USING GEOGRAPHIC INFORMATION SYSTEMS TO SELECT SITES FOR
WETLAND RESTORATION IN WEST CENTRAL
OHIO'S AGRICULTURAL AREAS

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

By

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Janice M. Hartkorn ENTITLED Using Geographic Information Systems to Select Sites for Wetland Restoration in West Central Ohio’s Agricultural Areas BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES OF Master of Science.

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ABSTRACT

Hartkorn, Janice M. M.S., Department of Biological Sciences, Wright State University, 2008. Using Geographic Information Systems to Select Sites for Wetland Restoration in West Central Ohio’s Agricultural Areas.

The Mississippi River Basin, includes a major part of Ohio has encountered increasing phosphorus and nitrogen loads from agricultural fields since the 1800’s when intensive agriculture moved into the Midwest. Agriculture has drained ninety percent of Ohio’s native wetlands. A portion of those drained wetlands can be restored to functional wetlands to intercept excess nutrients from non-productive or low yield agricultural fields to improve overall water quality. Little is known about finding potential restoration sites, partly because of the difficulty in locating sites capable of supporting successful restoration.

This study investigated the utility of Geographic Information Systems (GIS) as a tool to improve the process of identifying and selecting sites for wetland restoration throughout Greene and Clark Counties in west central Ohio. Site selection was based on a scoring system that utilizes geographic information data sets available in the public domain. Combined with a scoring system, the suitability of selected sites for potential wetland restorations was quantified. Identification of the appropriate restoration sites was based on the Ohio Wetland Inventory data set properties. Suitability of a site for building wetlands was based on factors, such as: soil type, potential water supply, agricultural land, topography and isolation from development. Each attribute was scored and weighed to predict restoration potential. Sites were prioritized based on those that met necessary wetland restoration criteria and scored high. A methodology utilizing vector data sets was used to narrow the two county searches to show land that has ideal conditions: hydric soils, one kilometer from development, 0-2% slope, agricultural land and shallow depth to water. Land with these characteristics has the potential to be a restored wetland. These GIS methods could be customized for any geographic location, to locate specific wetland types and to locate sites that have the necessary restoration characteristics of hydric soils, land availability and low slopes.
# TABLE OF CONTENT

1. INTRODUCTION .......................................................................................................... 1  
   1.1 Wetland Losses and Water Quality Degradation.................................................. 1  
   1.2 Denitrification ....................................................................................................... 2  
   1.3 Phosphorus Sequestering ...................................................................................... 3  
   1.4 Wastewater Treatment Plants, Agriculture and Their Wetland Relationships .... 4  
   1.5 Definition of Wetlands and Restoration Principles .............................................. 5  
   1.6 Unsuccessful Restorations and the Use of Reference Wetlands ............................ 7  
   1.7 Geographic Information Systems Versatility........................................................ 9  
   1.8 Current Methods for Locating Sites for Wetland Restoration ............................ 11  
   1.9 Available Data Sets............................................................................................. 13  
      1.9.1 Vector and Raster Data Sets ........................................................................ 14  
   1.10 Data Set Descriptions........................................................................................ 15  
      1.10.1 Hydric Soils ............................................................................................... 15  
      1.10.2 Land Cover................................................................................................. 17  
      1.10.3 Land Use .................................................................................................... 18  
      1.10.4 Topography and Depth-to-Water ............................................................... 19  
      1.10.5 Ohio Wetland Inventory (OWI) ................................................................. 21  
      1.10.6 Data Set Summary ..................................................................................... 21  
2. GOALS AND OBJECTIVES ....................................................................................... 23  
3. METHODS ................................................................................................................... 24  
   3.1 Study Area Background...................................................................................... 24  
   3.2 Meeting Objective 1: Publicly available data sets .............................................. 24  
   3.3 Meeting Objective 2: Combination of Data Set – Weighted Overlays.............. 25  
   3.4 Meeting Objective 3: Intersecting Data Sets for Ecologically Suitable Sites...... 28  
   3.5 Meeting Objective 4: Ground-Truthing............................................................. 28  
   3.6 Data Set Manipulations....................................................................................... 29  
      3.6.1. Data Set Standardization............................................................................. 29  
      3.6.2. Column Additions ....................................................................................... 30  
      3.6.3. Union, Edge Match and Dissolve ............................................................... 32  
4. RESULTS ..................................................................................................................... 33  
   4.1 Attribute Classification Scoring.......................................................................... 33  
   4.2 Weighted Overlays.............................................................................................. 36  
      4.2.1 Single Data Set Emphasis ............................................................................ 36  
      4.2.2 Weighted Overlays Dual Data Set Emphasis ............................................... 38  
   4.3 Test for Fen Restoration Potential ................................................................. 42
4.4 Development of the Intersection Vector Analysis .............................................. 43
4.5 Site Visits ............................................................................................................ 45
  4.5.1 Vector Intersection Analysis Using DTW 0-15’ Locations ......................... 45
  4.5.2 Shallow DTW Locations .............................................................................. 47
5. DISCUSSION ............................................................................................................ 49
  5.1 Hydric Soils Influences ....................................................................................... 49
  5.2 Low Slopes and DTW ......................................................................................... 51

**TABLE OF CONTENTS (CONTINUED)**

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3 Land Use and Land Cover ................................................................. 52</td>
</tr>
<tr>
<td>5.4 Agriculture/Open Urban and Slopes ......................................................... 53</td>
</tr>
<tr>
<td>5.5 Weighted Overlays ............................................................................... 53</td>
</tr>
<tr>
<td>5.6 Ultimate Data Sets to Consider ............................................................ 55</td>
</tr>
<tr>
<td>5.6.1 OWI Importance ............................................................................ 56</td>
</tr>
<tr>
<td>5.6.2 OWI: Scoring Attributes .................................................................... 57</td>
</tr>
<tr>
<td>5.6.3 Compilation of the OWI ..................................................................... 57</td>
</tr>
<tr>
<td>5.7 Data Compiling Issues ............................................................................ 58</td>
</tr>
<tr>
<td>5.8 Site Visits ................................................................................................. 58</td>
</tr>
<tr>
<td>5.9 Usefulness for Restorationists ................................................................. 59</td>
</tr>
</tbody>
</table>
6. CONCLUSIONS ..................................................................................................... 60

LITERATURE CITED ................................................................................................... 100
APPENDIX A: World Wide Web Address Access .................................................. 105
APPENDIX B: Methods for producing usable data sets within these methods ........ 107
APPENDIX C: Metadata code description details ................................................ 112
APPENDIX D: Reference Maps ............................................................................ 113
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hydric soils emphasized. Weighted overlay analysis #1 used the following percent influences: Depth-to-Water 1%, Land Cover 1%, Land Use 1%, Topography 1% and Soil Survey 96%.</td>
<td>63</td>
</tr>
<tr>
<td>2. Low slope topography. Weighted overlay analysis #2 used the following percent influences: Depth-to-Water 1%, Land Cover 1%, Land Use 1%, Topography 96% and Soil Survey 1%.</td>
<td>64</td>
</tr>
<tr>
<td>3. Undeveloped land use emphasized. Weighted overlay analysis #3 used the following: Depth-to-Water 1%, Land Cover 1%, Land Use 96%, Topography – 1% and Soil Survey 1%.</td>
<td>65</td>
</tr>
<tr>
<td>4. Agricultural/open urban land cover affect. Overlay analysis #4 used the following percent influences: Depth-to-Water 1%, Land Cover 96%, Land Use 1%, Topography 1% and Soil Survey 1%.</td>
<td>66</td>
</tr>
<tr>
<td>5. Low DTW emphasized. Weighted overlay analysis #5 used the following: Depth-to-Water 96%, Land Cover 1%, Land Use 1%, Topography 1% and Soil Survey 1%.</td>
<td>67</td>
</tr>
<tr>
<td>6. DTW and agricultural/open urban land use combined affect. Weighted overlay analysis #6 used the following: Depth-to-Water 47%, Land Cover 47%, Land Use 2%, Topography 2% and Soil Survey 2%.</td>
<td>68</td>
</tr>
<tr>
<td>7. Agricultural/open urban and undeveloped favored. Weighted overlay analysis #7 used the following: Depth-to-Water 2%, Land Cover 47%, Land Use 47%, Topography 2% and Soil Survey 2%.</td>
<td>69</td>
</tr>
<tr>
<td>8. Undeveloped land on low topography. Weighted overlay analysis #8 used the following: Depth-to-Water 2%, Land Cover 2%, Land Use 47%, Topography 47% and Soil Survey 2%.</td>
<td>70</td>
</tr>
<tr>
<td>9. Low topography on hydric soils. Weighted overlay analysis #9 used the following: Depth-to-Water 2%, Land Cover 2%, Land Use 2%, Topography 47% and Soil Survey 47%.</td>
<td>71</td>
</tr>
<tr>
<td>Figure No.</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>10.</td>
<td>Shallow DTW on undeveloped land. Weighted overlay analysis #10 used the following: Depth-to-Water 47%, Land Cover 2%, Land Use 47%, Topography 2% and Soil Survey 2%.......................... 72</td>
</tr>
<tr>
<td>11.</td>
<td>Low topography and shallow DTW favored. Weighted overlay analysis #11 used the following: Depth-to-Water 47%, Land Cover 2%, Land Use 2%, Topography 47% and Soil Survey 2%......................................................... 73</td>
</tr>
<tr>
<td>12.</td>
<td>Hydric soils on shallow DTW. Weighted overlay analysis #12 used the following: Depth-to-Water 47%, Land Cover 2%, Land Use 2%, Topography 2% and Soil Survey 47%.......................................................... 74</td>
</tr>
<tr>
<td>13.</td>
<td>Low topography and agricultural/open urban land cover emphasized. Weighted overlay analysis #13 used the following: Depth-to-Water 2%, Land Cover 47%, Land Use 2%, Topography 47% and Soil Survey 2%........................................ 75</td>
</tr>
<tr>
<td>14.</td>
<td>Agricultural/open urban land cover on hydric soils. Weighted overlay analysis #14 used the following: Depth-to-Water 2%, Land Cover 47%, Land Use 2%, Topography 2% and Soil Survey 47%.......................................................... 76</td>
</tr>
<tr>
<td>15.</td>
<td>Undeveloped land use on hydric soils. Weighted overlay analysis #15 used the following: Depth-to-Water 2%, Land Cover 2%, Land Use 47%, Topography 2% and Soil Survey 47%.......................... 77</td>
</tr>
<tr>
<td>16.</td>
<td>All equal percent influences. Weighted overlay analysis #16 used the following: Depth-to-Water 20%, Land Cover 20%, Land Use 20%, Topography 20% and Soil Survey 20%.......................................................... 78</td>
</tr>
<tr>
<td>17.</td>
<td>All equal percent influences and DTW excluded. Weighted overlay analysis #17 used the following: Depth-to-Water N/A, Land Cover 25%, Land Use 25%, Topography 25% and Soil Survey 25% .......................................................... 79</td>
</tr>
<tr>
<td>18.</td>
<td>Agricultural land on slopes greater than 6%. Slopes greater than six percent intersected with agricultural/open urban land cover represent 15.37% of the total land or 80,394 acres. Restoration could be accomplished on slopes &gt;6% since hydric soils are present.......................... 80</td>
</tr>
<tr>
<td>19.</td>
<td>‘Agricultural/open urban’ land use on slopes greater than 6% and hydric soils, which represents 8.30% of the total land or 43,407 acres. Even though steep slopes &gt;6% were rated low in suitability within these methods, this figure demonstrates that restoration of agricultural land could be accomplished on slopes &gt;6% since hydric soils are present.......................................................... 81</td>
</tr>
<tr>
<td>Figure No.</td>
<td>Page</td>
</tr>
<tr>
<td>-----------</td>
<td>------</td>
</tr>
<tr>
<td>20. All muck soils (Adrian, Carlisle and Linwood) were singled out of the hydric soils and included only 2,936 acres (0.56% of the total land). Muck soils are typical of hillside seeps and fens.</td>
<td>82</td>
</tr>
<tr>
<td>21. All muck soils (Adrian, Carlisle and Linwood) within one kilometer of slopes greater than six percent. Most muck soils are associated with being close to steep slopes. The number of acres includes 2,734 or 0.52% of the total land.</td>
<td>83</td>
</tr>
<tr>
<td>22. Impact of using shallow DTW for locating restoration sites.</td>
<td>84</td>
</tr>
<tr>
<td>23. Impact of using a wider range of DTW for locating restoration sites.</td>
<td>85</td>
</tr>
<tr>
<td>24. Impact of not using DTW for locating restoration sites.</td>
<td>86</td>
</tr>
<tr>
<td>25. Site location in north central Greene County selected from map in Figure 24</td>
<td>87</td>
</tr>
<tr>
<td>26. Site visit along Linebaugh Road in north central Greene County.</td>
<td>88</td>
</tr>
<tr>
<td>27. Site location in northwestern Greene County selected from map in Figure 24</td>
<td>89</td>
</tr>
<tr>
<td>28. Site visit in northwestern Greene County</td>
<td>90</td>
</tr>
<tr>
<td>29. Site location in north central Greene County selected from map in Figure 24</td>
<td>91</td>
</tr>
<tr>
<td>30a and 30b. Site visit in north central Greene County</td>
<td>92</td>
</tr>
<tr>
<td>31. Site location in eastern Greene County selected from map in Figure 24</td>
<td>93</td>
</tr>
<tr>
<td>32. Site visit in eastern Greene County</td>
<td>94</td>
</tr>
<tr>
<td>33. Site location in southeast Greene County selected from map in Figure 24</td>
<td>95</td>
</tr>
<tr>
<td>34a and 34b. Site visit in southeastern Greene County</td>
<td>96</td>
</tr>
<tr>
<td>35. Image taken from Google Earth near intersection of Federal Road and US 72.</td>
<td>97</td>
</tr>
<tr>
<td>36. Zoomed in on red circle from Figure 35.</td>
<td>97</td>
</tr>
<tr>
<td>37. Image taken from Google Earth near intersection of Hussey Road and US 68.</td>
<td>98</td>
</tr>
<tr>
<td>38. Zoomed in on Figure 37.</td>
<td>98</td>
</tr>
<tr>
<td>Figure No.</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>39.</td>
<td>Image taken from Google Earth near intersection of US 72 and I-71.</td>
</tr>
<tr>
<td>40.</td>
<td>Overview of the Ohio Wetland Inventory data set, excluding ‘Upland and Open Water’ attributes within Greene and Clark Counties.</td>
</tr>
<tr>
<td>41.</td>
<td>Overview of major roads within Greene and Clark Counties.</td>
</tr>
<tr>
<td>42.</td>
<td>Overview of Ohio and the location of Greene and Clark Counties.</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table No.                                           Page

1. Data sets available, the original source for digital data and the source date for Greene and Clark County ................................................................. 13

2. Hydric Soils found in Greene and Clark Counties with their geographic setting and unique features ........................................................................................................ 16

3. Percent Influence for Weighted overlay input matrix in ArcGIS module ....................... 26

4. Land use data set attribute classifications are determined to be restorable or not using personal knowledge of site conditions ................................................................. 31

5. Scoring matrix for the weighted overlay attributes within each data set ......................... 34

6. Acres and percent of the total acres each score in the weighted overlay analysis produced .................................................................................................................. 37

7. Data expectation tests acreage and percent of total land ................................................. 42

8. Vector analysis total restorable acres and the percentage of the total land area ............. 44
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1. INTRODUCTION

1.1 Wetland Losses and Water Quality Degradation

Since the 1780s, the contiguous United States and Ohio have lost fifty-three and ninety percent, respectively, of their original wetlands along with many vital wetland functions (Dahl 1990). Historically, agriculture has played an important role in the development of many countries.

The majority of wetland loss has been contributed to agricultural drainage and development (Dahl 2000 and Tiner 2003). Agriculture is also the largest contributor of non-point pollution world-wide (Novotny 1999). Non-point pollution refers to insults that have non-discrete sources of entry, which include nitrogen and phosphorus from agriculture, the leading source of both ground and surface water pollution in the United States (Luckeydoo et al. 2002; Pierzynski et al. 1994). Heavy application of nutrients on agricultural fields mixed with annual heavy rainfall during the spring could contribute to the eutrophication of waterways from excess nitrogen and phosphorus (Sharpley et al. 2001). The dual impact of wetland loss and increased nutrients from agriculture has increased the need for wetland restoration to improve water quality (Mitsch and Gosselink 2000; Chen et al. 2005).

One method of removing excess agricultural nutrients from farm runoff has been to direct the water into and through wetlands. Wetlands can provide a resource to limit the amount of excess nutrients from agricultural land from entering water bodies when
geographically located to intercept the contaminated runoff (Hammer 1992; Fink and Mitsch 2004; Sonune and Ghate 2004). Farmers are not typically willing to donate land to help improve water quality by creating a wetland for intercepting nutrients due to potential monetary losses.

To remedy this problem, assistance from local and federal governments is available for farmers to improve water quality, including implementing management practices to reduce nutrient loads from waterways (Anderson and Flaig 1995; Novotny 1999). Numerous projects across the United States have utilized wetlands for their ability to reduce nutrient loads (Environomics 1999). Wetlands have unique characteristics to cleanse our waterways.

1.2 Denitrification

Wetlands can rectify the excess nutrients entering our waterways. Wetlands support anaerobic bacteria which convert nitrate, a main ingredient of fertilizer, to \( \text{N}_2 \) gas by the process of denitrification (Mitch and Gosselink 2000), whereas cultivated soils are aerobic and do not undergo denitrification effectively. Wetlands are good total nitrogen removal systems. In a treatment wetland, total nitrogen removal can range from 3-98% (Spieles and Mitsch 2000). By positioning wetlands to intercept agricultural runoff discharges before entering into a stream, water contamination is reduced. Significant reduction of nitrogen and phosphorus loading which leads to hypoxia (low dissolved oxygen) in the Mississippi River Basin and the Gulf of Mexico can be accomplished (Mitsch and Gosselink 2000).
1.3 Phosphorus Sequestering

While wetlands are quite good at eliminating excess nitrogen, especially nitrate; phosphorus removal is less successful (White et al. 2000). The rate of storage and removal of phosphorus is slower than nitrogen because phosphorus adheres to available binding sites on sediments, which leads to soil saturation with phosphates (Kadlec 1997). As a result, nitrogen is consumed by the plants or undergoes ammonia volatilization or denitrification (Mitch and Gosselink 2000) and phosphorus entering the system is stored in the soil and biomass (White et al. 2000). Removal of wetland biomass may enable the permanent elimination of both nitrogen and phosphorus (Meuleman et al. 2002; Martin et al. 2003; Mitsch and Gosselink 2000). Wang and Mitsch (2000) noted that depending on the type and amount of biomass present (Typha, Scirpus, and Phragmites), 0.32-1.6 g P meter\(^{-2}\) year\(^{-1}\) can be removed from waterways preventing soil saturation. Mitsch and Reeder (1991) modeled that 1.05 g phosphorus meter\(^{-2}\) year\(^{-1}\) can be retained in the sediments. Mitsch and Gosselink (2000) stated approximate phosphorus retention in wetlands ranges 1 to 2 g P m\(^{-2}\) yr\(^{-1}\) in the soil. In addition, wetlands that accumulate soil, such as peatlands, may work to permanently bury phosphorus and resist soil saturation (Mitch and Gosselink 2000). Many wetlands created for wastewater treatment have been shown to be effective in phosphorus removal for about five to ten years after which they become saturated with phosphorus and no longer retain significant amounts of phosphate (Kadlec and Knight 1996).
Rising populations mean wastewater treatment plants (WWTP) often have difficulty processing higher concentrations of nitrogen and phosphorus entering the facility; secondary and sometimes even tertiary treatments are not effective enough in wastewater treatment (Sonune and Ghate 2004). WWTP have limits on the amount of nutrients that are discharged in their treated effluent (Environomics 1999). Improving current WWTP technologies by adding tertiary treatments to WWTP would be costly (Gren 1995); but using the cleansing functions of wetlands would allow for a solution to the larger problem of excess nitrogen and phosphorus removal.

A WWTP deciding to upgrade a facility might try to purchase nitrogen and phosphorus credits from another regulated point-source to compensate for their excessive nutrient load entering a waterbody (Gren 1995). Credits could be purchased or traded between companies where one company is exceeding their pollution limit and another company is below their set limit (Environomics 1999); thus, the total amount of pollution emitted does not change. One problem with this type of cap and trade program is that overall water quality does not improve, but remains the same.

Some farmland is essentially drained wetlands and it should be simple to restore portions of those fields into their native wetland state. Extreme, high water tables result in less productive agricultural land where drainage systems are inadequate, damaged or difficult to maintain (Mitsch and Gosselink, 2002). Simple removal or blockage of these drainage systems allows soils to re-flood and converts low yielding agricultural land back to wetland (Mitsch and Gosselink, 2000). Development of a wetland plant community on these re-flooded or saturated hydric soils makes them into a fully functioning wetland.
The restored wetlands have the potential to remove excess nitrogen and phosphorus originating in the remaining part of the farm (Fink and Mitsch 2004).

Wetlands that intercept runoff from agricultural fields can reduce the amount of nutrients from the streams that could be used as a nutrient trading credit, if done within the same watershed (EPA 2003a). This credit could be sold to a WWTP that cannot meet its allowable discharge limits (Environomics 1999). Farmers would receive monetary compensation for turning non-productive agricultural fields into wetlands for nutrient trading credits. Agricultural land is undeveloped and is generally low cost making it desirable for wetland restoration projects. Wetland restoration and creation can be an important tool in combating transport of high nutrient loads to sea (Trepel and Palmeri 2002). By reducing nutrient loading in Ohio’s waters using restored wetlands, water quality in the Gulf of Mexico will eventually see an improvement.

1.5 Definition of Wetlands and Restoration Principles

Lands that contained wetland soils, termed hydric, were formed over a long period of time (Hammer 1992) and some of these lands were drained for agriculture (Dahl 1990). Many of the drained parcels retained hydric soil characteristics and typically have high seasonal water table (Wetland Training Institute, Inc. 1995) and meet two of the three criteria of a wetland (Hammer 1992). Characteristics that define jurisdictional wetlands and aide in wetland restoration are: hydric soils, wetlands with suitable seed, undeveloped areas and availability to bring the necessary amount of water to the soil surface (Wetland Training Institute, Inc. 1995; Mack 2001; White et al. 1998; White and Fennessy 2005; McCauley and Jenkins 2005; Van Lonkhuyzen et al. 2004).
Wetlands, defined as transitional areas between land and water by the EPA (EPA 2003 Appendix A). Wetlands must contain the proper hydrologic regime, hydric soils and wetland plants (Environmental Laboratory 1987). Wetlands can provide many vital functions, such as: improved water quality, flood control, storm water storage, storm water detention, nutrient transformation, nutrient storage, wildlife habitat, recreation, groundwater recharge, aesthetics, education and research venues (Mitsch and Gosselink 2000).

US EPA (2000) defined wetland restoration as ‘the return of an ecosystem to a close approximation of its condition prior to disturbance’ and creation occurs by human activity on land that is ‘persistent upland or shallow-water area’ (Mitsch and Gosselink 2000). US EPA (2000) restoration guiding principles include:

- Preserve and protect aquatic resources
- Restore ecological integrity
- Restore natural structure and function
- Work within the watershed/landscape context
- Address ongoing causes of degradation
- Develop clear, achievable and measurable goals
- Focus on feasibility
- Use reference sites
- Anticipate future changes
- Involve a multi-disciplinary team
- Design for self-sustainability
- Use passive restoration, when appropriate
- Restore native species
- Avoid non-native species
- Use natural fixes and bioengineering
- Monitor and adapt where changes are necessary

Restoration should be economically and socially acceptable in order to achieve the necessary support for success (Clewell, et al. 2005; Palmeri and Trepel 2002).
The definition of success is determined by the original goal of the restoration. Society for Ecological Restoration International Science and Policy Working Group (2004) have defined when restoration has been accomplished using: determine species in reference site and provide appropriate community structure, contain indigenous species, functional groups necessary for continued development, capable of sustaining reproducing populations of the species necessary for continued stability, functions normally for stage of development, suitably integrated into large landscape, potential threats to health and integrity are eliminated or reduced, sufficiently resilient to normal periodic stress events and self-sustaining like reference site. The restorationists need to have identified conceptual tasks, preliminary tasks, implementation planning, implementation tasks, post-implementation tasks, evaluation and publicity comprising of fifty-one guidelines (Clewell et al. 2005) to have a successful project. Understanding and utilizing US EPA’s (2000) and Society for Ecological Restoration International Science and Policy Working Group’s (2004) principles aid in eliminating restoration failure.

1.6 Unsuccessful Restorations and the Use of Reference Wetlands

Many wetland restoration projects fail (Whigham 1999) because the knowledge of vital wetland functions or how to achieve them is lacking for the wetlands to be self-sustaining in the natural landscape (Mitsch and Gosselink 2000; Van Lonkhuyzen et al. 2004). Whigham (1999) has shown that characteristics of wetlands: soil type, hydrology and vegetation are often not considered in restoration practices. Further, connectivity throughout the landscape, such as adjacency to existing wetlands for seeds or threats from urban areas are often overlooked (Findlay et al. 2002). To increase wetland restoration
success, the restorer needs to have an understanding of historic ecosystem structure and
unique functions for a specific area (Whigham 1999), clearly defined goals for the
restoration project (Clewell et al. 2005) and an understanding of the use of reference
wetlands (Mitsch and Gosselink 2000).

Reference or natural wetlands possess high quality characteristics and are utilized
in future wetland restoration comparisons as ideal successful restoration sites (Mitsch and
Gosselink 2000). While many of the original remaining wetlands in Ohio have been
modified, Ohio EPA uses reference wetlands that are high quality with little disturbance
or represent the best attainable conditions for an area (Brooks et al. 2004). The Ohio
Rapid Assessment Method (ORAM) for wetlands (Mack 2001) encompasses the wetland
size, buffers, surrounding land uses, water sources, habitat, special features, plant
communities, plant distribution and other habitat features to delineate the quality of the
wetland. ORAM has become a versatile method for Ohio wetland assessment to judge
the success of a restoration project and a model assessment method for other states.
Fennessy et al. (2007) rated many rapid assessment methods and concurs that the ORAM
is an adequate land scoring mechanism for assessment of wetland restoration.

When the restorationist understands the need for water availability, soil type, and
probable historic vegetation, the criteria for a jurisdictional wetland will probably be met
by reproducing these conditions. Other factors will influence the potential for restoration
including land availability, land market value, topographic relief, hydrologic
manipulation impacts on adjacent land, relationship to floodplains, nearby existing
wetlands, land use planning and even agricultural history (Clewell et al. 2005). The
proper development and management of restoration projects reduce errors that compromise project quality and effectiveness (Clewell et al. 2005).

Consideration of all guidelines is difficult for restorationists. Selection of restoration sites can be time consuming and costly; however, utilizing a Geographic Information System (GIS) for site selection has been effective in similar tasks (Cedfeldt et al. 2000; White and Fennessy 2005; Lonkhuyzen et al. 2004). GIS is becoming a common planning tool for municipalities and organizations across the United States.

1.7 Geographic Information Systems Versatility

Geographic Information System (GIS) programs are versatile in their ability to demonstrate spatial relationships by analyzing large areas quickly and quantifying spatial attributes (Van Lonkhuyzen et al. 2004; Dai et al. 2001). GIS applications range from habitat restoration (White and Fennesey 2005; Van Lonkhuyzen et al. 2004; Roise et al. 2004) to city planning (Holden and Turner 1997; Dai et al. 2001), environmental monitoring (Salem 2003) to delivery routes (Tarantilis et al. 2004) and even mapping the human body (Coates 1997 Appendix A). GIS is flexible due to its ability to utilize different formats of data (raster and vector) (McCauley and Jenkins 2005), provide answers to different goals and fine tune the analysis to make each site selection accurate based on unique qualities (Van Lonkhuyzen et al. 2004).

GIS has been used in many wetland restoration projects. Goals for projects have included site selection for transportation corridors (Roise et al. 2004), constructed wetlands to remove nutrients (Tanner et al. 2005 and Dunne et al. 2005) and to describe wetland functionality (Cedfeldt et al. 2000).
Wetland function costs are being considered more often. Roise et al. (2004) determined the location of a transportation corridor based on habitat quality, hydrology, water quality and construction costs. The environmental costs were compared to where construction costs were minimized (Roise et al. 2004).

Tanner et al. (2005) and Dunne et al. (2005) utilized wetlands for nutrient removal from dairy farms. Although Tanner et al. (2005) and Dunne et al. (2005) did not use GIS within their methods, a wetland restoration method could be used to locate treatment wetlands for dairy wastewater discharge or confined animal feeding operation runoff.

Flood flow alteration, surface water quality improvement and wildlife habitat used GIS to determine wetland functions or value (Cedfeldt et al. 2000). The methods used land cover, digital elevation models, watershed boundaries, surface water, soils, roads, landfills and dams data sets. By using GIS, the data sets located wetlands have the potential to be functionally important and field investigators can focus attention on these significant wetlands (Cedfeldt et al. 2000).

Projects have used a variety of data types. Both vector and raster were used to find isolated depressional wetlands (McCauley and Jenkins 2005), aerial photographs were used to determine water fluctuations (Williams and Lyon 1997) and remote sensing was used to determine what type of classification technique most successfully identifies wetlands (Ozesmi and Bauer 2002). GIS has the ability to use many different data types, perform numerous overlays, queries and buffering techniques; thus, GIS can perform ‘what if...’ scenarios for when goals change from wetland function to size and placement in the watershed (Lonkhuyzen et al. 2004; Palmeri and Trepel 2002). Another unique
function that GIS provides is the ability to visually display multiple characteristics about sites on one map, which allows for quantitative selection or weighing of desirable factors within the selected area (Roise et al. 2004a; Roise et al. 2004b; Van Lonkhuyzen et al. 2004).

White and Fennessy (2005) and Van Lohkhuyzen et al. (2004) have stated that many characteristics influence the success of wetland restoration. Hydrology, soils, topographical variability and surrounding land use make GIS an ideal tool to automate the process. Poor planning and ignorance of the underlying wetland functions cause restorations to fail (Van Lohkhuyzen et al. 2004; Mitsch and Gosselink 2000).

1.8 Current Methods for Locating Sites for Wetland Restoration

When seeking to find sights suitable for restoring wetlands for compensatory mitigation of wetland losses, several criteria are desirable above and beyond the ability to recreate the appropriate hydric soils, hydrologic regime and hydrophytic vegetation (Amon, J.P. personal communication). The restored wetland will need to be maintained in perpetuity, so a site on or adjacent to publicly owned land where management experts are available is important. Transportation to existing wetland or complementary upland habitat is desirable because it would improve the ecological system present on that site. The mitigator will want to turn over the land to the managing entity and the managers will want the location that meets their economic management and social needs. Vacant land, poor agricultural land, and land in or near existing parcels that has hydric soils and an apparent historic source of water sufficient to re-hydrate the landscape is also vital. Cost of the land is likewise important. Land able to be developed near existing
developed properties is expensive (Amon, J.P. conversations with developers), so land away from large population centers is often more desirable and affordable. If the available land is in a populated metropolitan area, it may be suitable for restoration if its development potential is minimal.

Based on these concepts, it appears that the following factors available in GIS system format may be useful in locating land for developers and conservationists seeking sites for wetland restoration.

1. Hydric soils
2. Land use
3. Land cover
4. Depth to water table
5. Distance from development
6. Distance from wetlands
7. Distance from public land
8. Slope of land – improves hydrologic possibilities
9. Availability of above information

Invariably, site visits must be made to assess many of these factors and a variety of important factors not considered that may be unique to each site.

This thesis will examine and evaluate Geographic Information Systems (GIS) to improve the process of selecting sites for wetland restoration by selecting optimal data sets that are needed to predict overall restoration potential, intersect the datasets to identify specific sites that meet the ecological need for wetland restoration and compare the GIS based predictions with actual sites to determine the accuracy in identifying potential restoration areas.
1.9 Available Data Sets

Data sets utilized were obtained from the Ohio Department of Natural Resource’s website (ODNR GIMS Appendix A) at no cost (Table 1).

Table 1. Data sets available, the original source for digital data and the source date for Greene and Clark County. The source and the source date were comparable between Greene and Clark County. All data can be downloaded from <http://www.dnr.state.oh.us/gims>.

<table>
<thead>
<tr>
<th>Source for Digital Layer</th>
<th>Data Sets</th>
<th>Soils</th>
<th>OWI</th>
<th>Land Use</th>
<th>Land Cover</th>
<th>DRASTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark</td>
<td>Soil Survey of Clark Co.</td>
<td>Landsat Thematic Mapper</td>
<td>Aerial Photo by ODNR</td>
<td>Landsat Thematic Mapper</td>
<td>Ground Water Pollution Potential of Clark County, Ohio Report No. 38</td>
<td></td>
</tr>
<tr>
<td>Greene</td>
<td>Soil Survey of Greene Co.</td>
<td>Landsat Thematic Mapper</td>
<td>Aerial Photo by ODNR</td>
<td>Landsat Thematic Mapper</td>
<td>Ground Water Pollution Potential of Greene County, Ohio Report No. 30</td>
<td></td>
</tr>
</tbody>
</table>

Other data sets were considered for use, such as zoning, contours and hydrology. Due to inconsistency in the data sources between counties, only six types of data sets were used for Greene and Clark. All data sets were first manipulated in vector format and then converted into 5-meter square resolution raster cells for the weighted overlay analysis (see section 3.3). Analysis on vector data utilizing inclusion based methods is described in section 3.4.
1.9.1 Vector and Raster Data Sets

When using GIS, a choice between vector and raster data sets needs to be made. Each type of data has its advantages and disadvantages. Earth Systems Research Institute (ESRI 2006) defines vector data as records of spatial information as x,y coordinates in a rectangular or planer coordinate system and is used to accurately record ground information, such as streets, boundaries and streams. A vector may contain three items: points (x,y coordinates), lines (series x,y coordinates) and polygons (series x,y) coordinates that form an enclosed shape (ESRI 2006). The accuracy of the vector data is dependent on the number of x,y coordinates that are used to depict the feature. For instance, the more x,y coordinates used to show each bend of a meandering stream help determine the accuracy of the stream measurements.

ESRI (2006) defines raster data as a set of grids organized by rows and columns where each cell contains a number representing a geographical feature and is used to display information about an area that is continuous. The accuracy of the item location within a data set depends on the resolution of the raster (ESRI 2006). The raster is similar to the pixels a digital camera has; the smaller the area the raster cells encompass, the greater the detail.
1.10 Data Set Descriptions

1.10.1 Hydric Soils

Hydric soils are defined as being formed under conditions of saturated, flooding or ponding in the upper part of the soil to develop anaerobic conditions during the growing seasons (Ohio NRCS 2007 Appendix A). Anaerobic conditions are those that have reduced nutrients, specifically ferrous iron, causing soils to be gray; ferric iron causes red coloring in aerobic conditions, also termed *mottling* (Tan 2000) when found within a reduced hydric soil matrix and an indication of temporary exposure to oxygen. Hydric soils are ecologically significant and are the best indicator of the land having a high restoration potential because they are or were wetlands (Van Lonkhuyzen et al. 2004).

Restorationists have proven that non wetland sites that contain hydric soils have a higher restoration success rate than those sites where hydric soils are not present (Van Lonkhuyzen et al. 2004; White and Fennessy 2005). Wetland restoration, by definition, can only be conducted on hydric soils; whereas, wetland creation is done on soils that were not historically wetlands or non-hydric (USEPA 2000). Non-hydric soils are sometimes known to have hydric inclusions and as a result, were not considered within this study. Hydric soils were selected using the soil survey’s descriptions, unique features and geographic setting for each county (Table 2).
Table 2. Hydric Soils found in Greene and Clark Counties with their geographic setting and unique features (Soil Survey Staff, NRCS/USDA, <http://soils.usda.gov/technical/classification/osd/index.html> - and personal communication with Amon, J.P.).

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Clark</th>
<th>Greene</th>
<th>Geographic Setting</th>
<th>Unique Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adrian</td>
<td>x</td>
<td></td>
<td>Herbaceous organic material over sandy deposits and occupies shallow closed depressions on outwash plains, lake plains, lake terraces, and flood plains, but can occur within moraines and till plains.</td>
<td>0-1% slopes, typically a marsh, organic matter from herbaceous plants with some woody materials. Some areas have sphagnum moss at 1-4&quot;at the surface. Main vegetation is marsh grasses.</td>
</tr>
<tr>
<td>Brookston</td>
<td>x</td>
<td></td>
<td>Loamy till of Wisconsinan Age in depressions on till plains and moraines.</td>
<td>0-3% slopes, very deep, poorly drained soils formed in up to 20 inches of silty material and underlying loamy till. Native vegetation is forests, marshes and sedge meadows. Row crops or pastures grown if drained.</td>
</tr>
<tr>
<td>Carlisle</td>
<td></td>
<td>x</td>
<td>Depressions within lake plains, outwash plains, ground moraines, and flood plains. Soils formed in woody and herbaceous organic materials.</td>
<td>0 to 2% slopes, truck crops and pastures grown or woodlands present. Organic material present. Native forest and fens.</td>
</tr>
<tr>
<td>Drummer</td>
<td></td>
<td>x</td>
<td>Nearly level or depressional parts of outwash plains, stream terraces, and till plains of Wisconsin Age. They formed in 40 to 60 inches of loess or other silty material and in the underlying loamy stratified outwash.</td>
<td>0 to 2% slopes, most areas have crops and native vegetation is hydrophytic grasses, reeds and sedges.</td>
</tr>
<tr>
<td>Kokomo</td>
<td></td>
<td>x</td>
<td>Depressions on till plains and formed in loamy materials overlying loam till.</td>
<td>0 to 2% slopes, most areas have crops and native vegetation is deciduous hardwood forests.</td>
</tr>
<tr>
<td>Linwood</td>
<td>x</td>
<td>x</td>
<td>Lake plains, drainage ways, outwash plains end moraines, seeps ground moraines and have formed in former lakes or ponds that range in size from a few acres to several hundred acres.</td>
<td>Slopes less than 2%, highly decomposed woody, organic materials underlain by loamy glacial deposits. Drained areas used for crops and native vegetation are forests and fens.</td>
</tr>
<tr>
<td>Lippincott</td>
<td>x</td>
<td></td>
<td>Outwash plains and terrace soils with high in limestone gravel or sand and in some places a layer of silty or loamy alluvium or loess as much as 8 inches thick. They have loose, calcareous sandy and gravelly outwash at a depth of 40 to 60 inches.</td>
<td>0 to 2% slopes, row and pastures present and native vegetation is deciduous swamp forests.</td>
</tr>
<tr>
<td>Milldale</td>
<td>x</td>
<td>x</td>
<td>On till plains, lake plains, and low terraces of late Wisconsin age. Some on monadnocks on till plains. They formed in till overlying limestone or dolostone.</td>
<td>0 to 2% slopes, most areas are cultivated or woodlands and native vegetation is deciduous forest or wet prairie.</td>
</tr>
<tr>
<td>Milford</td>
<td></td>
<td>x</td>
<td>On low broad summits or in depressions on glacial lake plains thought to be of Wisconsin Age. Formed in lacustrine sediments. Some areas have a thin mantle of outwash overlying the lacustrine sediments.</td>
<td>0 to 2% slopes, cultivated crops present and native vegetation is marsh grasses and sedges.</td>
</tr>
<tr>
<td>Patton</td>
<td>x</td>
<td>x</td>
<td>On nearly level to depressional parts of stream terraces and glacial lake plains. Formed in medium textured and moderately fine textured glaciolacustrine deposits and typically are underlain by stratified silty and loamy outwash sediments of Wisconsinan Age.</td>
<td>0 to 2% slopes, cultivated crops present and native vegetation is hydrophytic vegetation including grasses, sedges, widely spaced trees and wet prairies.</td>
</tr>
<tr>
<td>Ragsdale</td>
<td>x</td>
<td></td>
<td>In depressions, swales, and drainageways on terraces and uplands. The soils formed in more than 60 inches of loess.</td>
<td>0 to 2% slopes, cultivated crops present and native vegetation is hydrophytic vegetation includes swamp grasses, reeds, sedges, and deciduous swamp forest.</td>
</tr>
<tr>
<td>Sloan</td>
<td>x</td>
<td>x</td>
<td>Sloan soils are on flood plains or in depressions along streams receiving sediment from areas of Wisconsinan age glaciation. Formed in loamy alluvium washed mainly from soils formed in loamy, calcareous drift.</td>
<td>0 to 2% slopes, drained areas have crops. Areas near streams are in pasture or woodland. cultivated crops present and native vegetation is deciduous forest.</td>
</tr>
<tr>
<td>Wallkill</td>
<td>x</td>
<td></td>
<td>Formed in alluvial mineral soil deposits over organic soil materials occurring along streams that run through organic soil areas and along the margins of depressional areas adjacent to upland mineral soils.</td>
<td>0 to 3% slopes, drained areas have vegetable crops or sod farms. Partially drained areas have pasture and woodlands with native water tolerant species, i.e. elm, red maple.</td>
</tr>
<tr>
<td>Westland</td>
<td>x</td>
<td>x</td>
<td>In depressions and on flats on outwash plains, stream terraces, and glacial drainage channels. Formed in loamy material that can be capped with up to 20 inches of loess or silty material. They are deep to calcareous, stratified gravelly and sandy outwash.</td>
<td>0 to 2% slopes, most areas have crops and native vegetation is a combination of forested and herbaceous wetland.</td>
</tr>
</tbody>
</table>
Hydric soils that are not currently classified as a wetland in the OWI are typically drained wetlands and are mainly agriculture (McCauley and Jenkins 2005). By simply removing the drainage systems in agricultural fields, a wetland restoration could be accomplished by returning the water supply to the pre-agricultural state. Drainage is frequently accomplished by ditching or placement of field drainage tile or a combination of the two (Environmental Laboratory 1987). The smallest soil unit within the soil surveys is approximately three acres (Environmental Laboratory 1987) and non-hydric soils may contain hydric inclusions.

Non-hydric soils with hydric inclusions were not included in the hydric soil selection due to the Greene County Soils Survey not including the hydric inclusions within their listing of hydric soils (USDA and NRCS 2007). The listing of non-hydric soils with hydric inclusions has become obsolete and no data available to predict the proportion or total amount of inclusions within a soil type (Ohio NRCS 2007 Appendix A). Site visits were suggested to determine if inclusion soil should be considered hydric or not. These soils could be examined in future studies to determine their wetland creation potential.

1.10.2 Land Cover

Land cover is a term used to classify the surface cover into various types of land (Appendix C). Land covers that are considered suitable for wetland restoration include: agricultural/open urban, shrub/scrub, wooded and barren. Open water, non-forested wetland and urban are not suitable for restoration. The land cover data set was compiled
using Landsat Thematic Mapper (TM). TM is a sensing device on the Landsat satellites that scans a 30 by 30 meter area or 0.22 acres and stores seven individual images in spectral bands ranging from the blue wavelengths to those in the thermal infrared spectrum (GIS Development 2005 Appendix A). The 30 by 30 meter grids’ spectral bands were then analyzed to produce a vector land cover data set that was used in this study. The large area that was scanned generalized land cover less than 0.22 acres in size and many acres are never ground-truthed for accuracy.

1.10.3 Land Use

Developed areas were considered unattainable restoration sites and were excluded from the site selection process. Similarly, areas surrounding developed lands were excluded in site selection within the vector analysis (section 3.4) due to excessive nutrients and chemicals from lawns and roads in runoff that would enter and potentially harm a wetland (Van Lonkhuyzen et al. 2004). Development and road expansion projects also increase the price of land, which decreases the likelihood of land becoming available for restoration or conservation projects. These developed areas and roads also cause habitat fragmentation. Development fragments habitat areas by limiting the potential wetland function for flood storage, groundwater recharge or water purification (Tiner 2003) and reduces habitat size making it unusable for some species that require a minimum amount of habitat (McCauley and Jenkins 2005). Habitat fragmentation also increases edge effects and may alter the proportion of edge to non-edge habitat in a way that threatens wildlife and plant community structure (Mitsch and Gosselink 2000).
The Beaver Creek Wetlands is an example of a nearly continuous wetland habitat extending from south of US 35 to north of SR 235 in Greene County along Beavercreek. Habitats connected to each other through corridors, like those in the Beaver Creek Wetlands enable dispersion of fauna and flora (Mörberg, et al. 2007; McCauley and Jenkins 2005).

1.10.4 Topography and Depth-to-Water

Topography or slope and Depth-to-Water (DTW) were part of a larger data compilation called DRASTIC: Depth-To-Water, Net Recharge, Aquifer Media, Soil Media, Topography, Impact of the Vadose Zone and Media Hydraulic Conductivity of the Aquifer. These parameters define a DRASTIC model or the groundwater pollution potential.

The 1987 Corps of Engineers’ Manual (Environmental Laboratory 1987) requires that a site has wetland hydrology only if the soil is saturated (including inundation) to within twelve inches of the surface for 12.5 percent of the local growing season (as determined by the United States Department of Agriculture). Saturation includes the heights of the water table and any associated capillary fringe. One feasible way to determine water levels within these methods is to use DTW. The two data sets were used to select flat land with water close to the surface for these methods.

The DTW layer within the DRASTIC data set has attribute increments of five feet and the needed resolution to find areas with at least twelve inches of water would need to be sub-meter; therefore, the DTW is lacking the needed resolution. However, the DTW
layer could demonstrate some of the seasonal water levels in relation to wetlands. The DTW data sets were compiled from well logs and are not regularly spaced. The areas between wells are extrapolated by using the known wells’ DTW. The infrequency of wells in some locations caused those areas to not be as accurate as areas with more wells.

The Topography or Slope layer within DRASTIC best described the flatness of the land. Low sloped land would allow for a large numbers of acres to be returned to wetland status when small changes to the drainage systems occur. Restoration on flat land discourages the development of ponds or areas with deep water that does not support wetland species (Kentula et al. 1993). Wetland restoration/creation where ponds are formed creates a ‘doughnut’ wetland around the edges of the pond (Amon, J. P., personal communication; Kentula et al. 1993). The topography data set was compiled from contours. Ideally, contours would be used to allow for more manipulation and analysis; however, the contours were not readily available for both counties. Each quadrangle within the two counties would need to be edgematched. Approximately sixty quadrangles would have to have their contours adjusted and combined to form continuous coverage for both counties. The topography for the counties in the DRASTIC data set was derived from United State Geological Survey 7 ½ minute quadrangle maps (Vormelker et al. 1995; Jones 1995).

Potential uses of the DRASTIC data set could include determining low permeability or high recharge areas. Future studies could utilize the entire DRASTIC data set to determining where low pollution potential to groundwater could occur because those areas would be ideal to construct wetlands. The low permeability soils in those areas would allow water retention for extended periods of time.
1.10.5 Ohio Wetland Inventory (OWI)

The Ohio Wetland Inventory data set was used in locating areas that are currently classified as wetlands. When possible, a restoration site should be in the proximity of another wetland to create a corridor for migration, but more importantly, to serve as a ‘seed bank’ and animal source to the new restoration site (White et al. 1998).

The National Wetland Inventory was not utilized because the Landsat TM was compiled during the fall (dry season) of 1985 and the OWI were taken in May 1985. May is typically wet for this region based on field evidence (Dane Mutter, personal communication). The NWI underestimates the number and types of wetlands and the OWI overestimates them. I chose to overestimate to have a more robust reference wetland data set. The codes and their associated text (Appendix C) were found in the data set metadata. The woods on hydric soils were determined if wooded areas within the OWI were located on hydric soil and are thus wetlands (GIMS Appendix A). The purpose of using the OWI data set was to prioritize the potential restoration sites by identifying areas around the OWI that appeared to be appropriate for restoration.

1.10.6 Data Set Summary

Hydric soils are the major consideration for wetland restoration (Wetland Training Institute, Inc. 1995). Land use and land cover are similar in their characteristics of the land and will produce similar results. Land cover compilation was conducted in the same manner for both counties, so cross comparisons can be conducted. Exclusion of developed sites was ideal to limit sprawl threats and excess chemicals associated with
urbanization. DTW can aid in predicting where water is close to the surface, but data compilation lacks reliability and resolution due to the extrapolation process used to describe the areas. The slope or topography data set could be useful in finding unique areas for restoration, such as fens. Using the OWI to prioritize restoration activities will aid in producing high quality, more successful and self-sustaining wetlands. Creating a wetland corridor will aid in increasing many wetland functions and allow for a local seed source to be used.
2. GOALS AND OBJECTIVES

The goal of this thesis is to examine and evaluate Geographic Information Systems (GIS) as a tool to improve the process of selecting sites for wetland restoration in two adjacent counties in west central Ohio. Objectives include: 1) determine which publicly available data sets are able to produce sites wetland restoration that satisfy the Army Corps of Engineers and Ohio EPA guidelines for high quality wetlands; 2) evaluate combining data of several types to determine the optimal data sets needed to predict overall restoration potential; 3) intersect the datasets to identify specific sites that contain the characteristics of known wetlands; and 4) compare the GIS based predictions with actual sites to determine the accuracy in identifying potential restoration areas. I hypothesize that hydric soils on low slopes that are undeveloped or on agriculture lands are most likely to be successful for wetland restoration.
3. METHODS

3.1 Study Area Background

I analyze data from Greene and Clark Counties in west central Ohio, USA which encompass 523,066 acres (NRCS 2008). These counties have been chosen because they appear to have a high number of acres of putatively restorable agricultural land available for direct observation and the most necessary data sets available. Cities with over 30,000 people in Greene County include Fairborn, Kettering and Beavercreek (US Census Bureau Appendix A). A portion of Wright-Patterson Air Force Base is included within the analysis in Greene County. Springfield, located in Clark County, is the largest city in both counties with over 65,000 people (US Census Bureau Appendix A). The Beaver Creek Wetlands is a major wetland restoration corridor within this study area located in southwestern Greene County and many restoration projects are accomplished in recent years due to the activities of the Beaver Creek Wetland Association, established in 1988.

3.2 Meeting Objective 1: Publicly available data sets

Data sets found in the public domain are viewed for completeness, accuracy and usefulness in locating those sites that possess wetland restoration characteristics. Soil surveys, DTW, Slope, Land Use and Land Cover are utilized (Table 1).
3.3 Meeting Objective 2: Combination of Data Set – Weighted Overlays

Weighted overlay is a process that applies a numerical value to varying and complex data sets in order to create an integrated analysis. The steps in performing a weighted overlay are: 1.) select an evaluation scale, 2.) add raster, 3.) set scale values, 4.) assign weighted to input raster and 5.) run the weighted overlay tool (ESRI 2006). This method provides the two county area with a continuous restoration suitability score. The weighted overlays determine the effects of different percent influences used and usefulness of the data sets. The overall suitability of the areas is displayed. The optimum data sets are chosen to best describe the area and predictors of restorable land.

A range of zero to nine are selected for a simple evaluation scale. The scale values or scoring matrix used are described in section 4.1. Next, data needs to be added, but the original data needs to be converted from vector into raster format. A grid or cell size of five meter or 0.00128 acres is selected, which is small enough to capture all areas within the data set. Other cell sizes can be used depending on the goal; Dai et al. (2001) utilizes a twenty meter cell size when converting land use data sets to raster and White and Fennessy (2005) use twenty-five meter cell size.

For example, in these methods, every five square meters within the counties for hydric soils is either classified as hydric or non-hydric. Each raster cell is classified as hydric if the majority (greater than fifty percent) of the land within the five square meter cell was hydric. The remaining four data sets: land use, land cover, slope and DTW are all converted to raster data using a five square meter cell size.

The scale values or scoring matrix could not use zero. All zeroes are changed to one and ones changed to two within the weighted overlay tool wizard. The final step
before running the overlay function, the percent influence needs to be assigned. The percents used needs to total one hundred percent and no data set could have an influence of zero. Figures 1-17 are produced using the percent influences noted in Table 3.

Table 3. Percent Influence for Weighted overlay input matrix in ArcGIS module. Percent influence used for each run is noted.

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Depth-To-Water</th>
<th>Land Cover</th>
<th>Land Use</th>
<th>Topography</th>
<th>Soil Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Influence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
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<tr>
<td>14</td>
<td>2</td>
<td>47</td>
<td>2</td>
<td>2</td>
<td>47</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>2</td>
<td>47</td>
<td>2</td>
<td>47</td>
</tr>
<tr>
<td>16</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>17</td>
<td>--</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

To determine the final suitability of an area in Figure 1, each attribute score within the data sets is multiplied by the percent influence the data set is given. These multiplied factors are then added together and displayed on the final suitability using the selected value scale of one to nine.

In Figure 1, for example, all percent influences for the other data sets are one percent, so even an attribute scored nine would only have a suitability score of one.
Example: Hydric soils attribute = 9 and weighed influence = 96 percent. So, 9*0.96 = 8.64 and rounds to 9. Non-hydric soils attribute = 0, which converted to 1. So, 1*0.01 = 0.01 and rounds to 1. Thus, only hydric soils have the highest suitability of nine for Figure 1.

\[
\text{Attribute score} \times \text{percent influence for data set} = \text{attribute influence}
\]
\[
\text{Summation of attribute influences} = \text{Final Suitability Score}
\]

Pairing the data sets by using percent influences that favored two sets per overlay is thought to provide a more realistic suitability map. In reality, numerous characteristics affect the possible land usage and by influencing two data sets more than the other data sets, a better understanding of where potential restoration sites are located. The final two analyses utilize equal percent influences to determine the unweighed interaction of the data sets.

The overlays are not only conducted to find the potential restoration sites, but to look at the data sets as a whole. To determine which data sets describe the area the best and if excluding a specific data set could be justified, all data sets were examined using the weighted overlay tool.

The weighted overlays (Figures 1-17) depict Greene and Clark Counties with continually scored restoration suitability based on weighing of various attributes and applying a percent influence to each data set (Table 3). The resulting values for each figure range from one to nine; nine has the highest restoration potential shown in red and one has the lowest restoration potential shown in blue. In Figures 1-5, only one data set is weighted heavily. In Figures 6-15, suitability is affected by having two data sets...
weighted heavily. Equal weights are used for all data sets to produce Figure 16. Figure 17 uses equal percent influence, but excludes the use of DTW.

3.4 Meeting Objective 3: Intersecting Data Sets for Ecologically Suitable Sites

The intersection analyses use data in vector format and three different methods to determine suitable land for wetland restoration. This intersection procedure rules out areas based on their attributes. The iterations conducted on the vector data utilized various selection tools in ArcGIS: intersections and buffering. The intersection tool selects only those features that are common within all data sets. The buffering tool can be used in several ways including selecting areas:

- completely within,
- completely contained,
- have their centers in,
- contain the center of,
- intersect,
- are within distance of.

For this study, ‘are within distance of’ selection is useful in finding areas in a particular proximity, such as the proximity to an OWI wetland or creating a buffer surrounding developed land.

3.5 Meeting Objective 4: Ground-Truthing

To determine if these methods produce potential wetland restoration sites, visual site inspections are conducted. Areas with the largest concentration of potential restoration sites that are along roads from the intersection analysis are ground-truthed. Areas not containing any potential sites are also ground-truthed to determine if the data
sets contain any obvious flaws. Site visits are conducted from the roadside because of restricted access to private property. The current land use is noted (developed, agricultural, etc.), indication of soil types (wet/dry), vegetative state, topography and any manmade drainage devices.

Areas that are found in the weighted overlay analysis and in first vector analysis are also examined using Google Earth’s and Greene County Geographic Information Management System’s aerial photographs. Current land use and dark or wet spots on the soil can be seen on the aerial photographs. The drainage patterns seen can aid in determining if there are man-made drainage devices.

3.6 Data Set Manipulations

3.6.1. Data Set Standardization

All data sets are analyzed using Environmental Systems Research Institute’s (ESRI, Redlands, California, USA) ArcGIS version 9.0 and 9.2. Verification of each data set’s geographic projection is conducted to ensure that each layer would be in alignment. The original geographic projection used was: Ohio State Plane, zone: 5001, Units: Meters, Spheroid: Clarke 1866, and Horizontal Datum: North American Datum of 1927. Slight positional inaccuracies in the production of the data set caused the common county boundary to not always match. Additional edge matching is required to ensure the polygon lines connected from one county to the other for a more uniform coverage of the area analyzed. Each data set is categorized and manipulated to extract needed
information for this project. Full descriptions of all processes used within ArcGIS are described in Appendix B.

3.6.2. Column Additions

Each data set’s attribute table is a spreadsheet which shows polygon numbers, areas and other information for each polygon. For simplified analysis, two additional columns are added in the attribute data table for the soil, land use, land cover and OWI data set using ArcGIS. The first column contains text that describes the numerical coding that is in the metadata. The addition of a text column reduces the amount of time referring to the tables within the metadata. For example, within the land cover data set, the numerical code two is ‘agricultural/open urban’ according to the metadata; therefore the new text column that is added contains the phrase ‘agricultural/open urban’. This step is not completely necessary; however, it proves to be useful throughout the analysis. The second column added is to include the scoring matrix (see section 4.1).

The land use data set for Clark County has greater detail in the description of the land than Greene County. For example, Clark County has land use broken down into more specific categories: confined feeding operations, farmsteads, cropland and pasture; whereas Greene County shows all these classifications as agriculture. An equalization of the land use categories is needed to compare land across the county line. This is accomplished by determining if land uses are restorable or not (Table 4) based on best personal judgment. As previously mentioned, a new column is added and contained the text ‘Yes’ or ‘No’ from Table 4.
Table 4. Land use data set attribute classifications are determined to be restorable or not using personal knowledge of site conditions.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Restorable</th>
<th>Land use</th>
<th>Restorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaches</td>
<td>Yes</td>
<td>Drive-in-Movies</td>
<td>No</td>
</tr>
<tr>
<td>Cropland</td>
<td>Yes</td>
<td>Educational</td>
<td>No</td>
</tr>
<tr>
<td>Deciduous Forest Land</td>
<td>Yes</td>
<td>Electric Power Generating Plants</td>
<td>No</td>
</tr>
<tr>
<td>Evergreen Forest Land</td>
<td>Yes</td>
<td>Electric Utilities</td>
<td>No</td>
</tr>
<tr>
<td>Farmsteads</td>
<td>Yes</td>
<td>Fairgrounds</td>
<td>No</td>
</tr>
<tr>
<td>Forested Wetlands</td>
<td>Yes</td>
<td>Gas Utilities</td>
<td>No</td>
</tr>
<tr>
<td>Orchards and Groves</td>
<td>Yes</td>
<td>Golf Courses</td>
<td>No</td>
</tr>
<tr>
<td>Other Agricultural Land</td>
<td>Yes</td>
<td>Health Care</td>
<td>No</td>
</tr>
<tr>
<td>Parks</td>
<td>Yes</td>
<td>Highways</td>
<td>No</td>
</tr>
<tr>
<td>Pasture</td>
<td>Yes</td>
<td>Industrial section</td>
<td>No</td>
</tr>
<tr>
<td>Sand Areas Other Than Beaches</td>
<td>Yes</td>
<td>Industrial section and</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commercial Complexes</td>
<td></td>
</tr>
<tr>
<td>Shrub and Brush Rangeland</td>
<td>Yes</td>
<td>Junk Yard</td>
<td>No</td>
</tr>
<tr>
<td>Transitional Areas</td>
<td>Yes</td>
<td>Landfills and Waste Dumps</td>
<td>No</td>
</tr>
<tr>
<td>Undeveloped</td>
<td>Yes</td>
<td>Marinas</td>
<td>No</td>
</tr>
<tr>
<td>Vineyards</td>
<td>Yes</td>
<td>Military</td>
<td>No</td>
</tr>
<tr>
<td>*Borrow Pits</td>
<td>Yes</td>
<td>Mixed Urban or Built Up Land</td>
<td>No</td>
</tr>
<tr>
<td>*Quarries</td>
<td>Yes</td>
<td>Mobile Home, Trailer Parks</td>
<td>No</td>
</tr>
<tr>
<td>*Sand and Gravel pits</td>
<td>Yes</td>
<td>Municipal Sports Facilities</td>
<td>No</td>
</tr>
<tr>
<td>**Lakes</td>
<td>Yes</td>
<td>Nurseries and Ornamental</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horticultural Areas</td>
<td></td>
</tr>
<tr>
<td>**Non-forested Wetlands</td>
<td>Yes</td>
<td>Race Tracks</td>
<td>No</td>
</tr>
<tr>
<td>**Ponds</td>
<td>Yes</td>
<td>Rail</td>
<td>No</td>
</tr>
<tr>
<td>**Reservoirs</td>
<td>Yes</td>
<td>Recreation</td>
<td>No</td>
</tr>
<tr>
<td>**Streams and Canals</td>
<td>Yes</td>
<td>Religious</td>
<td>No</td>
</tr>
<tr>
<td>Airports</td>
<td>No</td>
<td>Residential</td>
<td>No</td>
</tr>
<tr>
<td>Apartment Complexes</td>
<td>No</td>
<td>Sewage Utilities</td>
<td>No</td>
</tr>
<tr>
<td>Campgrounds</td>
<td>No</td>
<td>Shopping Centers</td>
<td>No</td>
</tr>
<tr>
<td>Cemeteries</td>
<td>No</td>
<td>Single Unit Residential</td>
<td>No</td>
</tr>
<tr>
<td>Commercial and Service</td>
<td>No</td>
<td>Utilities</td>
<td>No</td>
</tr>
<tr>
<td>Communications</td>
<td>No</td>
<td>Water Control</td>
<td>No</td>
</tr>
<tr>
<td>Confined Feeding Operations</td>
<td>No</td>
<td>Water Utilities</td>
<td>No</td>
</tr>
</tbody>
</table>

Note: *Potential wetland creation and not restoration. **Sites considered restorable, but are excluded in selection process due to land cover data set classifications.
3.6.3. Union, Edge Match and Dissolve

Each data set for the counties is combined into one continuous layer. The combined data sets are examined to verify that all edges matched exactly. Slight variations (sub-meter) within the data sets occur at their edges. The lines are moved centimeters to make the corrections, so accuracy loss is minuscule. All edge matching is completed using ArcEdit, a module within ArcGIS. Arcs are adjusted slightly where needed to form a continuous line across one county to the other. In some areas, the common county line overlaps each other or did not touch. These errors are corrected in ArcEdit. Once the arcs are aligned bordering the county line, attributed polygons that are similar on either side were ‘dissolved’. This produces a continuous, edge matched data set with fewer polygons to analyze. With fewer polygons, data sets’ file size is reduced and allows for faster processing within ArcGIS.
4. RESULTS

4.1 Attribute Classification Scoring

In order to develop a method for ordinating (scoring) the various aspects of the data within the five major categories (depth to water, soil type, land cover, land use and topography), I used the GIS system to obtain the percent of the OWI with each attribute and the percentage of the total acres within the OWI. With that information and knowledge of other aspects related to the attribute, I developed an attribute weighting system based on the available data (Table 5). The percentages of total acres within the OWI are used to determine the weighted overlay scoring number in the last column in Table 5.
Table 5. Scoring matrix for the weighted overlay attributes within each data set. Scores were compared to percent of total acres (523,066), the percentage OWI data set (9,967 acres) and the percentage of total acres within the OWI. The ‘Percentage of the Total Acres within the OWI’ column aided in determining the ‘Attribute Scoring for Weighted Overlay’ column.

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Attribute</th>
<th>Total Acres</th>
<th>Percentage of Total Acres</th>
<th>Acres of the OWI Intersecting the Data Set</th>
<th>Percentage of the OWI Intersecting the Data Set</th>
<th>Percentage of the Total Acres within the OWI</th>
<th>Attribute Scoring for Weighted Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 5 (ft)</td>
<td>9,874</td>
<td>1.89</td>
<td>370</td>
<td>3.71</td>
<td>3.75</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>5 to 15 (ft)</td>
<td>129,395</td>
<td>24.74</td>
<td>4,389</td>
<td>44.03</td>
<td>3.39</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>15 to 30 (ft)</td>
<td>206,226</td>
<td>39.43</td>
<td>3,090</td>
<td>31.00</td>
<td>1.50</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>30 to 50 (ft)</td>
<td>123,392</td>
<td>23.59</td>
<td>1,572</td>
<td>15.77</td>
<td>1.27</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>50 to 75 (ft)</td>
<td>43,422</td>
<td>8.30</td>
<td>352</td>
<td>3.53</td>
<td>0.81</td>
<td>0</td>
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<tr>
<td></td>
<td>256,883</td>
<td>3,815</td>
<td>0.73</td>
<td>30</td>
<td>0.30</td>
<td>0.78</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>100+ (ft)</td>
<td>3,196</td>
<td>0.61</td>
<td>68</td>
<td>0.68</td>
<td>2.13</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Pits and water</td>
<td>3,746</td>
<td>0.72</td>
<td>96</td>
<td>0.97</td>
<td>2.57</td>
<td>0</td>
</tr>
<tr>
<td>Hydric</td>
<td>Hydric</td>
<td>242,383</td>
<td>46.34</td>
<td>8,195</td>
<td>82.22</td>
<td>3.38</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Non-hydric</td>
<td>280,683</td>
<td>53.66</td>
<td>1,772</td>
<td>17.78</td>
<td>0.63</td>
<td>0</td>
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<tr>
<td>Land Cover</td>
<td>Ag/Open Urban</td>
<td>417,687</td>
<td>79.85</td>
<td>3,631</td>
<td>36.43</td>
<td>0.87</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Wooded on Hydric</td>
<td>23,344</td>
<td>4.46</td>
<td>4,344</td>
<td>43.59</td>
<td>18.61</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Wooded on Non-Hydric</td>
<td>44,526</td>
<td>8.51</td>
<td>725</td>
<td>7.28</td>
<td>1.63</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Shrub/scrub</td>
<td>7,348</td>
<td>1.40</td>
<td>327</td>
<td>3.28</td>
<td>4.45</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Barren</td>
<td>1,195</td>
<td>0.23</td>
<td>11</td>
<td>0.11</td>
<td>0.91</td>
<td>1</td>
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<tr>
<td></td>
<td>Non-forested Wetland</td>
<td>2,757</td>
<td>0.53</td>
<td>714</td>
<td>7.16</td>
<td>25.89</td>
<td>0</td>
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<tr>
<td></td>
<td>Urban</td>
<td>22,109</td>
<td>4.23</td>
<td>92</td>
<td>0.92</td>
<td>0.42</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Open Water</td>
<td>4,102</td>
<td>0.78</td>
<td>123</td>
<td>1.23</td>
<td>3.00</td>
<td>0</td>
</tr>
<tr>
<td>Land Use</td>
<td>Undeveloped</td>
<td>471,142</td>
<td>90.07</td>
<td>9,650</td>
<td>96.82</td>
<td>2.05</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Developed</td>
<td>51,924</td>
<td>9.93</td>
<td>317</td>
<td>3.18</td>
<td>0.61</td>
<td>0</td>
</tr>
<tr>
<td>Topography</td>
<td>0 to 2 (% Slope)</td>
<td>308,114</td>
<td>58.91</td>
<td>7,058</td>
<td>70.81</td>
<td>2.29</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2 to 6 (% Slope)</td>
<td>98,988</td>
<td>18.92</td>
<td>1,263</td>
<td>12.68</td>
<td>1.28</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>6 to 12 (% Slope)</td>
<td>48,611</td>
<td>9.29</td>
<td>576</td>
<td>5.78</td>
<td>1.19</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>12 to 18 (% Slope)</td>
<td>39,374</td>
<td>7.53</td>
<td>578</td>
<td>5.80</td>
<td>1.47</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>18+ (% Slope)</td>
<td>24,233</td>
<td>4.63</td>
<td>395</td>
<td>3.97</td>
<td>1.63</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Pits and water</td>
<td>3,746</td>
<td>0.72</td>
<td>96</td>
<td>0.97</td>
<td>2.57</td>
<td>1</td>
</tr>
</tbody>
</table>
Although shallow DTW (0-5 feet) is selected to have high potential for restoration, few OWI had a DTW of 0-5 feet (3.71 percent Table 5); however, 3.75 percent of the total acres within the OWI had DTW 0-5 feet (Table 5). The data in Table 5 for DTW data set shows that the greatest numbers of total acres within the OWI are found where the DTW is 0 to 5; 5-15 feet (3.75; 3.39 percent Table 5). The ordination is made in a gradient from the shallowest water table down to the 15 to 30 foot depth to recognize that DTW is not able to provide the resolution required by the definition of wetland hydrology (0 to 12 inches below the surface) and there is a high probability that sites with high water table might be drained wetlands.

Hydric soils comprise 3.38 percent (Table 5) of the total acres within the OWI. Since hydric soils are required for the best ecologic outcome of wetland restoration, not wetland creation efforts, hydric soils are given the highest possible score even though there are wetlands that occur on non-hydric soils 0.63 percent of the total acres within the OWI (Table 5). This discrepancy may be an artifact of how the GIS system estimates whether a certain data point is classified as hydric or non-hydric when the hardcopy maps are digitized or how the OWI is surveyed to identify true wetlands.

Land cover has numerous attributes and it appears that about 37 percent (Table 5) of the OWI and only 0.87 percent of the total acres within the OWI (Table 5) contains Ag/ Open Urban. OWI sites occur most frequent (44 percent (Table 5)) on wooded sites with hydric soils attributes. Other wooded sites are given three or five points because it is possible that many have been misclassified in the original soil survey that began over fifty years ago. Wetland sites, open water and urban land cover are scored zero because restoration is inappropriate.
Land use includes only developed and undeveloped as possible attributes. It is economically and socially unacceptable to place wetlands on already developed land in most cases so developed land is given a zero value and undeveloped land is given the highest value of nine.

Most, but not all, wetlands in OWI occurred on slopes of 0 to 2% and a significant number occur on slopes of 2 to 6%. Since all slopes had some OWI wetlands associated with them and because it is physically more difficult to restore wetlands on sites with increasingly greater slopes, the scoring system is graduated with the slopes and somewhat in parallel with the acreage in OWI wetlands.

4.2 Weighted Overlays

4.2.1 Single Data Set Emphasis

Weighted overlays (Table 3) are made to obtain patterns of suitability. Each figure is modified by the attribute values given in Table 5 and the weighing is made to produce a score in a gradient from one to nine represented in the figures by colors ranging from blue for sites with lowest restoration potential to red where restoration potential is highest.

Figure 1, maximizing only hydric soils, shows drainage patterns and produces 242,388 acres (Table 6) with a score of nine. Most hydric soils are in eastern Greene County, northwestern and south central Clark County. Table 6 shows the amount of land in acres and in a percent of the total land in both counties with each possible suitability score (1-9).
Table 6. Acres and the percent of total acres each score in each weighted overlay analysis produced. Shaded cells indicate the figure where the highest acreage has a score of nine. The bolded numbers indicate the score with the highest acreage. Total number of acres for both counties is 523,065.

<table>
<thead>
<tr>
<th>Fig #</th>
<th>Score 1</th>
<th>Score 2</th>
<th>Score 3</th>
<th>Score 4</th>
<th>Score 5</th>
<th>Score 6</th>
<th>Score 7</th>
<th>Score 8</th>
<th>Score 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>280,676 / 54%</td>
<td>0</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>2</td>
<td>3,747 / 1%</td>
<td>112,215 / 21%</td>
<td>98,988 / 19%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>51,925 / 10%</td>
<td>0</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>4</td>
<td>28,966 / 6%</td>
<td>1,915 / 0.23%</td>
<td>7,344 / 1%</td>
<td>0</td>
<td>0</td>
<td>44,476 / 9%</td>
<td>0</td>
<td>23,393 / 4%</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>177,570 / 34%</td>
<td>206,227 / 39%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>129,395 / 25%</td>
<td>0</td>
<td>0</td>
<td>9,873 / 2%</td>
</tr>
<tr>
<td>6</td>
<td>11,415 / 2%</td>
<td>12,479 / 2%</td>
<td>32,312 / 6%</td>
<td>23,513 / 4%</td>
<td>201,256 / 38%</td>
<td>129,287 / 25%</td>
<td>103,829 / 20%</td>
<td>612 / 0.1%</td>
<td>8,362 / 2%</td>
</tr>
<tr>
<td>7</td>
<td>12,136 / 2%</td>
<td>1,438 / 0.3%</td>
<td>3,020 / 1%</td>
<td>906 / 0.2%</td>
<td>52,198 / 10%</td>
<td>6,157 / 1%</td>
<td>41,456 / 8%</td>
<td>22,487 / 4%</td>
<td>383,266 / 73%</td>
</tr>
<tr>
<td>8</td>
<td>1,966 / 0.4%</td>
<td>18,892 / 4%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>112,147 / 21%</td>
<td>0</td>
<td>0</td>
<td>277,048 / 53%</td>
</tr>
<tr>
<td>9</td>
<td>5,451 / 1%</td>
<td>148,842 / 28%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>129,058 / 25%</td>
<td>57,988 / 11%</td>
<td>0</td>
<td>181,725 / 35%</td>
</tr>
<tr>
<td>10</td>
<td>19,860 / 4%</td>
<td>17,886 / 3%</td>
<td>13,930 / 3%</td>
<td>0</td>
<td>0</td>
<td>219,131 / 42%</td>
<td>127,168 / 24%</td>
<td>115,465 / 22%</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>4,978 / 1%</td>
<td>141,304 / 27%</td>
<td>56,242 / 11%</td>
<td>10,817 / 2%</td>
<td>74,937 / 14%</td>
<td>108,018 / 21%</td>
<td>118,504 / 23%</td>
<td>0</td>
<td>8,265 / 2%</td>
</tr>
<tr>
<td>12</td>
<td>122,799 / 23%</td>
<td>106,211 / 20%</td>
<td>48,851 / 9%</td>
<td>0</td>
<td>60,786 / 12%</td>
<td>96,823 / 19%</td>
<td>80,543 / 15%</td>
<td>0</td>
<td>7,051 / 1%</td>
</tr>
<tr>
<td>13</td>
<td>4,671 / 1%</td>
<td>7,500 / 1%</td>
<td>5,189 / 1%</td>
<td>29,796 / 6%</td>
<td>86,937 / 17%</td>
<td>102,627 / 20%</td>
<td>13,231 / 3%</td>
<td>16,590 / 3%</td>
<td>256,522 / 49%</td>
</tr>
<tr>
<td>14</td>
<td>22,296 / 4%</td>
<td>5,977 / 1%</td>
<td>44,473 / 9%</td>
<td>107 / 0.02%</td>
<td>214,620 / 41%</td>
<td>2,441 / 0.5%</td>
<td>2 &lt; 0.1%</td>
<td>23,286 / 4%</td>
<td>209,861 / 40%</td>
</tr>
<tr>
<td>15</td>
<td>37,177 / 7%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>258,255 / 49%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>227,633 / 44%</td>
</tr>
<tr>
<td>16</td>
<td>2,496 / 0.5%</td>
<td>3,276 / 1%</td>
<td>27,871 / 5%</td>
<td>82,103 / 16%</td>
<td>79,637 / 15%</td>
<td>120,728 / 23%</td>
<td>69,652 / 13%</td>
<td>131,247 / 25%</td>
<td>6,054 / 1%</td>
</tr>
<tr>
<td>17</td>
<td>1,951 / &lt;1%</td>
<td>3,364 / 1%</td>
<td>19,665 / 4%</td>
<td>31,350 / 6%</td>
<td>83,601 / 16%</td>
<td>61,506 / 12%</td>
<td>124,495 / 24%</td>
<td>31,481 / 6%</td>
<td>165,653 / 32%</td>
</tr>
</tbody>
</table>

Figure 2 emphasizes flat topography (0-2 percent slope) within the overlay.

Many of the regions scored nine in Figure 1 are repeated suggesting that low slope and hydric soils may share some common factor. Land that receives a score of nine included 308,115 acres (Table 6).
Figure 3 focuses on ‘undeveloped’ or ‘restorable’ and 471,140 acres or ninety percent (Table 6) scored nine. The areas in blue: Xenia, Springfield, WPAFB and Beavercreek are very distinguished. Most of Greene County is ‘undeveloped’.

In Figure 4 emphasizing land cover, depicts similar ‘developed’ as in Figure 3, but contains more mid-range scores. Water bodies, such as Lake Shawnee (eastern Greene County) are apparent. The land cover data set is heavily weighted and the majority of the land (eighty percent (Table 6) is high suitability and classified as ‘agricultural/open urban’.

Figure 5 focuses on DTW and high suitability scores having shallow DTW are in few locations (9,873 acres (Table 6)). The high suitability locations are not in areas where there is a known shallow water table, as in the Beaver Creek Wetlands, river valleys and location of known aquifers. In the Beaver Creek Wetlands, water emerges at surface most of the year, but Figure 5 does not indicate this area. Areas with high suitability are in north central and northeastern Clark County and western and south central Greene County and one small area in west central Greene County. The highest percentage of land is scored three (thirty-nine percent) and score of one is second (thirty-four percent) (Table 6).

4.2.2 Weighted Overlays Dual Data Set Emphasis

Figure 6 focuses on DTW and land cover. Only two percent of the total land (Table 6) has a score of nine. Land with scores of five, six and seven comprises the majority of the land with thirty, twenty-five and twenty percent, respectively. The same
high suitability areas Figure 5 found in eastern Greene County and north central Clark County are also found in Figure 6.

Figure 7 depicts ‘developed’ or ‘Urban’ areas. Both land use and land covers are heavily weighed (forty-seven percent) (Table 3) and high suitability scoring is abundant throughout both counties. Seventy-three percent of the total land score nine and ten percent score five (Table 6). The lowest score is developed areas in both data sets and scores of two are those areas that are scored low in either data set; water bodies shown in Figure 4 are visible as lighter blue.

Figure 8 use equal influences for topography and land use (Table 3). A score of nine (fifty-three percent (Table 6)) is dominant; scores six and five are second and third, twenty-two and twenty-one percent, respectively (Table 6). As in Figure 7, Clark County’s urban areas, major roads and WPAFB are easily seen.

Figure 9 amplifies flat land on hydric soils. When equal influences of forty-seven percent are used for hydric soils and topography (Figure 9), scores of nine (thirty-five percent), two (twenty-eight percent) and five (thirty-five percent) had the highest percentages (Table 6). Figure 9 depicts that many sites with hydric soils are flat and may be good sites for restoration. Eastern Greene County and northwestern Clark County have high suitability scores; however, stream/drainage patterns are apparent throughout both counties.

Figure 10 shows areas where DTW is the primary driver of high scores, but not always consistent with known wetland sites having high water tables. DTW and land use have equal percent influence. Acres with a score of five contain 219,131 acres or forty-two percent of the total land area (Table 6). Area with scores of six and seven contained
127,168 acres and 115,465 acres, respectively (Table 6). Low suitability scores include the developed areas: WPAFB, Springfield and Xenia.

Figure 11, similar to Figure 10, identifies the same areas indicating that these DTW values have a strong influence when combined with topography or land use. Areas with a score of nine, DTW of 0-5 feet, are the same areas as seen in Figures 5, 6 and 10. DTW and Topography had equal percent influence (forty-seven percent (Table 3)) and twenty-seven percent (Table 6) of the total land scored two. Scores of seven and six contain twenty-three percent and twenty-one percent, respectively, of the total land (Table 6).

In Figure 12, the high suitable DTW areas occur in the same locations when combined with hydric soils suggesting that they might be related to hydric natures of those soils that occur on flat lands (Figure 11). Equal percent influences (forty-seven percent (Table 3)) for DTW and hydric soil are used in Figure 12. In Figure 12, a score of one encompasses twenty-three percent (Table 6) of the land. Land with a score of two and six (twenty and nineteen percent (Table 6), respectively) comprise the majority of the land. A suitability score of nine is seen in eastern Greene County and in northwestern Clark County, which are the same areas seen in Figures 5, 6, 10 and 11. The shallow DTW are the only areas that obtained this high suitability score.

Land cover and topography have equal percent influences (forty-seven percent (Table 3)) in Figure 13. Areas with relatively low slopes and land cover that is undeveloped are scored nine contain the highest percentage of land (forty-nine percent or 255,772 acres (Table 6). A similar pattern in Figure 2 and Figure 13, where topography weighed heavier, is apparent. Western Greene County, northwestern Clark County and
many areas throughout both counties have high suitability; however, since hydric soils are not included in this overlay, Figure 13 should not be important in indicating restorable wetlands.

Figures 14 and 15 have equal influences for hydric soils/land cover and hydric soils/land use, respectively. Both figures produce similar maps of high suitability sites. Figure 15 has a higher percentage of land scoring nine: forty-four percent, versus forty percent (Table 6), indicating that land cover is more restrictive in site selection.

Figure 16 depicts the shallow DTW areas also seen in Figures 5, 6, 10, 11 and 12, are scored nine in spite of the equal percent influences used for the other data sets. Table 6 shows approximately the same amount of acres in Figures 5, 6, 10, 11 and 12 with a score of nine (average of 8,205 acres). The developed areas of WPAFB, Springfield, Xenia and Beavercreek are scored low as seen in Figures 3, 4, 6, 7, 8, 10, 12, 13, 14 and 15, which weighed the land use and/or land cover heavier. The stream/drainage patterns throughout both counties are also apparent. Scores of eight comprise the highest percentage of the total land (twenty-five percent (Table 6)).

Figures having the highest percentage of land with a suitability of nine include 2-4, 7-9 and 13 (Table 6). These figures do not assign the DTW data set a heavier percent influence. Land use and land cover overlays produced similar looking maps (Figures 3 and 4, 8 and 13, 14 and 15).

Figure 17 does not utilize the DTW data set and gives equal influence for all other data sets. The highest number of acres has a score of nine (165,653 Table 6). Eastern Greene County, northwestern Clark County and many drainage patterns have a high score. Developed areas and lakes have a low score.
4.3 Test for Fen Restoration Potential

Conceptually, lands with steeper slopes are more difficult to restore to wetland and because of ecological problems, might be a small part of agricultural practices. I stated that restoration within this study is to be done on low slopes, specific types of wetlands are associated with steeper slopes, particularly fens. I examined how specific hydric soils (mucks) are related to slope on agricultural land. Land with slopes greater than six percent are considered unlikely for restoration within these methods because 16.5 percent of OWI (Table 5) occur on land with slopes greater than six percent and these slopes make construction methods more expensive.

‘Agricultural/open urban’ land cover classification was selected and intersected with slopes greater than six percent (Figure 18), which included 80,394 acres or 15.37 percent of the total land (Table 7).

Table 7. Data expectation tests acreage and percent of total land (523,066 acres).

<table>
<thead>
<tr>
<th>Description</th>
<th>Acres</th>
<th>% of Total Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag land on slopes &gt; 6%</td>
<td>80,394</td>
<td>15.37</td>
</tr>
<tr>
<td>Ag land on slopes &gt; 6% on Hydric soils</td>
<td>43,407</td>
<td>8.30</td>
</tr>
<tr>
<td>All muck soils selected</td>
<td>2,936</td>
<td>0.56</td>
</tr>
<tr>
<td>Muck soils within 1Km of slopes &gt;6%</td>
<td>2,734</td>
<td>0.52</td>
</tr>
</tbody>
</table>

To determine if the agricultural land on steeper slopes has other restoration qualities, the land on steep slopes are intersected with hydric soils (Figure 19) and result in containing 8.30 percent of the total land (Table 7).

Since seepage wetlands, like fens are associated with muck soils (Adrian, Carlisle and Linwood) are selected from the soil survey data set (Figure 20). Muck soils include 0.56 percent of the total land (Table 7). Fens are also associated with hillsides,
specifically, at the base of a hillside (Amon et al. 2002). A one kilometer buffer around slopes greater than six percent is developed to include the areas at the base of a hillside. Muck soils within one kilometer buffer could be a potential fen restoration site. Muck soils within one kilometer of a slope greater than six percent are selected (Figure 21) and include 0.52 percent of the total land area (Table 7). Only 202 acres of muck soils are not within one kilometer of land with slopes greater than six percent (Table 7). The remaining 2,734 acres are potential fen restoration sites.

4.4 Development of the Intersection Vector Analysis

In order to find areas with the identified characteristics, I perform an intersection analysis. The following attributes within each data set: hydric soils, DTW (0-5 feet), slope (0-2 percent), land outside a one kilometer buffer around land use classified as ‘unrestorable’ or ‘developed’ and land cover as ‘agricultural/open urban land’ are isolated. The selected attributes of each of the five data sets are isolated from each data set. They are intersected with each other, so that the final map (Figure 22) would only locate land that contained all five attributes for the first analysis. The resulting analysis did not contain as many acres as anticipated using DTW 0-5 feet. Only 4,114 acres or 0.79 percent of the total land area (Table 8) was included in each analysis (also referred to as ‘Base Map’).
Table 8. Vector analysis results of total restorable acres and the percentage of the total land area (523,065 Acres). Base map is comprised of hydric soils, land use undeveloped, land use excluding one kilometer around developed land, land cover agricultural/open urban, slope 0-2% and varying DTW as noted for each figure below.

<table>
<thead>
<tr>
<th></th>
<th>Figure 22 DTW 0-5’</th>
<th>Figure 23 DTW 0-15’</th>
<th>Figure 24 DTW Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acres</td>
<td>% of Total Land</td>
<td>Acres</td>
</tr>
<tr>
<td>Base Map of Selected Sites</td>
<td>4,114 0.79</td>
<td>33,902 6.48</td>
<td>74,249 14.20</td>
</tr>
<tr>
<td>Selected Sites within 100 Meters of OWI</td>
<td>1,652 0.32</td>
<td>12,548 2.40</td>
<td>22,199 4.24</td>
</tr>
<tr>
<td>Selected Sites within 30 Meters of OWI</td>
<td>276 0.05</td>
<td>2,223 0.43</td>
<td>4,088 0.78</td>
</tr>
</tbody>
</table>

To determine the proximity of potential sites to existing wetlands, the OWI has two buffers created: 100 and 30 meters. Two buffers are intersected with the first analysis selection. Only 0.32 percent of the selected sites (Table 8) are within one hundred meters of an OWI wetland and 0.05 percent is within thirty meters (Table 8). The majority of the land is located in eastern Greene County.

To increase the amount of potential restoration site, a second vector analysis uses the same attributes as selected in the first analysis, except that the DTW data set is increased from 0-5 to 0-15 feet because 25 percent of the total land (Table 5) is classified 0-15 feet. In the second analysis, the base map includes 6.48 percent of the total land (Table 8). Eight times the amount of land in the first analysis is selected when DTW range is increased to 0-15 feet. The one hundred and thirty meter buffers around the OWI include 2.40 percent and 0.43 percent of the total land (Table 8), respectively. The
majority of the land is in eastern Greene County; however, some land is in scattered areas are in central and western Greene County, northeastern and eastern Clark County.

To optimize the site selections and determine if there is accuracy within the data set, the DTW data set is not utilized in the third vector analysis. Only hydric soils, slope (0-2 percent), land outside a one kilometer buffer around land use classified as ‘unrestorable’ or ‘developed’ and land cover as ‘agricultural/open urban land’ are selected. More land is selected when DTW is not used. The third analysis includes 14.20 percent of the total land (Table 8) and the OWI buffers of one hundred and thirty meters include 4.24 percent and 0.78 percent (Table 8), respectively. The third analysis contains the highest amount of potentially restorable land with an increase in areas in eastern and southern Greene County, and eastern Clark County.

4.5 Site Visits

4.5.1 Vector Intersection Analysis Using DTW 0-15’ Locations

Site visits were selected from the third vector analysis (Figure 24), where large portions of potential restoration areas can be viewed via roadside. Figures 25, 27, 29, 31 and 33 depict the final parcels selected, roads, OWI wetlands and the location of where the photographs were taken.

In Figure 25, a site visit was conducted along Linebaugh Road just north of Ludlow Road. The surrounding area was undeveloped and in agriculture. A photograph (Figure 26) was taken on 6/24/05 facing west to show what the third analysis depicted as a potential restoration site. The area was very flat and a small change in the drainage
pattern of the area could result in affecting more than ten acres. Figure 26 did show some wetland vegetation although it was not shown to be an OWI wetland. There were OWI wetlands nearby, to the north and south of where the photo is taken. This area can restore connectivity to the nearby OWI wetlands to create a larger corridor.

Yellow Springs Fairfield Road and the intersection of Byron Road contained potential restoration sites according to the third analysis (Figure 27). A photograph (Figure 28) was taken on 6/24/05 facing south. A large agricultural field contains a grassed drainage way. No drainage tiles can be seen. Even though removal of potential tiles or blocking the drainage way would return water to the surface over a large areas due to the flatness of the land, the grassed drainage way was already providing a way for excess nutrients to be removed from the runoff.

Figure 29 was visited and two photographs (Figures 30a and 30b) were taken along Cortsville Road near US 42 on 6/25/05. The photos were taken of both sides of the road facing east and west. The land use is agricultural and it is very flat. The approximate six foot diameter pipe traveling under the road can be blocked to allow water to backup on the western side of the road. Smaller and more frequent pipes can be inserted along the road just below the grade to allow water to pass under during times of flooding. Since row crops are planted, the more likely area to return to a wetland would be the eastern or fallow side.

Rodgers Road was traveled (Figure 31) and a photograph was taken near US 35 on 6/25/05. The drainage ditch shown in Figure 32 has water more than one foot deep and it continues throughout the fields. The weather conditions during that time were infringing on drought conditions. Agriculture drainage systems collect huge amounts of
water even during periods of drought. This ditch could be dammed in several areas or could have the tiles removed to bring the water table close to the surface for restoration. Since the ditch is more than three feet deep, damming in several place would provide a less time consuming way to return the water table to the surface.

Carpenter Road, near the intersection of Davis Road in southeastern Greene County was visited on 6/25/05 (Figure 33). Although there were no potential restoration sites located where the road passed through the area, agriculture with drainage ditches were present (Figure 34a and 34b). The photographs were taken east and west of Carpenter Road. Grassed drainage ways were visible (Figure 34b), but drainage tile could not be seen. Figure 34a shows a weir, which suggests that the areas did need to have drainage to plant crops, but could experience the need to limit the amount of water draining from the fields. The weir could be blocked at various levels to allow a particular level of water to remain in the fields. Blocking the weir would raise the water table to allow wetland vegetation to return to the area for a potential restoration site. The hill (greater than two percent slope) in the background of Figure 34a (facing east) confirms why that area is not considered restorable within these methods.

4.5.2 Shallow DTW Locations

The areas found to have shallow DTW were viewed using Google Earth and Greene County Geographic Information Management System (Figures 35-39). The areas were located by matching roads shown in Figure 22. The areas of interest appear to be agriculture with soils that are dark. Drainage patterns seen in aerial photos suggest there
are ditches within the fields. Straight lines and right angles (Figures 34 and 35) for streams prove man-made features are present. Areas are in agriculture with few homes or developed areas are nearby.
5. DISCUSSION

5.1 Hydric Soils Influences

Numerous studies conclude that having the correct hydrology is the first and foremost important factor for wetland restoration (Hausman et al. 2007; Mitsch and Gosselink 2000; Fennessy et al. 2007). Many agricultural fields have been drained using ditch and tile systems where hydric soils were present. Hydric soils were formed under conditions of saturated, flooding or ponding in the upper part of the soil to develop anaerobic conditions during the growing seasons (Ohio NRCS 2007 Appendix A) and were once wetlands (Amon et al. 2005; Hammer 1992). Locating hydric soils was key to finding restorable land within this project and would have a high restoration success rate. Restorations are more successful when restored on former wetland sites (McCauley and Jenkins 2005). Figures 1, 9, 14-17, 19, and 22-24 utilize hydric soils and are the only figures that should be used in considering potential restoration sites.

This project may have overestimated the number of hydric soils, giving an over estimate of the potential restoration sites. The NRCS (2008) soil mart site allowed for extraction of specific soils type acres included within each county. The acres of hydric soils for both counties totaled 133,530 acres and 242,383 acres (Table 5) and were said to
be hydric. Closer examination of the soil data set is required to determine if there is a severe error within the data set.

Certain soils types have characteristics that will support a specific wetland and can be isolated to find potential restoration sites. More research is needed to determine what soil type supported what type of wetland. For instance, if historic swamp wetlands were analyzed to determine the type of soil present, an assumption could be made and any restorationists that would want to restore a swamp would have the best success on that particular soil type. The soil type could be singled out and other criteria could be examined to find potential swamp restoration sites.

Muck soils support fens and hillside seeps (Amon et al. 2002) and isolation of these soils shows where potential restorations for high quality, category three delineated wetlands (Mack 2001) could be located. Although, hydric soils are not always required for fen restoration (Amon et al. 2005) the success rate increases when wetland restoration is conducted on historic wetland locations.

Non-hydric soils with hydric inclusions were not included in the hydric soil selection due to the exclusion within the hydric soils listings (USDA and NRCS 2007). The inability to know the amount of hydric inclusions in any soil type and the listing has become obsolete (Ohio NRCA 20007 Appendix A). McCauley and Jenkins (2005) included hydric soil and hydric inclusions within their study. Including these obsolete classifications would over estimate the amount of potential land for restoration. By not including these soils, I was conservative in the land that could be considered for restoration. These inclusion soils could be selected from the soil data set and examined to determine their restoration potential.
5.2 Low Slopes and DTW

Locating flat land to restore was another important land characteristic within these methods. By restoring on low sloped land, slight variations in the drainage channels could affect a larger number of acres. Hausman et al. (2007) found that even a 15-20 cm difference in water table elevation affected the wetland vegetation.

DTW data set severely reduced the amount of high suitability land within this project even though DTW is stated to be most important factor in obtaining hydrology to support wetland vegetation (Hausman et al. 2007). This demonstrated an error within the DTW data set during its original compilation. DTW data sets were comprised of water well logs on file with the Ohio Department of Natural Resources, Division of Water, Water Resource Section (Vormelker et al. 1995; Jones 1995). Groundwater wells were typically in areas with high populations and not in agricultural fields. This limited the number of well logs in agricultural to extrapolate the data within the DTW data set. The accuracy of the data set was questionable in agricultural areas. The compilation of the DTW data set was skewed and not considered a vital data set within these methods for predicting restoration potential.

The resolution of DTW data set was in meters and not the inches that was needed. Figure 17 and 24 eliminated the usage of DTW and provided more realistic maps locating restoration sites. Future studies should exclude the usage of DTW to locate potential restoration sites.
5.3 Land Use and Land Cover

White and Fennessey (2005) utilized land cover data sets for their model and scored *Agricultural/open urban*, *shrub* and *wetland* classifications the highest. I scored the wetland classification as zero because you cannot restore what is already a wetland. I scored *Shrub/scrub* lower than White and Fennessey’s (2005) study due to the percentage of the OWI that contain *Shrub/scrub*. *Water* and *urban* were scored zero for these methods and in White and Fennessey’s (2005) study. Scoring the land use and land cover attributes was justified by the characteristics of the OWI.

The overlays that contained either land use or land cover or a combination of them produced visually similar maps, suggesting that the attributes within the land use and land cover data sets were too similar. In the land cover data set, Clarence J. Brown Reservoir is apparent in northeastern Clark County and is not visible within the land use data set also suggesting the land use data set is too general. The land cover data set is more consistent over the two counties for comparison because land cover did not have to undergo personal interpretation of the attributes to determine if it was restorable or not.

The land suitable for restoration was severely limited in Clark County due to the land use having more land considered developed than Greene County and less hydric soils present. Reclassification of developed areas in Clark County, eliminating the land use data set and reducing the buffer around the ‘unrestorable’ land could increase the number of potential restoration areas in Clark County. Land cover is better to describe the usage of an area; the land use data set should be excluded in future research.
5.4 Agriculture/Open Urban and Slopes

Agriculture was assumed to not occur on steeper slopes (greater than six percent); however, contour farming permits farmers to plant on steeper slopes (NRCS 2005). Intersecting agricultural land occurring on steeper slopes with hydric soils allowed land originally considered unrestorable to be considered since hydric soils are present and were historically wetlands (Ohio NRCS 2007 Appendix A).

Hausman et al. (2007) also focused on returning hydrology to agricultural fields. The removal of the top soil layer of an agricultural area reduced invasive species, promoted wetland plant species, removed persistent chemicals and restored hydrology to a larger area (Hausman et al. 2007). The removal of the top layer of soil was not considered within my methods, but could be removed if warranted by prior land use. The soil removal would eliminate weeds, pesticides and other undesirables; however, it could also remove good seeds and soils.

5.5 Weighted Overlays

By conducting a weighted overlay that contained equal percent influences, the suitability of the land can be seen simultaneously and depict a more realistic map. One data set alone cannot describe a potential site, but grouping data sets will describe the area better (White and Fennessy 2005). The number of potential iterations within the weighted overlay that could be done is seemingly infinite. Not adjusting any attribute scoring matrix, the possible number of iterations is over sixty-one million and would increase if the attribute scoring matrix was adjusted. Patterns over the two county area
can be seen: potential riparian wetlands, wetlands associated with steep slopes (fens) and
depressional wetlands on flat, shallow DTW in agriculture.

When comparing Figures 1 and 2, flat topography and hydric soils identify
roughly the same parts of the landscapes as high suitability and suggest that most hydric
soils are associated with nearly level ground. Figure 3 outlines the major roads in Clark
County and urban centers in Greene and Clark Counties. Figure 4 depicts the utility of
land cover as a factor because open bodies of water, such as C.J. Brown Reservoir
northeast of Springfield and Lake Shawnee in southwestern Greene County are clearly
visible. The open bodies of water are not an appropriate restoration target. In Figures 5
and 6, little land is identified as having near surface groundwater, suggesting that this
parameter is of limited utility when trying to identify potential wetland restoration sites,
even when DTW is combined with land cover. Land use and land cover, while important
aspects of the decision process provided as much detailed information (Figure 7) as
would be needed to make a site choice and the same can be said for the information built
from the combination of land use and topography (Figure 8). Figure 9, which combined
two elements known to be important for wetland construction, appears to add detail to the
maps produced and shows both till plain and stream valley association sites. Combining
DTW with acceptable land use (Figure 10), topography (Figure 11) or hydric soil (Figure
12) reinforces the idea that DTW is of limited utility in this process. Figures 14 and 15
are similar and demonstrate how land use and land cover affect the site selection process.
DTW’s affect is apparent in reducing the amount of land with high suitability when no
percent influence is made (Figure 16 and 17).
5.6 Ultimate Data Sets to Consider

Data sets: land cover, hydric soils and topography produced more realistic potential sites than other combinations of the data sets within these methods. Similarly, White and Fennessy (2005) used ‘local’ or the physical parameters that define a wetland: hydrologic regime, vegetative character, soil character, and topography. For these methods, hydrologic regime was thought to be described well within the DTW data set; however, the DTW was not compiled to the accuracy or resolution needed to be utilized in site selection within these methods. White and Fennessy (2005) also utilized hydric soils, land use and topography, but also included: stream orders, watershed position and streams meeting water quality standards. I assumed that if agricultural land were present on hydric soils, the historic land use was a wetland. If the hydrology could be returned to the area, a wetland could be restored (Mitsch and Gosselink 2000; Tiner 2003; Dahl 2000).

Rapid assessments often use varying elements when delineating a site. Fennessy et al. (2007) evaluated many assessment methods, including the ORAM. The core elements of many assessments are: hydrology, vegetation, landscape setting and soils/substrate. When comparing what the assessments look at, my methods have utilized all factors, excluding the hydrology; however, hydrology is assumed to return when drainage in agriculture is removed on hydric soils. The correct data types were selected adequately according to how a rapid assessment method would be conducted. The ideal characteristics for potential restoration sites within these methods would include: hydric soils, low slopes (0-2 percent) and land cover of Agricultural/Open Urban.
Other data sets that have been used in GIS projects include: streams (White and Fennessy 2005); digital elevation models and digital raster graphics (McCauley and Jenkins). Van Lonkhuyzen et al. (2004) utilized: elevation contours, historic topography, soils, historic wetland, historic depressions, vegetation, streams and land use. While these types of data were considered, their lack of availability made them undesirable.

Since hydric soils are the most necessary attribute of a restored wetland, future analysis would select hydric soils and then clip all other data sets where hydric soils are present. The data sets would be a lot smaller and would allow for faster analysis for both raster and vector analysis.

5.6.1 OWI Importance

Prioritizing restoration sites that provide connectivity to other restoration sites or OWI (McCauley and Jenkins 2005) would increase the success rate and biodiversity (White and Fennessy 2005). The OWI wetlands were considered reference wetlands for this project and their known characteristics were used to determine the scoring matrix. Other studies resulted in different scores based on their goals. White and Fennessy (2005) scored land cover’s shrub the same as wetland because their goal was to find all wetland areas, not just restoration sites as these methods provide. Van Lonkhuyzen et al. (2004) also wanted to find mitigation sites, but included historic conditions and adjacent vegetation not available in public records.
5.6.2 OWI: Scoring Attributes

The known or reference wetland characteristics of the OWI data set (Brooks et al. 2004; Mitsch and Gosselink 2000) influenced the scoring matrix used in the weighted overlays. Hydric soils, land use and topography were all scored based on the percentage of OWI that contained a particular attribute. Land cover was scored based on the focus of this study to restore agricultural lands and the remaining attributes were based on the OWI characteristics. The DTW was not scored based on the OWI, but the importance of obtaining the correct hydrology for a wetland. The DTW is not a vital data set within these methods regardless of the scoring matrix.

5.6.3 Compilation of the OWI

The compilation of the NWI was determined to underestimate wetlands in Ohio, whereas the OWI overestimates wetlands. The time of year the imagery was taken affected the reflectance signatures of the specific wetland types (Ozesmi and Bauer 2002). The OWI images were taken during a wet period and the NWI were taken during a drier period during 1985 (Mutter, D. personal communications; ODNR GIMS Appendix A). The use of aerial photography is preferred for mapping wetlands (Ozesmi and Bauer 2002). The large geographic areas that Landsat scan are an advantage over aerial photographs. For these methods, the OWI was selected to include all possible areas that are wetlands to prioritize areas for a seed source and connectivity.
5.7 Data Compiling Issues

GIS causes the user to rely on data sets that another person had compiled, which allows uncontrollable errors into this project. The classification or schematic used when data compliers looked at aerial photographs varied from person to person making aerial photographs subjective. Each county differed within the land use data set. Edgematching across the county line was an issue. If counties were analyzed separately, the edgematching issue would have been eliminated; however, faster analysis and comparison of the two counties was the main reason to perform the joining of the counties.

The fast pace in which landuse/landcover changed was another factor to consider. The data sets used within these methods were considered current even though they were derived from images at least twelve years old. Aerial photographs can be used to supplement lacking current land use information as aerial photographs are taken more frequently (Ozesmi and Bauer 2002). Site visits also aid in concluding if an area is restorable or not.

5.8 Site Visits

The site visits confirmed that using these GIS methods did aid in finding areas able to be restored. Some areas were overlooked due to selection data being too restrictive. Site visits viewed areas on flat land and mainly in agriculture. Many parcels had their own unique qualities proving to be worthwhile restoration projects. Fennessy et al. (2007) concluded that rapid assessment methods should involve a site visits and not
rely solely on GIS. These methods could be utilized by finding larger areas of possible restoration and land patterns.

5.9 Usefulness for Restorationists

Restorationists’ common issue when planning wetland restoration is ‘what areas have the potential to be restored?’ These methods developed a scoring criteria based on characteristics of known wetlands (OWI) to locate potential sites. Flat land, hydric soils, undeveloped and agricultural use were all determined to be common factors in the OWI and would allow for the best chances of restoration success.

The use of these reference wetlands was ideal in finding a site location for a restoration project (Brooks et al. 2004; Mitsch and Gosselink 2000). Mitigators could use Figure 17 and 24 to start their search for farmers willing to return their non-productive agricultural fields into their historic state as a wetland. Figure 17 utilized all data set except for DTW to depict an overview of where the highest potential for restoration can be done. Figure 24 (hydric soils, slopes 0-2 percent, one kilometer from development and agricultural/ open urban), is the most realistic site selection map within these methods for any type of wetland restoration. For fen wetland restoration, Figure 21 should be used.
6. CONCLUSIONS

Hydric soils are the most important factor indicating a restorable site with the consideration of land cover and topography. Buffering around developed areas in land use might have been too restrictive in Clark County because of the manner in which the land was classified. Land use and land cover displayed similar characteristics; however, neither land use or land cover should be isolated from future studies because they each have unique classifications within them that allow for more specific site selections.

DTW was not considered a vital data set within these site selection; however, DTW did show sites of interest where water is very close to the surface that might have easier hydrology to restore than other areas. DTW taken from the DRASTIC scores underestimate the water table and the resolution the data set is in is not conducive to finding wetland restoration sites. DTW data set should not be used in further analyses.

Ideal wetland restoration sites would include hydric soils on Agricultural/Open Urban land cover and low slopes (0-2 percent). The drainage systems in the agricultural fields selected as potential sites could be removed to bring the needed hydrology. Some areas contain agricultural land with hydric soils on slopes greater than six percent and wetland restoration for unique wetland types, such as fens could be conducted.

Site visits are the final step in determining if a site is restorable or not. Potential sites were visited and conclude that these methods predict an area’s restoration potential.
Greene and Clark Counties could be examined individually without combining the data sets. Aerial photographs should be used subjectively when viewing potential restoration sites. Overall, these methods have located potential wetland restoration sites and could be the start of many restoration projects.
FIGURES 1-39
Figure 1. Hydric soils emphasized. Weighted overlay analysis #1 used the following percent influences: Depth-to-Water 1%, Land Cover 1%, Land Use 1%, Topography 1% and Soil Survey 96%.
Figure 2. Low slope topography. Weighted overlay analysis #2 used the following percent influences: Depth-to-Water 1%, Land Cover 1%, Land Use 1%, Topography 96% and Soil Survey 1%.
Figure 3. Undeveloped land use emphasized. Weighted overlay analysis #3 used the following: Depth-to-Water 1%, Land Cover 1%, Land Use 96%, Topography – 1% and Soil Survey 1%.
Figure 4. Agricultural/open urban land cover affect. Overlay analysis #4 used the following percent influences: Depth-to-Water 1%, Land Cover 96%, Land Use 1%, Topography 1% and Soil Survey 1%.
Figure 5. Low DTW emphasized. Weighted overlay analysis #5 used the following: Depth-to-Water 96%, Land Cover 1%, Land Use 1%, Topography 1% and Soil Survey 1%.
Figure 6. DTW and agricultural/open urban land use combined affect. Weighted overlay analysis #6 used the following: Depth-to-Water 47%, Land Cover 47%, Land Use 2%, Topography 2% and Soil Survey 2%.
Figure 7. Agricultural/open urban and undeveloped favored. Weighted overlay analysis #7 used the following: Depth-to-Water 2%, Land Cover 47%, Land Use 47%, Topography 2% and Soil Survey 2%.
Figure 8. Undeveloped land on low topography. Weighted overlay analysis #8 used the following: Depth-to-Water 2%, Land Cover 2%, Land Use 47%, Topography 47% and Soil Survey 2%.
Figure 9. Low topography on hydric soils. Weighted overlay analysis #9 used the following: Depth-to-Water 2%, Land Cover 2%, Land Use 2%, Topography 47% and Soil Survey 47%.
Figure 10. Shallow DTW on undeveloped land. Weighted overlay analysis #10 used the following: Depth-to-Water 47%, Land Cover 2%, Land Use 47%, Topography 2% and Soil Survey 2%.
Figure 11. Low topography and shallow DTW favored. Weighted overlay analysis #11 used the following: Depth-to-Water 47%, Land Cover 2%, Land Use 2%, Topography 47% and Soil Survey 2%.
Figure 12. Hydric soils on shallow DTW. Weighted overlay analysis #12 used the following: Depth-to-Water 47%, Land Cover 2%, Land Use 2%, Topography 2% and Soil Survey 47%.
Figure 13. Low topography and agricultural/open urban land cover emphasized. Weighted overlay analysis #13 used the following: Depth-to-Water 2%, Land Cover 47%, Land Use 2%, Topography 47% and Soil Survey 2%.
Figure 14. Agricultural/open urban land cover on hydric soils. Weighted overlay analysis #14 used the following: Depth-to-Water 2%, Land Cover 47%, Land Use 2%, Topography 2% and Soil Survey 47%.
Figure 15. Undeveloped land use on hydric soils. Weighted overlay analysis #15 used the following: Depth-to-Water 2%, Land Cover 2%, Land Use 47%, Topography 2% and Soil Survey 47%.
Figure 16. All equal percent influences. Weighted overlay analysis #16 used the following: Depth-to-Water 20%, Land Cover 20%, Land Use 20%, Topography 20% and Soil Survey 20%.
Figure 17. All equal percent influences and DTW excluded. Weighted overlay analysis #17 used the following: Land Cover 25%, Land Use 25%, Topography 25% and Soil Survey 25%.
Figure 18. Agricultural land on slopes greater than 6%. Slopes greater than six percent intersected with agricultural/open urban land cover represent 15.37% of the total land or 80,394 acres. Restoration could be accomplished on slopes >6% since hydric soils are present.
Figure 19. ‘Agricultural/open urban’ land use on slopes greater than 6% and hydric soils, which represents 8.30% of the total land or 43,407 acres. Even though steep slopes >6% were rated low in suitability within these methods, this figure demonstrates that restoration of agricultural land could be accomplished on slopes >6% since hydric soils are present.
Figure 20. All muck soils (Adrian, Carlisle and Linwood) were singled out of the hydric soils and included only 2,936 acres (0.56% of the total land). Muck soils are typical of hillside seeps and fens.
Figure 21. All muck soils (Adrian, Carlisle and Linwood) within one kilometer of slopes greater than six percent. Most muck soils are associated with being close to steep slopes. The number of acres includes 2,734 or 0.52% of the total land.
Figure 22. Impact of using shallow DTW for locating restoration sites. In the first analysis, the base map contains land with: flat topography (0-2% slopes), DTW 0-5 feet, hydric soils, 1 km or more outside developed land and land use is agricultural/open urban. A total 4,113 acres are selected. The sites within 100 and 30 meters of an OWI wetland is shown in yellow (1,652 acres) and red (276 acres), respectively.
Figure 23. Impact of using a wider range of DTW for locating restoration sites. In second analysis, the base map contains land with: flat topography (0-2% slopes), DTW 0-15 feet, hydric soils, 1 km or more outside developed land and land use is agricultural/open urban. The base map contains 33,902 acres. The sites within 100 and 30 meters of an OWI wetland is shown in yellow (12,548 acres) and red (2,223 acres), respectively.
Figure 24. Impact of not using DTW for locating restoration sites. In third analysis, the base map contains 74,249 acres with characteristics of having: flat topography (0-2% slopes), hydric soils, 1 km or more outside developed land and land use is agricultural/open urban. The sites within 100 and 30 meters of an OWI wetland is shown in yellow (22,199 acres) and red (4,088 acres), respectively.
Figure 25. Site location in north central Greene County selected from map in Figure 24. Map depicts location of high suitability (hashed areas) for restoration and neighboring Ohio Wetland Inventory classification.
Figure 26. Site visit along Linebaugh Road approximately 0.5 miles north of Ludlow Road in north central Greene County. Photo was taken facing west on 6/24/05. The OWI does not include this area and since wetland vegetation was seen from the road (circled in red), restoration or enhancement of the surrounding area could be performed by changing the drainage. The OWI in Figure 25 shows wetlands categorized as ‘woods on hydric soils’, a potential seed bank, to the north and south of this area.
Figure 27. Site location in northwestern Greene County selected from map in Figure 24. Map depicts location of high suitability (hashed areas) for restoration and neighboring Ohio Wetland Inventory classification.
Figure 28. Site visit in northwestern Greene County along Yellow Springs Fairfield Road near the intersection of Byron Road. Photo was taken facing south on 6/24/05. Grassed drainage ways in center of photograph (circled in red) are best management practices to reduce nutrient runoff in agriculture. By filling in the drainage way or blocking it in several places, an increase in the number of acres that would be inundated or saturated with water could occur. Restoration of this very flat land with hydric soils could be done without much excavation of soils.
Figure 29. Site location in north central Greene County selected from map in Figure 24. Map depicts location of high suitability (hashed areas) for restoration and neighboring Ohio Wetland Inventory classification.
Figure 30a and 30b. Site visit in north central Greene County taken from Cortsville Road near Rife Road on 6/25/05. Figure 30a (left) was taken facing west and Figure 30b (right) was taken facing east. There was a large pipe that allowed water to pass from the west side to the east side of the road. The roadway was elevated a few feet above grade. The pipe could be blocked to allow water to pond along the road berm on the west side. The surrounding land was very flat and this ponding of water could encompass many acres to be restored to wetland since hydric soils are present here, however, the east side of the road appears to be fallow and would be more suitable for a wetland restoration versus the row crops in Figure 30a.
Figure 31. Site location in eastern Greene County selected from map in Figure 24. Map depicts location of high suitability (hashed areas) for restoration and neighboring Ohio Wetland Inventory classification.
Figure 32. Site visit in eastern Greene County along Rogers Road facing west on 6/25/05. During the time the photo was taken, the area had not received significant rainfall and still a large amount of water still present, over one foot deep. There were no drainage tiles viewed due to the banks being heavily vegetated. The drainage tiles in this area could be removed or the main drainage ditch could be dammed in several areas to force the water to stay in the fields. The flat topography would allow large amounts of land to be affected by the tile removal and/or ditch damming.
Figure 33. Site location in southeast Greene County selected from map in Figure 24. Map depicts location of high suitability (hashed areas) for restoration and neighboring Ohio Wetland Inventory classification.
Figure 34a and 34b. Site visit in southeastern Greene County. Figure 34a (east) and Figure 24b (west) taken on 6/25/05. Although this area in Figure 24a was not found to be restorable due to the topography having greater than 0-2% slope, the land is flat. The vegetated drainage areas in Figure 34b were seen throughout this area, but the weir (Figure 34a circled in red) was a unique feature. The weir could be blocked to return water to the surface over this flat land.
Figure 35. Image taken from Google Earth near intersection of Federal Road and US 72. Area in red circle contains the DTW 0-5 feet classification. Dark soil markings clearly visible and the area has hydric soils and shallow DTW. The stream, also inside the red circle, is very straight and has right angles (western edge), which is inductive of a drainage ditch.

Figure 36. Zoomed in on red circle from Figure 35. Image taken from Greene County Geographic Information Management System (GIMS). Dark soil markings are more visible.
Figure 37. Image taken from Google Earth near intersection of Hussey Road and US 68. Area in red circle contains the DTW 0-5 feet classification. Dark soil markings clearly visible and concluding that the area has hydric soils and shallow DTW, but this is subjective. The surrounding area appears to be agricultural and not many homes nearby.

Figure 38. Zoomed in on red circle from Figure 37. Image taken from Greene County Geographic Information Management System (GIMS). Dark soil markings are more distinguished.
Figure 39. Image taken from Google Earth near intersection of US 72 and I-71. ‘Hot spot’ area in red circle contains the DTW 0-5 feet classification. Aerial image of the area is not very clear. The surrounding area appears to be agricultural and some buildings do appear. A conclusion on the drainage of the land cannot be made. The subjective aerial photograph west of the circled area does show dark or possible wet soils.
LITERATURE CITED


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LITERATURE CITED (CONTINUED)


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APPENDIX A

World Wide Web Address Accessed


APPENDIX A (CONTINUED)


APPENDIX B

Methods for producing usable data sets within these methods

Data was selected based on how original data sets were compiled (Table 1). The five data sets all underwent PROJECTDEFINE command within ARC INFO command line. Here the following was typed in for proper projection of all data sets (example for soil coverage):

```
ARC: projectdefine
Usage: PROJECTDEFINE <COVER | GRID | FILE | TIN> <target>
ARC: projectdefine cover soil
Define Projection
Project: projection stateplane
Project: units meters
Project: datum nad27
Project: zone 5001
Project: parameters
```

Extracting the data from within the data sets was determined set by set based on the attributes needed for thesis analyses. One column with the attribute that would be scored was selected that could then be manipulated without changing any of the original data. A column was added within the data table by using TABLES within ARC INFO (example for soil coverage):

```
Tables: additem soil.pat hydric 10 10 c
```

For soils, using the Table module within ARC INFO, selection of hydric soils was accomplished by:

```
Tables: select soil.pat
```
Tables: resel hydric-id = ‘Bs’
Tables: asel hydric = ‘Bt’ and so on

Once all hydric soils were selected, the hydric column that was added was then calculated equal to ‘Yes’. In Tables, using the hydric column that was not equal to ‘Yes’ was selected and calculated to ‘No’.

For land cover, ‘codename’ was added as a column within the table, where the lc-id codes were selected and using the metadata, the ‘codename’ was calculated to be a specific land cover. Land use was generalized due to inconsistencies of the two county classification schematic. The tables had a ‘developed’ column added and then all polygons with predetermined development status were selected and the new column was calculated appropriately. Ohio Wetland Inventory data set was coded and similar to the land cover data set, OWI needed to be decoded.

The pollution potential or DRASTIC data was used to extract the depth-to-water (DTW) and Topography (slope) for use in these methods. Two copies of the DRASTIC data set were made naming them: DTW and topography. The columns that were not needed within the two copies were deleted to condense the data set. These columns that were deleted were the other layers within this complex DRASTIC data set. For example, DTW had the columns containing the aspect, Topography, etc. deleted. Like in previous data sets, another column was added where decoding occurred.

Once all data sets for both counties had one attribute column that would be the basis of all future manipulations, the data sets were combined into one continuous data set by using UNION (example for soil):

ARC: Union soil_greene soil_clark soils
Once the union of all like data sets was completed, the data sets were simplified by using DISSOLVE (example for soil):

ARC: Dissolve soils soils dissolved hydric poly

By simplified the data sets, the future processes will run faster.

The county boundary between Greene and Clark County was examined within ARC EDIT module to ensure that a clean UNION was performed. The accuracies of the data sets for each county differ slightly. Slivers or gaps were seen along the boundary. Common boundary lines were snapped together and ARCs were deleted if they were overshoots. Dangles were extended to reach the boundary line. This process was time consuming, but ensured that analyses performed would not be compromised along the county boundary.

After each data set was edge matched, the polygons would need to undergo a BUILD (example for soils):

ARC: Build soils soils poly node line

This process restructures the polygons and recalculated the area and perimeters.

In the final version of each data set another column was added that contains the scores of each attribute assigned. The analyses are based on these numeric values.

For weighted overlay analysis, all vector coverages were converted into raster format (example for soils):

ARC: polygrid soil soil_grid
Cell size: 5 (meters)
**Commands used within these methods**

Using the converted raster files and ARC Map’s tool box, the spatial analysis-overlay-weighted overlay tool can be found. Data sets to be analyzed were selected and percent influences were set. Process took approximately forty minutes to one hour to run.

For the data set intersections, the vector format of the data sets was used. All coverages were converted into shapefiles to perform analysis within ARC Map. The attributes of concern within each data set were selected from the data tables, which were then converted into a shapefile. These shapefiles were usually intersected with another shapefile depending on if the data was to be included or excluded.

Step methods used intersection, symmetrical, buffers and clipped to produce the outcomes based on methods to find restorable sites.

To produce tables 5, 6 7 and 8: each shapefile that had any manipulation done to eliminate or include polygons had to undergo a new area calculation:

Add Area Fields to the in your shapefiles attribute Table:

1. Right-click on the layer and choose Open Attribute Table.
2. Click Options > Add field.
3. Add a field called Area with a Type of Double, Precision (width) of 16 and Scale (number of decimal places) of (usually) 2. The Area field is added to the end of the attribute table.
4. Right-click on the Area field name and click Calculate Values... and click Yes when asked if you want to edit outside an edit session.
5. When the field calculator pops up, click the Advanced checkbox.
6. In the Pre-logic VBA Script Code text box, type (or copy and paste from this text or from the Help page referenced below):

   ```vba
   Dim dblArea as double
   Dim pArea as IArea
   Set pArea = [shape]
   dblArea = pArea.area
   ```
7. Type dblArea in the lower text box and click OK. The values are calculated using the Map units. You can check the Map units by looking at the General Tab in the Data Frame Properties.

Once the new area was calculated, the summarize tool could be used to select an attribute within the data set and then calculate the area based on the attribute selected.
C.1 Metadata code description details

C.1.1 Landcover data set

The data was compiled using Landsat’s Thematic Mapper where 30 by 30 meter square areas of land were scanned. The spectral scale measured is related to known land characteristics during the season the data was acquired.

- **Urban** – open impervious surfaces: roads, buildings, parking lots and similar hard surface areas which are not obstructed from aerial view by tree cover.
- **Agriculture/open urban** areas – cropland and pasture; parks, golf courses, lawns and similar grassy areas not obstructed from view by tree cover.
- **Shrub/scrub** – young, sparse, woody vegetation; typically areas of scattered young tree samplings
- **Wooded** – deciduous and coniferous trees.
- **Open water**
- **Non-forested wetlands** – includes wetlands identified from 2994 Thematic Mapper data as well as from the Ohio Wetlands Inventory.
- **Barren** – strip mines, quarries, sand and gravel pits, beaches. Many of the Urban features identified in this inventory are constructed from materials obtained from the Barren features. Because of this, there will on occasion be Urban areas identified as Barren as well as barren areas identified as urban.

C.1.2 Ohio Wetland Inventory data set:

- Upland areas within the county
- Woods on hydric soil – only if digital soil survey available for county showing hydric soils
- Open water (excludes Lake Erie)
- Shallow marsh (emergent vegetation in water less than three feet)
- Shrub/scrub wetland (emergent woody vegetation in water less than three feet)
- Wet meadow (grassy vegetation in water less than six inches)
- Farmed wetland (wet meadow in agricultural areas) only if digital soil survey available for county showing hydric soils
Figure 40. Overview of the Ohio Wetland Inventory data set, excluding ‘Upland and Open Water’ attributes within Greene and Clark Counties. Urban roads were not shown. Ideally, a transparency could be made to overlay onto other figures to find exact location of potential restoration sites.
Figure 41. Overview of major roads within Greene and Clark Counties. Urban roads were not shown. Ideally, a transparency could be made to overlay onto other figures to find exact location of potential restoration sites.
Figure 42. Overview of Ohio and the location of Greene and Clark Counties. Urban centers are shown.