Methodology for Quantifying Wetland Landscape Parameters for Highway Right of Way Decisions Utilizing GIS

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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and hereby certify that, in their opinion, it is worthy of acceptance.

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Abstract

Wetland are a type of habitat which forms an interface between aquatic and terrestrial ecosystems. A growing problem in the state of Missouri and around the nation is the loss of the natural wetlands due to the expansion of communities. Specifically, the construction of new roadways impacted the wetlands of Missouri. Because of this loss of wetlands by many development activities species like the northern crayfish frog and the tiger salamander are declining in the state. Section 404 of the Clean Water Act (CWA) establishes a program to regulate the discharge of dredged or fills material into waters of the United States including wetlands. Because of its roadway activities Missouri Department of Transportation (MoDOT) must construct compensatory wetlands when natural wetlands are impacted and is trying to improve functionality of these wetlands with help of different research techniques. In addition, MoDOT must select rights-of-way of limiting wetland impacts can be one of the criteria. A geographic information system (GIS) is a useful tool in this research because of the spatial occurrence of the wetlands. Various landscape parameters such as road density, percentage of open water surrounding wetlands are quantified with the help of a GIS and a score is applied to each wetland on the basis of their importance as amphibian habitat. A methodology is discussed that begins to aggregate condition information to develop and score for natural and compensatory wetlands.

Chapter 1

1. Introduction

During the 1700s, wetlands were regarded as swampy lands that bred diseases, restricted overland travel, impeded the production of food and fiber, and generally were not useful for frontier survival [Dahl and Allord, 1990]. It was generally thought that wetlands create obstacles for development and that wetland sites should be used for other purposes.

During the middle of the twentieth century, society's views about wetlands changed considerably. Awareness of the need to preserve wetlands has increased as the importance and value of wetlands has become clear [Dahl and Allord, 1990].

Scientists have documented that wetlands are transition areas between aquatic ecosystems and upland areas. Wetlands are characterized not only by inundation or saturation but by plants able to grow under saturated conditions, and soils reflecting periodic inundation [Kusler, 2004]. Scientists have not always agreed upon a single definition a of wetland but are motivated to do so now because of the regulatory impacts of that designation.

1.1 What is a Wetland?

The U.S. Army Corps of Engineers (USACE) (Federal Register, 1982) and the Environmental Protection Agency (EPA) (Federal Register, 1980) jointly define wetlands as: "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

Wetlands have the following general diagnostic environmental characteristics.

(1) The prevalent vegetation consists of macrophytes which are unicellular species which exist individually, or in chains or groups and constitute the basic foodstuff for numerous aquaculture species that are typically adapted to areas having hydrologic and soil conditions. Hydrophytic species, due to morphological, physiological, and/or reproductive adaptations, have the ability to grow, effectively compete, reproduce, and/or persist in anaerobic soil conditions.

(2) Soils are present that have been classified as hydric; that is formed under conditions of saturation, flooding or ponding long enough during a growing season to develop anaerobic conditions or they possess characteristics that are associated with reducing soil conditions.

(3) The area is inundated either permanently or periodically at mean water depths less than 6.6 ft, or the soil is saturated to the surface at some time during the growing season of the prevalent vegetation.

Except in certain situations as defined in the USACE Wetland Delineation Manual, evidence of a minimum of one positive wetland indicator from each parameter (hydrology, soil, and vegetation) must be found in order to make a positive wetland determination [USACE].

1.2 Importance of Wetlands

Wetlands play an essential part in the regulation of river flow; the spread of groundwater in wetland deposits when they are well developed can constitute a large reserve which absorbs the variations of water flow. Alluvial deposits which are soil or sediments deposited by rivers made up of various materials including fine particles of silt and clay, act rather like sponges which absorb surplus water before releasing it later. In these alluvial areas, only part of the water follows along the course of the river, which allows water to move more slowly through the system, thus prevents flooding and shore erosion.

When the flow of water passes through these alluvial areas, significant quantities of nitrates or pesticides contained in the water are eliminated by the action of bacteria trapped in the soil or by the vegetation. Wetland plants also transform nitrogen or phosphorus into less toxic or unavailable forms reducing fish kills caused by these chemicals. This water, after wetland filtration, has a more constant temperature with a high quality.

Wetlands are habitats that form the edge between aquatic and terrestrial ecosystems. Wetlands provide wildlife habitat for a wide range of terrestrial and semi-aquatic animals and numerous plant species. The mix of aquatic and terrestrial habitats within a wetland provides a variety of food sources. Because they are often highly productive they provide abundant food for migratory waterfowl and wading birds.

Because wetlands provide such a diversity of habitat for so many animals, they are of great use to humans through recreation, education and timber production. In recreation and education, wetlands provide areas for both consumptive and non-consumptive uses. Consumptive uses involve hunting and fishing, while non-consumptive uses include canoeing, bird watching, and studying animals and plants. All of these activities benefit local economies through the purchases of travel, lodging and recreational equipment. In fact, the U.S. Fish and Wildlife Service periodically assess the value of hunting and fishing to the U.S. economy and suggests that these are billiondollar industries. Wetlands also provide health benefits through exercise and relief from stress.

Economic use values of wetlands comprise the direct use of a wetland's goods, such as the consumption of fish for food, trees for fuel wood or as a building material, and water for drinking, cooking and washing. Use values also include the indirect use of a wetland's services, such as water retention capacity (including man-made for irrigation or energy production) and nutrient recycling [Kirsten and Brander, 2004].

1.3 Loss of Wetlands

Despite this critical role in providing environmental, social and economic benefits, wetlands are continually defenseless. During the past two centuries, conversion and drainage of wetlands have resulted in dramatic losses of wetland acreage in the U.S. At the time of European settlement in the early 1600's, the area that was to become the conterminous United States had approximately 221 million acres of wetlands. About 103 million acres remained as of the mid-1980s [Dahl and Johnson, 1991]. Historical events, technological innovations, and the values of society had detrimental effects on wetlands. For three hundred years, wetlands were considered as a significant obstacle for development, and land owners and administrators decided to use wetland lands for other purposes. Six states lost 85 percent or more of their original wetland acreage and another twenty two lost 50 percent or more [Dahl and Allord, 1990], (as shown in Figure 1.)

Figure1. States with notable wetland losses 1780's to mid-1980 [Dahl, 1990].

Missouri lost approximately 87% of its original wetlands between the 1780s and the 1980s [Dahl and Allord, 1990]. Millions of wetland acres in Missouri were drained to grow crops and more recently they were drained for development. The loss of these wetlands not only affected wildlife habitats for many wetland dependent species, but also reduced flood storage and other valuable wetland functions.

Throughout Missouri, the Missouri Department of Transportation (MoDOT) encounters wetlands as roads are constructed and expanded. So wetlands and wetland habitat in Missouri can be impacted by the nature of the MoDOT mission. The northern crayfish frog is vulnerable specie of special concern in Missouri and populations of tiger salamanders are also declining in the state. These species depend on wetlands and could thus be impacted by MoDOT activities.

1.4 Government regulation

Section 404 of the Clean Water Act (CWA) establishes programs to regulate the discharge of dredged or fill material into waters of the United States, including wetlands

[USEPA, 1972]. Activities in waters of the United States regulated under this program include fill for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports) and mining projects. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States, unless the activity is exempt from Section 404 regulation (e.g., certain farming and forestry activities).

This approach for assist transportation planners in locating and selecting restoration sites in response to the impacts to wetlands of a transportation project. In 1972, the federal government, through the Clean Water Act, began to regulate the fate of wetlands. Proposed activities are regulated through a permit review process. An individual activity is required for potentially significant impacts. Individual permits are reviewed by the U.S. Army Corps of Engineers, which evaluates applications under a public interest review, as well as the environmental criteria set forth in the CWA Section 404(b) (1) Guidelines [USACE,1899].

To comply with regulations governing wetland areas, permit applicants were required to consider the impacts of their actions. Section 404 of the Clean Water Act requires (1) that effort be made to avoid the loss of wetland areas, (2) if it is not possible to avoid wetlands, effort must be made to minimize impact to wetlands, and (3) compensatory mitigation of the wetland loss [Roise, Gainey and Shear, 2004].

This regulation gives rise to requirements for mitigation of unavoidable impacts to wetlands that transportation projects and other activities may have on aquatic ecosystems that are a part of waters of the U.S. This typically involves construction of compensatory wetlands, and/or their enhancement or restoration within an affected ecosystem. The mitigation approach supports the policy of no net loss of wetlands.

1.5 Research Project

A growing problem in the state of Missouri and around the nation is the disappearance of natural wetlands due to the expansion of communities and other development activities. Specifically, the construction of new roadways can impact the wetlands of Missouri. When wetlands are to be impacted, MoDOT constructs compensatory wetlands, attempting when possible, to place them within the existing right- of-way (ROW) or adjacent to construction projects limits.

The overall goal of the project is to create a guidance document to assist MoDOT (and other state departments of transportation) in the statewide function of selecting ROW locations to minimize wetland (as a habitat) impacts and to increase the effectiveness of compensatory wetlands constructed when natural wetlands are impacted by road construction and maintenance. The goal will be accomplished through the integration of amphibian biology into the development of a geographic information system (GIS) for evaluating potential ROW locations and potential compensatory wetland locations and designs. GIS is necessary because of the spatial nature of the occurrence of wetlands within the landscape.

The overall project objectives are to (1) identify landscape factors that are correlated with wetland performance as an amphibian habitat through evaluation of actual compensatory wetlands, (2) translate the knowledge of the spatial factors into a GIS analysis in order to allow for the future evaluation of proposed ROW locations, (3) translate the knowledge of these factors into the generation of compensatory wetlands design criteria, (4) creat new compensatory wetlands based on the criteria and monitor their health, and (5) incorporate all information into specific guidance for MoDOT that is consistent with the agency's responsibilities and constraints.

1.6 Research Objectives

This thesis documents research associated with the GIS effort of the overall project. The specific objectives of this effort are

- To identify applicable parameters that can be used to evaluate compensatory wetlands to determine their contribution to wetland habitat in order to be able to identify those locations with greatest value in terms of constituting a viable habitat.
- To develop a spatial analysis methodology to apply a "score" to wetlands on the basis of their importance level for highway right of way decisions so that MoDOT and other state DOT's recognize of which wetlands are most beneficial for animal habitat utilizing GIS.
- To demonstrate the use of the methodology in relations to biological parameters of wetland health.
- To create GIS data layers of these applicable parameters for the existing MoDOT compensatory wetlands and Missouri Department of Conservation (MDC) ponds also being evaluated for the biological parameters.

For the purposes of this project the methodology is developed using compensatory wetlands rather than natural wetlands.

1.7 GIS and Its Importance

"A geographic information system (GIS) can be defined as a system for entering, storing, manipulating, analyzing, and displaying geographic or spatial data [Lyon and McCarthy, 1995]." There are different ways of organizing data into an information system, and the choice of a particular spatial data structure is an important decision while designing a GIS. There are two common data models used to represent geographic and spatial data: the vector data model and the raster data model.

The vector data model is the most ubiquitous in GIS, and most closely resembles traditional maps [Schuurman, 2004]. Vector data use a series of points (i.e., x, y coordinates) to define the boundries of places or things of interest and they may constitute a point, a line or a polygon. This type of data uses less computer memory space and is preferred for display purposes because of the truer rendition of the shape of the object of interest [Lyon and McCarthy, 1995]. Places or things that have neither length nor area are represented as point features. Examples of point features are the center of a wetland site and a street intersection. Line features are considered as one dimensional and have length but not area and are constructed by an arc or a chain linking two points. Examples of line features are streets, rivers and railway routes. Polygon features have area at a given scale and are defined by a set of lines. Examples of polygon features are a state is boundary, a wetland boundaries and census blocks.

Raster data models divide the world into a sequence of identical, discrete entities, by imposing a regular grid [Schuurman, 2004]. Raster data are stored in a grid or pixel which is referenced to some coordinate system. Raster data are easy to handle but require larger amounts of storage space. It is generally used to represent continuous data such as elevation, land use, and watershed extent.

Non-spatial or attribute data are equally important in GIS. These data are stored in tables that are always associated with a spatial location. These tables contain information about a set of geographic features and are usually arranged so that each row represents a feature and each column represents one feature attribute. In raster datasets, each row of such an attribute table is linked to a certain zone of cells having the same value.

There are various types of commercial software in GIS. For the development of this methodology ArcGIS has been used [ESRI, 2008 http://www.esri.com/].

Due to the spatial and temporal distribution of wetlands over large areas, technologies which capture the synoptic view of the earth are favored for analysis [Lyon and McCarthy, 1995]. Identifying these landscape factors and integrating them into GIS to perform an analysis is the means by which to score wetlands on the basis on their significance level for decision making.

Chapter 2

2. Literature Review

2.1 Wetland Function and Value

Research on the valuation of wetlands has been performed on the basis of wetlands functions and values. Previously, the terms wetland function and values were not well defined. Definitions of these terms are important in wetlands assessment because it is these definitions that lead one to the types of information that should be collected for wetland analysis.

To understand these definitions, one must understand the four important characteristics in describing and assessing wetlands related to "function" and "value" [Kusler, 2004]

- The first set of wetland characteristics are related to a **"Natural process occurring within wetlands"** and includes such processes as denitrification, biomass production, and flow retardation. Multiple natural processes occur within a single wetland. In the valuation of a particular wetland prior to any impact by human activities, decision makers may have to limit their evaluation to a few natural processes.
- The second set of wetland characteristics relevant to the definitions of function and value of wetlands is **"off-site natural resource characteristic critical to the onsite functioning of wetlands"** that includes regional hydrology, ecosystem context, connectivity of the wetland to other wetlands and water, the rarity of that type of wetland in the landscape, the presence or absence of buffers, and other landscape-level natural resource relationships.

- The third set of wetland characteristics relate to the **"cultural context"** of wetlands in the landscape (roads, dams, houses etc.). The cultural features often affect onsite and offsite natural functions. For example, the presence of a dam in the surrounding landscape of a wetland and whether the dam is upstream or downstream can affect the water level in a wetland.
- The fourth set of characteristics pertains to the attitudes of society to the roles or outputs of wetlands. Who wants what? For example, who values flood storage or habitat and how much? How strongly do they feel about these roles or outputs?

Thus the term wetland function exactly fits into the first set of characteristics and to some extent into the second set of characteristics. The term wetland value fits into the third and fourth sets of characteristics because the term 'wetland value' was used to signify cultural features and a societal connotation of wetland and its worth. A wetland could be valuable to society in terms of health and safety, historical and cultural significance, education, research, scientific significance, aesthetic significance, economic significance [Kusler, 2004].

2.2 Wetland Evaluation

In response to the goal of no net loss of wetlands, included under the Clean Water Act, numerous wetland assessment methods have been developed. The development of inventory data of wetlands is one type of assessment that provides identification of the location, area extent and type of wetland in the landscape. The US Congress directed the U.S. Fish and Wildlife Service (USFWS) in 1986 to develop a national wetland inventory to provide the location and types of wetlands for public and government use. This National Wetlands Inventory (NWI), which is approximately 89% complete (USFWS,

1998) has identified the location of wetlands in the U.S. using stereoscopic pairs of infrared photographs [USEPA, http://www.epa.gov/].

Rapid wetland assessment techniques have been and continue to be the mostly used methodologies. One of the most widely method is known as the Wetland Evaluation Technique or WET 2.0. This technique was developed by the U.S. Army Corps of Engineers to support wetland permit decisions. This tool uses the presence or absence of wetlands characteristics as correlative predictors of wetland function. It does not provide the quantitative measurement of functional performance; rather it is designed to predict the quantitative likelihood (high, medium, low) that a wetland performs a given function.

2.3 Example Evaluation

2.3.1 Juneau Wetland Management Plan

The city and borough of Juneau (CBJ) selected WET for the establishment of the Juneau Wetland Management Plan. Classification of the wetlands was based on the consideration of environmental functions provided by the wetland unit, the public's preference for the protection or development of each wetland unit, and the availability of non-wetland practicable alternative development sites. According to the WET technique fourteen functions of a wetland have to be evaluated. These functions are recharge, discharge, surface hydrolologic control, sediment/toxicant retention, nutrient export, riparian support, erosion sensitivity, salmonid habitat, disturbance sensitive wildlife, ecological diversity, replacement cost, down slope beneficiary or passive economic service, recreation actual, and recreation potential [Juneau Wetlands Management Plan Volume II 2005]. These wetland functions were quantitatively scored within the range of "very low" to "very high" for potential presence or performance within each wetland unit. CBJ developed a new quantitative methodology to convert the fourteen environmental function scores developed under WET into one "converted function value" that depicts the environmental importance of each wetland unit. After grouping wetland function into the three categories of (1) support for aquatic habitat, (2) support for human uses, and (3) support for terrestrial habitat; CBJ derived "weighting factors" for each of the wetland functions. Weighing of wetland function was performed on the basis of

- Confidence: Ability to infer values for a wetland unit based on direct measurement of other wetlands.
- Component contribution: Relative contribution of function to aquatic habitat, human use support, or terrestrial support.
- Sensitivity to human presence: Degree of vulnerability of wetland functions due to human activity in the vicinity.
- Economic value based on the availability of substitutes: Alternative availability to serve environmental function of the wetland function. For example, the riparian support function has a higher weightage than toxicant retention function because a public sewer system can perform as a toxicant removal but there is no substitute for riparian support.

2.3.2 North Carolina Coastal Region Evaluation of Wetland Significance

The North Carolina Department of Environmental Health and Natural Resources' Division of Coastal Management (DCM) has developed a wetland mapping and functional assessment which is called the North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS) [Strategic Plan for Coastal Management in North Carolina, 1999]. NC-CREWS is a procedure based on spatial data layers contained in a

GIS that is used to develop a wetland function model. This wetland function model is linked to an existing database created by the DCM. NC-CREWS examines various wetland functions but only three functions (terrestrial wildlife habitat, nonpoint source pollution reduction and flood water storage) are considered in this first version. Each wetland function has a number of parameters that are combined in a GIS to give each wetland unit an overall score for each function. The wetland is rated as high, medium or low for the wetland function in consideration.

The terrestrial wildlife habitat function considers the quality of habitat provided for terrestrial habitants. The three parameters considered are interior size, percent surrounding habitat that is natural vegetation, and the length of a wildlife corridor that links to other natural vegetation. To calculate interior habitat, a 100 meter buffer zone around the perimeter is subtracted from the total area [Sutter and Wuenscher, 1997].

The rating strategy for wildlife habitat parameters is shown in Table 1.

Table 1 —Ratings assigned to wildlife habitat parameters [Strategic Plan for Coastal Management in North Carolina, 1999].

Parameter	**High Rating**	**Medium Rating**	**Low Rating**
Interior Size	> 74 acres	0–74 acres	None
Surrounding Habitat	>50% wetlands	<50% wetlands	Isolated from other wetlands
Wildlife Corridor	>600 feet	<600 feet	Isolated from natural habitat

The nonpoint source rating system considers three parameters. The first parameter is the nature of nearby land use, with the percent of surrounding habitat as the criteria. The second parameter is distance from a water source. The third parameter is the position of the wetland relative to stream orders. The rating scheme of the nonpoint pollution parameters is shown in Table 2.

Table 2 —Ratings assigned to nonpoint source pollution parameters [Strategic Plan for Coastal Management in North Carolina, 1999].

Parameter	**High Rating**	**Medium Rating**	**Low Rating**
Proximity to sources	> 50% perimeter abuts agriculture + developed	> 50% perimeter abuts agriculture + developed + pine plantation	>50% perimeter natural vegetation
Distance to water sources	Within 300 ft of a permanent source	Within 300 ft of an intermittent stream	> 300 ft from a permanent or intermittent source
Wetland position	Intermittent or 1st order stream	2nd or 3rd order stream	Higher than 3rd order stream

The position of the wetland in the landscape and the width of the wetland perpendiculars to the stream are the parameters considered for rating the floodwater storage capacity of a wetland. Table 3 summarizes the floodwater storage rating criteria.

Table 3- Floodwater storage rating criteria [Strategic Plan for Coastal Management in North Carolina, 1999].

Parameter	High rating	Medium Rating	Low Rating
Position in landscape	>25% of stream bordered by developed land	5-25% of stream bordered by developed land	<5% of stream bordered by developed land
Width of wetland perpendicular to stream	> 100 feet 50–100 feet	50-100 feet	< 50 feet

The selection of wetland restoration sites is vital for the success of mitigation projects. A field evaluation of compensatory wetland mitigation projects throughout North Carolina revealed that the majority failed to meet project goals (Pfeifer and Kaiser 1995). Regulatory preferences for onsite mitigation often limit success as wetland restoration is attempted at inappropriate sites [King and Bohlen, 1994; Pfeifer and Kaiser, 1995]. Unrealistically low cost estimates, permittee responsibility for planning, and overly optimistic expectations for marginal sites have led to high rates of restoration failure [Roise, Gainey and Shear, 2004]. Accurate cost estimates of wetland restoration and demands by mitigation regulators for success are necessary for a mitigation program to achieve successfully and efficiently overall wetlands, flood plain, and watershed goals (King and Bohlen, 1994).

The DCM mapped and inventoried all of the wetlands in the region to perform a functional assessment of each wetland. To evaluate wetland function, the NC-CREWS

(Sutter and Wuenscher, 1997) was used. NC-CREWS uses a GIS to incorporate different data layers and algorithms into a wetland rating system [Sutter and Wuenscher, 1997]. NC-CREWS considers a hierarchical modeling structure to assign values to a range of wetland functions to estimate the relative importance of wetlands. There are four broad classes of functions that are rated from a combination of sub-function ratings: Water Quality, Hydrology, Wildlife Habitat, and Risk of Development [Roise, Gainey and Shear, 2004]. For example, wildlife habitat is divided into the sub functions of terrestrial habitat and aquatic habitat. These sub-functions are rated according to parameter ratings e.g., terrestrial habitat is combination of internal habitat, and landscape habitat. In addition to rating existing wetlands, potential restoration sites are also classified for Habitat, Water Quality, and Hydrology by NC-CREWS [Roise, Gainey and Shear, 2004].

All of the evaluated wetlands are rated as high, medium, or low for each wetland function. For example, to assign a value to the function Water Quality, the capability to cleanse water is partly determined by the proximity to sources of nonpoint source pollution. The wetland function Water Quality is assigned a high value if it is within 300 feet of permanent surface water, medium if it is within 300 feet of an intermittent stream, and low if is greater than 300 feet from permanent or intermittent surface water.

A wetland is rated as high for landscape habitat function when it is linked to a corridor greater than 600 feet wide connected to contiguous habitat, medium when it is a corridor less than 600 feet wide connected to contiguous habitat, and low when it is isolated from natural vegetation [Roise, Gainey and Shear, 2004].

It is assumed that the greater the area of a wetland the greater its importance. Greater wetland area is associated with larger amounts of water which give shelter to many animal species. Thus, a 100-acre wetland rated high would likely be more ‘important’ in ecological terms than a 10 acre wetland rated high.

Most of the functions in NC-CREWS depend on the spatial arrangement of wetland sites within the watershed, although some also depend on the distance to other wetlands [Roise, Gainey and Shear, 2004]. While evaluating wetland function, one should understand the relationship between the functional rating and the spatial arrangement of wetland sites. When two adjacent sites, or even sites within some distance of each other, are candidates for restoration, the question arises as to whether restoring one site will change the rating for the other site? If so, ratings will have to be recalculated for those sites [Roise, Gainey and Shear, 2004].

2.3.3 Eastern Ontario Wetland Valuation System

The Eastern Ontario Natural Heritage Working Group developed a methodology by which all known wetland features within eastern Ontario (Canada) would be assigned a relative value [Burns and Wilson, 2003]. This valuation system represents the relative significance of the wetland with respect to multiple criteria. These criteria which measure or infer ecological characteristics that are important in determining the importance of an ecosystem, is applied using the best available data within a GIS.

The Ontario Ministry of Natural Resources (OMNR) determined which wetlands and wetland complexes are provincially significant. They developed a standard evaluation system, which scores individual wetlands or wetland complexes based on biological, social, hydrological and special features components. Wetlands which receive a high ranking in the evaluation system are classified as provincially significant.

For the wetland valuation system, OMNR incorporates nine criteria based upon the ecological function/value of wetlands, the best available data, and the modeling capabilities of GIS. This wetland valuation system scores all known wetlands with a value between 0 and 3 for each criterion. A score of 3 designates that the wetland is most valuable while a score of 1 means it is least valuable. A score of 0 mean that the feature is not a wetland or has no value with respect to specific criteria. Table 4 lists nine criteria and their ranking within a wetland valuation system.

Table 4. Ontario Ministry of Natural Resources wetland evaluation criteria [Burns and Wilson, 2003]

Criteria	Measure	Score
Wetland Size	No wetland present	0
	Area ≤ 20 ha	1
	Area > 20 ha and ≤200 ha	2
	Area > 200 ha	3
Wetland Interior	100 m edge removed with ≤ 4 ha remaining	0
	100 m edge removed with > 4 ha remaining	1
	150 m edge removed with > 4 ha remaining	2
	200 m edge removed with > 4 ha remaining	3
Wetland Edge	Wetland with no water feature contained within or adjacent to a wetland	0
	Ratio of water perimeter (within and adjacent to wetland) to wetland perimeter ≥0.0 and < 0.5	1
	Ratio of water perimeter (within and adjacent to wetland) to wetland perimeter ≥0.5 and < 1.0	2
	Ratio of water perimeter (within and adjacent to wetland) to wetland perimeter ≥ 1.0	3
Adjacent Vegetation	Adjacent vegetation surrounding ≤ 50% of wetland boundary; or 50 m buffer surrounding wetland ≤ 50% vegetated and adjacent vegetation surrounding > 50% of wetland boundary	0
	50 m buffer surrounding wetland > 50% vegetated and adjacent vegetation surrounding > 50% of wetland boundary	1
	120 m buffer surrounding wetland > 50% vegetated and adjacent vegetation surrounding > 50% of wetland boundary	2
	240 m buffer surrounding wetland > 50% vegetated and adjacent vegetation surrounding > 50% of wetland boundary	3
Wetland	No wetland present	0

Disturbance	Wetland area and 2 km buffer area contains a road density ≥ 2429 m/km^2 Wetland area and 2 km buffer area contains a road density ≤ 2429 m/km^2 and ≥ 914 m/km^2 Wetland area and 2 km buffer area contains a road density ≤ 914 m/km^2	1 2 3
Wetland Habitat Linkage	Distance ≥ 1000 m to nearest wetland Distance < 1000 m and ≥ 750m to nearest wetland Distance < 750 m and ≥ 500 m to nearest wetland Distance < 500 to nearest wetland	0 1 2 3
Wetland Hydrological Linkage	Distance ≥ 4000 m to nearest hydrological wetland; or wetland not hydrologically connected Distance < 4000 m and ≥ 1500 m to nearest hydrological connected wetland Distance < 1500 m and ≥500 m to nearest hydrological connected wetland Distance < 500 m to nearest hydrological connected wetland	0 1 2 3
Headwater Wetland	Wetland absent from first order stream; or wetland is not the source of a first order stream Wetland is the source of the first order stream	0 3
Wetland Flood Attenuation	Wetland absent Riverine wetland or lacustrine wetland (if area < 50% size of lake) present Palustine wetland or lacustrine wetland (if area ≥ 50% size of lake) present Isolated wetland present	0 1 2 3

Each criterion is applied to all known wetlands using the best available data from a GIS. A final score for an individual wetland is computed by summing scores of all wetland criteria. Each wetland will be assigned value between 3 and 27. A score of 27 designates that the wetland is the most valuable and a score of 3 indicates that it is the least valuable. Values of less than zero could only be applied to areas that are not actually wetlands.

This wetland valuation method provides a means to access the biological and ecological importance of known wetlands in eastern Ontario [Burns and Wilson, 2003].

This combination of nine criteria resulted in the creation of a final wetland valuation system GIS layer which provides a landscape level analysis of wetland habitats in eastern Ontario.

2.4 Buffer Zones for Wetlands

The terrestrial habitat adjacent to and surrounding wetlands is important for the management of natural resources. Most conservationists and land managers comprehend that this land protects adjoining aquatic resources by filtering chemical pollutants, moderating temperature, and removing other pollution caused by human activities such as timber harvesting, road building, agriculture and urbanization. Furthermore, scientists generally agree that patches or strips of terrestrial habitat ranging from 30 to 60 meters wide can function as essential barriers around core aquatic habitats to protect them from surrounding land-use practices [Semlitch and Jensen, 2001]. These upland "buffer zones" receive much attention for their value in protecting aquatic resources.

Biologists who study semi-aquatic species have long observed the value of the uplands adjacent to wetlands to numerous species of turtles, salamanders, dragonflies, plants, and other organisms for their survivals. This biodiversity protection is a function of the use by target species for life history functions such as feeding, mating, nesting, and overwintering.

Numerous studies over the past decade document the use of terrestrial habitat adjacent to streams and wetlands by a broad range of taxa, including mammals, birds, reptiles, and amphibians [Semlitch and Jensen, 2001].

Buffer zones have been shown to be a valuable component of a habitat. They should surround the upland portion of the core habitat to preserve the terrestrial habitat and aquatic habitat from surrounding land-use practices that could damage these areas. Semlitch and Jensen have reported that a 164-meter terrestrial buffer has been shown to protect salamanders. Scaled criteria could account for specific wetland attributes and major factors impacting habitat quality, such as land-use practices in the surrounding areas [Semlitch and Jensen, 2001]. The study recommends that terrestrial habitat closest to the water enjoys full protection, while a second outer area further out retains limited protection but allows certain minimal impact land uses to take place. For more complete protection, a third "transition zone" would encircle the buffer zone. This transition area would be explicitly for compatible land-use practices.

The zones are more explicitly described here and are shown in Figure 2.

1. Starting from the wetland edge, a first terrestrial zone would buffer the core aquatic habitat and protect water resources;
2. Starting again from the wetland edge and overlapping with the first zone, a second terrestrial zone would comprise the core terrestrial habitat defined by semi-aquatic focal species or species-group use; and
3. Starting from the outward edge of the second zone, a third terrestrial zone would buffer the core terrestrial habitat from edge effects and surrounding land-use practices.

It is not necessary to protect more habitat than is needed nor to exclude all activities from terrestrial areas around wetlands.

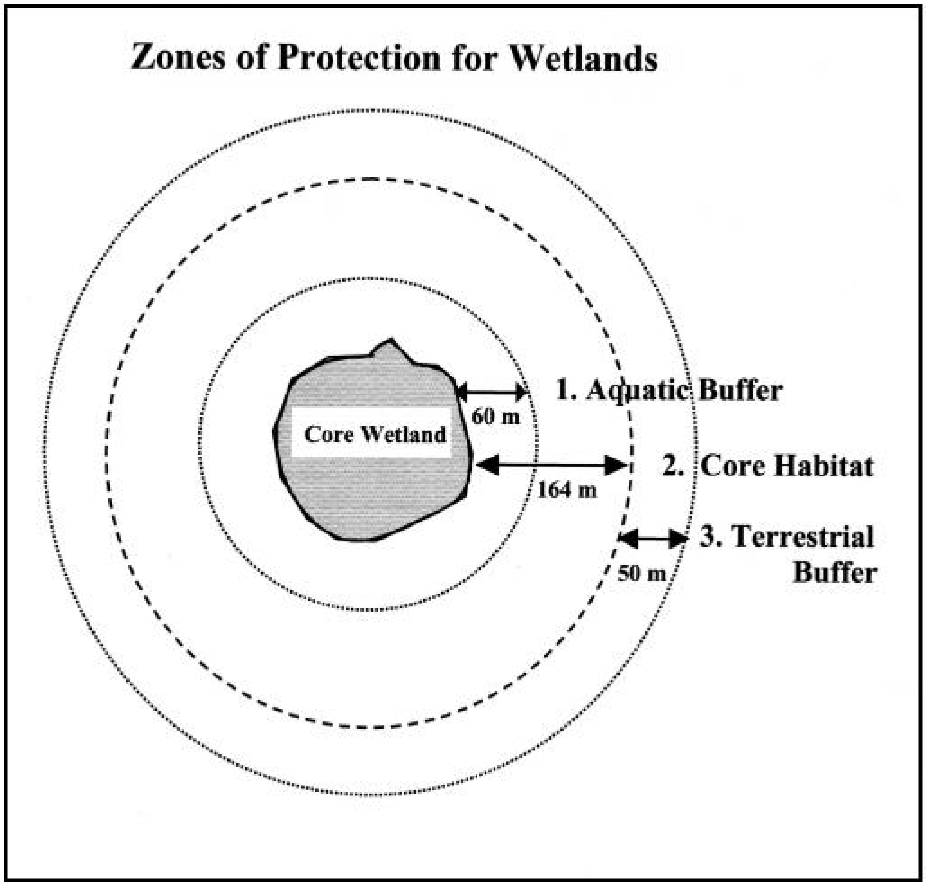

Figure 2. Zones of protection of wetlands [Semlitch and Jensen, 2001]

2.5 Summary

This literature review emphasizes the importance of a clear understanding of the definitions of wetland "function" and "value" in wetland assessment. Rapid wetland assessment techniques such WET used (by U.S. Army Corps of Engineers) predict the quantitative likelihood (high, medium, low) that a particular wetland performs a given function. The City and Borough of Juneau (CBJ) evaluated fourteen different wetland functions and scored these functions within range of "very low" to "very high". NC-CREWS quantified parameters with the use of GIS to assign them high, medium, or low ratings. A study by NC-CREWS also makes it obvious that the selection of a wetland mitigation site is important in the success of the mitigation project. OMNR developed a wetland valuation system, listing nine criteria based on the ecological function/value of wetland and scoring them between 0 and 3. All of these different wetland evaluations techniques identify important landscape parameters which should be quantified to score the wetlands for amphibian health considerations.

It is necessary to consider amphibian habitat parameters in the larger landscape beyond the wetland because amphibians travel these longer distances. Analysis of the parameters at different location distances from the wetlands can also be useful because closer attributes seem to have a greater impact. Use of a GIS to perform spatial analysis of parameters in the larger landscape and to consider the impact of distance from a wetland are not currently being incorporated into analysis and can be a significant contribution to the process of wetland scoring.

Chapter 3

3. Methodology

In this GIS-based methodology to evaluate wetlands, various landscape parameters have been considered and quantified with the use of a GIS. Quantification allows for the scoring and comparison of each individual wetlands as to their significance as amphibian habitat. The quantification can be applied to a group of wetlands as might be important when evaluating alternative right-of-way locations.

3.1 Identification of parameters

Various parameters are evaluated in the methodology which seeks to assess wetland contribution to amphibian health. Analysis of the parameters will also be able to provide engineers and planners from state departments of transportation information about the appropriate site selection for compensatory wetlands. This is necessary because selection of an appropriate site is such an important factor in the success of a mitigation project.

3.1.1Parameters

The parameters analyzed within the methodology are described below.

1. Wetland area (size) – The larger the area of the wetland the larger the habitat for amphibians. Thus, wetlands of a larger area are given higher scores.
2. Road density – Researchers investigated that there is an inverse relationship between habitat health and roads in the vicinity of a wetland. One of the potential factors in the decline of amphibians is mortality on roads. Throughout the world, traffic volumes have increased markedly in the past two decades (United Nations, 1992). Many amphibians need more than one habitat for forage, breeding and

when movement occurs across the roads, mortality can be substantial. Wetlands surrounded by a greater density of existing roads are given lower scores than those having a lower density of roads.

3. Land use/ land cover - Different Land use/ land covers can affect differently on the amphibian's health. The proximity of various categories of various land use land cover such as agricultural land, urban area, provide more or less amphibian habitat and impact the quantity of that habitat. Construction of roads, parking lot and buildings increases the area of impervious land which increases runoff and inputs of pollutants and toxic materials. Wetlands near agriculture land may receive runoff where fertilizers and pesticides are applied. This may increase concentrations of toxic materials in the wetland which can be detrimental to amphibian health. Even within the vegetated category, land covers that provide undisturbed habitat (i.e., pasture, woods) are rated higher than vegetation such as cropland .Wetland to adjacent to undisturbed vegetation are scored higher than wetlands adjacent to less undisturbed vegetation or agricultural or urbanized areas where there is ongoing disturbance.
4. Proximity to other wetlands - The greater the number of other wetlands close by a particular wetland the greater the benefit to the amphibian environment in terms of habitat breeding opportunities. Wetlands that are closer together the wetlands are given a higher score as compared to wetlands that are not near to another wetland
5. Wetland hydrological linkage - Wetland hydrological linkage is important in determining the ecological significance of a wetland. Streams located near the

wetland can be a useful parameter because these streams can provide water to the wetlands. Standing water can be important factor for the breeding of amphibians. However, perennial streams may contain fish that can prey on amphibians. Streams are categorized into perennial and intermittent streams as well as by total length. Distance to a channelized stream or ditch is an important factor in scoring a wetland. The greater the distance the lower the score of that wetland and vice versa. Intermittent streams are rated higher than perennial streams because of the absence of potentially predatory fish.

6. Topography surrounding the wetland - The slope surrounding the wetland determines the ease with which amphibians can move across the landscape. The steeper the slope, the lower the rating for amphibians.

3.2 Study Area

The overall project study area, of which this study is just one part, consists of MoDOT compensatory wetlands and Missouri Department of Conservation (MDC) ponds for a total of 49 constructed wetlands in northern Missouri. The point locations of the wetlands are shown in Figure 3 as identified by the UTM coordinates taken by a GPS instrument during site visits. This thesis represents the methodological development and demonstration via information collection and analysis on two wetlands. A description of further identification of the 49 the wetlands are shown in Table 5.

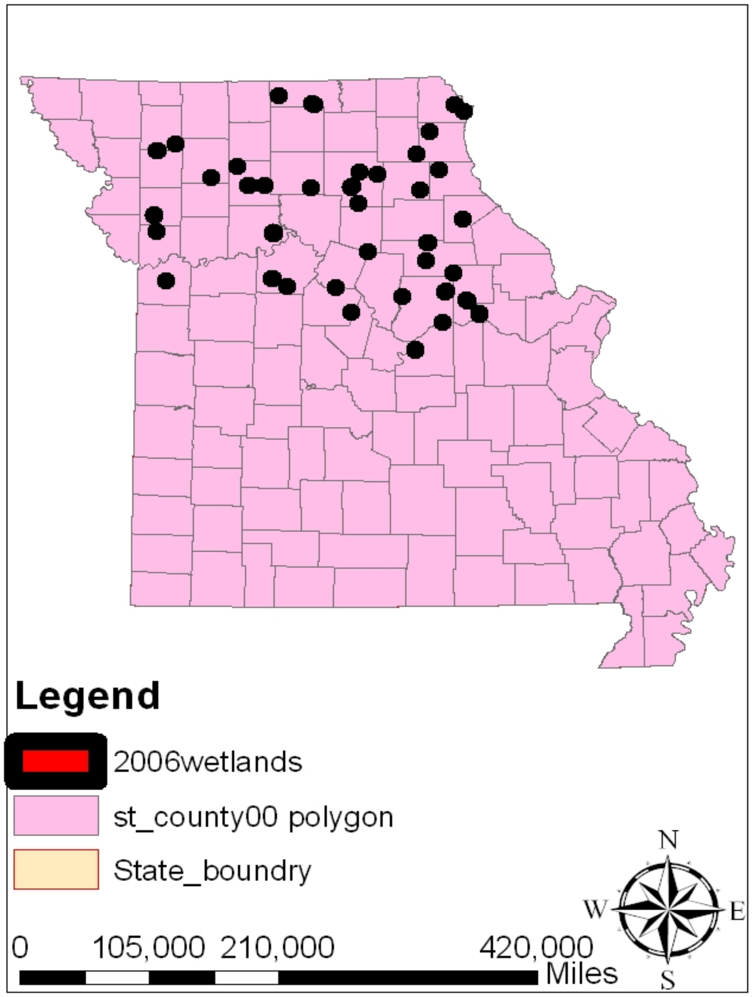

Figure 3. Point locations of compensatory wetlands in the overall project.

Table 5. Attribute table of digitized compensatory wetland locations in ArcGIS

1	SITE_NAME	AGENCY	COUNTY	AREA(sq m)
2	Redman Unit 1	MDC	Macon	1841.616
3	Rose Pond 4-5 year old unit	MDC	Clark	1031.356
4	Clark County 136	MoDOT	Clark	22607.218
5	Putnam County 136	MoDOT	Putnam	2069.803
6	Redman Unit 3	MDC	Macon	964.139
7	Mineral Hills Geranium Trail Pond	MDC	Putnam	307.604
8	Mineral Hills Open Pond	MDC	Putnam	682.101
9	Poosey	MDC	Livingston	973.771
10	Gallatin	MDC	Davies	192.028
11	Elam Bend Small Forested	MDC	Gentry	246.765
12	Elam Bend Large Forested	MDC	Gentry	631.622
13	King Lake Ditch	MDC	DeKalb	706.981
14	King Lake Pond	MDC	DeKalb	333.549
15	Dunn Ford Small Forest Edge Pond	MDC	Marion	113.024
16	Henry Sever	MDC	Knox	386.897
17	Diggs Koi Pond	MDC	Audrain	152.319
18	Whetstone Creek Pond	MDC	Callaway	357.212
19	Whetstone Creek Wetland	MDC	Callaway	7436.871
20	White Open Pond	MDC	Audrain	1041.004
21	White Forested Pond	MDC	Audrain	817.611
22	Rudolph Bennitt	MDC	Randolph	337.246
23	Blind Pony Field Pond	MDC	Saline	751.534
24	Blind Pony Forested Pond	MDC	Saline	590.137
25	Prairie Home	MDC	Cooper	162.259
26	Atlanta	MDC	Macon	654.223
27	Daniel Boone Fish Pond	MDC	Warren	941.176
28	Daniel Boone South Side Pond	MDC	Warren	484.743
29	Danville Ag Pond	MDC	Montgomery	879.432
30	Danville Roadside Forested Pond	MDC	Montgomery	163.996
31	Little Dixie Herp Pond	MDC	Callaway	279.358
32	Center Ralls County Wetland	MoDOT	Ralls	15935.771
33	Shelby County T	MoDOT	Shelby	244.938
34	Audrain County 15	MoDOT	Audrain	6188.866
35	Macon T	MoDOT	Macon	784.187
36	Macon 36	MoDOT	Macon	73931.388
37	Linn 36	MoDOT	Linn	53792.127
38	Livingston 36	MoDOT	Livingston	4620.178
39	Livingston Beetsma Small Corner Pond	MoDOT	Livingston	1099.203
40	Livingston Beetsma NE Corner Ditch	MoDOT	Livingston	1435.340
41	Howard/Cooper 5	MoDOT	Howard	3026.394
42	Osage MariOsa Scrub Shrub	MoDOT	Osage	2386.552
43	Osage MariOsa Large Pond	MoDOT	Osage	20719.905
44	Carroll County 139	MoDOT	Carroll	185869.986
45	Callaway 94	MoDOT	Callaway	3696.938
46	Clay County Smithville Lake South	MoDOT/USACE	Clay	21632.651
47	Clinton County Smithville Lake North	MoDOT/USACE	Clinton	37571.130
48	Jackson County 40 Blue Springs	MoDOT	Jackson	16296.253
49	Saline County 65/70	MoDOT	Saline	19078.720
50	Deer Ridge	MDC	Lewis	499.911

3.3 Buffer Analysis Surrounding Wetland

Semlitch and Jensen (2001) have proposed at least three terrestrial zones adjacent to core aquatic and wetland habitats as necessary for optimal amphibian habitat. Because amphibians may travel up to 2 km, this is analysis uses five rings, encompassing a larger area, rather than the original three. These concentric rings are drawn with the help of the 'multiple buffers' tool in ArcMap. Landscape analysis is performed over multiple rings that have their outer edge at 214 m, 0.5 km, 0.75 km, 1 km and 2 km from the outer extent of the wetland as shown below in Figure 4.

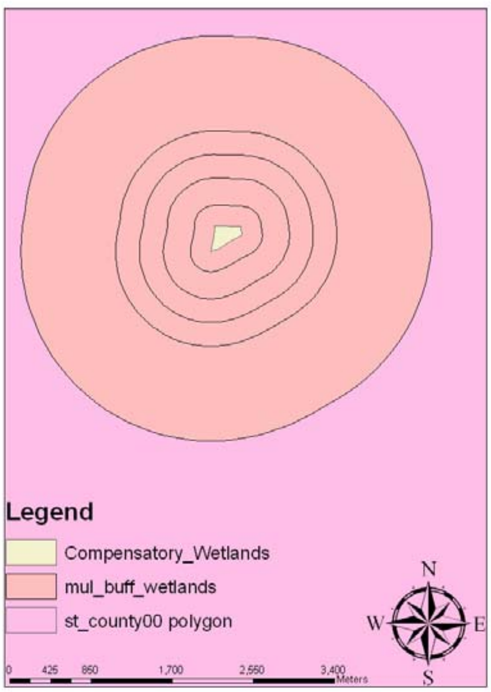

Figure 4. Multiple buffer rings used for analysis of compensatory wetlands.

3.4 Proximity Analysis

The quantity of the previously identified parameters (e.g., area of a particular land cover, length of streams and slope) is measured in each ring with the use of a GIS.

Proximity analysis is performed by dividing the parameter by the distance of the midpoint of the ring from the wetland. This ensures that the greater the distance from the wetland, the lesser the impact of that value of the parameter.

3.4.1 Mid-point Distances for Each Concentric Ring

- 1^{st} ring: 214 m/2 = 107 m
- 2^{nd} ring: 214 + [(500-214)/2] = 357 m
- 3^{rd} ring: 500 + 125 = 625 m
- 4^{th} ring: 750 + 125 = 875 m
- 5^{th} ring: 1000 + 500= 1500 m

3.5 Data Sources

All data used in the demonstration of this methodology were collected from federal and state agencies, as well as from university and commercial sources. Wetland locations were collected as a part of the overall project and provided as digitized wetlands shape file [Christopher Shulse, 2008]. All other data has been downloaded from the Missouri Spatial Data Information Service (http://www.msdis.missouri.edu/).

3.6 Normalization

Utilizing many different parameters means that individual layers of information can be presented with multiple units. For aggregation and comparison purposes, a common unit of measurement must be utilized. One way to address this issue is through data normalization, where a dimensionless parameter is calculated. For example, the following formula can convert interval data into a normalized scale from 0.0 to 1.0.

$$S_i = (X_i - X_{min})/(X_{max} - X_{min}) \qquad \text{Equation 1}$$

where S_i is the normalized value for the original value X_i, X_{min} is the lowest value, and X_{max} is the highest original value within the entire preparation values for that particular parameter. For some of the parameter, the average normalized value is subtracted from one in order that for all parameters a larger value indicates a greater contribution to amphibian health.

3.7 Weight of Parameters

Different landscape parameters have different effects and thus on wetland scoring. The relative importance of the each parameter must be evaluated against the other parameters under consideration in an overall assessment. Every parameter quantified in this development of the methodology is assigned relative weight. The quantification of the parameter determines how much and how far for the attribute, while the weight indicates the extent to which the attribute or attribute category contributes to amphibian habitat. The magnitude of the applied weight (1 to 5) is consistent with values reported in the literature. The maximum value of 5 is based upon needing to account for 5 categories of land cover /land use.

3.8 Score of Wetland

A wetland is scored by the multiplication of the average normalization value by the relative weight of the parameter.

Chapter 4

4. Results

Two MDC ponds, Redman Unit 1 and the Rose Pond, are analyzed for this methodology demonstration and all parameters are quantified to obtain overall 'score' for comparison.

4.1 Redman Unit 1

4.1.1 Road Density

A GIS buffer analysis is used to quantify the road density parameter. All existing road layers are merged with the use of the 'merge' tool in ArcMap so that they can be analyzed as a single layer (Figure 5). As discussed previously, five concentric rings are created around the wetland with the use of 'multiple buffers' tool. The value of the parameter (i.e., the length of the roads) is calculated by overlaying the analysis concentric rings on the existing road layer with the help of 'intersect' tool (Figure 6).

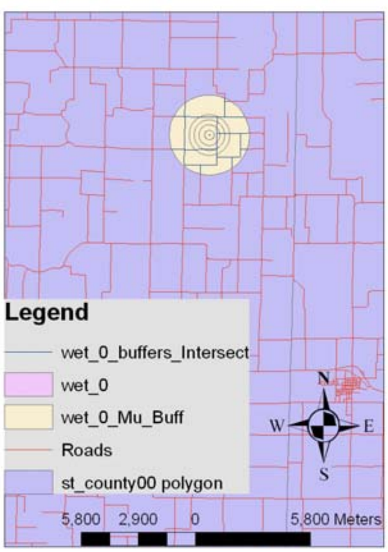

Figure 5. Existing road layer.

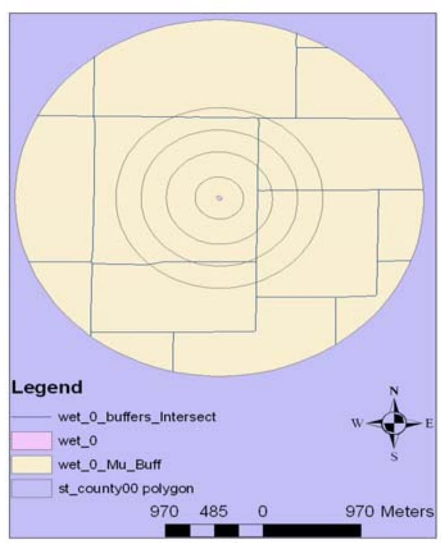

Figure 6. Overlay analysis.

The length of the road segments in the rings are calculated with the help of the 'calculate geometry' tool in ArcMap. Available GIS layers did not characterize the width of the road under consideration. A standard width of a single lane highway is 6.1 meters (20 feet). The area of the road is calculated by the multiplying the length of the road by the standard width.

The percentage road density is calculated by the following equation:

Percentage Road Density = Area of roads in the ring*100/ Area of that particular ring

The road density calculation for the MDC Redman unit 1 wetland of MDC is used to show the sample calculations with the wetland area 1841.62 $m^{2.}$

4.1.1.1 Area of the Concentric Rings

- Area of (Ring 0) = Area of circle of radius 214 m^2 – Area of wetland in m^2

  $= \pi * 214^2 - 1841.62$

  $= 141957.82 \ m^2$

- Area of (Ring 1) = $\pi (500^2 - 214^2) = 641200.56 \ m^2$
- Area of (Ring 2) = $\pi (750^2 - 500^2) = 981250 \ m^2$
- Area of (Ring 3) = $\pi (1000^2 - 750^2) = 1373750 \ m^2$
- Area of (Ring 4) = $\pi (2000^2 - 1000^2) = 9420000 \ m^2$

4.1.1.2 Distance for Proximity Analysis

A high density of roads is not good for amphibian habitat. In addition, the evaluation of the proximity of the road density is also an important factor for amphibian habitat. How far or how close the roads are from the wetland can be vital information for amphibian because they travel in the surrounding area and they may be killed by vehicles on the roads. Thus, to analyze for proximity, the percentage road density is divided by the distance from the wetland. This distance is taken from the edge of the wetland to midpoint of the each concentric ring.

Maximum and minimum values for normalization can be calculated easily with the 'statistic' tool in ArcMap. All road density/distance (RD/DIST) values (as shown in Table 6) are normalized to the maximum value of 0.002466 and the minimum value of 0.00014.

Table 6. Attribute table for calculation of road density parameter.

Ring No.	BUFFER DISTANCE	Road_Name	LENGH(meters)	AREA_ROAD(Sq. m)	PER_RD_DEN	Mid_pt_dis(meters)	RD/DIST	NORM
1	0.50	KK	406.008	4949.24	0.7719	357	0.00216	0.8761
1	0.50	KK	406.008	4949.24	0.7719	357	0.00216	0.8761
2	0.75	KK	563.689	6871.37	0.7003	625	0.00112	0.4512
2	0.75	KK	563.689	6871.37	0.7003	625	0.00112	0.4512
3	1.00	KK	1331.370	16229.40	1.1814	875	0.00135	0.5449
3	1.00	KK	1331.370	16229.40	1.1814	875	0.00135	0.5449
4	2.00	KK	2347.560	28616.80	0.3038	1500	0.00020	0.0769
4	2.00	KK	2347.560	28616.80	0.3038	1500	0.00020	0.0769
4	2.00	KENNEDY ST	624.995	7618.69	0.0809	1500	0.00005	0.0163
4	2.00	KENNEDY ST	624.995	7618.69	0.0809	1500	0.00005	0.0163
2	0.75	KENNEDY ST	547.405	6672.87	0.6800	625	0.00109	0.4380
2	0.75	KENNEDY ST	547.405	6672.87	0.6800	625	0.00109	0.4380
3	1.00	KENNEDY ST	513.500	6259.56	0.4557	875	0.00052	0.2067
3	1.00	KENNEDY ST	513.500	6259.56	0.4557	875	0.00052	0.2067
4	2.00	KENNEDY ST	571.089	6961.57	0.0739	1500	0.00005	0.0144
4	2.00	KENNEDY ST	571.089	6961.57	0.0739	1500	0.00005	0.0144
1	0.50	NICOLLET RD	463.096	5645.14	0.8804	357	0.00247	1.0000
1	0.50	NICOLLET RD	463.096	5645.14	0.8804	357	0.00247	1.0000
2	0.75	NICOLLET RD	308.347	3758.75	0.3831	625	0.00061	0.2442
2	0.75	NICOLLET RD	308.347	3758.75	0.3831	625	0.00061	0.2442
3	1.00	NICOLLET RD	275.144	3354.01	0.2442	875	0.00028	0.1081
3	1.00	NICOLLET RD	275.144	3354.01	0.2442	875	0.00028	0.1081
4	2.00	NICOLLET RD	2179.860	26572.50	0.2821	1500	0.00019	0.0710
4	2.00	NICOLLET RD	2179.860	26572.50	0.2821	1500	0.00019	0.0710
3	1.00	ORCHID ST	83.866	1022.33	0.0744	875	0.00009	0.0290

4.1.1.3 Weight of Parameters

Weighting for this parameter is based on the average normalized values for each ring. Average normalization values for each ring are calculated and again the average of these values is taken into consideration to assign a weight to this piece of wetland information. In order that all parameters score in the same direction (i.e. larger values mean larger negative contribution to wetland habitat) the calculated normalized value is transformed by subtracting it from 1. Average normalization value for this wetland is 0.292.

4.1.1.4 Score of Wetland

Score of the wetland is calculated by multiplying average normalized value by the weight of the parameter. The calculated normalized value is subtracted from 1 to obtain a value 0.708. So particular wetland score is 0.708*4= 2.832, as shown in Table 7.

Table 7. Weighting for road density parameter.

Transformed Average Normalization Value	Weight for road density parameter
0-0.2	1
0.21-4	2
0.41-6	3
0.61-0.8	4
0.81-1	5

4.1.2 Land Use Land Cover (LULC)

Larger Land use and land cover parameters are quantified into five different categories (urban density, cropland, grassland, woods and open water). These five categories have different effect on wetland evaluation and amphibian habitat. LULC data for 2005 Missouri in raster format was gathered from the Missouri Spatial Data Information Service (MSDIS). The raster data is shown in Figure 7. This data is converted into vector format with the help of a ‘raster to polygon’ tool. A layer indicating the multiple buffers around a wetland is intersected with the LULC layer. The area of each LULC is calculated by inserting a field into the attribute table and using the 'calculate geometry' tool and the percentage of each category is calculated with a common equation as follows

Percentage of LULT = Area of LULT in the ring*100/ Area of that particular ring Equation 3

The proximity analysis is performed by dividing by the distance of the midpoint of the ring as described earlier.

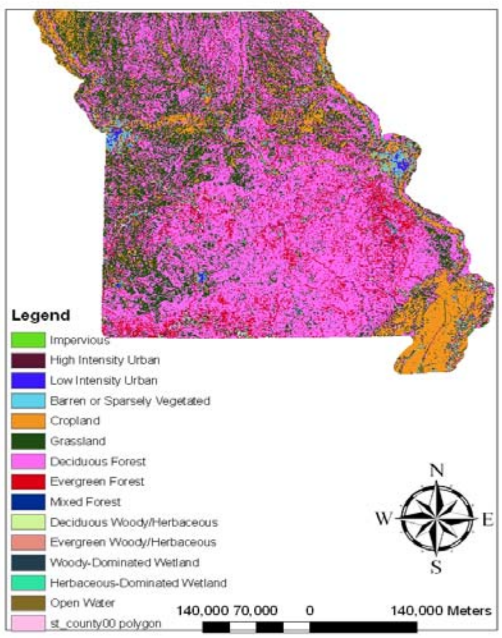

Figure 7. LULT raster data for Missouri.

As every category in LULC differently on wetland scoring and amphibian health differently, each LULC category is assigned a different weight according to that as shown in Table 8. For the amphibians adapted to woodlands the weights for grassland and woodland in Table 8 would have to be switched.

Table 8. Weight of each category of LULC

Category of LULC	Weight
Open water	5
Grassland	4
Woods	3
Cropland	2
Urban density	1

The LULC categories are described below

4.1.2.1 Urban Density

A higher urban density can cause a detrimental effect on amphibian health because of the occurrence of many human activities such as the construction of roads and parking lots that disturb the habitat. Impervious, low density urban and high density categories were added together to form the "Urban" category as shown in Figure 8. All these LULC are selected with the help of the 'select by attributes' tool in the attribute table as shown in Figure 8. Normalization is performed with the maximum value and minimum value of percentage urban density divided by distance (per_urb_dens/dist) value as shown in Table 9 which are 0.004115 and 0.000004, respectively.

The average normalized value for each ring is calculated and again the average of all these values is calculated as 0.213.

4.1.2.1.1 Score of Wetland for Urban Density

The average normalization value 0.213 is multiplied by the weight of the urban density category to obtain the score of the wetland which is 0.213*1= 0.213.

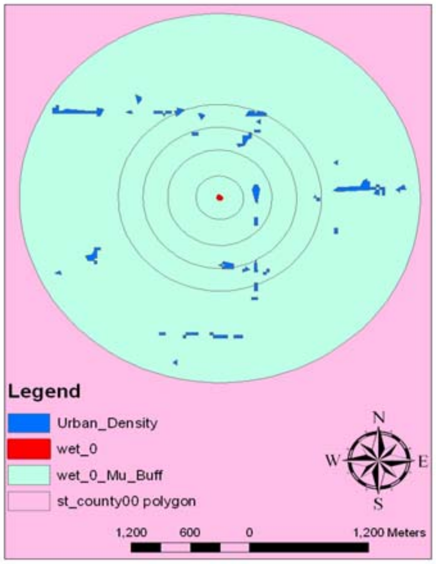

Figure 8. Urban locations.

Table 9. Attribute table of the calculation of the urban density parameter.

Ring No.	BUFFER_DISTANCE	GRIDCODE	AREA (m2)	PER_URBAN _DENS	DISTANCE (m)	PER_URB_DENS/DIST	NORM
1	0.50	1	9419.710	1.46907	357	0.004115	1.0000
1	0.50	1	2700.000	0.42109	357	0.001180	0.2859
2	0.75	1	1800.000	0.18344	625	0.000294	0.0704
2	0.75	3	8608.440	0.87729	625	0.001404	0.3405
2	0.75	1	576.563	0.05876	625	0.000094	0.0219
2	0.75	3	6456.300	0.65797	625	0.001053	0.2551
3	1.00	1	1680.520	0.12233	875	0.000140	0.0330
3	1.00	1	8395.940	0.61117	875	0.000698	0.1689
3	1.00	1	2340.610	0.17038	875	0.000195	0.0464
3	1.00	1	1255.960	0.09143	875	0.000104	0.0244
3	1.00	1	1800.000	0.13103	875	0.000150	0.0355
3	1.00	3	297.038	0.02162	875	0.000025	0.0050
3	1.00	1	576.343	0.04195	875	0.000048	0.0107
3	1.00	1	900.000	0.06551	875	0.000075	0.0172
3	1.00	3	1679.300	0.12224	875	0.000140	0.0330
3	1.00	1	1881.410	0.13695	875	0.000157	0.0371
3	1.00	1	2759.880	0.20090	875	0.000230	0.0549
3	1.00	1	900.000	0.06551	875	0.000075	0.0172
3	1.00	1	900.000	0.06551	875	0.000075	0.0172
3	1.00	1	743.343	0.05411	875	0.000062	0.0141
4	2.00	3	3520.900	0.03738	1500	0.000025	0.0051
4	2.00	1	1349.660	0.01433	1500	0.000010	0.0014
4	2.00	1	2700.000	0.02866	1500	0.000019	0.0037
4	2.00	1	1800.000	0.01911	1500	0.000013	0.0021
4	2.00	1	22552.800	0.23941	1500	0.000160	0.0379

4.1.2.2 Cropland

Cropland is agriculture land around the wetland. Agricultural practices might result in reduced habitat and ongoing disturbance of the land. Barren and sparsely vegetated land is also included in the cropland category for this analysis by providing only marginal habitat. The locations of cropland are shown in Figure 9. Normalization is performed with the maximum and minimum values of percentage cropland divided by distance (per_crp_dens/dist) value as shown in Table 10. The values are 0.2076 and 0.00 respectively.

The average normalized value for each ring is calculated and again the average of all these values is calculated which is 0.138.

4.1.2.2.1 Score of Wetland for Cropland

The average normalized value 0.138 is multiplied by the weight of the cropland category 2 to obtain the score of the wetland which is 0.138*2= 0.276.

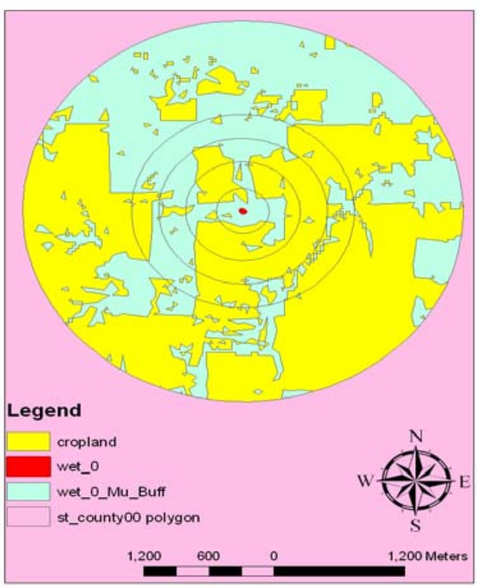

Figure 9. Locations of cropland.

Table 10. Calculation of cropland parameter.

Ring No	FER_DISTA	GRIDCODE	Area (m2)	PER_CRP_DENS	DISTANCE(m)	PER_CRP_DENS/DIST	NORM
0	0.214	5	23516.9000	16.5661	107	0.1548	0.7458
0	0.214	5	1803.6300	1.2705	107	0.0119	0.0572
0	0.214	5	0.8572	0.0006	107	0.0000	0.0000
0	0.214	5	31544.5000	22.2210	107	0.2077	1.0004
1	0.500	5	576.5630	0.0899	357	0.0003	0.0012
1	0.500	5	5160.7900	0.8049	357	0.0023	0.0109
1	0.500	5	108717.0000	16.9552	357	0.0475	0.2288
1	0.500	5	3514.9800	0.5482	357	0.0015	0.0074
1	0.500	5	6392.5600	0.9970	357	0.0028	0.0135
1	0.500	5	364920.0000	56.9120	357	0.1594	0.7679
2	0.750	5	576.5630	0.0588	625	0.0001	0.0005
2	0.750	5	68031.7000	6.9332	625	0.0111	0.0534
2	0.750	5	615.8790	0.0628	625	0.0001	0.0005
2	0.750	5	17390.7000	1.7723	625	0.0028	0.0137
2	0.750	5	200.0350	0.0204	625	0.0000	0.0002
2	0.750	5	615.8790	0.0628	625	0.0001	0.0005
2	0.750	5	615.8790	0.0628	625	0.0001	0.0005
2	0.750	5	1228.9800	0.1252	625	0.0002	0.0010
2	0.750	5	576.5630	0.0588	625	0.0001	0.0005
2	0.750	5	557947.0000	56.8608	625	0.0910	0.4382
3	1.000	5	786.8900	0.0573	875	0.0001	0.0003
3	1.000	5	615.8790	0.0448	875	0.0001	0.0002
3	1.000	5	483.1840	0.0352	875	0.0000	0.0002
3	1.000	5	4997.5400	0.3638	875	0.0004	0.0020
3	1.000	5	615.8790	0.0448	875	0.0001	0.0002

4.1.2.3 Woods

Mixed forest, evergreen forest, deciduous forest, deciduous forest/herbaceous and evergreen woody/herbaceous land covers were combined to create the woods category as shown in Figure 10.

Normalization is performed with the maximum and minimum values of the percentage of woods area divided by the distance (per_woods/dist) value as shown in Table 11, which are 0.0020 and 0.00, respectively.

The average normalized value for each ring is calculated and again the average of all these values is calculated which is 0.182.

4.1.2.3.1 Score of Wetland for Woods

The average normalization value of 0.182 is multiplied by the weight of the wood category 3 to obtain the score of the wetland which is 0.182*3= 0.546.

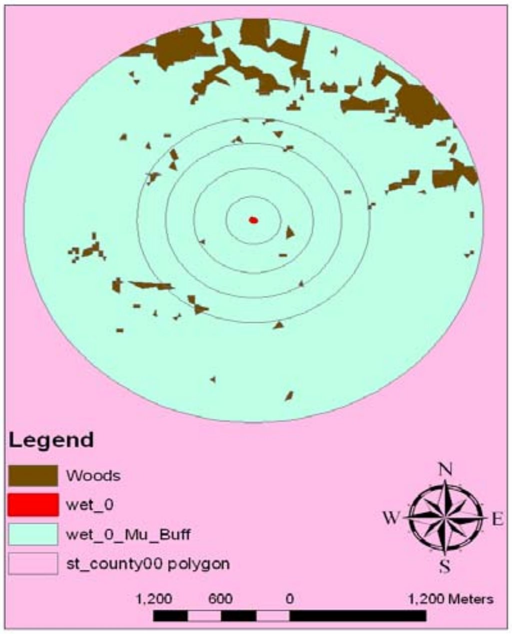

Figure 10. Woods locations.

Table 11. Calculation of percentage of woods parameter.

Ring No.	Buffer_Distance	GRIDCODE	Area(m2)	Distance(m)	per_woods	per_woods/dist	Norm
1	0.50	10	4734.5800	375	0.73839	0.00207	1.000
1	0.50	10	1255.9600	375	0.19588	0.00055	0.265
1	0.50	7	1800.0000	375	0.28072	0.00079	0.380
2	0.75	10	882.9220	625	0.08998	0.00014	0.070
2	0.75	10	999.7780	625	0.10189	0.00016	0.079
3	1.00	10	1212.7000	875	0.08828	0.00010	0.049
3	1.00	7	1672.6500	875	0.12176	0.00014	0.067
3	1.00	7	576.3430	875	0.04195	0.00005	0.023
3	1.00	10	2879.3400	875	0.20960	0.00024	0.116
3	1.00	10	615.8790	875	0.04483	0.00005	0.025
3	1.00	10	1971.9900	875	0.14355	0.00016	0.079
3	1.00	10	1800.0000	875	0.13103	0.00015	0.072
3	1.00	10	17.0781	875	0.00124	0.00000	0.001
3	1.00	10	5232.4300	875	0.38089	0.00044	0.210
3	1.00	10	3266.9700	875	0.23781	0.00027	0.131
3	1.00	7	1804.2600	875	0.13134	0.00015	0.073
3	1.00	10	576.5630	875	0.04197	0.00005	0.023
3	1.00	10	2390.6300	875	0.17402	0.00020	0.096
3	1.00	10	615.8790	875	0.04483	0.00005	0.025
3	1.00	10	1800.0000	875	0.13103	0.00015	0.072
3	1.00	7	202.6410	875	0.01475	0.00002	0.008
3	1.00	10	1700.1800	875	0.12376	0.00014	0.068
3	1.00	10	229.2070	875	0.01668	0.00002	0.009
3	1.00	7	1419.7600	875	0.10335	0.00012	0.057
3	1.00	7	4089.1100	875	0.29766	0.00034	0.164

4.1.2.4 Grassland

Grassland/pasture is better for amphibian habitat than agricultural land. Locations of grassland around the wetland are shown are Figure 11.

Normalization is performed with the maximum and minimum values of the percentage of the grassland divided by distance (per_grss_land/dist) as shown in Table 12 which are 0.8086 and 0.00, respectively.

The average normalization for each ring is calculated and again the average of all these values is calculated as 0.204.

4.1.2.4.1 Score of Wetland for Grassland

The average normalization value 0.204 is multiplied by the weight of the grassland category 3 to obtain the score of the wetland which is 0.204*4= 0.816.

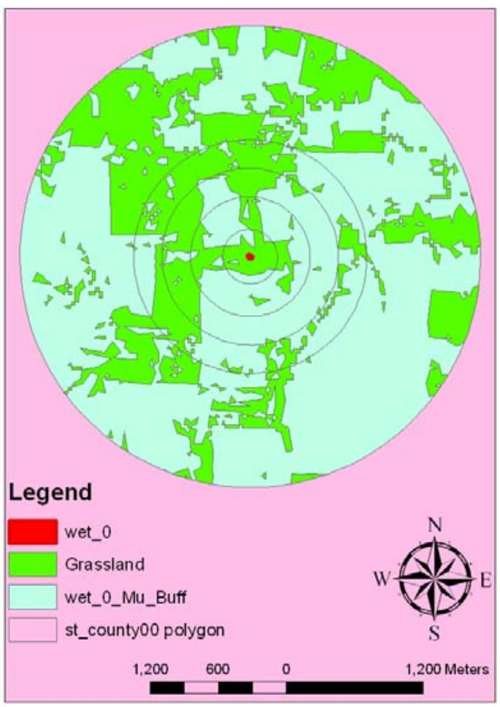

Figure 11. Locations of grassland.

Table 12. Calculation of grassland parameter

Ring No.	Buffer_Distance	GRIDCODE	Area (m2)	per_grss_land	Distance	per_grss_land/Dist	NORM
0	0.214	6	122823.000	86.5208	107	0.8086	1.000
1	0.500	6	576.563	0.0899	375	0.0003	0.000
1	0.500	6	2507.610	0.3911	375	0.0011	0.001
1	0.500	6	615.879	0.0961	375	0.0003	0.000
1	0.500	6	576.343	0.0899	375	0.0003	0.000
1	0.500	6	1045.900	0.1631	375	0.0005	0.001
1	0.500	6	615.879	0.0961	375	0.0003	0.000
1	0.500	6	5372.270	0.8378	375	0.0023	0.003
1	0.500	6	157714.000	24.5967	375	0.0689	0.085
2	0.750	6	11993.700	1.2223	625	0.0020	0.002
2	0.750	6	1295.620	0.1320	625	0.0002	0.000
2	0.750	6	71.758	0.0073	625	0.0000	0.000
2	0.750	6	581.218	0.0592	625	0.0001	0.000
2	0.750	6	1213.670	0.1237	625	0.0002	0.000
2	0.750	6	814.528	0.0830	625	0.0001	0.000
2	0.750	6	334520.000	34.0912	625	0.0545	0.067
2	0.750	6	1728.630	0.1762	625	0.0003	0.000
3	1.000	6	167.753	0.0122	875	0.0000	0.000
3	1.000	6	449.099	0.0327	875	0.0000	0.000
3	1.000	6	2879.390	0.2096	875	0.0002	0.000
3	1.000	6	4158.950	0.3027	875	0.0003	0.000
3	1.000	6	4359.980	0.3174	875	0.0004	0.000
3	1.000	6	615.879	0.0448	875	0.0001	0.000
3	1.000	6	1215.080	0.0884	875	0.0001	0.000
3	1.000	6	545.981	0.0397	875	0.0000	0.000

4.1.2.5 Open Water

Herbaceous-dominated wetlands are also included in this category for analysis as shown in Figure 13. Normalization is performed with the maximum and minimum values of the percentage open water divided by the distance (per_open_wat/dist) values as shown in Table 13 which are 0.003665 and 0.00, respectively.

The average normalized value for each ring is calculated and again the average of all these values is calculated which is 0.267.

4.1.2.5.1 Score of Wetland for Open Water

The average normalized value of 0.267is multiplied by the weight of the open water category 5 to get the score of the wetland which is 0.267*5= 1.335

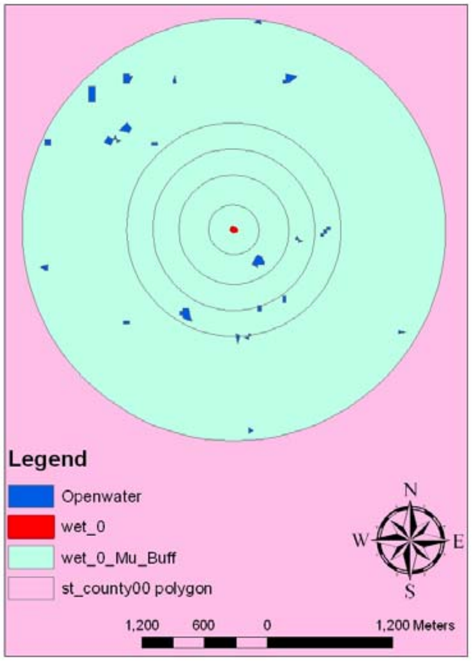

Figure 12. Wetland and open water locations.

Table 13. Calculation of percentage of open water parameter.

Ring No.	Buffer_distance	GRIDCODE	Area(m2)	per_open_wat	Dist(m)	per_open_wat/dist	Norm
1	0.50	15	8388.580	1.30826	375	0.003665	1.000
2	0.75	14	576.343	0.05874	625	0.000094	0.026
2	0.75	14	576.563	0.05876	625	0.000094	0.026
2	0.75	15	372.173	0.03793	625	0.000061	0.017
3	1.00	14	900.000	0.06551	875	0.000075	0.020
3	1.00	14	900.000	0.06551	875	0.000075	0.020
3	1.00	14	900.000	0.06551	875	0.000075	0.020
3	1.00	14	1800.000	0.13103	875	0.000150	0.041
3	1.00	15	1427.830	0.10394	875	0.000119	0.032
3	1.00	14	8251.170	0.60063	875	0.000686	0.187
3	1.00	14	432.106	0.03145	875	0.000036	0.010
3	1.00	14	758.787	0.05523	875	0.000063	0.017
4	2.00	15	1490.500	0.01582	1500	0.000011	0.003
4	2.00	15	6300.000	0.06688	1500	0.000045	0.012
4	2.00	15	1295.620	0.01375	1500	0.000009	0.003
4	2.00	14	6396.970	0.06791	1500	0.000045	0.012
4	2.00	15	9000.000	0.09554	1500	0.000064	0.017
4	2.00	14	6422.790	0.06818	1500	0.000045	0.012
4	2.00	14	576.343	0.00612	1500	0.000004	0.001
4	2.00	14	576.563	0.00612	1500	0.000004	0.001
4	2.00	15	3600.000	0.03822	1500	0.000025	0.007
4	2.00	14	4500.000	0.04777	1500	0.000032	0.009
4	2.00	15	1800.000	0.01911	1500	0.000013	0.003
4	2.00	15	2781.410	0.02953	1500	0.000020	0.005
4	2.00	15	1800.000	0.01911	1500	0.000013	0.003

4.1.3 Hydrological Linkage

There are no streams within 2km of this pond so score of this wetland is zero. The calculation of the parameter is discussed in the Rose Pond section.

4.1.4 Slope

Digital elevation model data were gathered from MSDIS in raster format. With the use of the 'spatial analyst' tool in ArcMap, the slope is calculated in percentage. All slopes are converted into integer format with the use of the 'int' tool and then converted into vector format. Concentric rings around the wetlands layer are intersected with the 'intersect' tool as shown in Figure 13. The slopes surrounding Redman Unit 1 fall into four categories. Slope category 0 designates slopes between 0 and 0.5%. Slope category 3 includes slopes between 2.5 and 3.5%. A slope designation of 0 can be very difficult to use in mathematical analysis so a value of 1 was added to each slope category as shown in Table 14.

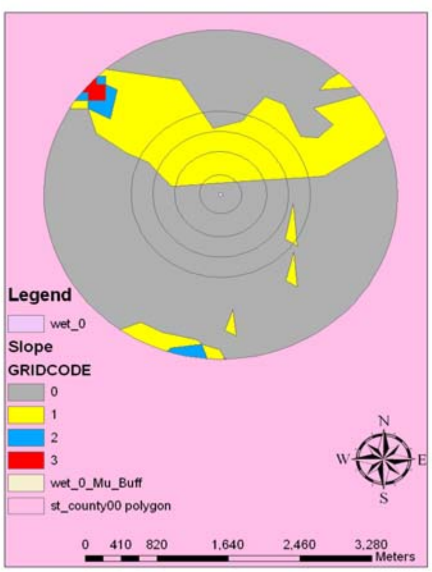

Figure 13: Slope analysis surrounding wetland.

Table 14. Calculation of slope parameter

Ring No.	Buffer_distance(km)	Slope	Zero_removal	Dist(m)	Norm
0	0.214	1	2	107	0.3333
0	0.214	0	1	107	0.0000
1	0.500	1	2	357	0.3333
1	0.500	0	1	357	0.0000
2	0.750	1	2	625	0.3333
2	0.750	0	1	625	0.0000
3	1.000	1	2	875	0.3333
3	1.000	1	2	875	0.3333
3	1.000	0	1	875	0.0000
4	2.000	2	3	1500	0.6667
4	2.000	1	2	1500	0.3333
4	2.000	2	3	1500	0.6667
4	2.000	3	4	1500	1.0000
4	2.000	1	2	1500	0.3333
4	2.000	2	3	1500	0.6667
4	2.000	1	2	1500	0.3333
4	2.000	1	2	1500	0.3333
4	2.000	1	2	1500	0.3333
4	2.000	1	2	1500	0.3333
4	2.000	2	3	1500	0.6667
4	2.000	1	2	1500	0.3333
4	2.000	0	1	1500	0.0000

Table 15. Weight of slope parameter

Average Normalization Values	Weight for slope parameter
0-0.2	1
0.21-4	2
0.41-6	3
0.61-0.8	4
0.81-1	5

4.1.4.1 Normalization

Slope values are normalized to maximum value of a 4 and minimum value of 1. Normalized values are shown in the last column of attribute table as shown in Table 14.

Average normalization value for each ring is calculated and again averages of those values are taken which comes out to be 0.236. It should be subtracted by 1 to obtain value of 0.764

4.1.4.2 Score of Wetland

Average normalization value is 0.764 so weight of the parameter is 4 from Table 15. Score of the wetland is 0.764 *4= 3.056

4.2 Rose Pond

4.2.1 Road Density

The length of the road, percentage road density and percentage road density / midpoint distance is calculated as discussed previously. The value of percentage road density / midpoint distance is normalized with maximum and minimum values of 0.005318 and 0.000039, respectively. The average normalized value is calculated which is 0.240. This value is subtracted from 1 which comes out to be 0.760. The weight of the parameter is 4 from Table 7. And the score of the wetland calculated to be 0.760* 4= 3.040.

4.2.2 Land Use Land Cover

4.2.2.1 Urban Density

The area of urban density, percentage urban density and values from the proximity analysis are calculated. Percentage urban density/midpoint distance values are normalized with maximum and minimum values of as 0.000032 and 0.000006 respectively. The average normalized value is calculated which is 0.0320.The weight for the the parameter is 1 from Table 8 and the score of the wetland is calculated by 0.0320* 1 = 0.0320

4.2.2.2 Cropland

The area of cropland, percentage cropland and values from the proximity analysis are calculated. Percentage cropland/midpoint distance values are normalized with maximum and minimum values of 0.383869 and 0.000001 respectively. The average normalized value is calculated which is 0.0926.The weight for the parameter is 2 from Table 8 and the score of the wetland is calculated by 0.0926* 2= 0.1852.

4.2.2.3 Woods

The area of woods, percentage woods in each ring and values from proximity analysis are calculated. Percentage woods area/midpoint distance values are normalized with maximum and minimum values of 0.006232 and 0, respectively. The average normalized value is calculated which is 0.2332.Weight of the parameter is 2 from Table 8. Score of the wetland is calculated as 0.2332* 4= 0.9328.

4.2.2.4 Grassland

The area of grassland, percentage grassland and values from the proximity analysis are calculated. Percentage grassland/midpoint distance values are normalized with maximum and minimum values of 0.389133 and 0 respectively. The average normalized value is calculated which is 0.2017.The weight of the parameter is 3 from Table 8 and the score of the wetland is calculated as 0.2017* 4= 0.8068.

4.2.2.5 Open Water

The area of open water, percentage open water in each ring and values from the proximity analysis are calculated. Percentage open water area/midpoint distance values are normalized with the maximum and minimum values of 0.26089 and 0 respectively.

The average normalized value is calculated which is 0.0574.The weight of the parameter is 2 from Table 8. With the score of the wetland is calculated to be 0.0574* 5= 0.2874.

4.2.3 Hydrological Linkage

This parameter is quantified with the overlay analysis of multiple buffers ring layers on the layer of streams and rivers in Missouri as shown in Figure 14. Data including creeks, streams and rivers was gathered from MSDIS. The length of each stream segment was calculated with the help of the 'calculate geometry tool' in ArcMap. Streams are categorized into three types of flows as perennial, intermittent and artificial path. Proximity analysis is performed by dividing the stream length by the distance of the wetland edge to the midpoint of that particular ring.

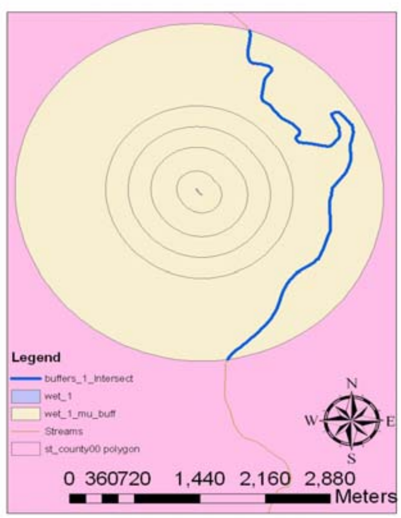

Figure 14. Analysis of hydrological linkage.

4.2.3.1 Normalization

Normalization is performed against the maximum and minimum values of the length/distance quantity in the attribute table as shown in Table 16. These values are 3.9649 and 0.5524, respectively.

When evaluating an entire set of wetlands, as for a right-of-way analysis the maximum and minimum values identified when considerating of all of the wetlands. This procedure is to be used because the evaluation is based on a comparison all of the wetland rather than on the assignments of an absolute score. Average normalization value is calculated and as 0.431.

Table 16. Calculation of hydrological linkage parameter.

Ring No.	Buffer_Distance	FTYPE	NAME	DESCRIPT	Length (m)	Distance(m)	LEGHT/DIST	Norm
4	2	STREAM/RIVER	Fox River	Stream / River (perennial)	828.728071842	1500	0.552485	0.000
4	2	STREAM/RIVER	Fox River	Stream / River (perennial)	894.110599151	1500	0.596074	0.013
4	2	STREAM/RIVER	Fox River	Stream / River (perennial)	4484.410315601	1500	2.989610	0.714
4	2	STREAM/RIVER	Fox River	Stream / River (perennial)	5947.453536076	1500	3.964970	1.000

4.2.3.2 Score of Wetland for Stream

To obtain the score of the wetland the average normalization value is multiplied by the weight of the stream category. Here, the intersected stream is perennial so its weight is 3 (Table 17). Therefore, the score of the wetland is 0.431*3= 1.293.

Table 17. Weight for the categories of stream

Category of stream	Weight
Intermittent	5
Perennial	3
Artificial Path	1

4.2.4 Slope

All land within 2 km of this wetland has a slope to be category of 0. As described previously, one is added to this value for ease of normalization, the normalized value is 0, which is then transformed by subtracting it from 1 to produce a value 1. The weight of the parameter is 5 from Table 15 thus; the overall score for the category of slope is 5.

4.3 Discussion

A comparison of Redman Unit 1 and Rose Pond is accomplished by assessing individual as well as overall scores as in Table 18.

Table 18. Comparison of scores of two MDC ponds.

Parameter	**Redman Unit 1**	**Rose Pond**
Road density	2.832	3.040
Urban density	0.213	0.320
Cropland	0.276	0.185
Woods	0.546	0.932
Grassland	0.816	0.806
Open water	1.335	0.287
Hydrological linkage	0	1.293
Slope	3.056	5
Summation	**9.074**	**11.863**

Chapter 5

5 . Conclusion

In this research, a study of the history, definition and importance of wetlands is accomplished. Reasons for loss of wetlands and the U.S. government's role in regulating the discharge of dredged or fill material into waters of the United States, including wetlands, is discussed. Various wetland evaluation techniques from other researchers and their concepts for scoring wetlands on certain wetland functions and values are also reported.

The identification of applicable landscape parameters are which can be important to the scoring wetland as amphibian habitat was accomplished resulting in the selection of the parameters of road density, land use land cover, hydrological linkage to streams and ground slope surrounding wetland.

Spatial analysis was performed with help of ArcGIS software. GIS data layers for specified parameters were prepared and the parameters were quantified to assess how a particular wetland performs if such landscape parameters are available in the surrounding area. Proximity analysis was performed because the nearness of such landscape parameters from the wetland can be a vital factor for amphibian health.

A methodology was developed which should help MoDOT, MDC and other state DOT's to assess wetland performance from the surrounding landscape, keeping amphibian health in mind. The assessment can be used to evaluate alternative right-of-way to determine the contribution to amphibian habitat from the different routes. It will also help DOT's to account for existing feature as such existing roads and nearby streams or rivers when selecting and designing compensatory wetlands.

Chapter 6

6. Future Work

There are a number of topics that should be addressed in subsequent research.

- Concentric rings around a wetland may overlap with the concentric rings around another wetland. A wetland this close to another wetland is positive condition for amphibian habitat. One must still determine how to account for this benefit without over counting the parameter attributes.
- This methodology is demonstrated with two individual wetlands. Every parameter needs to be quantified for all 49 compensatory wetlands.
- Normalization of the each parameter should be performed utilizing maximum and minimum values resulting after all 49 wetlands are quantified.
- Additional investigation into the weights applied to the parameter values is necessary to determine if they are appropriate.
- The analysis may need to include other parameters in order to accurately represent the impact of the landscape on amphibian habitat.
- Overall wetland scores must be compared with measure of amphibian health to determine if the method is valid and to assist in the development of weights.

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