Borders
  - Other ownership
  - VNF ownership

- Other
  - Index Map Boundary

- Transportation
  - Main Highways

Notes: All index maps are in 1:40,000 scale, mapped by author. Sources: ESRI and Wayne National Forest GIS Department.
Figure A.2: Map 1: Potential sites in northeastern Vinton County
Figure A.3: Map 2: Potential sites in southeastern Hocking County
Figure A.4: Map 3: Potential sites in southeastern Hocking County

Legend

Restoration Category
- High
- Moderate 1
- Moderate 2
- Moderate 3
- Low 1
- Low 2

Political
- Other ownership
- WNIF property
- Hocking County

Hydrology
- Streams

Notes: All index maps are in 1:40,000 scale. Mapped by author.
Sources: ESRI and Wayne National Forest GIS Department.
Figure A.5: Map 4: Potential sites in eastern Hocking County
Figure A.6: Map 5: Potential sites in northeastern Hocking County
Figure A.7: Map 6: Potential sites in southwestern Perry County
Figure A.8: Map 7: Potential sites in southern Perry County
Figure A.9: Map 8: Potential sites in southern Perry County
Figure A.10: Map 9: Potential sites in eastern Perry County
Figure A.11: Map 10: Potential sites in southeastern Perry County
Figure A.12: Map 11: Potential sites in western Morgan County
Figure A.13: Map 12: Potential sites in northern Athens County
Figure A.14: Map 13: Potential sites in northern Athens County
Figure A.15: Map 14: Potential sites in northwestern Athens County
Figure A.16: Map 15: Potential sites in northwestern Athens County
Appendix B: Riparian area and poor soil indicators

I) Riparian area indicators
- Blackened water-stained leaves on ground surface
- Wetland plant species (sedges, rushes, willow trees, cattails, lilies)
- Standing water on ground surface
- Flood carried debris
- Water lines on trees with moss above or silt lines on vegetation
- Scoured (bare) areas on ground surface with or without sediment
- Wetland drainage pattern (drainage flow in & out of area w or w/out debris)

II) Hydric soil indicators (upper 6-12 inches)
- Grayish, blueish, or greenish soil color below thick, dark (black, dark brown) surface layer (gleyed soil) is very reliable
- Gleyed soil with chroma of 1 or 2 and yellow, orange, and reddish brown spots
- Potential rotten egg smell
- Mucky ground surface of 0.75 to 1 inch (or deeper) with gleyed soil under
- Gleyed soils found in wettest mineral soils with extended saturation
- Dry soils are brighter (yellow, brown, red) with grayish mottles (plate 27)

II) Munsell readings for hydric soil indicators (Hue, Value, Chroma in this order)
- Dominant 2 or less chroma if bright mottles present
- Dominant 1 or less chroma if no mottles present
- 4 or 5 value and 2 chroma if bright (yellow, orange) mottles present
- 4 value and 1 chroma with bright mottles present
- 5 or more value and 1 or less chroma
- 6 or more value and 2 or less chroma
- Neutral (gleyed) hue and value of 4 or more
- 10Y, 5GY, 10GY, 10G, 5BG, 10BG, 5B, 10B, or 5PB hue with value of 4 or more and chroma of 1
- 5G hue with value of 4 or more and chroma of 2 or less
- Possibly 5Y hue with value of 4 and chroma of 1
Appendix C: Accuracy assessment checklist

I) General Information
   1. Potential Site Object ID number: _________________________
   2. Area description: ________________________________________________

II) Criteria Information
   A) Low Slope
      1. Ground surface along transect: flat, steep, or mixed? ______________
      2. Does this site meet this criterion? ________________________________

   B) Riparian Area Location
      1. Evidence of flooding or inundation on or adjacent to transect/s? ______
         _______________________________________________________________
         _______________________________________________________________
      2. Evidence of other riparian area indicators on or adjacent to transect/s? ______
         _______________________________________________________________
         _______________________________________________________________
      3. Does this site meet this criterion? ________________________________

   C) Poorly Drained Soils
      1. Soil sample site ID and paces? _________________________________
      2. Maximum depth of soil probe? _________________________________
      3. Color description of soil in sample: ______________________________
         _______________________________________________________________
      4. Is ground surface mucky or contain organic material? ______________
      5. Munsell reading at 8”: _________________________________________
      6. Evidence of inundation or high water table at sample site? ____________
         _______________________________________________________________
      7. Does this site meet this criterion? ________________________________

   D) Restoration Ranking
      1. What potential restoration category should this site be? ______________
III) Wetland Plant Species

1. Are there any aquatic or emergent wetland plants (lilies, sedges, cattails), trees, or shrubs along, or adjacent to transect? 

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

2. Are there any noticeable wetland adaptations in any wetland plant species occurring? 

____________________________________________________________

IV) Impact Analysis

1. Is there any evidence of agricultural impact at the site? 

2. If so, describe: 

____________________________________________________________________
____________________________________________________________________

3. Is there any evidence of mining impact? 

4. If so, describe: 

____________________________________________________________________
____________________________________________________________________

V) Existing Wetlands

1. Any existing wetlands located on or adjacent to transect or observed on walk in and out of site? 

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________