

LANDSCAPE ANALYSIS USING GIS METHODOLOGY FOR THE EVALUATION
AND PREDICTION OF RELATIONSHIPS OF AMPHIBIAN HEALTH IN MISSOURI
WETLANDS

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by
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LANDSCAPE ANALYSIS USING GIS METHODOLOGY FOR THE EVALUATION
AND PREDICTION OF RELATIONSHIPS OF AMPHIBIAN HEALTH IN MISSOURI
WETLANDS

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Dedication

This work is dedicated to all my family, specially my son Iván Andrés Rodríguez-Romero, my little star; thanks for bringing so much happiness into my life. Special thanks to my husband, José J. Rodríguez, for all his support and encouragement during my years at MU. Thanks to my parents, Ermelindo Romero (PE) and Miriam Ramírez, for their encouragement to pursue graduate studies. I would like to thank my aunt Iris M. Romero for her positive encouragement and her advice during my graduate studies at MU. Thanks to my sister Mayra Romero, for always being there whenever I need her. This work is also dedicated to my grandparents (RIP), Florencio Ramírez, Ernestina Hernández, Ermelindo Romero and Milagros Valentín, for their love and support. To my nieces, Valeria Z. Rivera, Amanda I. Rivera, Angélica C. Romero and Astrid N. Romero, this work is for you. I would also like to thank my mother-in-law Juana Rodríguez for all her prayers that made this work possible.

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LANDSCAPE ANALYSIS USING A GIS METHODOLOGY FOR THE EVALUATION AND PREDICTION OF RELATIONSHIPS OF AMPHIBIAN HEALTH IN MISSOURI WETLANDS

Abstract

It is important for state departments of transportation (DOTs) to make decisions regarding transportation route locations that minimize negative impacts to wetland fauna. Here a new methodology to quantify wetland health is developed using landscape characteristics for 49 wetlands in northern Missouri and relating them to wetland health. Wetland health was defined in this project as the presence of sensitive or rare amphibian species, such as tiger salamanders or northern crayfish frogs, which are very sensitive to habitat disturbance. The biology assessment involved in this project was performed as part of other research. Crops, forest, grass, and herbaceous land covers, length of stream, length of roads, length of flowpath from wetland to stream, change in elevation between wetland and nearest drainage channel are landscape characteristics that are considered because they are assumed to affect positively or negatively wetland habitat for amphibians. A commercial geographic information system (GIS) ArcGIS 9.2 was used to quantify the landscape characteristics. Two types of wetlands were identified: non-pairs and pairs. Non-pair wetlands were defined as those wetlands in which the 600 m buffer zone and beyond did not overlap with the buffer zones of other wetland. A pair wetland was defined as one in which the concentric rings of the buffer zones overlapped with the concentric rings of another wetland. Five buffers were generated around each wetland encompassing 0-300 meters, 0-600 meters, 0-900 meters, 0-1500 meters, and 0-

2100 meters. A distance parameter was incorporated in the variable values because it was hypothesized that distance from the landscape feature to the wetlands could be a factor for the prediction of the health of the wetlands. The variables were then normalized which allows for the addition and subtraction of dimensionless landscape characteristics with different units (e.g., length of roads, grass area). Multiple linear regression analyses were performed at the different spatial scales mentioned above, to test the relationship between wetland health and landscape variables. It was found that proximity to roads negatively affects wetland health up to a distance of 900 meters, while crops can have a negative effect up to a distance up to 2100 meters.

Chapter 1

1. Introduction

1.1. Wetlands

Wetlands are the integration of aquatic and terrestrial systems (Euliss et al. 2004). The Clean Water Act (CWA) defines wetlands as: "those areas that are inundated or saturated by surface or groundwater 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" (40 CFR 230.3(t)).

Wetlands have decreased in areal extent in the past several centuries due to the belief that they were worthless lands and because of the increase in the demand for agricultural lands. Approximately 50% of wetlands in the conterminous United States have been drained since European settlement, usually for agricultural purposes (Tiner 1984). Wetlands are transitional areas between aquatic ecosystem and upland areas National Research Council (NRC 1995). NRC stated that wetlands are lands subject to periodic inundation or saturated soil conditions and that they are characterized by plants that grow in saturated conditions and soils reflecting periodic inundation.

Two operational wetland definitions are the most common: those of the U.S. Fish and Wildlife Service (FWS) and the U.S. Army Corps of Engineers (USACE). The FWS defines wetlands as "lands transitional between terrestrial and aquatic systems where the

water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes: (1) the land periodically supports predominately hydrophytes; (2) the substrate is predominately undrained hydric soil; and (3) the substrate is nonsoil, is saturated with water or covered by shallow water at some time during growing season of each year” (FWS 2009). The USACE uses a wetland definition that is slightly different from the CWA: “those areas that are inundated or saturated 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 conditions. Wetlands generally include swamps, marshes, bogs and similar areas” (USACE 1987).

Wetlands perform a number of critical functions. They moderate the impacts from flooding, control erosion, purify water, and provide habitat for fish and wildlife (EPA 2009). Wetlands act as a “sponge” for flood water and release it back into the surrounding area at a later time. The rushing water during a storm is attenuated by wetland vegetation, which reduces the erosive effects by slowing the velocity of floodwaters and settling the suspended soil particles. Wetlands act as filters, because of the location between land and water. They intercept pollutants before they enter lakes, rivers or streams because pollutants are filtered by the soil and plants. Wetlands provide essential habitat for various species: birds, reptiles, amphibians, fish, insects and mammals, of which 45% are rare or endangered due to the high rate of wetland loss (EPA 2009).

1.2. Amphibians

Amphibians are the most highly threatened group of vertebrates (Houlahan et al. 2000; Stuart et al. 2004), as they are sensitive to habitat disturbances, especially in the larval stage (Hecnar and M'Closkey 1996). Amphibians can act as ecological indicators of wetland health (Hecnar and M'Closkey 1996). For biological assessments, they are especially promising because they provide a firm linkage between wetlands and surrounding landscapes features (EPA 2009). Amphibians are often considered having a higher level of exposure and vulnerability to changes in their environment than many other vertebrates due to their physiology and habitat requirements (Sparling et al. 2000).

In this research, data on amphibian presence/absence are used to indicate wetland health. The amphibian data will provide the framework for the development of a model based on landscape characteristics for predicting the health of wetlands.

1.3. Landscape surrounding wetlands

The distribution of amphibians in terrestrial habitats is essential to determining how much habitat is necessary to ensure persistence of an amphibian population (Tremham et al. 2005). Human activities kilometers away from a wetland might have an effect on the biological community of the wetland (Findlay et al. 2000). Knowing about how landscape variables affect the distribution of species is useful for the conservation of the species and landscape planning (Pellet et al. 2004). Law et al. (1991) stated that determining the most relevant physical parameters in a landscape can be used as a basis for decision-making and the design of responses to specific environmental management challenges.

Terrestrial habitats surrounding and adjacent to wetlands are critical for the management of natural resources and biodiversity conservation (Semlitsch and Jensen, 2003). The land immediately adjacent to a wetland is as important as the riparian areas surrounding the wetlands. For instance the composition of landscape features surrounding wetlands has been shown to be important for pond-breeding amphibian species (Zanini et al. 2008).

1.4. Compensatory wetlands

Urban development and commercial activities often result in wetlands losses and degraded wetland functions. In particular, construction of highways, airports, urban developments, sewage treatment plants and commercialized areas frequently affect wetlands values (USACE 2009).

Section 404 of the CWA regulates the alteration of wetlands. The objective of the CWA is to “to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” (EPA 2009). The CWA prohibits the disposal of fill material in waters of the United States, including wetlands without a permit. The impact of a proposed discharge needs to be avoided and minimized. If the impact is unavoidable, compensatory mitigation, such as wetland mitigation banking, is necessary to replace the functions of the wetland that might be lost.

EPA defines a wetland mitigation bank as: “a wetland area that has been restored and protected to provide compensation for impacts to wetlands” (EPA 2009). A mitigation bank is created when a government agency, corporation, or other bank sponsor undertakes wetland restoration and protection activities under a formal agreement with

the USACE. Under the CWA section 404, those who intend to deposit fill in or dredge a wetland or other waters of the U.S. must apply for a permit from the USACE (EPA 2009).

The EPA and the USACE promote a policy of no net loss of wetlands by implementing wetland restoration and protection policies. This is accomplished by increasing the effective use of wetland mitigation banks and the strengthening of requirements for wetland mitigation. The wetlands compensatory mitigation requirements emphasize best available science, promote innovation and focus on results. When applicants cannot avoid impacting a wetland, federal regulations require that they replace it with a mitigation wetland.

2. Justification for research

Many species of amphibians require both aquatic and terrestrial habitats and are limited to areas where there is sufficient moisture for reproduction and survival and access to adjacent terrestrial habitat (Jameson 1957; Wilbur 1987; John-Alder and Morrin 1990; Vos and Stumpel 1995).

Few attempts have been made to model amphibian population dynamics (Halley et al. 1996; Gibbs 1993) and fewer have been spatially explicit to consider landscape complementation (Vos and Stumpel, 1995). Zanini et al. (2008) stated that increasing urbanization and habitat alteration make it particularly important to find ways to assess the impact of land cover changes on the distribution of natural populations.

3. Objectives

The objectives of this study are to associate landscape features surrounding constructed wetlands to amphibian health. Biological amphibian assessment data from forty-nine constructed wetlands in Missouri were used in this study to relate amphibian health to landscape characteristics. Some of the wetlands are under the Missouri Department of Transportation (MoDOT) jurisdiction and some of them are under the Missouri Department of Conservation (MDC) jurisdiction. Personnel from both agencies collaborated in the various project activities.

The biological assessment consisted of amphibian surveys which were conducted at each wetland during three time periods in 2006 (March/April, May/June, and July/August). Data from all three periods were pooled (Shulse 2009) and analyzed in first stage of the overall research project.

The overall objective of this research project is to create a document for MoDOT that will help in the evaluation of future rights-of-way (ROW) that will minimize the negative impacts to wetlands health. The specific goal of this part of the research is to analyze spatial landscape characteristics for all wetlands in the study to predict wetland health using amphibians as a surrogate, which will help in the decision making for the most appropriate location of a ROW. The specific four goals of this portion of the study are to:

- Identify characteristics of the landscape surrounding wetlands which can be used to predict wetland health.

- Link the landscape characteristics of wetlands with the quality of amphibian habitat. The features around each wetland will be determined using ArcGIS 9.2 (ESRI 2009), which will be used to assess the spatial characteristics of the landscape surrounding the wetlands which will be use in the future evaluation of proposed ROW locations.
- Derive equations for predicting wetland health using landscape parameters extracted from GIS. Such approaches are necessary because biological assessments are costly, time consuming and related studies or data are not always accessible. Analyzing information such as: land use/land cover areas, roads, streams and elevations, one can estimate the impact a proposed road can have on the amphibian population. The methodology included the quantification of the variables to predict wetland health, the use of a distance component in each variable to assess the impact of the closeness of the wetland edge to the feature and the normalization of the variables which allowed the sum of the variables with different units.
- Analyze the set of equations to derive patterns and trends that can be of potential use in the decision making process for locating ROWs.

4. Benefit from the research

It is critical, whenever possible, to manage existing natural wetlands in a manner consistent with amphibian conservation and to use every opportunity to re-create quality amphibian habitat when mitigation is necessary (Leja 1998). The purposes of this study are the quantification of the landscape characteristics surrounding the constructed wetlands in the study and the prediction of the extent to which the landscape conditions impact the health of the habitat.

Use of this methodology will help in the decision-making process for the optimum location of a proposed ROW to where it causes the least impact on the amphibian population. The derived model, through the resulting guidance document, will aid in the initial suitability assessment for ROW locations by MoDOT. The guidance document could also be used by agencies such as MDC to make decisions regarding the future siting and development of artificial wetlands to improve and extend habitat.

Chapter 2

2. Literature Review

2.1. Wetlands

Wetlands were classified in the past as worthless land. Many were drained, filled and completely lost. Approximately 53% of the wetlands estimated to have originally existed in the conterminous United States from 1780s were lost by the mid 1980s, primarily due to human-induced land use conversion (Dahl and Johnson, 1991). For example, Missouri had as much as 4.8 million acres of wetlands before European settlement. By 1980, the number of wetlands in the state had dropped dramatically, to 643,000 acres (Missouri Department of Natural Resources 2008). Today however they are recognized as a necessary component of a vital landscape.

Wetlands are areas of seasonally, intermittently or permanently waterlogged soil or inundated land. They are areas where water covers the soil, or where water is present either at or near the surface of the soil all year or for varying periods of time during the year (EPA 1995). More precisely, USACE (1987) defines wetlands as “those areas that are inundated or saturated 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 conditions.”

There are many different types of wetlands, each with its own unique properties and characteristics. The main types of wetlands are marshes, swamps, bogs, and fens

(EPA 2009). Marshes are defined as wetlands frequently or continually inundated with water, characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions. They receive most of their water from surface water, and some are fed by groundwater. Marshes are divided into two primary categories: tidal and non-tidal. Tidal marshes are influenced by the motion of ocean tides and they can be found along protected coastlines in middle and high latitudes worldwide. They are most prevalent in the United States on the eastern coast from Maine to Florida and continuing on to Louisiana and Texas along the Gulf of Mexico. Some are freshwater marshes, others are brackish (somewhat salty), and still others are saline. Non-tidal marshes are mostly freshwater marshes, but some are brackish or alkaline. They occur along streams in poorly drained depressions, and in shallow water along the boundaries of rivers, lakes and ponds. Non-tidal marshes are the most frequent and widely distributed wetlands in North America.

A swamp is any wetland dominated by woody plants. They are characterized by saturated soils during the growing season, and standing water during certain times of the year. Some swamps are dominated by shrubs, plants, birds, fish, and invertebrates (e.g., freshwater shrimp, crayfish, and clams). Swamps are divided into two major classes: forested swamps, and shrub swamps. Forested swamps are found throughout the United States. They are often inundated with floodwater from nearby rivers and streams. Sometimes, they are covered by many feet of very slowly moving or standing water. Shrub swamps are similar to forested swamps, except that shrubby vegetation predominates.

Bogs are wetlands characterized by spongy peat deposits, acidic waters, and a floor covered by a thick carpet of sphagnum moss. Bogs receive all or most of their water from precipitation rather than from runoff, groundwater or streams. As a result, bogs are low in the nutrients needed for plant growth, a condition that is made worse by acid forming peat mosses. The demanding physical and chemical characteristics of bogs result in the presence of plant and animal communities that demonstrate many special adaptations to low nutrient levels, waterlogged conditions, and acidic waters, such as carnivorous plants.

Fens are peat-forming wetlands that receive nutrients from sources other than precipitation: usually from upslope sources through drainage from surrounding mineral soils and from groundwater movement. Fens are less acidic than bogs and have higher nutrient levels. They are able to support a much more diverse plant and animal community. These systems are often covered by grasses, sedges, rushes, and wildflowers.

Wetlands are among the most productive ecosystems in the world, comparable to rain forests and coral reefs. Wetlands are important systems that support both aquatic and terrestrial species. They provide shelter and sustain a diversity of fauna including invertebrates, water birds, fish and amphibians. They provide great volumes of food that attract many animal species. These animals use wetlands for part of or all of their life-cycle (EPA 1995).

Wetlands are places where sediments accumulate, nutrients are recycled and water is purified. Wetlands have important filtering capabilities for intercepting surface water runoff from higher dry land before the runoff reaches open water. As the runoff

water passes through, the wetlands retain excess nutrients and some pollutants, and reduce sediment that would clog waterways and affect fish and amphibian egg development (EPA 1995).

2.2. Clean Water Act

The Clean Water Act (CWA) was passed in 1972 to protect the Nation's waterways and to stop pollution from being discharged into waterways. The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by reducing the impact of point and nonpoint pollution sources, providing assistance to publicly owned treatment works for the improvement of wastewater treatment.

Pollution originating from a single, identifiable source, such as a discharge pipe from a factory or sewage plant, is called point-source pollution. Pollution that does not originate from a single source, or point, is called nonpoint-source pollution. Pollutants regulated under the CWA include "priority" pollutants (including various toxic pollutants) "conventional" pollutants (such as biochemical oxygen demand [BOD], total suspended solids [TSS], fecal coliform, oil and grease, and pH), and "non-conventional" pollutant (including any pollutant not identified as either conventional or priority). The CWA regulates both direct and indirect discharges. Direct discharges involves the discharge of pollutants to waters of the US (40 CFR 122). Indirect discharges means a non-domestic discharge introducing pollutants to a publicly owned treatment works (40 CFR 403.3).

2.2.1. Section 404 of the Clean Water Act

Section 404 of the CWA regulates the discharge of dredged and fill material into the waters of the United States, including lakes, rivers, and wetlands. The Code of Federal Regulations (40 CFR 230.3(s)) defines the term “waters of the United States” as:

1. “All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;
2. All interstate waters including interstate wetlands;
3. All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairiepotholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:
 - a. Which are or could be used by interstate or foreign travelers for recreational or other purposes; or
 - b. From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
 - c. Which are used or could be used for industrial purposes by industries in interstate commerce;
4. All impoundments of waters otherwise defined as waters of the United States under this definition;
5. Tributaries of waters identified in (1) through (4);
6. The territorial seas;

7. Wetlands adjacent to waters (other than waters that are themselves wetlands) identified (1) through (6); waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA.”

In 1972, the United States, through the CWA, began to regulate wetland areas. Section 404 prohibits actions harmful to wetlands where such impacts can be avoided. When the impacts are unavoidable, the impact must be mitigated by creating or enhancing wetlands to compensate for any unavoidable loss in wetland area and function (40 CFR 230.10(a)(3)). “No net loss” of wetlands is a federal policy goal that emerged in 1989 and it means that wetlands should be conserved wherever possible, and that acres of wetlands converted to other uses must be offset through restoration and creation of other wetlands, maintaining or increasing the total wetland resource base (United States Department of Agriculture [USDA] 1998).

The USACE and the EPA define “waters of the United States” to include most wetlands. Regulated activities under this program, besides filling or excavating in a wetland for development, include water resources projects such as construction of dams or bridges, stream channelization and diversion, infrastructure development and wetland conversion for farming and forestry. Section 404 establishes a permit program to ensure that such activities comply with environmental requirements.

The USACE or a state program approved by the EPA, has the authority to issue such permits and to decide whether to attach conditions to them. To achieve no net loss of wetlands within the Section 404 program, a permittee is first expected to avoid deliberate discharge of materials into wetlands and then to minimize discharges that

cannot be avoided. When damages are unavoidable, the USACE can require the permittee to provide “compensatory mitigation” as a condition of issuing a permit. Compensatory mitigation specifically refers to restoration, creation, enhancement, and in some cases, preservation, of other wetlands as compensation for impacts to natural wetlands. The permit recipient, either on a permit-by-permit basis or within a single-user mitigation bank, carries out “permittee-responsible” mitigation. In third-party mitigation (i.e., commercial mitigation bank, in-lieu fee program, cash donation, or revolving fund program), another party accepts a payment from the permittee and assumes the permittee's mitigation obligation. Most compensatory mitigation has been undertaken by permit recipients, rather than by third parties. The Katy-Cypress Wetlands Mitigation Bank (KCWMB), in the state of Texas, is one example of a privately owned wetland which allows landowners to meet federal and state wetland guidelines. The owners of KCWMB can sell wetlands to landowners to offset any wetland that is impacted ensuring no net loss of wetlands (KCWMB, 2010).

2.2.2. MoDOT policies and regulations

Missouri Department of Transportation (MoDOT) projects relating to waters of the U.S. include potential stream impacts at linear crossings, filling of jurisdictional wetlands, stream channelization, and filling of designated special aquatic sites (MoDOT 2009). Under Section 404 of the CWA, any impacts to wetlands are required to be mitigated by the construction of a new wetlands. MoDOT creates mitigation wetlands near impacted wetlands, often adjacent to the road (MoDOT 2007).

The CWA requires the Federal Highway Administration (FHWA) and MoDOT to evaluate every project and determine whether the project could have a negative impact on any waters of the U.S. including wetlands. The FHWA and MoDOT must use the best available scientific information and the 1987 USACE Wetland Delineation Manual (USACE 1987) to evaluate their projects and they must provide data to support their determination of impact. Under section 404 of the CWA, no action can be taken that will fill waters of the U.S. without first obtaining authorization under a nationwide or individual permit, based on the extent of impacts. One option for wetland and stream mitigation is to construct a wetland and/or stream bank mitigation before mitigation is needed for a specific project (MoDOT 2007). The wetland and stream mitigation bank concept is explicit in federal and state guidance for unavoidable wetland and stream impacts permitted under section 404 of the CWA. The idea uses a banking analogy where constructed wetland or stream mitigation (money) is given credit (deposited) to an account to be used (spent) in the future (NRC 2001).

2.3. Wetland mitigation

Mitigation measures can take five different forms (40 CFR 1508.20):

1. “Avoiding the impact
2. Minimizing the impact
3. Rectifying the impact
4. Reducing or eliminating the impact
5. Compensating for the impact.”

Wetland mitigation is the replacement of wetland functions through the creation or restoration of wetlands. Mitigation is required as a condition of many permits issued under state law (Part 303, Wetlands Protection of the Natural Resources and Environmental Protection Act, 1994) and federal law (Section 404 of the Clean Water Act). The goal of wetland mitigation is to replace wetland functions which provide public benefits, such as flood storage, water quality protection, fish and wildlife habitat, and groundwater recharge.

2.4. Wetland Animals

Wetlands are home to a diverse plants and animals. Wetlands provide habitat for a multitude of land animals, semi-aquatic animals (e.g. snakes, turtles, alligators, beavers and muskrats), and plants. Different species of birds can be found around some wetlands, swamps especially, because they are often home to dead trees, which make great places for birds to nest (EPA 2009).

2.4.1. Amphibians

Amphibians are the group of the vertebrate animal taxa that have the highest proportion of species threatened with extinction (Stuart et al. 2004). Many amphibian populations have disappeared or are in decline throughout the world. Further, more than 60 different species of amphibians with severe abnormalities have been found in the U.S. and several other countries (Blaustein et al. 2003).

Amphibians live in diverse habitats, often in large numbers, and fulfill several important ecological roles. As consumers, amphibians help regulate populations of the organisms they consume, chiefly invertebrates. Amphibians are consumed by a variety of

larger predators such as reptiles, birds, mammals, fish, predatory invertebrates, and other amphibians. When consumed by larger predators, energy and nutrients is transformed from the predator (FWS 2009).

Current wetland regulations focus primarily on aquatic habitats, and criteria to define critical upland habitats and regulations to protect them are often ambiguous or lacking (Porej et al. 2004). Pond-breeding amphibians are an integral part of wetland ecosystems. However, the replacement or creation of quality amphibian habitat is usually not one of the goals of wetland replacement (Porej et al. 2004).

Dodd and Smith (2003) stated that the species with complex life cycles such as pond-breeding amphibians (e.g., pond frogs, spadefoot frogs) need special attention because of the spatial heterogeneity of the habitats they require for living. Pond-breeding amphibians require aquatic and terrestrial habitats to complete their lifecycles, and preservation of both habitats is necessary for maintaining local populations. The amphibian life is associated with the biphasic life cycle in which adults move to a water body to breed and deposit eggs that then hatch into tadpoles or larvae. The larvae metamorphose into juveniles over time. The juveniles disperse to other semiaquatic or terrestrial habitat (hundreds or even thousands of meters from the breeding sites). Most of their life cycle is spent in terrestrial habitats, where juveniles and adults feed and find refuge.

Semlitsch (1998) states that part of the reason that terrestrial habitats adjacent to wetlands are not protected is due to the lack of a clear understanding of the distances from shorelines that are biologically relevant to the wetlands. Semlitsch and Jensen

(2003) proposed the use of stratified criteria that would include three terrestrial zones adjacent to core aquatic and wetlands habitats (Figure 2.1):

- The Aquatic Buffer, the first terrestrial zone (measured from the wetland edge), would buffer the core aquatic habitat and protect water resources.
- The Core Habitat, the second terrestrial zone (measured from the wetland edge), would comprise the core terrestrial habitat defined by semi-aquatic species or species-group use.
- The Terrestrial Buffer, the third terrestrial zone (measured from the outward edge of the second zone), would buffer the core terrestrial habitat from edge effects and surrounding land use practices.

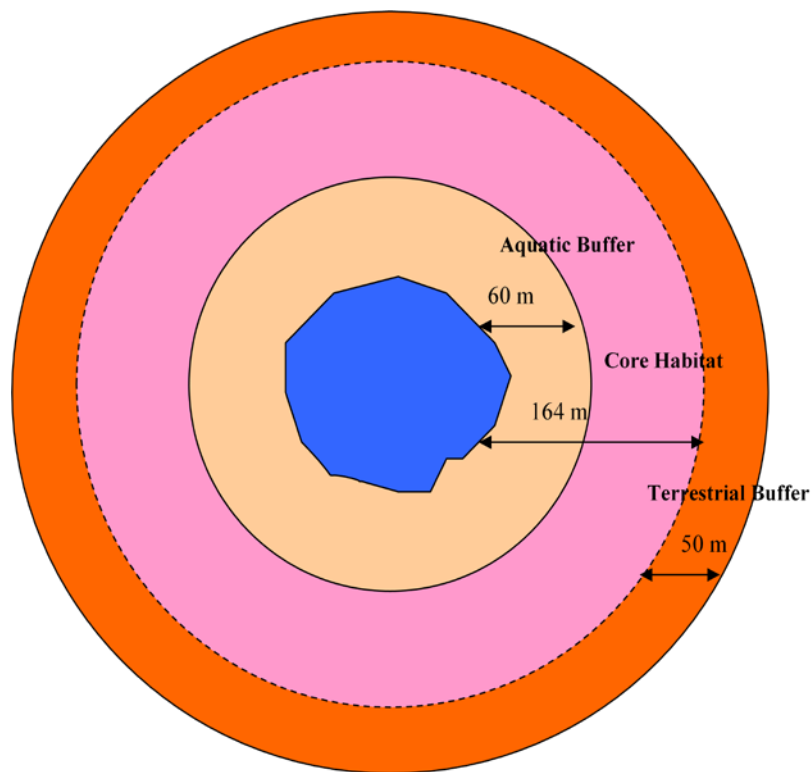


Figure 2.1. Zones for protection of wetlands (Semlitsch and Jensen 2001).

2.5. Geographic Information Systems

Geographic information systems (GIS) have increased in use primarily because they provide an efficient method of managing complex data and information that have a spatial context (Stanley et al. 2005). The most commonly used representations of space in a GIS are the vector and raster data models. The vector model uses points, lines, and polygons objects to represent data (Berry 1997). In a raster model, systematically spaced grid cells serve as the basic unit of analysis.

In the vector structure, geographic features are represented by points, lines and polygons that are referenced according to their location on the Earth's surface given the application of some reference coordinate system (Garbrecht et al. 2001). Objects in the vector structure can be subject to certain topological rules, that describes the object's spatial relationship to other (i.e. neighboring) objects. This explicit and unambiguous definition of and linkage between objects makes vector structure attractive and allows for automated analysis and interpretation of spatial data in GIS environments (Meijerink et al. 1994).

The raster structure divides space into a systematically spaced two-dimensional grid cell, where each cell contains a value representing the attribute being mapped. Each grid cell is referenced by a row and column number, corner cells registered to geographic coordinates. In the raster model, a point is represented by a single grid cell, a line by a string of connected cells, and areas by a group of adjacent cells (Garbrecht et al. 2001).

Vector and raster structures have both advantages and disadvantages. Vectors structures are well suited to represent networks, connected objects and features that are

defined by discrete boundaries, while raster structures are best when the attributes they represent are continuously and smoothly varying in space (Garbrecht et. al 2001).

GIS software allows environmental data to be stored, analyzed and displayed spatially (Nuckols et al. 2004). Geographically referenced data can be imported and topology can be generated among these features to construct a data layer. Tabular (attribute) data corresponding to features in the layer can also be associated with each data layer. Analytical functions within the GIS software can be used to query and transform both topology and attribute data through linkages established within a database management system (Nuckols et al. 2004). GIS provides the framework for making information usable for planners and decision makers with powerful analysis and visualization capabilities (Stanley et al. 2005).

2.6. Biological Assessments

Biological assessments are powerful tools for evaluating the health of wetlands. The information provided by these assessments can lead to the development of biological guides for ecologically effective designs. They can be used to help evaluate the performance of restoration, best management practices and construction projects.

Micacchion (2002) developed the Amphibian Index of Biotic Integrity (AmphiBI) for Wetlands for the State of Ohio. Data from natural wetlands was used to develop the AmphiBI that is now applied in Ohio's wetland protection program. The AmphiBI is a composite, cumulative score based on five different measurements ("metrics") of amphibian habitat quality for a particular wetland. The "metrics" are described below.

- The first metric is the Amphibian Quality Assessment Index (AQAI). To determine the AQAI, each species of wetland breeding amphibians is given a tolerance coefficient (Table 2.1) from 1 to 10. The higher the number, the less disturbance that the species is deemed to tolerate and the more specific and narrow their habitat needs. The AQAI is calculated by sampling adult and larval amphibian populations in a given wetland and multiplying the number by the tolerance coefficient and summing over the species. An example is shown in Table 2. 2, where the AQAI value is 5.79.
- The number of salamander species present is deemed to be a good general indicator of habitat quality.

Table 2.1. Wetland Amphibian Tolerance Coefficients and Rationale (Micacchion 2002).

Species	Tolerance Coefficient	Rationale
<i>Ambystoma jeffersonianum</i> complex (includes <i>A. platineum</i> and <i>A. tremblayi</i>)	5	Jefferson salamanders and associated hybrids require relatively intact wooded habitat adjacent to breeding pools with low to moderate levels of disturbance
<i>Ambystoma opacum</i>	9	Marbled salamanders require intact mature woods and vernal pools that fill in the late fall/early winter
<i>Ambystoma maculatum</i>	8	Spotted salamanders have only been collected in least disturbed wetlands or moderately disturbed wetlands where the disturbance has been recent
<i>Ambystoma texanum</i>	4	Smallmouth salamanders are the most ubiquitous of the ambystomid salamanders and will tolerate wetlands with relatively short hydro-periods
<i>Ambystoma tigrinum</i>	6	Tiger salamanders have been found in a range of wetlands with pools that have deep, long lasting hydrology and nearby uplands that are reasonably intact
<i>Ambystoma laterale</i>	10	Blue spotted salamanders are listed as state “endangered” due to their extremely limited range and can only be found in a few counties in extreme NW Ohio
<i>Hyla versicolor</i> and <i>Hyla chrysoscelis</i>	5	Tree frogs require some shrubs or trees adjacent to breeding pools and are less tolerant of other disturbances than most anurans
<i>Bufo spp</i>	1	American and Fowler’s toads require little except enough water to allow for their short reproductive cycle and will tolerate disturbances other amphibians cannot

Table 2.1. Wetland Amphibian Tolerance Coefficients and Rationale [Micacchion 2002]
(cont).

<i>Hemidactylium scutatum</i>	10	Four-toed salamanders are listed as state “special interest” and have a high fidelity to undisturbed forested sites with vernal pools
<i>Notophthalmus viridescens</i>	9	Red spotted newts are extremely intolerant of disturbance and are found only in well buffered intact wetlands
<i>Rana catesbeiana</i>	2	Bullfrogs which are widely spread, are most common in marshes, but can be found in forested and shrub sites and are tolerant of most disturbances
<i>Rana pipiens pipiens</i>	2	Leopard frogs breed in a range of sites, the main requirement is enough water for their breeding cycle and some suitable adjacent habitat
<i>Rana clamitans melanota</i>	3	Green frogs are found in a wide range of wetlands and are tolerant of most disturbances
<i>Rana sylvatica</i>	7	Wood frogs are dependent on forested wetlands and adjacent areas and require pools within a landscape of minimal disturbance
<i>Pseudacris crucifer</i> 2	2	Spring peepers breed in a range of sites, main requirement is enough water for breeding cycle and some suitable adjacent habitat
<i>Pseudacris triseriata</i>	3	Western chorus frogs are slightly less tolerant of disturbance than the closely related P. crucifer

Table 2. 2. Calculation of AQAI for a hypothetical forested vernal pool
(Micacchion 2002)

Species	Number of Individuals	Tolerance Coefficient	Subtotals
<i>Ambystoma maculatum</i>	50	8	400
<i>Ambystoma jeffersonianum</i>	30	5	150
<i>Ambystoma texanum</i>	20	4	80
<i>Notophthalmus viridescens</i>	25	9	225
<i>Pseudacris crucifer</i>	30	2	60
<i>Hyla versicolor</i>	20	5	100
<i>Rana pipiens pipiens</i>	30	2	60
<i>Rana clamitans melanota</i>	2	3	6
Totals	187	--	1081

$$\text{AQAI} = (1081/187) = 5.79$$

- The relative abundance of sensitive species is based on the total number of individuals of all species divided by the total number of disturbance intolerant species individuals in the wetland amphibian population (meaning they have a tolerance coefficient of 6 or greater).
- The relative abundance of tolerant species is based on the total population divided by individuals belonging to species more tolerant of disturbance (coefficients 1-5). These two metrics (relative abundance of sensitive species and relative abundance of tolerant species) are justified by the correlation between a) relative abundance of species, by tolerance, and b) the Ohio Rapid Assessment Method (ORAM) (Micacchion 2004) score, which is an assessment method designed to rate overall resource intactness (i.e., habitat quality), and upon which the wetland category (1 =low quality, 2 = medium quality, 3 = high quality) is determined (Micacchion 2004). ORAM is an index that categorizes wetlands by type and level of human disturbance.
- The presence of Spotted Salamanders and Wood Frogs is deemed to be itself a significant indicator of the biotic integrity of amphibian habitat.

The AmphIBI provides a score for the amphibian community that correlates strongly with the intactness (quality) of the wetland occupied. The AmphIBI is constructed from a sum of values assigned to each of these metrics. The values for each metric are 0, 3, 7, or 10.

The “breakpoints” for each of these criteria are shown in Table 2. 3

Table 2. 3. Scoring breakpoints for assigning metric scores for AmphiBI (Micacchion 2004)

Metric	Score 0	Score 3	Score 7	Score 10
AQAI	<3.00	3.00 - 4.49	4.50 - 5.49	≥ 5.5
Rel. Abundance Sensitive Species	0%	0.01 - 9.99%	10 - 49.99%	$\geq 50\%$
Rel. Abundance Tolerant Species	>80%	50.01 - 79.99%	25.01 - 50%	$\leq 25\%$
# of Pond-Breeding Salamander Species	0-1	2	3	>3
Spotted Salamanders or Wood Frogs	Absent	---	---	present

Hartel et al. (2006) conducted a four-year study regarding the distribution and aquatic habitat use of amphibian communities in two river basins in Transylvania (Romania). The objectives of their project were to inventory habitat diversity and habitat use by amphibians and to identify the most important factors influencing the amphibian species richness in the areas investigated. A total of 513 ponds were surveyed during this study, 84 of which were permanent. Each pond and its surroundings in a 800 m buffer was characterized using a number of habitat variables. The researchers used 17 variables for permanent ponds and 15 variables for temporary ponds, to characterize the breeding ponds and their surroundings terrestrial habitats. The variables for permanent ponds included area of pond, elevation, maximum depth, arable land within an 800 meter buffer, pH, conductivity, age, distance from various land uses (i.e., forest, green corridors, road, main urban areas, pastures/grass land, main urban areas and main roads)

and the presence of dirt roads. The variables used for temporary ponds are the same except that age and the main urban areas were not used in this case. The researchers used an additional variable: a combination of main roads and urban areas for the temporary ponds. They found that species richness (14 amphibian species) is significantly higher in permanent ponds than in temporary ponds. They concluded that the presence of high traffic roads within an 800-meter radius circle around a wetland explains more variation in species richness than the other habitat parameters considered in the case of permanent ponds. Also, the presence of dirt roads within a 800-meter radius circle around a wetland is the most important habitat factor in the case of temporary ponds.

2.7. Wetland Assessment

Wetland assessment procedures are tools in the trade of wetland science that provide a definitive procedure for identifying, characterizing, or measuring wetland functions and/or social benefits. They are used in a variety of contexts for regulatory, planning, management, and educational purposes.

The purpose of the USACE Wetlands Delineation Manual (1987) is to provide users with guidelines and methods to determine whether an area is a wetland for purposes of section 404 regulation under the CWA. The objectives of the manual are to present technical guidelines for identifying wetlands and distinguishing them from aquatic habitat and other nonwetlands, providing methods for applying the technical guidelines, and providing supporting information useful in applying the technical guidelines. The manual is limited in scope to wetlands that are a subset of “water of the United States” and are subject to section 404 requirements. It organizes environmental characteristics of

a potential wetland into three categories: soils, vegetation, and hydrology. The manual contains criteria for each category. With this approach, an area that meets all three criteria is considered a wetland. The USACE definition states that the term "wetlands" means "those areas that are inundated or saturated by surface water or groundwater 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"(33 CFR 328.3(b)).

The Wetlands Value Assessment (WVA) methodology (Mitchell 1992) is a quantitative habitat-based assessment model used primarily to prioritize project proposals submitted for funding within the guidelines of the Coastal Wetland Planning Protection and Restoration Act (CWPPRA). The methodology was developed by the FWS for application to the Louisiana coastal wetland types (fresh marsh, brackish marsh, saline marsh and cypress-tupelo swamp) that provide resting, foraging, breeding and nursery habitat to a diverse assemblage of fish and wildlife species. The methodology assesses changes in wetland quality and quantity that are expected as a result of a proposed project. The WVA is used to assess the effect of changes in wetland habitat on the fish and wildlife community. The methodology works under the assumption that optimal conditions for general fish and wildlife habitat within a given coastal wetland type can be characterized, and that existing or predicting conditions can be compared to the optimum to provide an index of habitat quality. Habitat quality is estimated through the use of a

mathematical model developed specifically for each wetland type. Each wetland model consists of:

1. a list of variables that are considered important in characterizing fish and wildlife habitat for each wetland type,
2. a Suitability Index graph for each variable, which defines the assumed relationship between habitat quality and different variable values and
3. a mathematical formula that combines the Suitability Index value, for each variable into a single value for wetland habitat quality, this single value is referred to as the Habitat Suitability Index (HIS).

The variables considered appropriate for describing habitat quality; in each wetland type were selected through a two-part procedure:

1. compiling a list of environmental variables thought to be important in characterizing fish and wildlife habitat in a coastal marsh or swamp system, and
2. reviewing variables used in species-specific models published by the FWS.

Some of the variables considered for all the types of wetlands are:

1. percent of wetland covered by persistent emergent vegetation,
2. percent of open water area dominated by aquatic vegetation,
3. water duration in relation to wetland surface,
4. percent of open water area ≤ 1.5 feet deep in relation to wetland surface,
5. average annual salinity, and
6. aquatic organism access (project area wetlands considered accessible by the organisms, such as fish and shellfish).

The final step in the WVA model development was to construct a mathematical formula that combines all suitability indices for each wetland type into the single HIS value. The individual suitability indices range from 0.0 to 1.0. The HIS also ranges from 0.0 to 1.0 and is a numerical representation of the overall habitat quality of the particular wetland study area being evaluated. The net benefits of a proposed project are estimated by predicting habitat conditions into the future for two scenarios: with the proposed project in place and without the proposed project. The output of the HIS model is assumed to have a linear relationship with the suitability of a coastal wetland system in providing fish and wildlife habitat. The goal is achieved through models built to estimate relationships between changes in habitat variables and habitat quality for the broadest possible range of fish and wildlife species. A ranking system is used to quantify changes in habitat quality and quantity that are projected to occur as a result of proposed wetland enhancement projects.

2.8. Wetlands and GIS

GIS is a useful tool for quantifying wetland habitat information. The technique can be useful for determining the best land use practices for landowners and managers and for identifying critical habitats for endangered or threatened wildlife population, which depend on adequate surrounding habitats for their survival, breeding, or both (Rieker et al. 2006).

Various GIS-based spatial decision support systems have been developed as primary means for use in wetland analysis. Ji et al. (1993) developed a GIS-based decision support function as a part of a spatial decision support system project (SDSS),

which was applied in coastal wetland permit analysis. The researchers define SDSS as a multidisciplinary approach which requires computerized analytical modeling abilities to manipulate large quantities of spatial-temporal data according to a defined set of objectives or constraints. The SDSS needs a mechanism to provide quick responses for dynamic resource and environmental issues (not specified). An analytical model, the wetland value assessment (WVA) methodology, described earlier, was implemented in the developed model. The system functional design includes: decision support requirements in coastal resource management, environmental impact assessment, and environmental database management. The system is designed as a decision-making mechanism with three subsystems: a resource management subsystem (RMS), an environmental impact assessment (EIAS), and environmental database management subsystem (EDBMS).

The RMS focuses on wetlands planning and landscape management issues that require rule-based modeling and spatial analysis (no more details are specified in the paper). The EIAS is focused on the following major coastal environmental impact issues:

1. coastal marine oil spill risk assessment, environmental sensitivity modeling, and contingency planning,
2. natural hazard damage assessment, and
3. coastal ecological risk assessment that emphasizes the impact of human and economic activities on the coastal ecological environments.

The EDBMS was designed to be composed of both vector-and raster-based GIS databases as well as associated environmental data and to provide an interface between the modeling subsystems (RMS and EIAS) and the host GIS.

The integration of this spatial decision support system into a host GIS environment involves complex system engineering for which development strategies were designed as follows,

1. System residence environment. The three subsystems will be integrated as the functional complement to ARC/INFO, the host GIS. The system can be invoked in the ARC/INFO operating environment and has access to ARC/INFO data handling and analysis modules. The coupled SDSS-GIS system will be able to share both GIS and SDSS capabilities (GIS analysis, graphic display, tabular reporting and analytical modeling).
2. System structure tree. The system is designed with a hierarchical structure. The first level is the system root, the ARC environment, from which the system is started. The subsystem run is performed at the second level of the system. The third level consists of the performance of different analytical modeling functions (not specified).
3. Model embedding. This is the core task of SDSS development. Models and other analysis approaches can be coded into the GIS environment with either ARC macro language (AML) or C language. The model integration into the GIS can be accomplished with the following approaches:

- a. the models are coupled with the relational database management system to retrieve model inputs from the database,
 - b. the analytical modeling becomes a part of the GIS operation, and
 - c. the domain decision-making processes are supported by generic GIS analysis, graphic display, and tabular reporting capabilities.
4. Modularity. The model base is designed to include three major modules: an analytical modeling module that contains all domain models, a modeling control module that provides a modeling inference mechanism (model interpreter) as well as decision supporting utility module including capabilities for retrieving multimedia information, graphic display of study areas, viewing and updating of model rules, and displaying decision-making rules.
5. Customized system interface. A customized system interface is a controlling component of the SDSS that provides the user with an interactive means to operate the system and perform the spatial decision- making tasks. The interface is developed as a menu-driven system created with AML that represents features of both GIS and SDSS in an integrated format. The system interface has the following capabilities: increasing ease of use of the system, providing a means to associate and manipulate all system resources in spatial decision-making and organizing the complex decision-making process into an efficient, integrated format and receiving initial modeling inputs.

Ji (1996) developed an approach using decision support GIS for handling information in ecosystem management and describes ways in which technical barriers

can affect ecosystem management. The following technical barriers were identified by resource managers and researchers in information synthesis and analysis in ecosystem management.

1. A large volume of various spatial and non-spatial data are obtained using different procedures and recording standards and thus are not in a ready format to support management at an ecosystem level.
2. When pursuing an ecosystem approach, scientists lack training, models and tools for information synthesis, environmental modeling, and ecological predictions at various spatial and temporal scales. Resource managers require new tools for management decision analysis and adaptation of resource management measures based on the most currently available scientific information.
3. Techniques are needed to combine spatial and temporal information in order to understand natural resource processes in relation to spatiotemporal dynamics of ecosystems.

To overcome these technical barriers, the author conducted research to study spatial analysis methodologies capable of:

1. compiling, synthesizing, and analyzing existing natural resources data for application issues in ecosystem management, focusing on data sets derived from past and current resource programs at a regional level,
2. exploring the new methods for use of spatial data and models at a landscape scale, and

3. developing customized application tools that make data and information and analytical methods easily available for resource managers and scientists.

Computerized GIS and remote sensing data were used as the primary technical means to develop decision support capabilities that included information synthesis, analytical visualization, spatial simulation, and modeling. Information synthesis included the two related components of designing an appropriate information structure for specific management tasks and integrating related data sets in specific technical application (ecosystem database). Each ecosystem database has one or more theme layers, possibly along with subtheme layers, and ancillary layers which are ecologically or geographically related to the subtheme layers. This database structure can provide a framework to synthesize related information in the context of a specific management theme by using interrelated data layer customized menus with the decision-support GIS.

The analytical visualization consists of the spatial domain of specific natural resources, identification of the resource characteristics, and examination of the spatial relations to other related resources or environmental processes. Implementation can be facilitated by analytical visualization with a decision support GIS. Examples include: interactive querying and displaying of GIS data sets through customized interface operations, graphically defining a spatial data search, and overlaying a large set of satellite imagery based on the areal extent of a displayed boundary of a vector data set, and identifying rule-based attribute information.

The researcher (Ji, 1996) stated that simulation and modeling possess spatial properties and are often constrained by temporal variables. With a decision-support GIS,

spatial simulation and modeling are tightly coupled with the GIS database for input and output, and are usually implemented through a customized interface by selecting embedded algorithms and analytical criteria. This study technique was developed to simulate the spatial behavior of wildlife species and to model habitat changes in response to wetland restoration projects. The approach was applied to simulate the movement of bird populations with respect to a specific geographic area, temporal duration and environmental conditions. These techniques made it possible and efficient to simultaneously analyze the impacts of multiple environmental factors on the bird distribution. No details about the results of the modeling with birds were published in the paper.

Akcakaya (1994) created a model that links GIS to models for viability analysis and risk assessment applied to endangered species, including the spotted owl in the northwest U.S. and the red-cockaded woodpecker in Louisiana. The model integrates landscape data on habitat requirements (elevation, slope and vegetation) with species data to analyze risks of extinction. The model analyzes habitat data exported from a GIS, and identifies the patches of habitat that can support a population. The structure of the patches includes their locations, sizes and distances from each other, which define the spatial structure of the population. The spatial structure is combined with species data and other information on the ecology of the species (such as age, density dependence for each population, spatial correlation and dispersal among populations) to complete a population model. The model performs a risk analysis, and runs multiple simulations, automatically changing parameters to analyze the sensitivity of risks to input data. The first goal was

application of the model on the spotted owl focusing on factors affecting the viability of the species through its range in the U.S. The second goal was to incorporate two sources of variability in determining the threats the species face. The first source of variability in the study included natural variations (resulting from temporal fluctuations in environmental factors) in the form of randomly distributed survival and fecundities. The second source of the variability was the demographic stochasticity and it was modeled to describe chance variations in reproduction, survival and dispersal. These types of natural variations (environmental and demographic) were used to express the model results in probabilistic terms, such as the viability of the species, in terms of the chance of survival or the risk of extinction. Habitat maps provided by the U. S. Forest Service were used in the model and the program found 18 habitat patches. The size distribution of the patches was very skewed, with the four largest patches making up about 95% of the total area of all patches, and the seven largest making up about 97%. Because of the large differences in sizes of neighboring populations, the model results were not very sensitive to the rate of inter-patch dispersal of juvenile spotted owls. The model predicted a large difference between lower and upper bounds on the viability of the northern spotted owl, based on the best-case and worst-case scenarios which were parameter combinations (not specified) that resulted in the best and the worst chances for survival. Sensitivity analyses demonstrated that the viability of the species was most sensitive to the set of dependence of fecundities and survival rates on habitat.

The goal of the application of the model for the red-cockaded woodpecker in Louisiana was to evaluate the impact of timber forest management practices on the

viability of the specie. The habitat of the red-cockaded woodpecker was characterized based on the stand type (i.e., dominant tree species), stand condition and basal area of pine species. These variables were input into the program in the form of GIS maps. The model was run with different management options (not specified) to compare their impacts in terms of the predicted risk of extinction, or rate of recovery of the species. The predictions of the risks were not published in this paper.

Ji and Jeske (2000) developed a spatial modeling approach to study environmental and land use impacts on the geographic distribution of wintering northern pintails in the Lower Mississippi River region. The environmental layers included data for landscape features, wildlife refuges, surface waters, forest and land use patterns. The land use data displayed forest types, such as pine and hardwood forest, croplands for rice, soybeans, and cotton, and pastures and coastal marshes. The modeling technique made it possible to test visual analysis-based research hypotheses, verify spatial associations and simulate movement trajectories of populations under spatial and temporal considerations. The study demonstrated that water availability, land use patterns, human disturbance and weather conditions are major factors that might affect the seasonal distribution of the populations.

Roise et al. (2004) stated that the requirements to regulate wetlands (minimize impacts and implement compensatory mitigation) can be quantified and that wetland management can be made more efficient through a combination of mathematical programming techniques utilizing a wetlands functional evaluation methodology and information contained within a GIS model of a landscape. The purpose of their work was

to find a way to improve the transportation planning process by including wetlands functions in a spatial analysis tool. This assessment method, entitled the North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS) is a procedure based on spatial data layers contained in a GIS. NC-CREWS parameters (Tables 2.5 through 2.7) were linked to existing GIS databases developed by the North Carolina Department of Environmental Health and Natural Resources' Division of Coastal Management (DCM). This tool allows transportation planners to quickly analyze alternative road corridors, the accompanying impacts to wetlands and possible sites to mitigate these impacts.

The wildlife habitat parameters and the ratings assigned to them are shown in Table 2.4 (taken from the NC-CREWS manual by Sutter and Wuenscher, 1997). The parameters considered are interior size, percent of the surrounding habitat that is natural vegetation, and the length of wildlife corridors that link to other natural vegetation.

Table 2.4. Ratings assigned to wildlife habitat parameters (Sutter and Wuenscher, 1997).

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 three parameters of the nonpoint source pollution rating system (taken from the NC-CREWS manual by Sutter and Wuenscher, 1997) are (1) proximity to agriculture, developed land, pine plantation, and natural vegetation using the percent of surrounding

habitat as the criteria, and (2) distance to a water source and (3) wetland position. Table 2.5 summarizes the rating values.

The position of the wetland in the landscape, the duration of the flooding and the width of the wetland perpendicular to the nearest stream are the parameters considered for rating the storage capacity of a wetland. Table 2. 6 summarizes the floodwater storage rating values.

Table 2.5. Ratings assigned to wildlife pollution parameters (Sutter and Wuenscher, 1997).

Parameter	High Rating	Medium Rating	Low Rating
Proximity to sources	> 50% perimeter abuts agriculture + developed	> 50% perimeter 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 1 st order stream	2 nd or 3 rd order stream	Higher than 3 rd order stream

Table 2. 6. Ratings assigned to floodwater storage parameters (Sutter and Wuenscher, 1997).

Parameter	High Rating	Medium Rating	Low Rating
Position in landscape duration of flooding	>25% stream bordered by developed land	5-25% of stream bordered by developed land	<5% of stream bordered by developed land
Duration of flooding	Long very long	Brief	Very Brief
Width of wetland perpendicular to stream	> 100 feet	50–100 feet	< 50 feet

Values of 1, 2 and 3 were assigned to the rankings of high, medium and low respectively. Linear programming is used to maximize the equation:

$$A_i X (F_{Hab} \times R_{Hab} + F_{NPS} \times R_{NPS} + F_{FS} \times R_{FS} - c) - C_{Road} - (F_{Hab})(H_{Loss}) - (F_{NPS})(NPS_{Loss}) - (F_{FS})(FS_{Loss})$$

subject to:

1. $R_{Hab} A_i X \geq H_{Loss}$
2. $R_{NPS} A_i X \geq NPS_{Loss}$
3. $R_{FS} A_i X \geq FS_{Loss}$
4. $C_{Road} + c A_i X \leq C_{Max}$

where:

A_i = acreage of land unit i for $i = 1 \dots n$ with n land units in study area,

$X_i = [0,1]$ decision variable to convert land unit i to wetland (1 site is to be mitigated, 0 otherwise)

F_{Hab} = scalar conversion factor of a habitat functional unit to dollars,

F_{NPS} = scalar conversion factor of a nonpoint source functional unit to dollars,

F_{FS} = scalar conversion factor of a floodwater storage functional unit to dollars,

R_{Hab} = sum of ratings for habitat parameters, integer in the range [3...9],

R_{NPS} = sum of ratings for nonpoint source parameters, integer in the range [3...9],

R_{FS} = sum of ratings for floodwater storage parameters, integer in the range [3...9],

c = cost per acre of converting land to wetland,

C_{Road} = cost of constructing a road corridor,

H_{Loss} = habitat functional units lost to road corridor,

NPS_{Loss} = nonpoint source functional units lost to road corridor,

FS_{Loss} = floodwater storage functional units lost to road corridor, and

C_{Max} = maximum dollar value available for road and mitigation project

In order for the NC-CREWS model to be workable in a GIS environment, the researchers made some assumptions: (1) that all of the parameters and functions are weighted equally; (2) that there is no requirement that specific parameter units removed from a corridor must be replaced by the same parameters in the mitigation sites and (3) that within the GIS layers, only entire sites may be considered for mitigation; no portion of a site can be used. The model, due to its simplicity, can be modified to meet needs in regions other than the coastal plain of North Carolina.

2.9. Wetland habitat/values quantification

The Guidance for Rating the Values of Wetlands in North Carolina (1995) incorporated the results of an EPA wetland program (not specified) to develop biological criteria for freshwater wetlands. The system rated the value of wetlands based on “ability” and “opportunity.” Ability is based on characteristics of the wetland such as plant structure, hydrologic regime and topographic position. Opportunity is based on characteristics in the surrounding area and watershed and determines whether a wetland fulfills a given value (i.e., the opportunity of a wetland to remove pollutants depends on the amount and type of pollutants the wetlands receives from the watershed). The North Carolina Guidance method involves the use of flowcharts, which use observable indicators for each wetland function, such as: percent coverage by broadleaved vegetation, percent of area of wetland with standing water and distance within 3000 feet of permanent surface water, and wetlands that have pockets of standing water for most of the year. Moving through the flowchart, numerical scores are assigned to each function based on the criteria provided in the flowchart. The numerical scores are multiplied by a

weighting factor to obtain the weighting rating. The system rates six values of wetlands and combines them into a weighed equation: water storage (weight=4), bank stabilization (weight=4), pollutant removal (weight=5), low flow augmentation (weight=2), wildlife habitat (weight=4), aquatic life (weight=1). The rating system was intended to be used with freshwater wetlands. This method only evaluated wetlands functions that have positive effects for people and society.

The Wetlands Biological Indicators for New Jersey (Hatfield et al. 2006) focused on various wetland assessment projects, conducted by the State of New Jersey, to aid in development of a rapid wetland assessment tool to serve as a useful tool in permitting and mitigation efforts and to establish legal baseline standards for wetland quality. One specific goal was to identify biological indicators that reflect the ecological health and condition of riverine wetlands. Wetland function refers to the services that the wetland performs for the environment, such as flood water retention, erosion reduction and sedimentation, and improved water quality. Ecological health is reflected in the type, conditions and number of organisms present in the wetland and/or the status of nutrients and contaminants within the wetland. It was stated that ecological health is generally considered a more direct measure of wetland quality or wetland condition. Biological assessments were performed to determine the ecological health of a wetland by directly measuring the status of taxonomic groups (protocols for test sampling were developed and implemented) closely aligned with the water body.

2.10. Roads and wetlands

Roads have a huge impact on the environment, with high amphibian mortality caused by traffic being reported in the literature and representing the most important source of variation in species richness (Ashley and Robinson 1996; Lodé 2000; Smith and Dodd 2003).

Findlay et al. (2000) found that road construction and the associated increase in human presence represents one of the major ways humans transform landscapes. The researchers documented lags in wetland biodiversity loss in response to road construction by fitting regression models that express species richness of different taxa (birds, mammals, plants, and herptiles) as a function of both current and historical road densities on adjacent lands. They found that the proportion of variation in herptile and bird richness explained by road densities increased significantly when past densities were substituted for more current densities in multiple regression models. They concluded that their results provide evidence that the full effects of road construction on wetland biodiversity may be undetectable in some taxa for decades. Such lags in response to changes in anthropogenic stress have important implications for land-use planning and environmental impact assessment.

Forman and Deblinger (2000) showed that the significant ecological effects of roads on plants and animals, including amphibians, average up to a distance of 600 m outward from a road. These studies in Massachusetts evaluated several ecological effects of roads, including traffic noise effects. The researchers estimated that about one-fifth of

the U.S. land area is directly affected ecologically by the system of public roads (Forman and Deblinger, 2000).

2.11. Landscape analysis/statistical analysis

A better understanding of the habitat and landscape characteristics associated with populations is beneficial to develop conservation strategies (Burne et al. 2005).

Relatively few landscape-level studies of amphibian density and movement have been conducted (Houlahan et al., 2000; McGarigal and Cushman, 2002). The majority of the studies have focused on relationships between forest cover and species occurrence, showing a positive relationship between amphibian population and area of forest in the surrounding landscape (Dupois and Stevenson 1999; Trenham and Shaffer 2005).

Knowledge is still quite rudimentary about the population-level implication of habitat area, edge, isolation and road mortality relationships. The effective conservation of amphibian populations is limited by the lack of specific ecological knowledge and lack of landscape level studies of the effect of habitat loss and fragmentation on movement, survival rates and population dynamics (Cushman 2006).

Burne et al. (2005) investigated the relationship between amphibian species richness and characteristics of breeding pools and their surroundings in 85 pools in eastern Massachusetts in 1996 and 1997. A total of 11 species were detected in the study, among them were wood frogs, spotted salamanders, spring peepers and tree frogs. The researchers defined amphibian species richness as the presence of breeding evidence of any species. They used within-pool characteristics, as well as landscape characteristics surrounding the breeding pools. Some of the within-pool characteristics used were:

coverage of pool by tree canopy, pool hydroperiod classification (ephemeral or permanent), coverage of pool by shrubs, coverage of pool by emergent vegetation, coverage of pool by submergent vegetation and coverage by floating-leafed plants. Some of the landscape characteristics used were coverage by developed land, occurrence of another breeding habitat within 1 km, coverage by wetland forest and coverage by upland woods. The researchers used data on landscape-scale parameters, which include estimates of landscape characteristics at three spatial scales, 0-30 m, 30-100 m, and 100-300 m from the pool edge. The test of the null hypothesis (variable is not significant) versus the alternative hypothesis (variable is significant) was conducted using the t-test for a single variable. The independent variable that produces the largest (absolute) t value is declared the “best” variable predictor of the dependent variable provided that the independent variable produces a p-value for the t-test that is below a specified alpha level, such as 0.15 or 0.10).

Based on a linear regression analysis, species richness was positively associated with three within-pool variables: tree-canopy cover ($t = -3.0$, $p = 0.004$), pool surface area ($t = 1.83$, $p = 0.071$), hydroperiod ($t = 2.23$, $p = 0.029$), amount of emergent vegetation ($t = 1.76$, $p = 0.082$), and the presence of another breeding pool within 1 km ($t = 2.87$, $p = 0.005$). These combined variables explained a significant amount of the variation observed in total amphibian species richness ($R^2=0.548$) among the study pools.

Houlahan et al. (2003) examined the effects of adjacent land use and water quality on wetland amphibian species richness and abundance in 74 Ontario, Canada wetlands. The species richness was based on 17 amphibian species found in eastern Ontario,

including 10 anurans (tailless, jumping amphibians with a broad body and developed hind legs, frogs, and toads). Wetlands characteristics used in the research were area, latitude, longitude, streams, presence of permanent ponds, and percentage of wetland that was marsh, swamps, bog or fen. Adjacent land use, such as road density, forest cover, building density, proportion of lakes or rivers, proportion of wetlands and distance to nearest wetlands were extracted using Arcview 3.2 and digital 1:10,000 Ontario base maps. One of the goals was to estimate the distance at which adjacent land uses affect wetland amphibian communities. For this purpose, small to large scales of land use data were sampled. The largest scale of 4000 m was chosen because other research suggests that land use to 2000 m and beyond can affect amphibian species richness (Findlay and Houlihan 1997). Values for each variable were estimated for a series of overlapping contours spanning distances of 0-100 m, 0-200 m, 0-250 m, 0-300 m, 0-400 m, 0-500 m, 0-750 m, 0-1000 m, 0-1250 m, 0-1500 m, 0-1750 m, 0-2000 m, 0-2250 m, 0-2500 m, 0-3000 m, and 0-4000 m from the wetland edge.

Simple linear regression was used to examine the bivariate relationship of amphibian species richness with a number of land use variables. The strongest positive bivariate relationships were with wetland area, proportion of wetlands, and forest cover, while the strongest negative relationships were with total centerline roads. The magnitude of the correlations of these variables generally attained a maximum between 2000 and 3000 m. Multiple regression analysis indicates that the land uses most strongly correlated with amphibian species richness are forest cover, proportion of wetlands and road density. Amphibian species richness showed statistically significant bivariate

relationships with a number of land-use variables (the strongest positive bivariate relationships were with wetland area, proportion of wetland, and forest cover, while the strongest negative relationships were with total centerline roads).

A multiple regression model including percent forest cover within 1750 m, distance to nearest wetland >20 ha, and total centerline roads within 200 m explained 24% of the variation in amphibian abundance with $p = 0.0001$, 0.020 and 0.080 respectively. Maximum total Kjeldahl nitrogen was the only retained nutrient variable (negative relationship) in a multiple regression analysis with wetland area, proportion of wetland at 2250 m and forest cover at 3000 m. The resulting model explained 42.3% of the variation in amphibian species richness. The researchers concluded that the effects of adjacent land use and water nitrogen levels on amphibian communities can extend over comparatively large distances.

Hecnar et al. (1998) surveyed 118 ponds in southwestern Ontario, Canada in order to investigate the amphibian species in the region. Thirteen pond-dwelling amphibians were found in the ponds. All of these species require ponds for breeding and larval development. The species richness was defined as any life stage (egg, tadpole, adult) present at the time of the visit. Regional features such as distances to other water bodies or roads, density of ponds, and amount of woodlands surrounding the ponds were measured from topographic maps or aerial photographs. The researchers used analysis of variance (ANOVA) to determine if species richness differed among regions, sub-regions or over time. For regional analyses, they used wetland regions which were based on

physiographic, vegetation, and ecology. For sub-regional analyses they used groups of ponds at the watershed scale.

In the ANOVA, species richness was the dependent variable, region and sub-region were grouping factors, and year was the repeated measure. In their ANOVA design, the researchers nested sub-regions within regions, allowing them to use a single analysis rather than separate ANOVAs for region and sub-region, each by individual years. To determine if species richness was related to local habitat or regional landscape variables, the Pearson product moment was used to rank correlation. Multiple regression was used to determine which variables best explained the variance in species richness. Thirty-eight variables (27 local habitat variables and 11 regional landscape variables) were used in the statistical analysis, including: pond age, pond area, perimeter, emergent vegetation, shrub cover, tree cover, distance to road, human population, and soil type. The results showed that species richness did not change significantly over time. Species richness was correlated with 12 of the 27 local habitat variables and seven of the 11 regional landscape variables. The highest correlation with local variables were negative for factors related to water depth and fish predators, and positive for those related to vegetative cover. For regional variables, the strongest correlations were with variables related to forest cover. Multiple regression analysis revealed that a combination of seven variables produced the best model ($R^2 = 0.54$) to account for variance in species richness in southwestern Ontario. Correlation of species richness with local factors indicated a strong negative relationship with increasing water depth ($t = -0.29$ $p < 0.001$), presence of predatory fish ($t = -0.31$, $p < 0.001$) and a positive relationship with variables related to

vegetation cover ($t = 0.42, p < 0.001$). The correlation analysis also revealed that a positive relationship between species richness and the amount of regional forest cover ($t = 0.59, p < 0.001$) with a negative relationship with increasing distance to nearest woodlands ($t = -0.46, p < 0.001$). In conclusion, the data indicated that differences exist among regions in the pattern of species incidences and species richness. Species richness was associated with a combination of local variables suggesting the importance of fish predation, and regional variables related to woodlands.

2.12. Summary

The above literature described some of the methods and techniques used to survey wetlands habitat and to relate them with amphibian species richness and abundance.

Some studies used GIS analysis to quantify landscape characteristics and related them to species richness in different regions of the U.S. Some researchers suggest methodologies, implementing GIS with a habitat model, to obtain results for a possible change in landscape characteristics or scenario.

In some studies, different landscape variables were used in statistical regression analyses to obtain the possible effects on the wetlands habitat. The statistical analyses include the linear relationship with individual variables related to wetland habitat, in order to determine which landscape variables are better predictors of the amphibian community. Also, multiple regression analysis was applied in some cases to obtain an overall effect of multiple variables on wetlands habitat. However, no studies implemented the distance of the wetland edge to the landscape further away and the distances from the wetland edge was not applied to the variables used to predict

amphibian abundance. These studies showed how to sum or integrate the different variables units of the regression equation (model) to obtain the amphibian abundance.

It is important to develop and implement new methodologies which address broader landscape areas surrounding the wetlands and to analyze the habitat interaction within it. Also, it is important to consider how multiple factors interact across different wetland buffer zones that could affect amphibian population. For example, to include the distances from the wetland edge into the landscape characteristics or quantification of variables and to develop a method to integrate different variables with different units (i.e., area, length, age) into a single model.

Chapter 3

3. Methodology

Amphibian data from 49 constructed wetlands in northern Missouri were used to develop regression equations that describe wetland health in terms of the surrounding landscape characteristics. Amphibian data (number of each species in the various lifecycle stages) has been collected and analyzed from the biological perspective to create a habitat quality rating for each wetland (Shulse 2008). This rating provides the dependent variable, Y, for the development of the regression equation relating landscape parameters to amphibian health. Based upon the literature review, the landscape characteristics considered for the independent variables are: roads, streams, forest, crops, grass, herbaceous area, elevation (from wetland centroid to nearest downstream) and length of flowpath from wetland centroid. This model is expected to provide information that can increase the effectiveness of constructed wetlands (i.e., allow for placement in appropriate areas) and can decrease the probability of negative effects on the habitat of the wetland due to road construction (i.e., avoiding especially valuable habitat areas).

3.1. Study Area

The study area consisted of selected Missouri Department of Transportation (MoDOT) compensatory wetlands and other constructed wetlands of the Missouri Department of Conservation (MDC). In total, 49 constructed wetlands in northern Missouri were used in the study (Figure 3.1). Twenty-nine are “wildlife” ponds in MDC wildlife areas and 20 are MoDOT compensatory mitigation wetlands.

The locations of the wetlands in Figure 3.1 were identified using a global positioning system (GPS) instrument during site visits (Shulse 2008). More information about the wetlands used in the study is shown in Table 3.1(i.e., wetland name, responsible agency, county and size of wetlands).

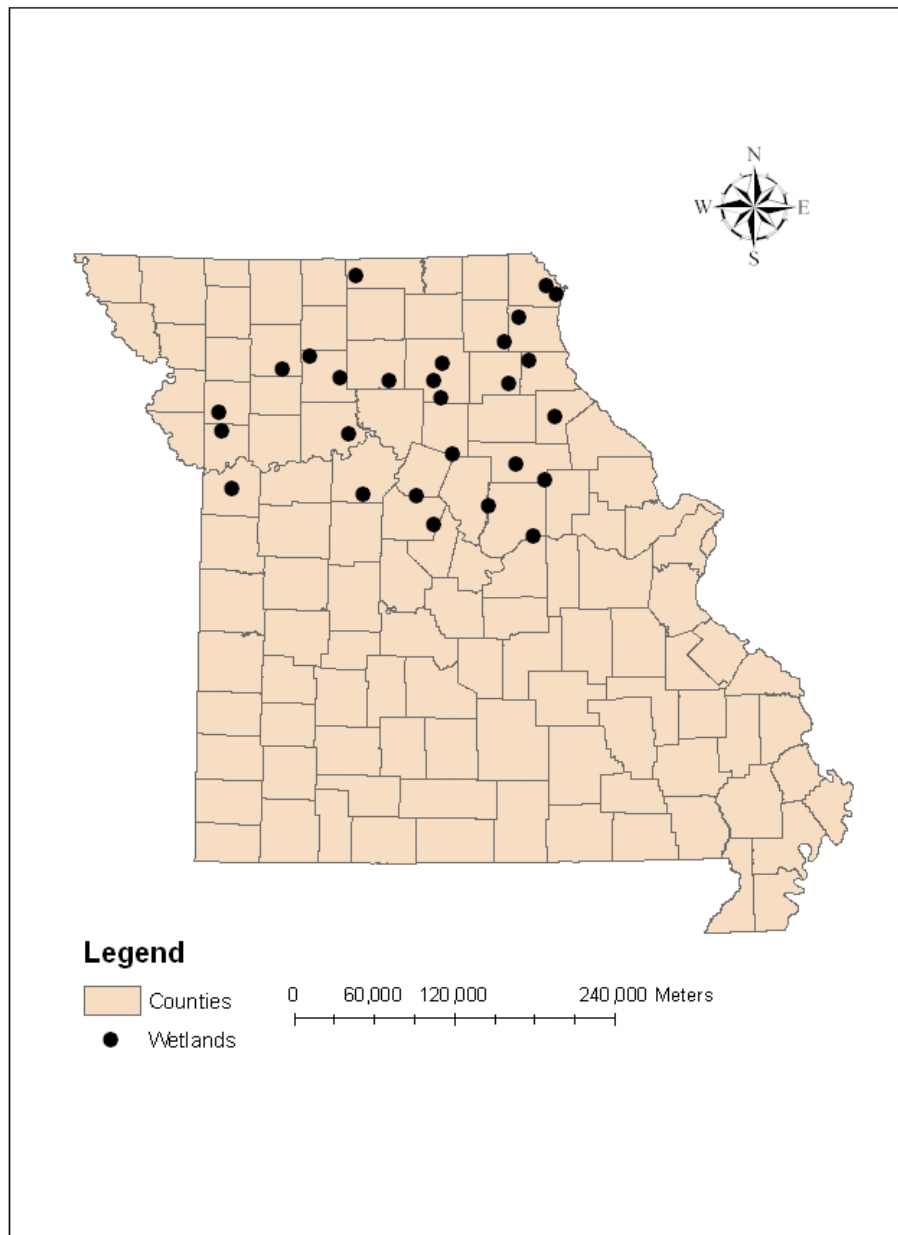


Figure 3.1. Locations of constructed wetlands analyzed in the study.

Table 3.1. Attribute table of wetlands assessed.

Site Name*	Agency	County	Area (m²)
Redman Unit 1	MDC	Macon	1841.616
Rose Pond 4-5 year old unit	MDC	Clark	1031.356
Clark County 136	MoDOT	Clark	22607.218
Putnam County 136	MoDOT	Putnam	2069.803
Redman Unit 3	MDC	Macon	964.139
Mineral Hills Geranium Trail Pond	MDC	Putnam	307.604
Mineral Hills Open Pond	MDC	Putnam	682.101
Poosey	MDC	Livingston	973.771
Gallatin	MDC	Davies	192.028
Elam Bend Small Forested	MDC	Gentry	246.765
Elam Bend Large Forested	MDC	Gentry	631.622
King Lake Ditch	MDC	DeKalb	706.981
King Lake Pond	MDC	DeKalb	333.549
Dunn Ford Small Forest Edge Pond	MDC	Marion	113.024
Henry Sever	MDC	Knox	386.897
Diggs Koi Pond	MDC	Audrain	152.319
Whetstone Creek Pond	MDC	Callaway	357.212
Whetstone Creek Wetland	MDC	Callaway	7436.871
White Open Pond	MDC	Audrain	1041.004
White Forested Pond	MDC	Audrain	817.611
Rudolph Bennitt	MDC	Randolph	337.246
Blind Pony Field Pond	MDC	Saline	751.534
Blind Pony Forested Pond	MDC	Saline	590.137
Prairie Home	MDC	Cooper	162.259
Atlanta	MDC	Macon	654.223
Daniel Boone Fish Pond	MDC	Warren	941.176
Daniel Boone South Side Pond	MDC	Warren	484.743
Danville Ag Pond	MDC	Montgomery	879.432
Danville Roadside Forested Pond	MDC	Montgomery	163.996
Little Dixie Herp Pond	MDC	Callaway	279.358
Center Ralls County Wetland	MoDOT	Ralls	15935.771
Shelby County T	MoDOT	Shelby	244.938
Audrain County 15	MoDOT	Audrain	6188.866
Macon T	MoDOT	Macon	784.187
Macon 36	MoDOT	Macon	73931.388
Linn 36	MoDOT	Linn	53792.127
Livingston 36	MoDOT	Livingston	4620.178

Table 3.1. Attribute table of wetlands assessed (cont.).

Livingston Beetsma Small Corner Pond	MoDOT	Livingston	1099.203
Livingston Beetsma NE Corner Ditch	MoDOT	Livingston	1435.340
Howard/Cooper 5	MoDOT	Howard	3026.394
Osage MariOsa Scrub Shrub	MoDOT	Osage	2386.552
Osage MariOsa Large Pond	MoDOT	Osage	20719.905
Carroll County 139	MoDOT	Carroll	185869.986
Callaway 94	MoDOT	Callaway	3696.938
Clay County Smithville Lake South	MoDOT/USACE	Clay	21632.651
Clinton County Smithville Lake North	MoDOT/USACE	Clinton	37571.130
Jackson County 40 Blue Springs	MoDOT	Jackson	16296.253
Saline County 65/70	MoDOT	Saline	19078.720
Deer Ridge	MDC	Lewis	499.911

*Numbers are roads, highways and interstates close to the wetland.

3.2. Biological Amphibian Assessment/ Dependent Variable

Biological data from 49 wetlands were collected by Shulse (2009) within 26 northern Missouri counties for assessment of the amphibian community. Amphibian surveys were conducted at each wetland during three time periods in 2006 (March/April, May/June, July/August). Data from the three periods were pooled. Sampling was conducted only when wetlands contained water. Area-constrained dip-netting and commercial minnow traps were used to capture amphibians. The amphibians were counted and recorded, and then released.

Data were analyzed from the biological perspective to create a habitat quality rating. The dependent variable used for the regression equations is the Amphibian Coefficient Index (ACI). This index is a measure of the combination of the sensitivity of the amphibian species to disturbance, the rarity of the species within Missouri and the range of the species within Missouri (Shulse 2009).

Each amphibian species observed was assigned a numerical conservation coefficient (CC) (Table 3.2). To obtain these coefficients, amphibian biologists at the University of Missouri and MoDOT discussed the ecology of each species and assigned a score of between 1 and 10 for three ecological criteria—sensitivity to disturbance, aquatic habitat sensitivity and rarity of the species within Missouri. Higher scores indicate higher conservation priorities. An amphibian species that is very sensitive to disturbance may need extra protection to ensure survival, so such a species would be assigned a high score. Likewise, rare species were also assigned a high score, as were species with a limited range in Missouri.

Table 3.2. Conservation coefficients for amphibian species sampled during the study in Missouri (Shulse, 2009).

Species	Core Zone Disturbance Sensitivity	Aquatic Habitat Sensitivity	Rarity	CC
Bullfrog	1	1	1	1
Green frog	2	1	2	2
Leopard frog complex	2	2	1	2
Crayfish frog	8	6	8	7
Cricket frog	3	2	1	2
Western Chorus frog	2	4	4	3
Spring Peeper	6	5	6	6
Gray Treefrog	7	6	4	6
Woodfrog	9	9	9	9
American Toad	1	3	1	2
Tiger salamander	7	6	10	8
Smallmouth salamander	6	7	6	6
Spotted salamander	8	6	9	8
Marbled salamander	9	9	9	9
Newt	9	6	8	8

The three scores for each category were averaged to obtain the CC. The CCs were used to calculate the amphibian conservation index score (ACI) for each wetland. The calculation of ACI involves multiplying the number of individuals of each species sampled by their respective CC value. The result is a subtotal for each species. Subtotals were summed over all species and the total was divided by the number of all individuals sampled. This provided the ACI score (ranging from 0 – 10) for each wetland (see example in Table 3.3) (Shulse 2009). Table 3.4 shows the ACI values for the non-pair wetlands (discussed subsequently). Table 3.5 shows the ACI values for the pair wetlands (discussed subsequently). The average ACI for non-pair wetlands is 2.29, while the average is 3.20 for pair wetlands.

Table 3.3. Amphibian conservation index calculation for the Redman Unit CA Pond 1 (Shulse, 2009).

Species	Number of Individuals	CC	Subtotals
Cricket frog	4	2	8
Smallmouth	40	6	240
Tiger salamander	0	8	0
American toad	0	2	0
Grey Treefrog	0	6	0
Newt	0	8	0
Spring Peeper	0	6	0
Chorus frog	0	3	0
Bullfrog	7	1	7
Green frog	10	2	20
Leopard frog	0	2	0
Totals	61		275

$$ACI = 275/61 = 4.51$$

Table 3.4. ACI values for non-pair wetlands.

ID	Site name	ACI
1	Rose Pond 4-5 year old unit	3.77
2	Clark County 136	0.00
3	Putnam County 136	2.95
4	Poosey	1.24
5	Gallatin	2.46
6	Dunn Ford Small Forest Edge Pond	4.07
7	Henry Sever	2.00
8	Diggs Koi Pond	1.00
9	Rudolph Bennitt	1.33
10	Prairie Home	2.75
11	Atlanta	1.09
12	Little Dixie Herp Pond	6.00
13	Center Ralls County Wetland	2.27
14	Shelby County T	3.00
15	Audrain County 15	1.90
16	Macon T	2.7
17	Macon 36	2.48
18	Linn 36	2.04
19	Livingston 36	0.00
20	Howard/Cooper 5	1.97
21	Carroll County 139	2.00
22	Callaway 94	0.00
23	Clay County Smithville Lake South	2.31
24	Clinton County Smithville Lake North	1.99
25	Jackson County 40 Blue Springs	1.99
26	Saline County 65/70	2.48
27	Deer Ridge	5.91

*Numbers are roads, highways and interstates close to the wetland.

Table 3.5. ACI values for pair wetlands.

ID	Site name	ACI
1	Redman Unit 1	4.51
2	Redman Unit 3	2.00
3	Mineral Hills Geranium Trail Pond	3.60
4	Mineral Hills Open Pond	1.44
5	Elam Bend Small Forested	4.98
6	Elam Bend Large Forested	3.53
7	King Lake Ditch	3.06
8	King Lake Pond	1.67
9	Whetstone Creek Pond	3.22
10	Whetstone Creek Wetland	2.00
11	White Open Pond	1.98
12	White Forested Pond	1.93
13	Blind Pony Field Pond	1.03
14	Blind Pony Forested Pond	5.89
15	Daniel Boone Fish Pond	2.48
16	Daniel Boone South Side Pond	4.88
17	Danville Ag Pond	6.20
18	Danville Roadside Forested Pond	7.45
19	Livingston Beetsma Small Corner Pond	2.37
20	Livingston Beetsma NE Corner Ditch	2.00
21	Osage MariOsa Scrub Shrub	2.41
22	Osage MariOsa Large Pond	1.68

*Numbers are roads, highways and interstates close to the wetland.

3.3. Parameters/Independent Variables

Multiple parameters were analyzed within the methodology.

- Road length. Several studies have demonstrated 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. In addition, they hinder amphibian movement and increase the fragmentation of the wetlands and may have impacts on populations and colonizing new wetlands.

- Land use/ land cover. Forest, crops, grass and herbaceous areas are the land covers used in the analysis. Based on the work of Semlitsch (2003), the landscape surrounding the wetland has been shown to impact amphibian survival. Forest areas are expected to have a positive relation with amphibian populations because they provided undisturbed habitat. Crop areas, although planted, are expected to have a negative relationship with amphibian abundance due to the disturbance (physical and chemical) associated with the agricultural processes. Grassland and herbaceous areas are expected to impact amphibian habitat positively.
- Streams. The hydrological linkage of a wetland to a stream is important because of the need for water in a wetland. Two types of streams are under consideration: perennial streams and intermittent streams. Perennial streams carry water almost all year long in a channel because of subsurface inflow. An intermittent stream flows only during the wet season (a few months per year), based on direct precipitation and surface runoff. Perennial streams are used as a surrogate for the potential presence of fish (possible flood case scenario) and may be expected to have a negative correlation with amphibian health (Hecnar et al.1998). Intermittent streams are used as a surrogate for amphibian habitat without fish and may be expected to have a positive impact on amphibian health.
- Landscape position. A wetland located in an upland position in the landscape will have less water storage, but a smaller probability of predatory fish, which would increase the probability of amphibian survival. A wetland located in a downward position in the landscape will have a greater water contribution from runoff, but

also a greater probability of predatory fish (potentially introduced during flooding events), which could cause a decrease in the amphibian population.

3.4. Data Acquisition/Resources

ArcGIS 9.2, commercial GIS software, was used to spatially analyze the 49 the wetlands (ESRI 2009).

- The GIS wetland location data layer was collected as a part of the overall project (Shulse 2008) and contains location information for all of the constructed wetlands involved in the research (Figure 3.1).
- GIS data layers used in the analysis (i.e., land use/land cover, streams, roads and topography) are readily accessible through the Center for Applied Research and Environmental Systems (CARES) and the Missouri Spatial Data Information Service (MSDIS) websites.
 - Land use/land cover (LULC)
 - Raster format at a scale of 1:24,000 from MSDIS (2005).
 - The categories in the land use/land cover are found in Table 3. 6.
 - The LULC raster layer used in the analysis is presented in Figure 3.2. Figure 3.3 shows wetland Linn 36 with associated LULC layers.

Table 3. 6. Land use/land cover descriptions (MSDIS 2005).

Class	Name	Description
1	Impervious	Non-vegetated, impervious surfaces. Areas dominated by streets, parking lots, buildings. Little, if any, vegetation.
3	High Intensity Urban	Vegetated urban environments with a high density of buildings.
3	Low Intensity Urban	Vegetated urban environments with a low density of buildings.
4	Barren or Sparsely Vegetated	Minimally vegetated areas including bluffs, quarries, and natural expanses of rock, mud, or sand. Areas in transition.
5	Cropland	Predominantly cropland including row, close-grown, and forage crops.
6	Grassland	Grasslands dominated by native warm season or non-native cool season grasses.
7	Deciduous Forest	Forest with greater than 60% cover of deciduous trees.
8	Evergreen Forest	Forest with greater than 60% cover of evergreen trees.
9	Mixed Forest	Forest with greater than 60% cover of a mixture of deciduous and evergreen trees.
10	Deciduous Woody/Herbaceous	Open Woodland including young woodland with less than 60% cover of deciduous trees.
11	Evergreen Woody/Herbaceous	Open Woodland including young woodland) with less than 60% cover of evergreen trees.
13	Woody-Dominated Wetland	Forest with greater than 60% cover of trees with semi-permanent or permanent flood waters.
14	Herbaceous-Dominated Wetland	Woody shrubland with less than 60% cover of trees with semi-permanent or permanent flood waters.
15	Open Water	Rivers, lakes, ponds, and other open water areas.

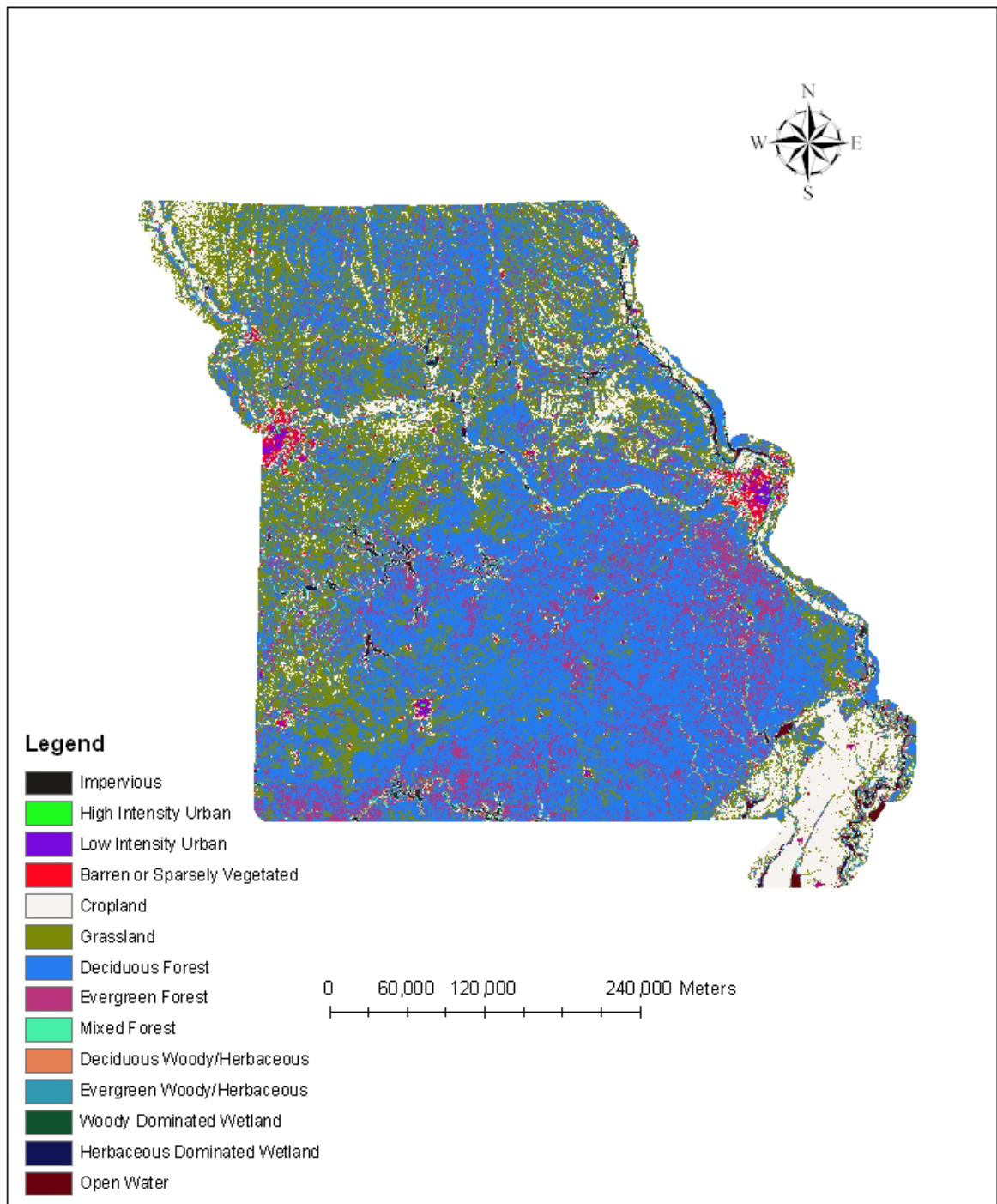


Figure 3.2. Land use/land cover raster layer for Missouri (MSDIS 2005).

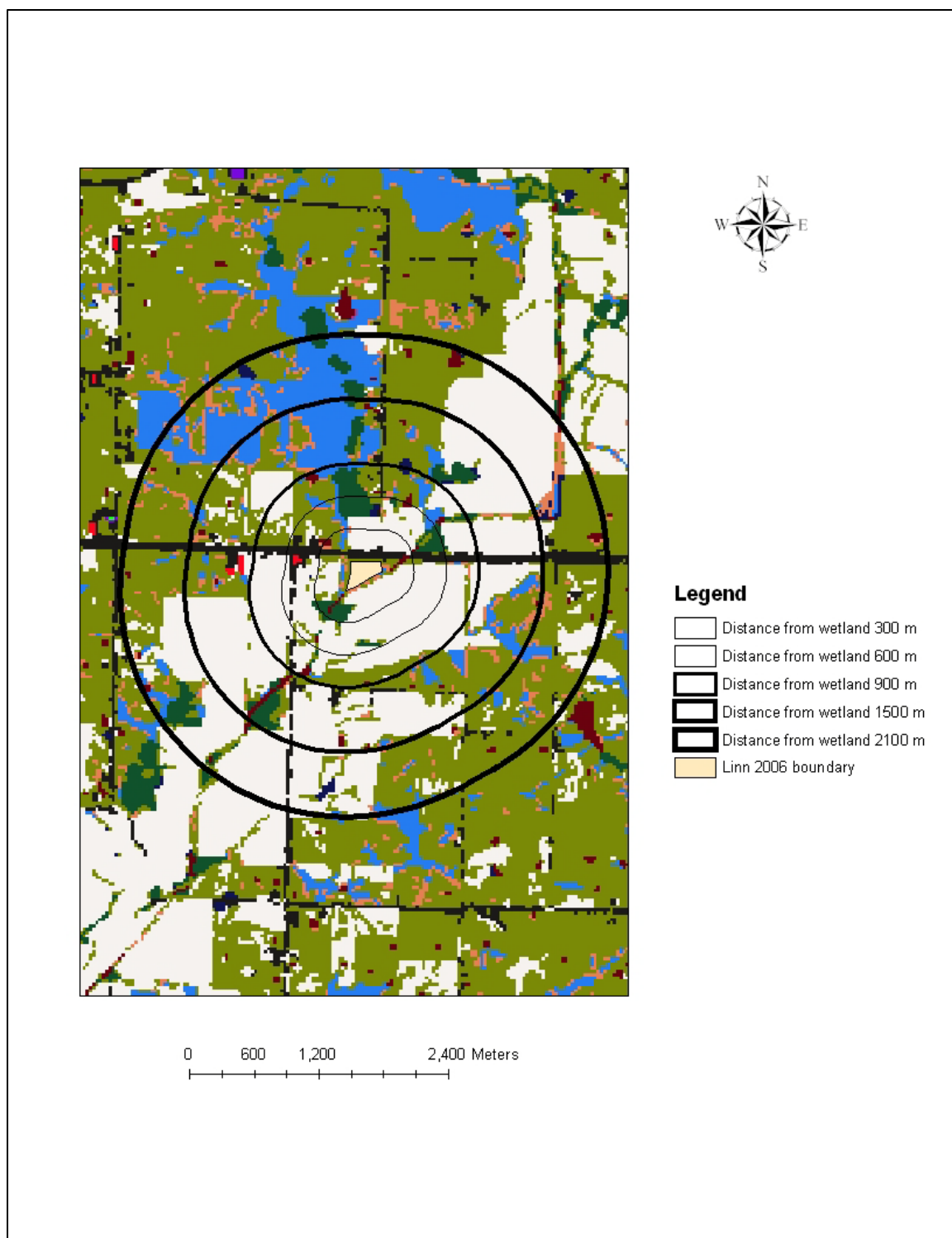


Figure 3.3. Linn 36 wetland with land use/land cover data layer (MSDIS 2005).

- Streams

- The vector layer includes rivers and streams at a scale of 1:24,000 (CARES 2004).
- Layer includes information about type of stream (perennial or intermittent) and artificial paths (an artificial transport path to an open water body that provides connectivity for stream networking).
- Attribute data associated with the layer includes the name and length of each stream segment.
- The stream layer used in the analysis is presented in Figure 3.4. Streams are represented as blue lines on the map. Figure 3.5 depicts Linn 36 wetland and the streams data.

- Roads

- Digital version includes the Missouri numbered routes, U.S. highways, interstate highways and MO numbered routes. Attribute data associated with the layer includes the name and length of each road segment (CARES 2007).
- Roads used in the analysis (Missouri numbered routes, U.S. highways, interstate highways and MO numbered routes) are presented in Figure 3.6. Figure 3.5 show the wetland Linn 36 and associated roads.

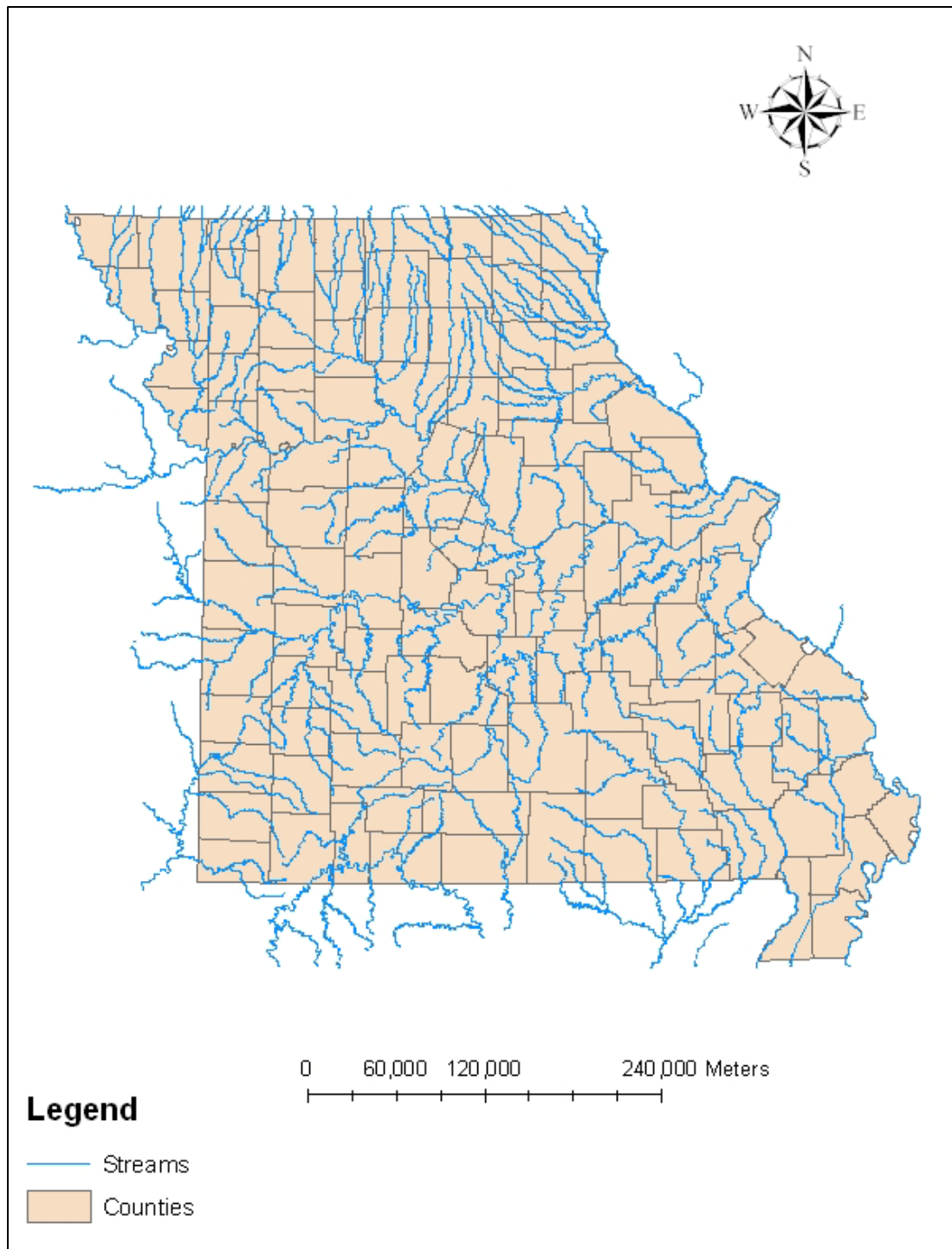


Figure 3.4. Missouri streams (CARES 2004).

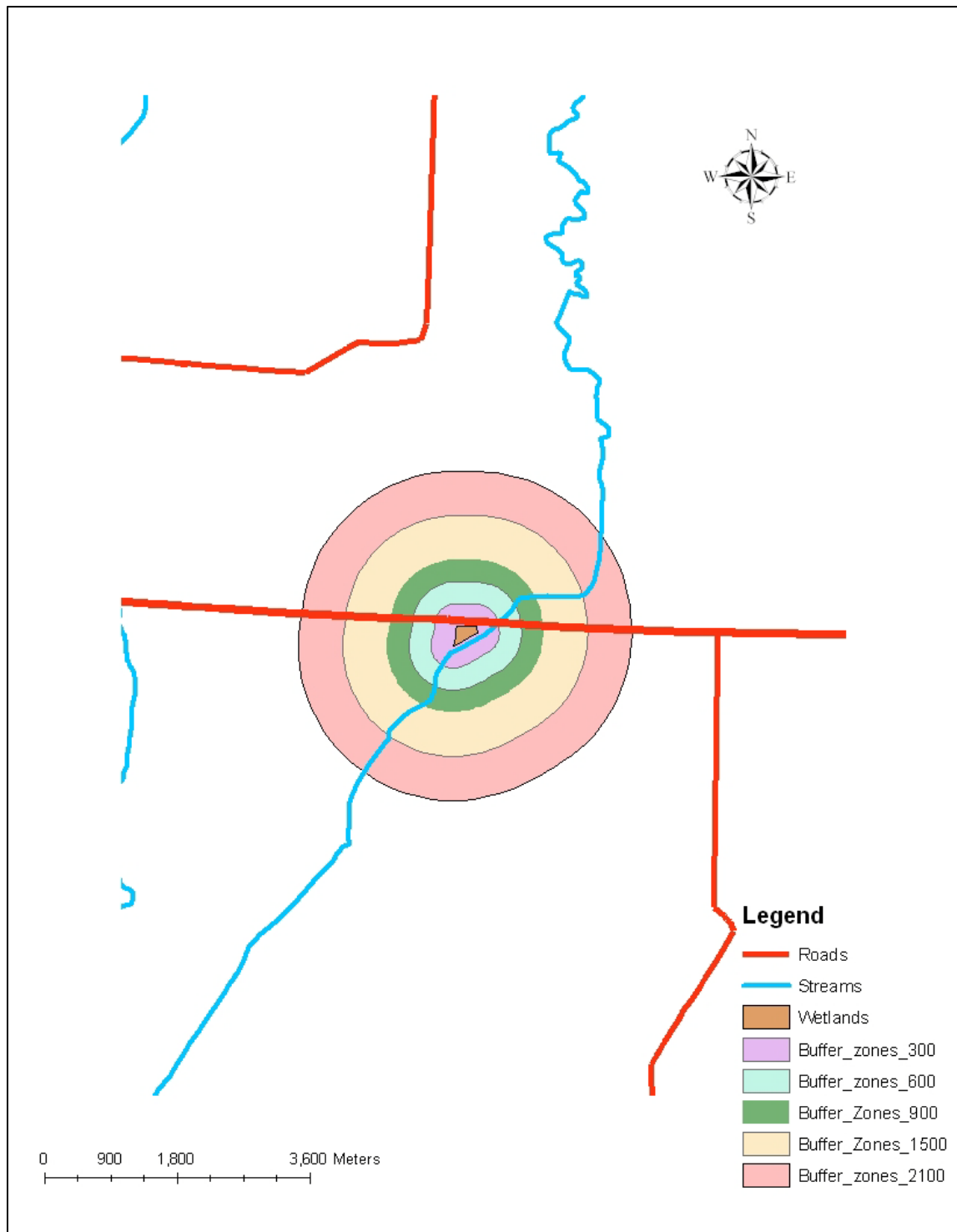


Figure 3.5. Linn 36 wetland with different distance ranges, streams and roads.

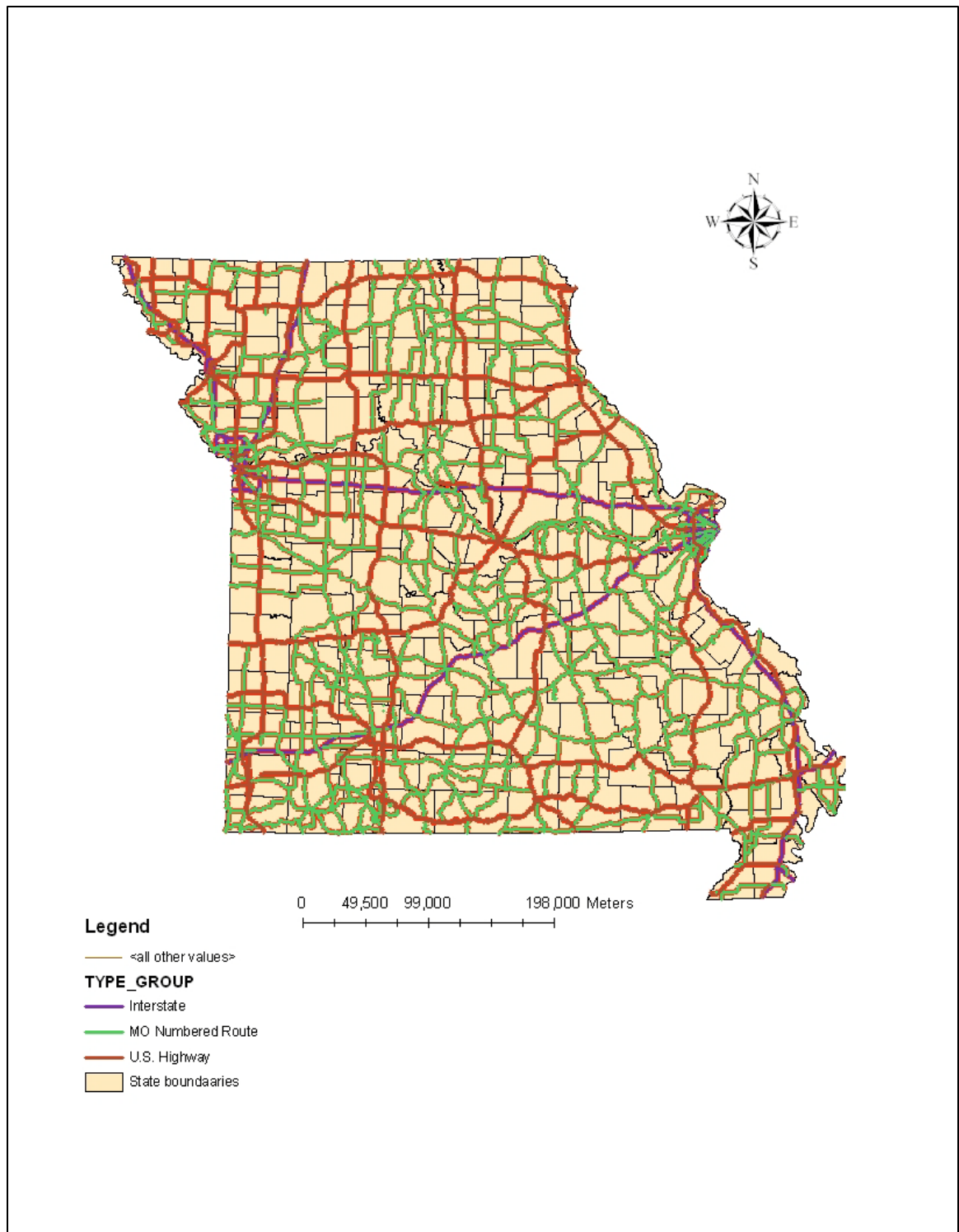


Figure 3.6. Vector road GIS data layer for Missouri (CARES 2007).

- Topography

- A 30 meter digital elevation model (DEM) was used in the analysis (CARES 2005).
- The topography layer used in the analysis is shown in Figure 3.7.

Figure 3.8 shows the Linn 36 wetland and associated topography.

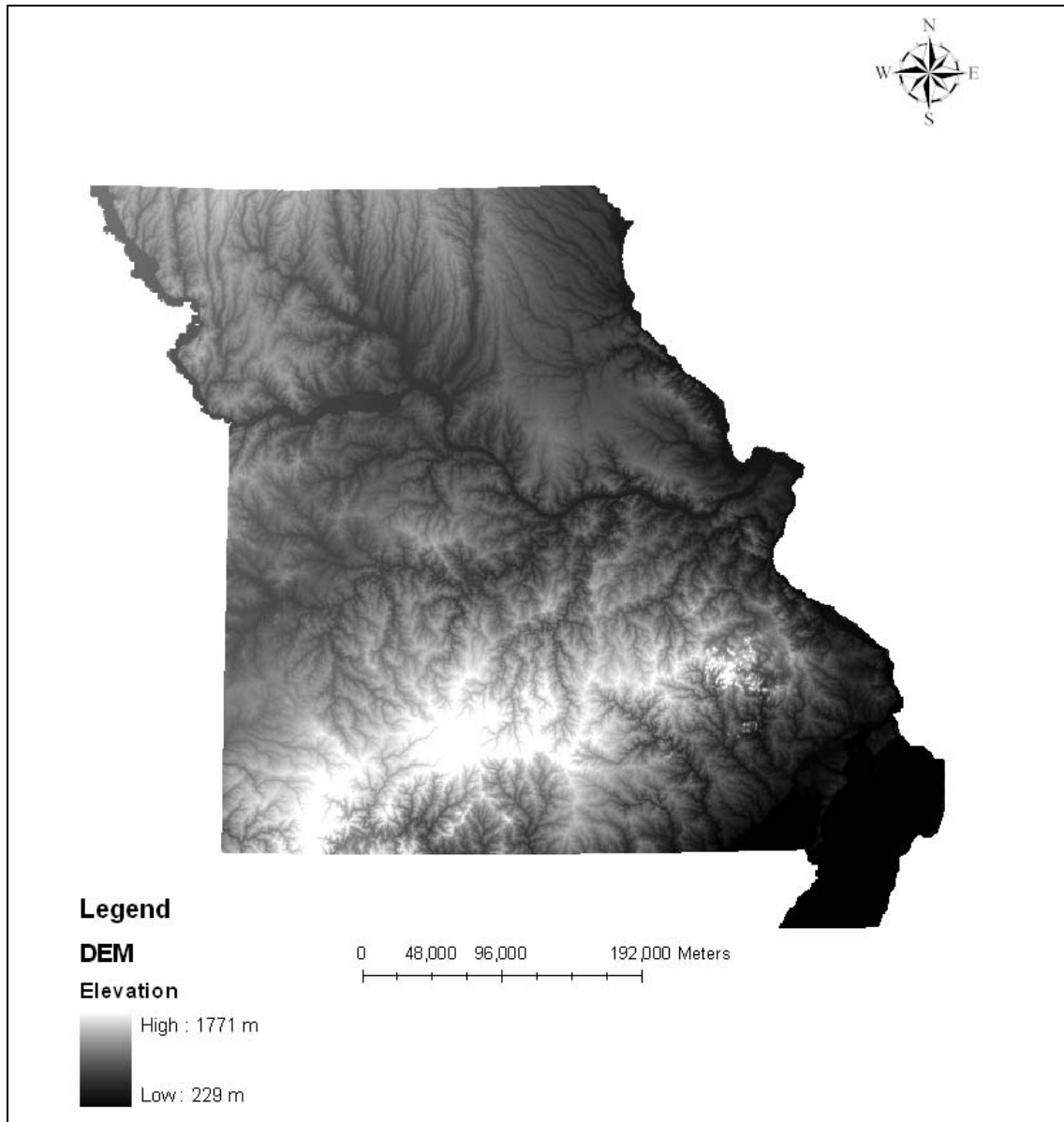


Figure 3.7. Missouri 30 m DEM (CARES 2005).

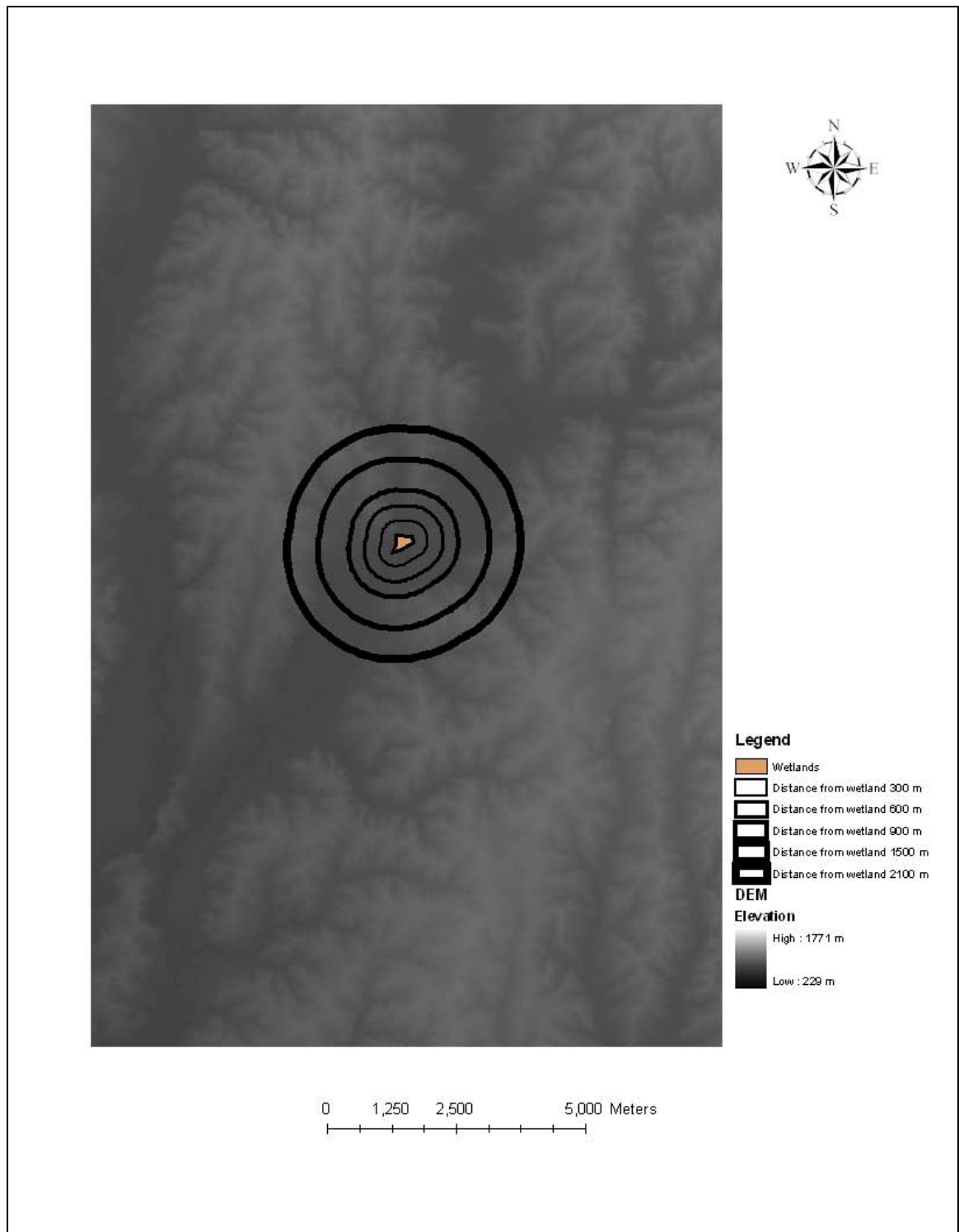


Figure 3.8. DEM for Linn 36 wetland (CARES 2005).

3.5. Prediction of amphibian health

The Amphibian Coefficient Index (ACI) is used as a surrogate for wetland health and is correlated with landscape parameters that can be identified and quantified with the use of a GIS. The quantification of parameters is necessary for the development of a regression equation to predict wetland health. Once developed, this equation can be used to predict or estimate amphibian health under different landscape/rights-of way-(ROW) scenarios for decision making.

3.6. Proximity Analysis

The quantification of features around each wetland were determined using ArcGIS 9.2. The landscape analyses consist of five circular buffers encompassing areas of up to 2.1 kilometers surrounding a given wetland. Polygons representing distance ranges of 300, 600, 900, 1500 and 2100 meters from the edge of each wetland are analyzed because it is hypothesized that distance from the landscape feature to the wetlands could be an important factor for the prediction of the health of the wetlands. For example, greater proximity to a highway may be expected to cause a more negative impact to the wetland health than a road that is far away from the wetland. Specifically, the 300 m ring includes the area between the edge of the wetland and a line 300 m from the wetland edge. The 600 m ring includes the area between the 300 m line and 600 m from the wetland edge. The tests were performed ignoring the distance component in order to compare the results with the results obtained with the distance component applied to the features.

The quantities of the previously identified parameters (e.g., area of forest, length of streams, length of roads) measured in a given ring were divided by the distance of the edge of the wetland to the midpoint of that ring. Dividing by the distance value will reduce the magnitude of a landscape feature score the further it is from the wetland. This treatment of the data will allow for testing of the hypothesis that the greater the distance from the wetland edge, the lesser the impact of that quantity on amphibian abundance.

The midpoint distances used for each buffer ring are:

- 1st ring: $300 \text{ m} / 2 = 150 \text{ m}$,
- 2nd ring: $300 \text{ m} + [(600 \text{ m} - 300 \text{ m}) / 2] = 450 \text{ m}$,
- 3rd ring: $600 \text{ m} + [(900 \text{ m} - 600 \text{ m}) / 2] = 750 \text{ m}$,
- 4rd ring: $900 \text{ m} + [(1500 \text{ m} - 900 \text{ m}) / 2] = 1200 \text{ m}$, and
- 5th ring: $1500 \text{ m} + [(2100 \text{ m} - 1500 \text{ m}) / 2] = 1800 \text{ m}$.

3.7. Data standardization

Data standardization allows for the transformation of parameters with various dimensions into dimensionless parameters with values between 0 and 1 utilizing equation 3.1:

$$S = (X_i - X_{\min}) / (X_{\max} - X_{\min}) \quad (\text{Equation 3.1})$$

where S is the standardized value, X_i is the original value in a ring, X_{\min} is the lowest value of all the values in that ring and areas closer in, and X_{\max} is the highest value of all the values in that ring and areas closer in. “Closer in” means that the X_{\min} and X_{\max} values are determined based on all of the values (of the feature) in that ring and all the values in the previous closer in rings. For example, in analyzing the forest area for the

900 m buffer, the X_{\min} and X_{\max} values will be based on the forest areas in the 900, 600 and 300 m buffer rings.

3.8. Summary of Landscape Features

The features of roads, streams, land use/ land cover, and topography within each ring area were evaluated to determine the contribution of each feature to wetland health.

- a. Roads. The length of the roads in each ring was measured. The length was divided by the distance from the wetland edge to the mid-point of the ring. The independent variable unit is a normalized value (explained in Section 3.7) of $[(\text{length of roads})/(\text{distance of wetland edge to mid-point of the ring})]$.
- b. Streams. The length of the streams in each ring was measured separately for perennial, intermittent streams and artificial paths. The length of stream was divided by the distance from the wetland edge to the mid-point of the ring. The independent variable unit is a normalized value of $[(\text{length of streams})/(\text{distance of wetland edge to mid-point of the ring})]$.
- c. Forest. Forest areas were extracted from the land use/land cover data layer. The forest area was determined for each ring for each wetland. The independent variable unit is a normalized value of $[(\text{area of forest})/(\text{distance of wetland edge to mid-point of the ring})]$.
- d. Crops. Crop areas were extracted from the land use/land cover data layer. The crop area was determined for each ring for each wetland. The

independent variable unit is a normalized value of $[(\text{area of crops})/(\text{distance of wetland edge to mid-point of the ring})]$.

- e. Grass. Grass areas were extracted from the land use/land cover data layer.

The grass area was determined for each ring for each wetland. The independent variable unit is a normalized value of $[(\text{area of grass})/(\text{distance of wetland edge to mid-point of the ring})]$.

- f. Herbaceous. Herbaceous areas were extracted from the land use/land cover data layer. The herbaceous area was determined for each ring for each wetland. The independent variable unit is a normalized value of $[(\text{area of herbaceous})/(\text{distance of wetland edge to mid-point of the ring})]$.

- g. Landscape position. The DEM layer and the digitized wetlands layer were used to determine the landscape position of each wetland. A wetland located in an upland position in the landscape would be expected to have less contributing water to support the wetland, but a smaller probability of predatory fish. A wetland located in a downslope position in the landscape would be expected to have a greater water contribution from runoff, but a greater probability of predatory fish (from flooding), which can cause a decrease in the amphibian population. ArcHydro was used to delineate the downstream flow path from each wetland centroid. The change in elevation between the wetland centroid and the nearest downslope stream elevation was used in the analysis as was the length of flow path of each wetland. The normalized value of the change in

elevation and the normalized value of the length of the flow path was calculated and used in the analysis as two independent landscape variables.

3.9. Statistical Analysis

The statistical package Minitab 15 (Minitab 2009) was used to perform the statistical analysis of the data. Minitab 15 was used to perform the linear regression analysis, the goodness of fit test and to check the significance of the individual variables for the different buffer zones. The procedure used to perform the regression analysis is found in Appendix A. A Pearson correlation analysis was also performed (procedure shown in Appendix B) to identify landscape independent variables that show high correlation.

Chapter 4

4. Results

4.1. Wetland non-pairs and pairs

Previous statistical analyses including the 49 wetlands resulted in regression coefficient values of 8-10%. However, after separating the data into two groups, the goodness-of-fit statistical parameter increased approximately 10% for each group. The data were divided between wetlands that were not near any other wetland and those wetlands that had a wetland close by. Two types of wetland arrangements were found: a non-pair group and a pair group. The non-pair group (Table 4.1) is defined as those wetlands for which the buffers (600-2100 m) do not overlap. The pairs group (Table 4.2) is defined as those wetlands close enough to each other such that the 600 buffers overlap (Figure 4.1). There are 27 non-pair wetlands and 22 wetlands that occur as pairs.

Table 4.1. List of non-pair wetlands.

ID	Site Name	Agency	County
1	Rose Pond 4-5 year old unit	MDC	Clark
2	Clark County 136	MoDOT	Clark
3	Putnam County 136	MoDOT	Putnam
4	Poosey	MDC	Livingston
5	Gallatin	MDC	Davies
6	Dunn Ford Small Forest Edge Pond	MDC	Marion
7	Henry Sever	MDC	Knox
8	Diggs Koi Pond	MDC	Audrain
9	Rudolph Bennitt	MDC	Randolph
10	Prairie Home	MDC	Cooper
11	Atlanta	MDC	Macon

Table 4.1. List of non-pair wetlands (cont.).

12	Little Dixie Herp Pond	MDC	Callaway
13	Center Ralls County Wetland	MoDOT	Ralls
14	Shelby County T	MoDOT	Shelby
15	Audrain County 15	MoDOT	Audrain
16	Macon T	MoDOT	Macon
17	Macon 36	MoDOT	Macon
18	Linn 36	MoDOT	Linn
19	Livingston 36	MoDOT	Livingston
20	Howard/Cooper 5	MoDOT	Howard
21	Carroll County 139	MoDOT	Carroll
22	Callaway 94	MoDOT	Callaway
23	Clay County Smithville Lake South	MoDOT/USACE	Clay
24	Clinton County Smithville Lake North	MoDOT/USACE	Clinton
25	Jackson County 40 Blue Springs	MoDOT	Jackson
26	Saline County 65/70	MoDOT	Saline
27	Deer Ridge	MDC	Lewis

Table 4.2. List of wetland pairs.

ID	Site Name	Agency	County	Pairs
1	Redman Unit 1	MDC	Macon	1
2	Redman Unit 3	MDC	Macon	1
3	Mineral Hills Geranium Trail Pond	MDC	Putnam	2
4	Mineral Hills Open Pond	MDC	Putnam	2
5	Elam Bend Small Forested	MDC	Gentry	3
6	Elam Bend Large Forested	MDC	Gentry	3
7	King Lake Ditch	MDC	DeKalb	4
8	King Lake Pond	MDC	DeKalb	4
9	Whetstone Creek Pond	MDC	Callaway	5
10	Whetstone Creek Wetland	MDC	Callaway	5
11	White Open Pond	MDC	Audrain	6
12	White Forested Pond	MDC	Audrain	6
13	Blind Pony Field Pond	MDC	Saline	7
14	Blind Pony Forested Pond	MDC	Saline	7
15	Daniel Boone Fish Pond	MDC	Warren	8
16	Daniel Boone South Side Pond	MDC	Warren	8
17	Danville Ag Pond	MDC	Montgomery	9
18	Danville Roadside Forested Pond	MDC	Montgomery	9
19	Livingston Beetsma Small Corner Pond	MoDOT	Livingston	10

Table 4.2. List of wetland pairs (cont.).

20	Livingston Beetsma NE Corner Ditch	MoDOT	Livingston	10
21	Osage MariOsa Scrub Shrub	MoDOT	Osage	11
22	Osage MariOsa Large Pond	MoDOT	Osage	11

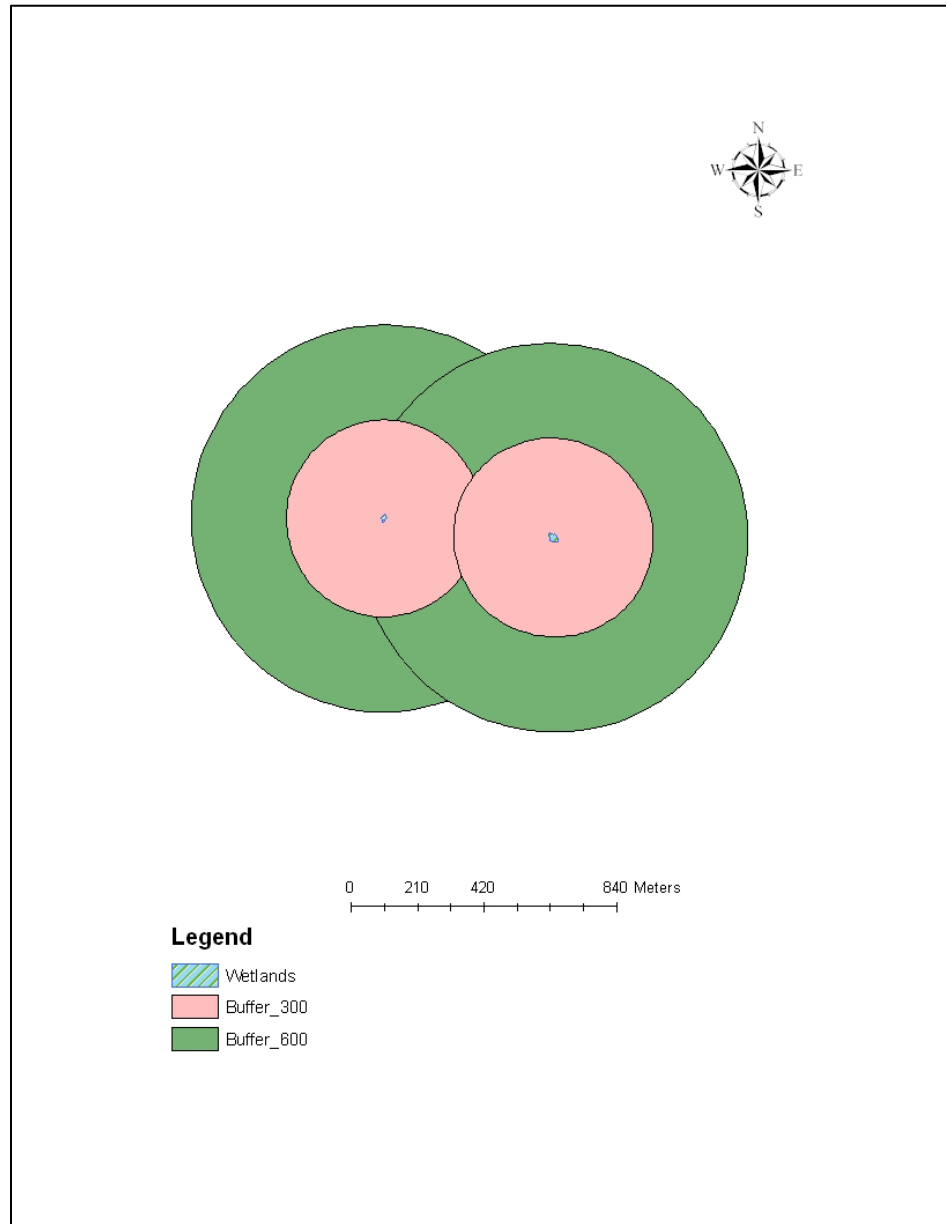


Figure 4.1. Elam Bend Small Forested and Elam Bend Large Forested wetlands shown overlapping within 600 m.

4.2. Normalization

Normalization of the variables was performed for all of the spatial scales of analysis (300, 600, 900, 1500, and 2100 meters) for all the wetlands. Normalization of was necessary for the addition of variables with different units. The normalization for both groups (each group separately) was calculated using the different variables, identified earlier for each ring zone. A ring zone is defined as an area from the wetland edge to the specific distance of the ring. For example, the 900 m ring zone includes all of the areas from the wetland edge up through 900 m. Normalized values for crops, forest, streams, roads, grass and herbaceous land covers, change in elevation between wetland centroid and elevation of nearest stream, and length of flowpath were calculated using Equation 3.1. Data standardization allows the transformation from variables of various dimensions to variables with dimensionless parameters with values between 0 and 1. For each ring zone there is a set of X_{\min} and X_{\max} for each variable. For example, the normalization of the crop variable values at 600 m (Table 4.3 and Table 4.4 for non-pair wetlands with distance and ignoring distance component) includes everything up to 600 m. The last column shows the normalized values of Scrops between 0 and 1.

4.3. Variables

Kleinbaum et al. (1998) recommends a ratio of $n \geq 5k$ for the number of observations (n) to predictor variables (k) to reduce effects of collinearity. In a regression analysis, a collinearity of two variables means that a strong correlation exists between them, making it difficult or impossible to estimate their individual regression coefficients reliably.

In this project there are 27 wetlands data points for the non-pairs. Calculating the number of variables for the 27 nonpairs wetlands, k is equal to 5.4, which means, up to five variables can be used in the regression analysis. Calculating the number of variables for the 22 pairs of wetlands k is equal to 4.4, which means up to 4 variables can be used in the regression analysis.

Eight variables considered as affecting the health of wetlands (ACI, Section 3.2) were quantified. As described in Section 3.7, all of the wetlands data points are normalized quantities:

- Scrops = normalized crop land cover variable,
- Sforest = normalized forest land cover variable,
- Sstreams = normalized stream length variable,
- Sroad = normalized road length variable,
- Sgrass = normalized grass land cover variable,
- Sherb = normalized herbaceous land cover variable,
- Slength = normalized length of flow path variable, and
- Selevation = normalized change in elevation variable.

Two types of streams were identified to affect wetland health, as explained in Section 3.3. The streams in all the buffer zones are perennial streams. No other analysis was necessary to distinguish between the perennial and the intermittent streams.

4.4 Analysis

Two types of data analyses were performed. The first involved the use of the distance from the edge of the wetland to the mid-point of each particular ring (more detail

in Section 4.4.1). The second did not involve the use of a distance component for the quantities of the variables.

4.4.1. Proximity Analysis

The analysis at each of the spatial scales used in the analysis (300, 600, 900, 1500 and 2100 m) for the non-pairs and for the pairs was performed using each variable for each different buffer ring incorporating distance from the edge of the wetland. The independent variable at each buffer ring was divided according to the following ring distances, described in more detail in Section 3.6. As mentioned earlier, this analysis was undertaken to analyze the impacts of the landscape features closer to or farther away from the wetland edge. For example, for the calculation of independent variables for the crops within the 600 m ring (Table 4.3), the crop area within the 300 m ring is divided by 150 m, which is the mid-point distance from the wetlands edge to the mid-point of the ring. To calculate the independent variable at 600 m, the crop area within 600 m is divided by 450 which is the distance from the wetland edge to the midpoint of the 600 m ring. The two independent variable values (i.e., from the 300 and the 600 m ring) are summed. The maximum and the minimum value of the sum are used to calculate the normalized variable value for crops. Again, the normalized values are between zero and one. Table 4.3 shows the normalized value of crops at a spatial scale of 600 m for the non-pair wetlands. Appendix C shows the full set of normalization variables with the distance component applied for the 600 m ring zone non-pair wetlands.

Table 4.3. Example for the calculation of independent variables for the crops at 600 m for non-pair wetlands for the proximity analysis.

ID	Crop area 300m ring (m²)	Crops area 600 m ring (m²)	ind var 300 m ring (m²/m)	ind var 600 m ring (m²/m)	Sum ind variables (m²/m)	Scrops
1	154357.00	518133.27	1029.05	1151.41	2180.45	0.5688
2	153206.50	535470.29	1021.38	1189.93	2211.31	0.5772
3	130960.24	293395.39	873.07	651.99	1525.06	0.3904
4	153978.60	299104.78	1026.52	664.68	1691.20	0.4356
5	711.70	72233.46	4.74	160.52	165.26	0.0203
6	722.91	239825.31	4.82	532.95	537.76	0.1217
7	86885.63	331609.66	579.24	736.91	1316.15	0.3335
8	110899.99	210784.87	739.33	468.41	1207.74	0.3040
9	9316.94	12806.68	62.11	28.46	90.57	0.0000
10	69728.18	398658.90	464.85	885.91	1350.76	0.3430
11	3660.21	49502.90	24.40	110.01	134.41	0.0119
12	5530.15	29757.88	36.87	66.13	103.00	0.0034
13	275848.31	591107.31	1838.99	1313.57	3152.56	0.8333
14	108902.17	275619.72	726.01	612.49	1338.50	0.3396
15	82768.35	233955.49	551.79	519.90	1071.69	0.2670
16	121170.57	115936.84	807.80	257.64	1065.44	0.2653
17	303341.79	400737.77	2022.28	890.53	2912.81	0.7681
18	327585.22	711481.39	2183.90	1581.07	3764.97	1.0000
19	233034.75	601614.85	1553.57	1336.92	2890.49	0.7620
20	126178.30	273421.67	841.19	607.60	1448.79	0.3696
21	277266.05	529957.74	1848.44	1177.68	3026.12	0.7989
22	275592.35	511306.38	1837.28	1136.24	2973.52	0.7846
23	104224.54	278563.10	694.83	619.03	1313.86	0.3329
24	102871.81	85428.91	685.81	189.84	875.65	0.2137
25	19530.25	19674.49	130.20	43.72	173.92	0.0227
26	212377.30	382081.69	1415.85	849.07	2264.92	0.5918
27	18343.00	19891.09	122.29	44.20	166.49	0.0207

4.4.2. Analysis ignoring distance component

The proximity analysis was necessary to quantify the closer landscape features and well as the farther away features and their impact in the ACI. Landscape features near a wetland may be expected to affect the wetland habitat to a greater extent than a feature that is farther away.

To calculate the normalization of the variables ignoring distance component, the area or length of the variable within each individual buffer ring was summed. As an example, for the 600 m buffer calculation, the crop area within the 300 m ring and the crop area within the 600 m ring were summed. The normalization values were calculated using the maximum value (1,039,066.61 m²) and the minimum value (22,123.62 m²) of all of the crop areas using the formula for normalization (Equation 3.1). Table 4.4 shows the calculation of the normalization values (Scrops) for the non-pairs wetlands at a scale of 600 m. The complete set of normalization variables ignoring the distance component is provided in Appendix D.

4.5. Pearson correlation

Pearson correlation analysis was used to identify independent landscape variables that show a high correlation, $r \geq 0.55$ (Lehtinen et al., 1999). This analysis was performed in four different data sets, the non-pair wetlands and the pair wetlands, with distance component applied and ignoring distance component.

Table 4.4. Example of the calculation of the normalization values for the non-pairs wetlands at a scale of 600 m ignoring distance component.

Wetland	Crop area, 300 m ring (m²)	Crop area, 600 m ring (m²)	Sum crops areas 300+600 (m²)	Scrops
1	154357.00	518133.27	672490.27	0.639531
2	153206.50	535470.29	688676.79	0.655448
3	130960.24	293395.39	424355.63	0.395531
4	153978.60	299104.78	453083.38	0.42378
5	711.70	72233.46	72945.16	0.049975
6	722.91	239825.31	240548.22	0.214785
7	86885.63	331609.66	418495.29	0.389768
8	110899.99	210784.87	321684.86	0.29457
9	9316.94	12806.68	22123.62	0
10	69728.18	398658.90	468387.08	0.438828
11	3660.21	49502.90	53163.11	0.030522
12	5530.15	29757.88	35288.03	0.012945
13	275848.31	591107.31	866955.62	0.830757
14	108902.17	275619.72	384521.89	0.35636
15	82768.35	233955.49	316723.84	0.289692
16	121170.57	115936.84	237107.41	0.211402
17	303341.79	400737.77	704079.56	0.670594
18	327585.22	711481.39	1039066.61	1
19	233034.75	601614.85	834649.60	0.798989
20	126178.30	273421.67	399599.97	0.371187
21	277266.05	529957.74	807223.79	0.77202
22	275592.35	511306.38	786898.73	0.752033
23	104224.54	278563.10	382787.64	0.354655
24	102871.81	85428.91	188300.72	0.163408
25	19530.25	19674.49	39204.74	0.016797
26	212377.30	382081.69	594458.99	0.5628
27	18343.00	19891.09	38234.09	0.015842

A correlation is a number between -1 and +1 that measures the degree of association between two variables. A positive value implies a positive association (increasing values in one variable correspond to increasing values in the other variable), while a negative value implies a negative association (increasing values in one variable corresponds to decreasing values in the other variable).

The Pearson correlation coefficient between two variables, given a set of observations $(X_1, Y_1), (X_2, Y_2), \dots, (X_n, Y_n)$, is calculated as:

$$r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{(n-1)S_x S_y} \quad \text{Equation 4.1}$$

where r is the correlation coefficient, X_i is the i^{th} X variable value, \bar{X} is the average value of the X variable, Y_i is the i^{th} Y variable value, \bar{Y} is the average of the Y variable value, S_x is the standard deviation of the X variable and S_y is the standard deviation of the Y variable.

Tables 4.5 through 4.24 show all of the Pearson correlation results for all the data sets. The bolded numbers indicate a high correlation between two variables. One of the two variables must be removed from the analysis in order to prevent multicollinearity, which means that highly correlated independent variables are explaining the same part of the variation in the dependent variable. Pearson correlations coefficients with $r \geq 0.55$ were used to identify independent landscape variables that show a high correlation. The P-value indicates the significance of the correlation and it is used to determine if the correlation coefficient is significantly different from zero, and, hence, that there is

evidence of an association between two variables. P-values are useful in determining the probability that the correlation is a real one and not a chance occurrence. As a rule of thumb, P-values less than 0.05 (for Pearson correlation) show statistical significance.

In each case for each ring zone, the non-pair wetlands and pair wetlands with distance and ignoring distance were considered and the removal of variables that were highly correlated was performed in a way such that a minimum number of variables were deleted from the analysis. For example, if Scrops is highly correlated with two other variables,

only Scrops was removed from the analysis. In this way the least number of variables, that are correlated with others variables, were removed from the final analysis, allowing the testing of the significance of the majority of the variables.

Table 4.5 shows the correlation of the variables for the non-pair wetlands at a scale of 300 m. Scrops was removed from the regression analysis due to the strong positive correlation with Sroad ($r = 0.577$, $P = 0.002$). Scrops was removed instead of Sroad, due to the expected negative impact of the roads close to wetlands edge, and also due to the ease of availability of measurements for road lengths (if the parameter is used in regression equation). Slength was removed due to the high positive correlation with Selev ($r = 0.656$, $P = 0.0$), and the fact that elevation information may be available from a DEM. A P-value equal to zero means that the correlation coefficient is very highly significantly different from zero.

Table 4.5. Pearson correlation coefficients and P-values for all variables for non-pair wetlands with a distance component applied at 300 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.436						
	0.023						
Sstreams	0.46	-0.201					
	0.016	0.314					
Sroad	0.577	-0.268	0.346				
	0.002	0.176	0.077				
Sgrass	0.005	-0.138	-0.02	-0.155			
	0.979	0.491	0.923	0.439			
Sherb	0.043	0.223	0.357	-0.012	0.335		
	0.83	0.265	0.068	0.953	0.088		
Selev	-0.379	0.289	-0.453	-0.394	-0.03	0.117	
	0.051	0.144	0.018	0.042	0.883	0.562	
S length	-0.153	0.056	-0.484	-0.256	0.283	0.148	0.656
	0.446	0.781	0.01	0.198	0.153	0.46	0

Cell content: Correlation, P-value

Table 4.6 shows the correlation of the variables for the non-pair wetlands at a scale of 600 m. Scrops was removed from the regression analysis due to the high negative correlation with Sforest ($r = -0.554$, $P = 0.003$) and positive strong correlation with Sroad ($r = 0.600$, $P = 0.001$). In this case, the least number of variables correlated were removed by deleting Scrops. Slength was removed due to the high positive correlation with Selev ($r = 0.656$, $P = 0.0$) and the potential availability of elevation data in subsequential studies.

Table 4.6. Pearson correlation coefficients and P-values for all variables for non-pair wetlands with a distance component applied at 600 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.554						
	0.003						
Sstreams	0.39	-0.257					
	0.044	0.195					
Sroad	0.600	-0.363	0.392				
	0.001	0.063	0.043				
Sgrass	-0.16	-0.017	-0.121	-0.33			
	0.426	0.934	0.547	0.093			
Sherb	-0.069	0.171	0.219	-0.225	0.539		
	0.733	0.394	0.272	0.259	0.004		
Selev	-0.334	0.366	-0.479	-0.428	0.062	0.117	
	0.088	0.06	0.011	0.026	0.759	0.562	
Slength	-0.12	0.069	-0.538	-0.299	0.311	0.177	0.656
	0.551	0.732	0.004	0.13	0.115	0.378	0

Cell content: Correlation, P-value

Table 4.7 shows the correlation of the variables for the non-pair wetlands at a scale of 900 m. Scrops was removed from the regression analysis due to the high negative correlation with Sforest ($r = -0.639$, $P = 0.0$) and Sroad ($r = 0.564$, $P = 0.002$). The least number of variables that are correlated were removed from the analysis by deleting Scrops. Slength was removed due to the high negative correlation with Sstream ($r = 0.569$, $P = 0.002$) and positive high correlation with Selev ($r = 0.656$, $P = 0.0$), with the least number of variables that are correlated being removed from the final analysis.

Table 4.7. Pearson correlation coefficients and P-values for all variables for non-pair wetlands with a distance component applied at 900 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.639						
	0						
Sstreams	0.38	-0.244					
	0.05	0.22					
Sroad	0.564	-0.398	0.392				
	0.002	0.04	0.043				
Sgrass	-0.175	-0.043	-0.106	-0.311			
	0.381	0.832	0.597	0.114			
Sherb	-0.09	0.147	0.268	-0.26	0.528		
	0.654	0.464	0.176	0.19	0.005		
Selev	-0.31	0.376	-0.489	-0.45	0.084	0.081	
	0.116	0.053	0.01	0.018	0.679	0.689	
Slength	-0.124	0.048	-0.569	-0.304	0.323	0.113	0.656
	0.539	0.814	0.002	0.123	0.1	0.575	0

Cell content: Correlation, P-value

Table 4.8 shows the correlation of the variables for the non-pair wetlands at a scale of 1500 m. Sforest was removed from the regression analysis due to the high positive correlation with Scrops ($r = -0.669$, $P = 0.0$) and because the northern Missouri amphibians being studied are prairie rather than forest species. Slength was removed due to the high negative correlation with Sstream ($r = -0.602$, $P = 0.001$) and high positive correlation with Selev ($r = 0.656$, $P = 0.0$).

Table 4.8. Pearson correlation coefficients and P-values for all variables for non-pair wetlands with a distance component applied at 1500 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.669						
	0						
Sstreams	0.297	-0.161					
	0.133	0.422					
Sroad	0.441	-0.375	0.365				
	0.021	0.054	0.061				
Sgrass	-0.277	-0.007	-0.07	-0.319			
	0.161	0.974	0.729	0.105			
Sherb	-0.133	0.163	0.259	-0.304	0.513		
	0.509	0.418	0.192	0.123	0.006		
Selev	-0.225	0.346	-0.548	-0.445	0.082	0.03	
	0.258	0.077	0.003	0.02	0.683	0.882	
Slength	-0.014	-0.022	-0.602	-0.291	0.205	0.022	0.656
	0.945	0.913	0.001	0.141	0.306	0.915	0

Cell content: Correlation, P-value

Table 4.9 shows the correlation of the variables for the non-pair wetlands at a scale of 2100 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.58$, $P = 0.002$) and again because Missouri amphibians being studied are not forest-oriented species. Selev was removed due to the high negative correlation with Sstream ($r = -0.575$, $P = 0.002$). Sstream was not removed because it is being used as a surrogate for the presence of predatory fish. Slength was removed due to the high negative correlation with Sstream ($r = -0.616$, $P = 0.001$) and

high positive correlation with Selev ($r = 0.656$, $P = 0.0$). Sstream was not removed for the reason mentioned above.

Table 4.9. Pearson correlation coefficients and P-values for all variables for non-pair wetlands with a distance component applied at 2100 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.58						
	0.002						
Sstreams	0.23	-0.105					
	0.249	0.603					
Sroad	0.423	-0.353	0.348				
	0.028	0.071	0.075				
Sgrass	-0.219	-0.067	-0.113	-0.287			
	0.271	0.738	0.575	0.146			
Sherb	-0.095	0.147	0.247	-0.288	0.419		
	0.637	0.463	0.215	0.146	0.03		
Selev	-0.142	0.299	-0.575	-0.429	0.132	0.029	
	0.48	0.13	0.002	0.025	0.512	0.887	
Slength	0.011	-0.08	-0.616	-0.27	0.197	0.022	0.656
	0.956	0.691	0.001	0.173	0.324	0.914	0

Cell content: Correlation, P-value

Table 4.10 shows the correlation of the variables for the non-pair wetlands at a scale of 300 m. Scrops was removed from the regression analysis due to the strong positive correlation with Sroad ($r = 0.577$, $P = 0.002$). Sroad was not removed due to the expected negative impact on the wetland habitat and, also due to the ease of availability of road length data. Slength was removed due to the high positive correlation with Selev ($r = 0.656$, $P = 0.0$).

Table 4.10. Pearson correlation coefficients and P-values for all variables for non-pair wetlands ignoring distance component at 300 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.436						
	0.023						
Sstreams	0.46	-0.201					
	0.016	0.314					
Sroad	0.577	-0.268	0.346				
	0.002	0.176	0.077				
Sgrass	0.005	-0.138	-0.02	-0.155			
	0.979	0.491	0.923	0.439			
Sherb	0.043	0.223	0.357	-0.012	0.335		
	0.83	0.265	0.068	0.953	0.088		
Selev	-0.379	0.289	-0.453	-0.394	-0.03	0.117	
	0.051	0.144	0.018	0.042	0.883	0.562	
Slength	-0.153	0.056	-0.484	-0.256	0.283	0.148	0.656
	0.446	0.781	0.01	0.198	0.153	0.46	0

Cell content: Correlation, P-value

Table 4.11 shows the correlation of the variables for the non-pair wetlands at a scale of 600 m. Scrops was removed from the regression analysis due to the high negative correlation with Sforest ($r = -0.588$, $P = 0.001$) and high positive correlation with Sroad ($r = 0.583$, $P = 0.001$). Sroad was not removed due to the expected negative impact on the wetland habitat, and because of road length data being a quantity that state departments of transportation may keep. Sherbs was removed due to the high positive correlation with Sgrass ($r = 0.644$, $P = 0.0$). Sgrass was not removed because the northern Missouri amphibians being studied are prairie species and Sgrass maybe

expected to contribute positively to the ACI. Slength was removed due to the negative strong correlation with Sstream ($r = -0.56$, $P = 0.002$) and high positive correlation with Selev ($r = 0.656$, $P = 0.0$), so the least number of variables were removed from the analysis.

Table 4.11. Pearson correlation coefficients and P-values for all variables for non-pair wetlands ignoring distance component at 600 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.588						
	0.001						
Sstreams	0.328	-0.255					
	0.094	0.199					
Sroad	0.583	-0.416	0.411				
	0.001	0.031	0.033				
Sgrass	-0.297	0.075	-0.2	-0.411			
	0.133	0.709	0.318	0.033			
Sherb	-0.157	0.132	0.111	-0.385	0.644		
	0.433	0.512	0.583	0.047	0		
Selev	-0.294	0.395	-0.48	-0.456	0.125	0.11	
	0.136	0.041	0.011	0.017	0.535	0.585	
Slength	-0.094	0.073	-0.56	-0.341	0.299	0.187	0.656
	0.641	0.716	0.002	0.082	0.13	0.351	0

Cell content: Correlation, P-value

Table 4.12 shows the correlation of the variables for the non-pair wetlands at a scale of 900 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.685$, $P = 0.0$) and because the amphibians of interest are not forest-oriented species. Slength was removed due to the negative strong

correlation with Sstreams ($r = -0.595$, $P = 0.001$) and strong positive correlation with Selev ($r = 0.656$, $P = 0.0$), so the least number of variables were removed from the analysis.

Table 4.12. Pearson correlation coefficients and P-values for all variables for non-pair wetlands ignoring distance component at 900 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.685						
	0						
Sstreams	0.308	-0.197					
	0.117	0.324					
Sroad	0.45	-0.432	0.392				
	0.018	0.025	0.043				
Sgrass	-0.278	-0.012	-0.157	-0.303			
	0.16	0.954	0.433	0.125			
Sherb	-0.169	0.123	0.275	-0.346	0.533		
	0.4	0.541	0.165	0.077	0.004		
Selev	-0.252	0.385	-0.479	-0.505	0.129	0.034	
	0.205	0.047	0.012	0.007	0.523	0.866	
Slength	-0.108	0.033	-0.595	-0.341	0.314	0.045	0.656
	0.593	0.871	0.001	0.082	0.111	0.824	0

Cell content: Correlation, P-value

Table 4.13 shows the correlation of the variables for the non-pair wetlands at a scale of 1500 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.673$, $P = 0.0$) and the amphibian reason given earlier. Selev was removed due to the strong negative correlation with Sstream

($r = -0.606$, $P = 0.001$). Sstream was not removed due to the potential importance of stream as a surrogate for predatory fish. Slength was removed due to the negative strong correlation with Sstreams ($r = -0.639$, $P = 0.0$) and strong positive correlation with Selev ($r = 0.656$, $P = 0.0$).

Table 4.13. Pearson correlation coefficients and P-values for all variables for non-pair wetlands ignoring distance component at 1500 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.673						
	0						
Sstreams	0.161	-0.073					
	0.423	0.719					
Sroad	0.162	-0.296	0.316				
	0.419	0.134	0.108				
Sgrass	-0.384	0.034	-0.146	-0.264			
	0.048	0.866	0.468	0.183			
Sherb	-0.208	0.158	0.182	-0.353	0.477		
	0.299	0.431	0.363	0.071	0.012		
Selev	-0.124	0.315	-0.606	-0.426	0.094	-0.043	
	0.537	0.109	0.001	0.027	0.639	0.832	
Slength	0.079	-0.073	-0.639	-0.262	0.117	-0.1	0.656
	0.695	0.717	0	0.187	0.563	0.618	0

Cell content: Correlation, P-value

Table 4.14 shows the correlation of the variables for the non-pair wetlands at a scale of 2100 m. Selev was removed due to the strong negative correlation with Sstream ($r = -0.629$, $P = 0.001$). Sstream was not removed due to the potential impact it can have on the wetland habitat, as a surrogate for predatory fish. Slength was removed due to the

negative strong correlation with Sstreams ($r = -0.625$, $P = 0.0$) and strong positive correlation with Selev ($r = 0.656$, $P = 0.0$). In this last case the least number of variables were removed from the analysis.

Table 4.14. Pearson correlation coefficients and P-values for all variables for non-pair wetlands ignoring distance component at 2100 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.453						
	0.018						
Sstreams	-0.006	0.005					
	0.976	0.982					
Sroad	0.137	-0.263	0.295				
	0.494	0.185	0.135				
Sgrass	-0.317	-0.068	-0.211	-0.302			
	0.107	0.736	0.29	0.125			
Sherb	-0.227	0.193	0.13	-0.406	0.508		
	0.254	0.335	0.519	0.036	0.007		
Selev	0.014	0.24	-0.629	-0.369	0.052	-0.082	
	0.943	0.227	0	0.058	0.797	0.684	
Slength	0.089	-0.147	-0.625	-0.202	0.045	-0.156	0.656
	0.657	0.464	0	0.312	0.823	0.436	0

Cell content: Correlation, P-value

Table 4.15 shows the correlation of the variables for the non-pair wetlands at a scale of 300 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.635$, $P = 0.001$) and because amphibians in Northern Missouri are not forest species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.697$, $P=0.0$) and strong positive correlation with Sforest

($r = 0.66$, $P = 0.0$). Scrops was not removed due to the expected negative impact on the ACI.

Table 4.15. Pearson correlation coefficients and P-values for all variables for pair wetlands with a distance component applied at 300 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.635						
	0.001						
Sstreams	0.338	-0.123					
	0.124	0.584					
Sroad	0.324	-0.093	0.129				
	0.142	0.681	0.566				
Sgrass	0.026	-0.537	-0.263	-0.097			
	0.909	0.01	0.237	0.668			
Sherb	-0.338	0.055	-0.134	-0.357	-0.196		
	0.124	0.807	0.553	0.103	0.381		
Selev	-0.697	0.66	-0.366	-0.091	-0.073	-0.002	
	0	0.001	0.094	0.686	0.746	0.993	
Slength	-0.377	0.096	-0.333	-0.429	0.01	0.267	0.373
	0.084	0.672	0.13	0.046	0.965	0.23	0.087

Cell content: Correlation, P-value

Table 4.16 shows the correlation of the variables for the non-pair wetlands at a scale of 600 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.765$, $P = 0.0$) and because amphibian in northern Missouri are not forest species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.752$, $P = 0.0$) and strong positive correlation with Sforest ($r = 0.721$, $P = 0.0$). Scrops was not removed due to the expected negative impact on the ACI.

Table 4.16. Pearson correlation coefficients and P-values for all variables for pair wetlands with a distance component applied at 600 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.765						
	0						
Sstreams	0.221	-0.091					
	0.323	0.687					
Sroad	0.443	-0.369	0.11				
	0.039	0.091	0.626				
Sgrass	0.055	-0.501	-0.347	-0.157			
	0.809	0.018	0.113	0.486			
Sherb	-0.243	-0.006	-0.028	-0.234	-0.045		
	0.275	0.978	0.901	0.295	0.841		
Selev	-0.752	0.721	-0.407	-0.52	-0.03	-0.029	
	0	0	0.06	0.013	0.894	0.897	
Slength	-0.419	0.096	-0.375	-0.424	0.192	0.359	0.373
	0.052	0.672	0.086	0.049	0.392	0.101	0.087

Cell content: Correlation, P-value

Table 4.17 shows the correlation of the variables for the non-pair wetlands at a scale of 900 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.783$, $P = 0.0$) and because amphibians in northern Missouri are not forest species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.792$, $P = 0.0$) and strong positive correlation with Sforest ($r = 0.767$, $P = 0.0$). Scrops was not removed from the analysis due to the expected negative impact on the ACI.

Table 4.17. Pearson correlation coefficients and P-values for all variables for pair wetlands with a distance component applied at 900 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.783						
	0						
Sstreams	0.199	-0.118					
	0.375	0.602					
Sroad	0.43	-0.393	0.238				
	0.046	0.071	0.285				
Sgrass	0.022	-0.477	-0.309	-0.22			
	0.923	0.025	0.161	0.325			
Sherb	-0.195	-0.037	-0.039	-0.291	0.044		
	0.385	0.872	0.861	0.189	0.846		
Selev	-0.792	0.767	-0.487	-0.533	-0.011	-0.03	
	0	0	0.022	0.011	0.961	0.893	
Slength	-0.468	0.098	-0.455	-0.436	0.349	0.402	0.373
	0.028	0.666	0.033	0.042	0.111	0.063	0.087

Cell content: Correlation, P-value

Table 4.18 shows the correlation of the variables for the non-pair wetlands at a scale of 1500 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.816$, $P = 0.0$) and because amphibians in northern Missouri are not forest species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.794$, $P = 0.0$) and strong positive correlation with Sforest ($r = 0.801$, $P = 0.0$). Scrops was not removed from the analysis due to the expected negative impact on the ACI.

Table 4.18. Pearson correlation coefficients and P-values for all variables for pair wetlands with a distance component applied at 1500 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.816						
	0						
Sstreams	0.17	-0.11					
	0.448	0.625					
Sroad	0.376	-0.361	0.253				
	0.084	0.099	0.257				
Sgrass	-0.009	-0.438	-0.278	-0.245			
	0.967	0.042	0.21	0.272			
Sherb	-0.117	-0.113	-0.021	-0.352	0.152		
	0.603	0.616	0.925	0.109	0.498		
Selev	-0.794	0.801	-0.513	-0.52	-0.03	-0.056	
	0	0	0.015	0.013	0.894	0.805	
Slength	-0.436	0.037	-0.483	-0.422	0.507	0.411	0.373
	0.043	0.868	0.023	0.05	0.016	0.058	0.087

Cell content: Correlation, P-value

Table 4.19 shows the correlation of the variables for the non-pair wetlands at a scale of 2100 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.829$, $P = 0.0$) and because amphibians in northern Missouri are not forest species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.776$, $P = 0.0$), strong positive correlation with Sforest ($r = 0.813$, $P = 0.0$) and strong negative correlation with Sstream ($r = -0.586$, $P = 0.004$). Slength was removed due to the strong positive correlation with Sgrass ($r = 0.602$, $P = 0.003$).

Scrops was not removed from the analysis due to the expected negative impact on the ACI.

Table 4.19. Pearson correlation coefficients and P-values for all variables for pair wetlands with a distance component applied at 2100 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.829						
	0						
Sstreams	0.196	-0.139					
	0.382	0.538					
Sroad	0.36	-0.36	0.306				
	0.1	0.1	0.167				
Sgrass	-0.006	-0.441	-0.254	-0.261			
	0.977	0.04	0.254	0.24			
Sherb	-0.129	-0.164	-0.046	-0.347	0.301		
	0.568	0.466	0.839	0.113	0.173		
Selev	-0.776	0.813	-0.586	-0.531	-0.087	-0.059	
	0	0	0.004	0.011	0.7	0.793	
Slength	-0.384	-0.009	-0.549	-0.431	0.602	0.459	0.373
	0.077	0.968	0.008	0.045	0.003	0.031	0.087

Cell content: Correlation, P-value

Table 4.20 shows the correlation of the variables for the non-pair wetlands at a scale of 300 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.635$, $P = 0.001$) and because amphibians in northern Missouri are not forested species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.697$, $P = 0.0$) and strong positive correlation with Sforest

($r = 0.66$, $P = 0.001$). Scrops was not removed from the analysis due to the expected negative impact on the ACI.

Table 4.20. Pearson correlation coefficients and P-values for all variables for pair wetlands ignoring distance component at 300 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.635						
	0.001						
Sstreams	0.338	-0.123					
	0.124	0.584					
Sroad	0.324	-0.093	0.129				
	0.142	0.681	0.566				
Sgrass	0.026	-0.537	-0.263	-0.097			
	0.909	0.01	0.237	0.668			
Sherb	-0.338	0.055	-0.134	-0.357	-0.196		
	0.124	0.807	0.553	0.103	0.381		
Selev	-0.697	0.66	-0.366	-0.091	-0.073	-0.002	
	0	0.001	0.094	0.686	0.746	0.993	
Slength	-0.377	0.096	-0.333	-0.429	0.01	0.267	0.373
	0.084	0.672	0.13	0.046	0.965	0.23	0.087

Cell content: Correlation, P-value

Table 4.21 shows the correlation of the variables for the non-pair wetlands at a scale of 600 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.784$, $P = 0.0$) and because amphibians in northern Missouri are not forest species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.734$, $P = 0.0$) and strong positive correlation with Sforest ($r = 0.744$,

P = 0.0). Scrops was not removed from the analysis due to the expected negative impact on the ACI.

Table 4.21. Pearson correlation coefficients and P-values for all variables for pair wetlands ignoring distance component at 600 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Scrops							
Sforest	-0.784						
	0						
Sstreams	0.178	-0.071					
	0.427	0.753					
Sroad	0.371	-0.403	0.168				
	0.089	0.063	0.454				
Sgrass	0.021	-0.467	-0.398	-0.157			
	0.925	0.029	0.067	0.485			
Sherb	-0.175	-0.048	0.024	-0.289	0.08		
	0.436	0.832	0.917	0.192	0.722		
Selev	-0.743	0.744	-0.425	-0.541	0.003	-0.047	
	0	0	0.049	0.009	0.989	0.837	
Slength	-0.419	0.094	-0.393	-0.451	0.319	0.408	0.373
	0.052	0.676	0.07	0.035	0.148	0.059	0.087

Cell content: Correlation, P-value

Table 4.22 shows the correlation of the variables for the non-pair wetlands at a scale of 900 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.712$, $P = 0.0$) and because amphibians in northern Missouri are not forest species. Selev was removed due to the strong negative correlations with Scrops ($r = -0.726$, $P = 0.0$) and Sroad ($r = -0.555$, $P = 0.007$) and strong

positive correlation with Sforest ($r = 0.80$, $P = 0.0$), so the least number of variables were removed from the analysis.

Table 4.22. Pearson correlation coefficients and P-values for all variables for pair wetlands ignoring distance component at 900 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Scrops							
Sforest	-0.712						
	0						
Sstreams	0.129	-0.145					
	0.568	0.519					
Sroad	0.288	-0.413	0.364				
	0.193	0.056	0.095				
Sgrass	-0.078	-0.427	-0.291	-0.235			
	0.729	0.047	0.189	0.293			
Sherb	-0.165	-0.093	-0.016	-0.372	0.227		
	0.463	0.681	0.944	0.088	0.309		
Selev	-0.726	0.8	-0.517	-0.555	0.024	-0.041	
	0	0	0.014	0.007	0.917	0.855	
Slength	-0.458	0.097	-0.489	-0.463	0.522	0.472	0.373
	0.032	0.668	0.021	0.03	0.013	0.027	0.087

Cell content: Correlation, P-value

Table 4.23 shows the correlation of the variables for the non-pair wetlands at a scale of 1500 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.808$, $P = 0.0$) and because amphibians in northern Missouri are not forest species. Selev was removed due to the strong negative correlation with Scrops ($r = -0.774$, $P = 0.0$) and strong positive correlation with Sforest ($r = 0.816$,

P = 0.0). Scrops was not removed from the analysis due to the expected highly negative impact on the ACI. Slength was removed for the analysis due to the strong positive correlation with Sgrass and Sherb ($r = 0.66$, $P = 0.001$ and $r = 0.597$, $P = 0.003$, respectively). Sgrass and Sherb were not removed from the analysis due to the expected positive impact on the ACI, and also because it allows for the least number of variables to be removed.

Table 4.23. Pearson correlation coefficients and P-values for all variables for pair wetlands ignoring distance component at 1500 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Scrops							
Sforest	-0.808						
	0						
Sstreams	0.125	-0.1					
	0.58	0.658					
Sroad	0.309	-0.34	0.283				
	0.161	0.122	0.201				
Sgrass	-0.098	-0.406	-0.232	-0.242			
	0.663	0.061	0.298	0.278			
Sherb	-0.188	-0.202	-0.07	-0.3	0.461		
	0.401	0.368	0.755	0.175	0.031		
Selev	-0.774	0.816	-0.521	-0.517	-0.027	-0.028	
	0	0	0.013	0.014	0.904	0.901	
Slength	-0.413	-0.003	-0.497	-0.42	0.66	0.597	0.373
	0.056	0.991	0.019	0.052	0.001	0.003	0.087

Cell content: Correlation, P-value

Table 4.24 shows the correlation of the variables for the non-pair wetlands at a scale of 2100 m. Sforest was removed from the regression analysis due to the high negative correlation with Scrops ($r = -0.648$, $P = 0.001$). Scrops was not removed from the analysis due to the expected highly negative impact on ACI. Sherb was removed due to the strong positive correlation with Sgrass ($r = 0.576$, $P = 0.005$) and because amphibians northern Missouri are prairie species, so Sgrass is expected to impact the ACI positively. Selev was removed due to the strong negative correlation with Scrops ($r = -0.635$, $P = 0.001$), the strong positive correlation with Sforest ($r = 0.7436$, $P = 0.0$) and the high negative correlation with Sstream ($r = -0.656$, $P = 0.001$), so the least number of variables were removed from the analysis. Slength was removed due to the high negative correlation with Sstream ($r = -0.616$, $P = 0.002$), high positive correlation with Sgrass ($r = 0.699$, $P = 0.0$) and the high positive correlation with Sherb ($r = 0.586$, $P = 0.004$), so the least number of variables were removed from the analysis.

Table 4.24. Pearson correlation coefficients and P-values for all variables for pair wetlands ignoring distance component at 2100 m.

	Scrops	Sforest	Sstreams	Sroad	Sgrass	Sherb	Selev
Sforest	-0.648						
	0.001						
Sstreams	0.175	-0.127					
	0.436	0.572					
Sroad	0.242	-0.363	0.376				
	0.278	0.097	0.085				
Sgrass	-0.057	-0.437	-0.216	-0.25			
	0.801	0.042	0.334	0.261			
Sherb	-0.191	-0.308	-0.113	-0.3	0.576		
	0.396	0.163	0.616	0.174	0.005		
Selev	-0.635	0.743	-0.656	-0.541	-0.123	-0.045	
	0.001	0	0.001	0.009	0.586	0.841	
Slength	-0.349	-0.107	-0.616	-0.44	0.699	0.586	0.373
	0.112	0.636	0.002	0.041	0	0.004	0.087

Cell content: Correlation, P-value

4.6 Non- pair wetland equations

4.6.1 Linear regression--distance component applied

The variables used in the regression analysis are the set of variables that are not highly correlated with each other. Variables that were highly correlated were removed in Section 4.5. Linear regression was used in the analysis because it is the standard method used in the literature to determine the significant independent variables and the

relationship with the dependent variable (Houlahan and Findley (2003), Lethinen et al. (1999), Herrmann et al. (2005), Hecnar (1997) and Knutson et al. (1999)).

For the different buffer zones, the multiple linear regression models that could describe the relationship between the ACI and the independent variables are shown in Tables 4.25 through 4.29. These tables show the multiple regression analyses for the non-pair wetlands at different spatial scales from which one can identify the significant variables for each buffer zone. The estimate is the average value of the coefficient for each variable in the regression equation. The standard error is the standard deviation from the average value or the estimate. As explained in Chapter 2, the test of the null hypothesis (variable is not significant) versus the alternative hypothesis (variable is significant) is conducted using the t-test for a single variable. The independent variable that produces the largest (absolute) t value is declared the “best” variable predictor of the dependent variable provided that the independent variable produces a p-value for the t-test that is below a specified alpha level. In this research, P-values ≤ 0.20 were checked to determine the significant variables in each ring zone. In a few cases, when the P-value was slightly larger than 0.20, but less than 0.22, the variable was considered significant.

The most significant variable for the 300 m ring zone (Table 4.25) is Sroad with a t-test value of -1.75 and a P-value of 0.096. For the 600 m ring (Table 4.26), the significant variable is Sroad with a t-test value of -1.57 and a P-value of 0.131. The significant variable for the 900 m ring zone (Table 4.27) is Sroad with a t-test value of -1.3 and a P-value of 0.207. The significant variable for the 1500 m ring zone (Table 4.28) is Scrops with a t-test value of -1.27 and a P-value of 0.219. For the 2100 m ring

zone (Table 4.29), the significant variable is Scrops with a t-test value of -1.28 and a P-value of 0.214.

Table 4.25. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands with a distance component applied to the 300 m ring.

Predictor	Estimate	Standard Error	t Statistic	P-value
Constant	3.0967	0.9598	3.23	0.004
Sforest	-0.715	1.329	-0.54	0.597
Sstreams	-0.56	1.203	-0.47	0.647
Sroad	-1.7178	0.9831	-1.75	0.096
Sgrass	-0.728	1.361	-0.53	0.599
Sherb	0.461	1.323	0.35	0.731
S elev	0.316	1.337	0.24	0.816

Table 4.26. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands with a distance component applied to the 600 m ring.

Predictor	Estimate	Standard Error	t Statistic	P-value
Constant	2.8135	0.9754	2.88	0.009
Sforest	-0.217	1.457	-0.15	0.883
Sstreams	-0.097	1.242	-0.08	0.938
Sroad	-1.7	1.081	-1.57	0.131
Sgrass	0.017	1.426	0.01	0.991
Sherb	-0.393	1.256	-0.31	0.757
Selev	0.515	1.346	0.38	0.706

Table 4.27. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands with a distance component applied to the 900 m ring

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	2.473	1.051	2.35	0.029
Sforest	0.095	1.499	0.06	0.950
Sstreams	0.038	1.235	0.03	0.976
Sroad	-1.443	1.106	-1.3	0.207
Sgrass	0.665	1.418	0.47	0.644
Sherb	-0.673	1.285	-0.52	0.606
Selev	0.536	1.357	0.39	0.697

Table 4.28. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands with a distance component applied to the 1500 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	2.83	1.039	2.72	0.013
Scrops	-1.441	1.136	-1.27	0.219
Sstreams	0.006	1.234	0	0.996
Sroad	-1.014	1.31	-0.77	0.448
Sgrass	0.981	1.273	0.77	0.450
Sherb	-0.861	1.175	-0.73	0.472
Selev	0.502	1.306	0.38	0.705

Table 4.29. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands with a distance component applied to the 2100 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	3.0288	0.8831	3.43	0.003
Scrops	-1.425	1.112	-1.28	0.214
Sstreams	-0.215	1.07	-0.2	0.843
Sroad	-1.145	1.239	-0.92	0.366
Sgrass	0.932	1.24	0.75	0.461
Sherb	-0.804	1.142	-0.7	0.489

4.6.2. Linear regression--ignoring distance component

Tables 4.30 through 4.34 describe the relationship between the ACI and the landscape characteristics based on linear regression analysis for the non-pairs wetlands at different spatial scales from which one can identify the significant variables for each buffer zone. The variables used in the regression analysis are the set of variables that are not highly correlated with each other. Variables that were highly correlated were removed in Section 4.5. As is the case when the distance component is applied, the most significant variable for the 300 m buffer zone (Table 4.30) is the Sroad with a t-test value of -1.75 and a P-value of 0.096. At a scale of 600 m (Table 4.31), the significant variable is Sroad with a t-test value of -1.33 and a P-value of 0.198. The significant variable at the 900 m ring zone (Table 4.32) is Scrops with a t-test value of -1.4 and a P-value of 0.176. At the 1500 m scale (Table 4.33) the significant variable is also Scrops with a t-test value of -1.48 and a P-value of 0.154. At the 2100 m scale (Table 4.34), the significant variable is Sgrass with a t-test value of 2.03 and a P-value of 0.056.

Table 4.30. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands ignoring distance component at the 300 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	3.0967	0.9598	3.23	0.004
Sforest	-0.715	1.329	-0.54	0.597
Sstreams	-0.56	1.203	-0.47	0.647
Sroad	-1.7178	0.9831	-1.75	0.096
Sgrass	-0.728	1.361	-0.53	0.599
Sherb	0.461	1.323	0.35	0.731
S elev	0.316	1.337	0.24	0.816

Table 4.31. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands ignoring distance component at the 600 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	2.641	1.042	2.54	0.019
Sforest	-0.12	1.434	-0.08	0.934
Sstreams	-0.209	1.071	-0.19	0.847
Sroad	-1.459	1.097	-1.33	0.198
Sgrass	0.038	1.141	0.03	0.973
Selev	0.426	1.315	0.32	0.749

Table 4.32. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands ignoring distance component at the 900 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	2.773	1.037	2.67	0.015
Scrops	-1.562	1.115	-1.4	0.176
Sstreams	0.433	1.087	0.4	0.694
Sroad	-0.833	1.318	-0.63	0.535
Sgrass	1.314	1.481	0.89	0.386
Sherb	-1.113	1.395	-0.8	0.434

Table 4.33. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands ignoring distance component at the 1500 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	3.0907	0.9991	3.09	0.006
Scrops	-1.713	1.157	-1.48	0.154
Sstreams	-0.5213	0.9551	-0.55	0.591
Sroad	-1.268	1.452	-0.87	0.392
Sgrass	1.337	1.384	0.97	0.345
Sherb	-1.073	1.212	-0.89	0.386

Table 4.34. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands ignoring distance component at the 2100 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	0.914	1.344	0.68	0.504
Scrops	1.511	1.428	1.06	0.303
Sforest	1.644	1.454	1.13	0.272
Sstreams	-0.3435	0.925	-0.37	0.714
Sroad	-1.086	1.592	-0.68	0.503
Sgrass	2.855	1.41	2.03	0.056
Sherb	-1.527	1.353	-1.13	0.272

4.7. Pair wetland equations

4.7.1. Linear regression--distance component applied

The variables used in the regression analysis are the set of variables that are not highly correlated with each other. Variables that were highly correlated were removed in Section 4.5. When the previously described analyses (Section 4.6) are applied to pair wetlands, the most significant variable for the 300 m ring zone (Table 4.35) is the Scrops with a t-test value of -1.95 and a P-value of 0.070. At a scale of 600 m (Table 4.36), the significant variables are Sroad with a t-test value of -1.62 and a P-value of 0.127 and Slength with a t-test value of -1.64 and a P-value of 0.121. The significant variables for the 900 m zone (Table 4.37) are Sroad with a t-test value of -1.43 and a P-value of 0.173, Slength with a t-test value of -1.70 and a P-value of 0.109. The significant variables for the 1500 m zone (Table 4.38) are Scrops with a t-test value of -1.38 and a P-value of 0.188 and Slength with a t-test value of -1.42 and a P-value of 0.177. For the 2100 m zone (Table 4.39) the significant variable are Scrops with a t-test value of -1.36 and a P-value of 0.194 and Sgrass with a t-test value of -1.37 and a P-value of 0.191.

Table 4.35. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands with a distance component applied to the 300 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	5.384	1.31	4.11	0.001
Scrops	-2.781	1.424	-1.95	0.070
Sstreams	-0.627	1.721	-0.36	0.721
Sroad	0.458	1.324	0.35	0.734
Sgrass	-1.315	1.236	-1.06	0.304
Sherb	-0.46	1.467	-0.31	0.758
Slength	-1.97	1.55	-1.27	0.223

Table 4.36. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands with a distance component applied to the 600 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	5.731	1.118	5.12	0
Scrops	-1.316	1.457	-0.9	0.381
Sstreams	-1.111	1.554	-0.72	0.485
Sroad	-2.664	1.649	-1.62	0.127
Sgrass	-1.503	1.315	-1.14	0.271
Sherb	-0.199	1.409	-0.14	0.89
Slength	-2.678	1.631	-1.64	0.121

Table 4.37. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands with a distance component applied to the 900 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	5.633	1.148	4.91	0
Scrops	-1.709	1.401	-1.22	0.242
Sstreams	-0.934	1.412	-0.66	0.518
Sroad	-2.295	1.605	-1.43	0.173
Sgrass	-0.679	1.308	-0.52	0.611
Sherb	0.21	1.507	0.14	0.891
Slength	-3.16	1.854	-1.7	0.109

Table 4.38. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands with a distance component applied to the 1500 m ring.

Predictor	Estimate	Standard Error	T Statistics	P-value
Constant	5.59	1.174	4.76	0
Scrops	-1.677	1.43	-1.17	0.259
Sstreams	-0.921	1.388	-0.66	0.517
Sroad	-2.382	1.725	-1.38	0.188
Sgrass	-0.533	1.473	-0.36	0.722
Sherb	0.041	1.55	0.03	0.979
S length	-2.976	2.101	-1.42	0.177

Table 4.39. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands with a distance component applied to the 2100 m ring.

Predictor	Estimate	Standard Error	T Statistics	P-value
Constant	5.149	1.116	4.61	0
Scrops	-0.654	1.28	-0.51	0.616
Sstreams	-0.18	1.27	-0.14	0.889
Sroad	-2.274	1.677	-1.36	0.194
Sgrass	-2.086	1.528	-1.37	0.191
Sherb	-0.596	1.454	-0.41	0.687

4.7.2. Linear regression-- ignoring distance component

The variables used in the regression analysis are the set of variables that are not highly correlated with each other. Variables that were highly correlated were removed in Section 4.5. Tables 4.40 through 4.44 describe the relationship between the ACI and the landscape characteristics based on linear regression analysis for the pairs wetlands with no distance component applied. As in the previous case, the most significant variable for the 300 ring zone (Table 4.40) is the Scrops with a t-test value of -1.95 and a P-value of

0.070. For the 600 m ring (Table 4.41), the significant variables are Sroad with a t-test value of -1.73 and a P-value of 0.103 and Slength with a t-test value of -1.43 and a P-value of 0.172. The significant variables for the 900 m ring (Table 4.42) are Scrops with a t-test value of -1.68 and a P-value of 0.114, Sroad with a t-test value of -1.57 and P-value of 0.137, and Slength with a t-test value of -1.97 and P-value of 0.068. The significant variables for the 1500 m ring zone (Table 4.43) are Scrops with a t-test value of -1.34 and a P-value of 0.178, Sroad with t-test value of -1.56 and a P-value of 0.138, and Slength with a t-test value of -2.06 and a P-value of 0.056. At 2100 m (Table 4.40) the significant variables are Sroad with a t-test value of -1.41 and a P-value of 0.177 and Sgrass with a t-test value of -1.58 and a P-value of 0.133.

Table 4.40. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands ignoring distance component at the 300 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	5.384	1.31	4.11	0.001
Scrops	-2.781	1.424	-1.95	0.070
Sstreams	-0.627	1.721	-0.36	0.721
Sroad	0.458	1.324	0.35	0.734
Sgrass	-1.315	1.236	-1.06	0.304
Sherb	-0.46	1.467	-0.31	0.758
Slength	-1.97	1.55	-1.27	0.223

Table 4.41. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands ignoring distance component at the 600 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	5.505	1.121	4.91	0
Scrops	-1.272	1.484	-0.86	0.405
Sstreams	-0.662	1.485	-0.45	0.662
Sroad	-2.501	1.442	-1.73	0.103
Sgrass	-1.144	1.376	-0.83	0.419
Sherb	-0.181	1.463	-0.12	0.903
Slength	-2.565	1.788	-1.43	0.172

Table 4.42. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands ignoring distance component at the 900 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	5.545	1.106	5.01	0
Scrops	-2.661	1.586	-1.68	0.114
Sstreams	-0.909	1.448	-0.63	0.539
Sroad	-2.127	1.353	-1.57	0.137
Sgrass	0.329	1.428	0.23	0.821
Sherb	0.515	1.616	0.32	0.755
Slength	-4.187	2.13	-1.97	0.068

Table 4.43 Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands ignoring distance component at the 1500 m ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	5.455	1.038	5.25	0
Scrops	-1.762	1.255	-1.4	0.178
Sstreams	-0.973	1.252	-0.78	0.448
Sroad	-2.431	1.562	-1.56	0.138
Slength	-3.309	1.61	-2.06	0.056

Table 4.44. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands ignoring distance component at the 2100 ring.

Predictor	Estimate	Standard Error	t Statistics	P-value
Constant	4.805	1.017	4.72	0
Scrops	-0.277	1.636	-0.17	0.868
Sstreams	-0.288	1.179	-0.24	0.81
Sroad	-2.069	1.468	-1.41	0.177
Sgrass	-2.468	1.563	-1.58	0.133

4.8. Relationship between ACI and wetlands variables

Tables 4.45 through 4.48 show the relationships between the ACI and landscape variables for each ring zone for the non-pairs wetlands and the pair wetlands. Only the significant variables ($P \leq 0.20$) in the multiple regression analysis (Tables 4.25 through 4.44) were considered for the regression equations. Table 4.45 shows the regression equations for the non-pairs wetlands with a distance component applied. At scales of 300 m through 900 m, the variability of the ACI is dominated by the constant and the Sroad variable. At the scales of 1500 m and 2100 m, the variability of the ACI is dominated by the constant and the Scrops variable. Table 4.46 shows the regression equations for the non-pair wetlands ignoring the distance component. At scales of 300 m and 600 m, the variability of the ACI is dominated by the constant and the Sroad variable. At scales of 900 m and 1500 m, the variability of ACI is dominated by the constant and the Scrops variable, while at 2100 m, the ACI variability is dominated by the constant and Sgrass. The confidence level chosen to test the significance of the regression equations is 0.20. All the regressions in all cases show P-values less than 0.20, which mean that the regressions are significant at an alpha level of 0.20 and the models significantly fit the

data. P-values less than 0.20 mean that there is a statistically significant association between the ACI and the independent variables.

Table 4.45. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands with a distance component applied

Ring zone (m)	Equation	R² (%)	P
300	ACI = 2.71 - 1.78 Sroad	17.5	0.030
600	ACI = 2.74 - 1.78 Sroad	17.2	0.032
900	ACI = 2.73 - 1.65 Sroad	15.1	0.046
1500	ACI = 3.15 - 2.12 Scrops	17.2	0.032
2100	ACI = 2.78 - 1.25 Scrops	4.8	0.272

Table 4.46. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for non-pair wetlands ignoring distance component

Ring zone (m)	Equation	R² (%)	P
300	ACI = 2.71 - 1.78 Sroad	17.5	0.030
600	ACI = 2.74 - 1.67 Sroad	15.8	0.040
900	ACI = 3.17 - 2.05 Scrops	17.0	0.032
1500	ACI = 3.11 - 2.23 Scrops	15.4	0.043
2100	ACI = 1.44 + 1.88 Sgrass	12.1	0.075

Table 4.47 shows the regression equations for the pair wetlands with a distance component applied. At the scale of 300 m, the variability in the ACI is dominated by the constant and the Scrops variable. At the scales of 600 m through 1500 m, the ACI variability is dominated by the constant, and the Sroad, and the Slength. At a scale of 2100 m, the variability of the ACI is dominated by the constant, and the Sroad variable and the Sgrass variable.

Table 4.48 shows the regression equations for the pair wetlands ignoring distance component. At a scale of 300 m, the variability of the ACI is dominated by the constant

and the Scrops variable. At the scale of 600 m the ACI variability is dominated by the constant, Sroad, and Slength. At the scales of 900 and 1500 m the ACI variability is dominated by the constant, Scrops, Sroad, and Slength. At a scale of 2100 m, the variability of the ACI is dominated by the constant, the Sroad variable, and the Sgrass variable.

Table 4.47. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands with distance component applied

Ring zone (m)	Equation	R² (%)	P
300	ACI = 3.83 - 1.98 Scrops	12.3	0.109
600	ACI = 4.24 - 2.90 Sroad - 2.18 S length	19.2	0.131
900	ACI = 4.27 - 2.87 Sroad - 2.24 S length	19.8	0.123
1500	ACI = 4.22 - 2.92 Sroad - 2.15 S length	18.7	0.140
2100	ACI = 4.74 - 2.45 Sroad - 2.26 Sgrass	20.2	0.117

Table 4.48. Relationship between the ACI and landscape characteristics based on a linear multiple regression analysis for pair wetlands ignoring distance component

Ring zone (m)	Equation	R² (%)	P
300	ACI = 3.83 - 1.98 Scrops	12.3	0.109
600	ACI = 4.33 - 2.73 Sroad - 2.33 S length	21.1	0.106
900	ACI = 5.39 - 2.39 Scrops - 2.39 Sroad - 3.31 S length	32.2	0.067
1500	ACI = 5.09 - 1.65 Scrops - 2.57 Sroad - 2.75 S length	25.6	0.141
2100	ACI = 4.66 - 2.25 Sroad - 2.42 Sgrass	19.5	0.127

The ACI values for non-pair wetlands and pair wetlands have different values. The non-pair wetland ACI values are lower than the ACI values of the pair wetlands. Table 3.4 shows the ACI values for the non-pair wetlands. Table 3.5 shows the ACI values for the pair wetlands. According to Table 4.47 and 4.48, the constants of the regression equations are higher in the equations of the pair wetlands. Table 4.49 shows the maximum and minimum values of the normalized values used in the regression equations (Table 4.45 and Table 4.46) for the non-pair wetlands at the different ring zones. Table 4.50 shows the range of values of the normalized variables used in the regression equations (Table 4.47 and Table 4.48) for the pair wetlands.

4.9. Summary

The Pearson correlation coefficient was used to identify which pairs of variables show a high correlation. When possible, the variables were removed in a way that maximized the number of variables used in the regression analysis. In other cases, Sstream, Sroad, Sgrass were included in the analysis and the other variable with which they were correlated was removed. These variables are important because the stream variable was used as a surrogate for fish predation, road data is easily accessible and the amphibians in the study are prairie species.

Multiple regression analyses was used to identify the significant variables in each buffer zone for both types of wetlands, with distance component and ignoring distance component. The significant variables show P-values less than 0.20. However, in some cases, if the P-value was slightly larger than 0.20 but less than 0.22, the variable was considered significant. The most significant variable in the closest buffer zone, 300 m,

for the non-pair wetland is Sroad, while the significant variable at 300 m for the pair wetland is Scrops.

Table 4.49. Range of variables used in the normalized values for non-pair wetlands.

Ring zone (m)	Variable	Range Variable
300	road	0-1.12 miles
600	road	0-1.86 miles
900	road crops	0-3 miles 12-490 acres
1500	crops	43-1433 acres
2100	crops grass	159-2649 acres 361-2135 acres

Table 4.50. Range of variables used in the normalized values for the pair wetlands.

Ring zone (m)	Variable	Range Variable
300	crops	0-48 acres
600	road length	0-1.4 miles 0.11-22 miles
900	crops road length	0.84-538 acres 0-1.96 miles 0.11-22 miles
1500	crops road length	1.6-1148 acres 0-6 miles 0.11-22 miles
2100	road grass	0-8 miles 68-1930 acres

Chapter 5

5.1. Conclusions

This project develops and demonstrates a new methodology to describe the relationships between landscape features and wetland health. Different landscape variables, which are expected to positively or negatively affect wetland health, were used in the analysis.

Analysis of spatial data from 49 wetlands reveals two different types of wetlands: non-pairs and pairs. Non-pair wetlands are defined as those wetlands in which the 600 m buffer zone and beyond do not overlap with the buffer zones of other wetlands. A pair wetland is defined as one in which the concentric rings of the buffer zones overlap with the concentric rings of another wetland. There are 27 non-pair wetlands and 22 pair wetlands in this study.

This methodology incorporates a distance factor in the variable values of the landscape characteristics (e.g., grass area, road length, stream length). Distance is important because it was hypothesized that distance from the landscape feature to the wetlands could be a factor for the prediction of the health of the wetlands. The values of the variables are divided by the distance of the edge of the wetland to the midpoint of that ring. Dividing by the distance value reduces the magnitude of a landscape feature score the further it is from the wetland.

The normalization of the values of the landscape variables allows the use of variables with different units in the same equation. The normalization of variables has the limitation that for any given variable, wetlands with the lowest values are set to zero or near zero even if they have some of the characteristics that supports or are detrimental to amphibians. Tables 4.49 and 4.50 show that the minimum values are zero or a small fraction of the maximum value, so the normalization does not skew the results. The regressions are thus accurate for the prediction of ACI. This methodology is good for comparison between alternative wetlands that maybe impacted by transportation activities.

Multiple linear regression was used to test for significant relationships between landscape variables and the ACI. The significant variable for the non-pair wetlands, with the distance component applied at 300 m, 600 m and 900 m is Sroads, while at 1500 m and 2100 m it is Scrops. The significant variable for the non-pair wetlands, ignoring the distance component at 300 m and 600 m is Sroads, at 900 m and 1500 m it is Scrops, and at 2100 m it is Sgrass. The significant variable for the pair wetlands, with the distance component applied is Scrops at 300 m, Sroad and Slength at 600 m through 1500 m, while at 2100 m the variables are Sroad and Sgrass. The significant variable for the pair wetlands, ignoring the distance component, at 300 m is Scrops, at 600 m through 1500 m is both Sroad and Slength, while at 2100 m is both Sroad and Sgrass. The regression coefficient of the equations show a higher value for the equations developed ignoring distance component for the pair wetlands (except at 2100 m). However, for the non-pair group the regression coefficients show very similar results with distance and ignoring

distance. The regression equations for the analyses ignoring the distance component are still important because the further out rings still show a distance impact because they may cause a change in the significant variable.

The regression equations to predict ACI values in the non-pair wetlands with the distance component applied and ignoring the distance component (Tables 4.45 and 4.46) show regression coefficients ranging from 4.8 % to 17.5 %. The regression coefficients are very similar for both groups (except at a scale of 2100 m). This means that the results applying the distance component are not affecting the results of the regression equations. Also, both set of equations are significant, the P-values of the equations show values less than 0.20 (except at 2100 m with distance applied). This means that the regressions are significant at an alpha level of 0.20 and that the models significantly fit the data. Dividing the landscape variables by distance does not make a difference in the results, so it is recommended to use the variable values ignoring the distance component.

In the case of pair wetlands (Tables 4.47 and 4.48) the regression coefficients show different regression coefficient results with the distance component applied and ignoring the distance component. The regression coefficients for the results ignoring the distance component are larger than the results applying the distance component. This means that dividing by distance is attenuating the impact of the variables in the ACI. It is recommended not to divide the landscape variables values by the distance. Also, both sets of equations are significant, their P-values are less than 0.20. This means that the regressions are significant at an alpha level of 0.20 and that the models significantly fit the data.

It should be noted that the procedure to remove highly correlated variables might influence the final result of the significant variables used in the regression equation for each buffer zone. For example, for the non-pair wetlands at 300 m, Sroad is highly correlated with Scrops. Scrops was removed and after performing the regression analysis it was found that the significant variable is Sroad, but it is likely that it could also be Scrop.

Tables 4.45 through 4.48 show the regression coefficients (R-squared) of all the regressions to predict the ACI. Values in this range are consistent with the values found in the literature. Houlahan and Findley (2003) found that multiple regression models using landscape characteristics (forest cover, length of road and wetland density) to predict amphibian species richness have regression coefficients in the range of 36-42%. Lethinen et al. (1999) found that the multiple regression coefficients of the multiple regression models, to predict the number of amphibian species, ranged from 37-41% using landscape characteristics, such as the density of roads. Herrmann et al. (2005) found that regression equations to predict larval amphibian assemblages (species richness and species densities) explained only 6.3-6.8% of the variability using landscape variables. Other researchers have documented that landscape variables alone account for a small percentage of the variability (< 35%) in their data set (Hecnar 1997, Knutson et al. 1999). It should be note that the above researchers used wetlands characteristics itself, such as area, perimeter, maximum depth and shore slope, besides landscape characteristics. This research focused only on landscape characteristics as a way to analyze the impacts of these characteristics from 300 meters up to 2100 meters. It is

possible that if wetland characteristics were added to the regression model, the regression coefficients could improve significantly.

The equations in Tables 4.46 through 4.48 at different distances from the wetland edge (depending on the type of wetland) can be used by a state department of transportation to evaluate the impact of alternative ROW locations on amphibian habitat. These equations can be used as a tool for initial assessment to locate roads minimizing impacts to wetland health. This is important because some amphibian species are declining which makes it a priority to conserve intact the surrounding land of the wetland.

The ACI values for pair wetlands are generally larger (mean of 3.20) than the ACI values of non-pair wetlands (mean of 2.29). This means that pair wetlands have a greater capacity to support rare or sensitive species (i.e., sensitive to disturbance). However, high ACI values can be the result of a larger number of less sensitive species or a smaller number of sensitive species. This should be taken into consideration if a pair wetland will be impacted versus a non-pair wetland. While all wetlands are important, pair wetlands may provide a greater contribution to a healthy habitat than the non-pair wetlands.

5.2. Future work

Future research should be address:

- Analysis should include other landscape parameters, such as developed areas (urbanized areas).

- Non-landscape parameters should be incorporated in the regression equations such as: pH, dissolved oxygen and total nitrogen as well as other landscape parameter such as slope, which could increase the variability of ACI.
- The regression equations to predict ACI need to be calibrated. This will require additional biological data and spatial data.
- The combination of normalized landscape variables at different scales (e.g., analyzing the significance of a combination of variables at 300 m and 600 m) could help to predict the variability of ACI more accurately.

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APPENDIX A. MINITAB 15 PROCEDURE FOR LINEAR REGRESSIONS

1. Start Minitab.
2. Go to file>Open> Worksheet (Figure A.1)
3. Choose the file of interest and Figure A.1 will appear.

	C1	C2-T SITE_NAME	C3-T AGENCY	C4-T COUNTY	C5 AREA	C6 ACI	C7 AGE	C8 Sage	C9 Crops Sum 300	C10 Crops Sum 300 /150	C11 Crops Sum 600	C12 Crops Sum 600/45
1	1	Rose Pond 4-5 year old unit	MDC	Clark	1031	3.77	11	0.18182	154357	1029.05	518133	1151.4
2	2	Clark County 136	MoDOT	Clark	22607	0.00	18	0.30909	153207	1021.38	535470	1189.9
3	3	Putnam County 136	MoDOT	Putnam	2070	2.95	3	0.03636	130960	873.07	293395	651.9
4	4	Poosey	MDC	Livingston	974	1.24	27	0.47273	153979	1026.52	299105	664.6
5	5	Gallatin	MDC	Davies	192	2.46	37	0.65455	712	4.74	72233	160.5
6	6	Dunn Ford Small Forest Edge Pond	MDC	Marion	113	4.07	24	0.41818	723	4.82	239825	532.9
7	7	Henry Sever	MDC	Knox	387	2.00	48	0.85455	86886	579.24	331610	736.9
8	8	Diggs Koi Pond	MDC	Audrain	152	1.00	48	0.85455	110900	739.33	210785	468.4
9	9	Rudolph Bennitt	MDC	Randolph	337	1.33	46	0.81818	9317	62.11	12807	28.4
10	10	Prairie Home	MDC	Cooper	162	2.75	41	0.72727	69728	464.85	398659	885.9
11	11	Atlanta	MDC	Macon	654	1.09	46	0.81818	3660	24.40	49503	110.0
12	12	Little Dixie Herp Pond	MDC	Callaway	279	6.00	19	0.32727	5530	36.87	29758	66.1
13	13	Center Ralls County Wetland	MoDOT	Ralls	15936	2.27	10	0.16364	275848	1838.99	591107	1313.5
14	14	Shelby County T	MoDOT	Shelby	245	3.00	8	0.12727	108902	726.01	275620	612.4
15	15	Audrain County 15	MoDOT	Audrain	6189	1.90	3	0.03636	82768	551.79	233955	519.9
16	16	Macon T	MoDOT	Macon	784	2.70	33	0.58182	121171	807.80	115937	257.6
17	17	Macon 36	MoDOT	Macon	73931	2.48	3	0.03636	303342	2022.28	400738	890.5
18	18	Linn 36	MoDOT	Linn	53792	2.04	3	0.03636	327585	2183.90	711481	1581.0
19	19	Livingston 36	MoDOT	Livingston	4620	0.00	4	0.05455	233035	1553.57	601615	1336.9
20	20	Howard/Cooper 5	MoDOT	Howard	3026	1.97	7	0.10909	126178	841.19	273422	607.6
21	21	Carroll County 139	MoDOT	Carroll	185870	2.00	1	0.00000	277266	1848.44	529958	1177.6
22	22	Callaway 94	MoDOT	Callaway	3697	0.00	1	0.00000	275592	1837.28	511306	1136.2
23	23	Clay County Smithville Lake South	MoDOT/USACE	Clay	21633	2.31	4	0.05455	104225	694.83	278563	619.0
24	24	Clinton County Smithville Lake North	MoDOT/USACE	Clinton	37571	1.99	3	0.03636	102872	685.81	85429	189.8
25	25	Jackson County 40 Blue Springs	MoDOT	Jackson	16296	1.99	5	0.07273	19530	130.20	19674	43.7
26	26	Saline County 65/70	MoDOT	Saline	19079	2.48	2	0.01818	212377	1415.85	382082	849.0
27	27	Deer Ridge	MDC	Lewis	500	5.91	56	1.00000	18343	122.29	19891	44.2
28												
29												
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Figure A.1. Minitab 15 spreadsheet.

4. Go to Stat>Regression (Figure A.2).

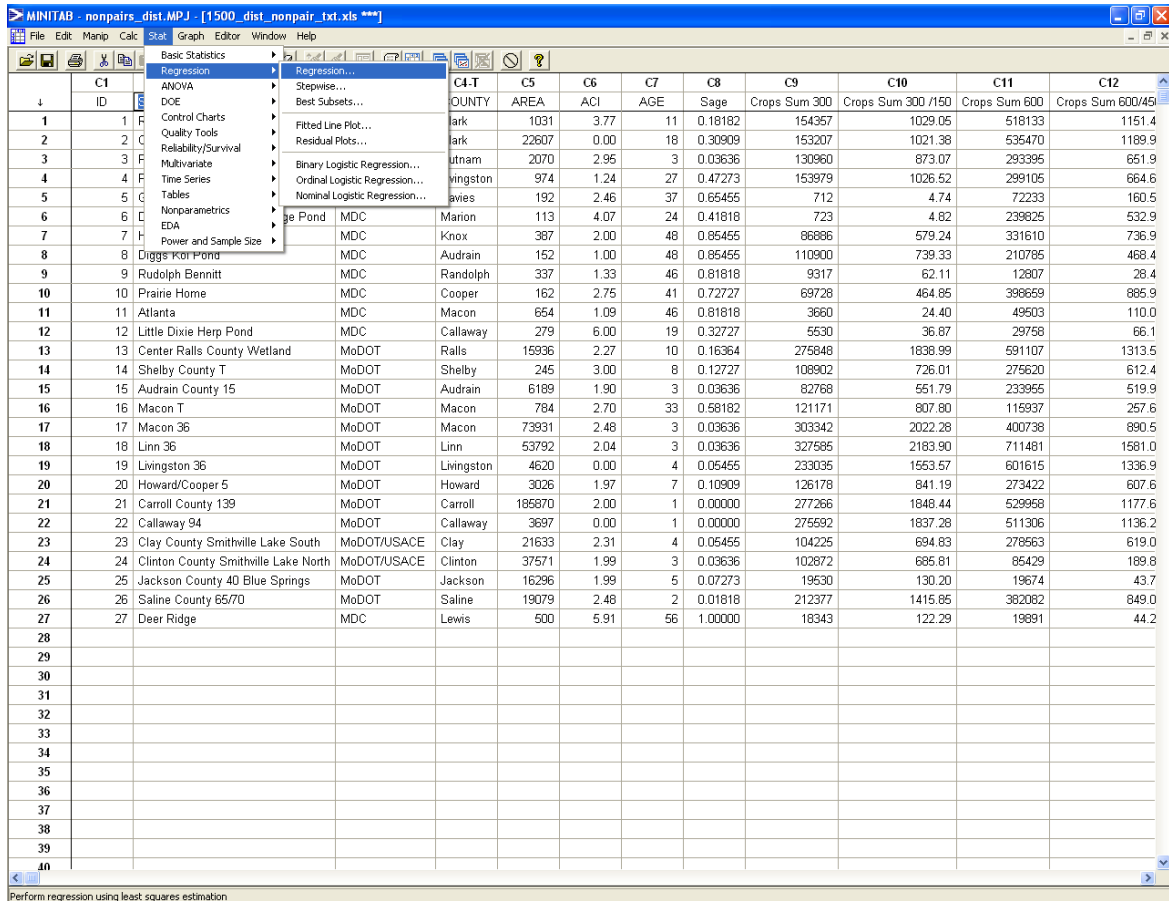


Figure A.2. Regression options.

5. The regression dialog box will appear (Figure A.3). The “Response” box is for the dependent variable and the “Predictors” box is for the independent variables.
6. Press “OK” and the software give the results for the linear equation (Figure 4 and Figure 5).

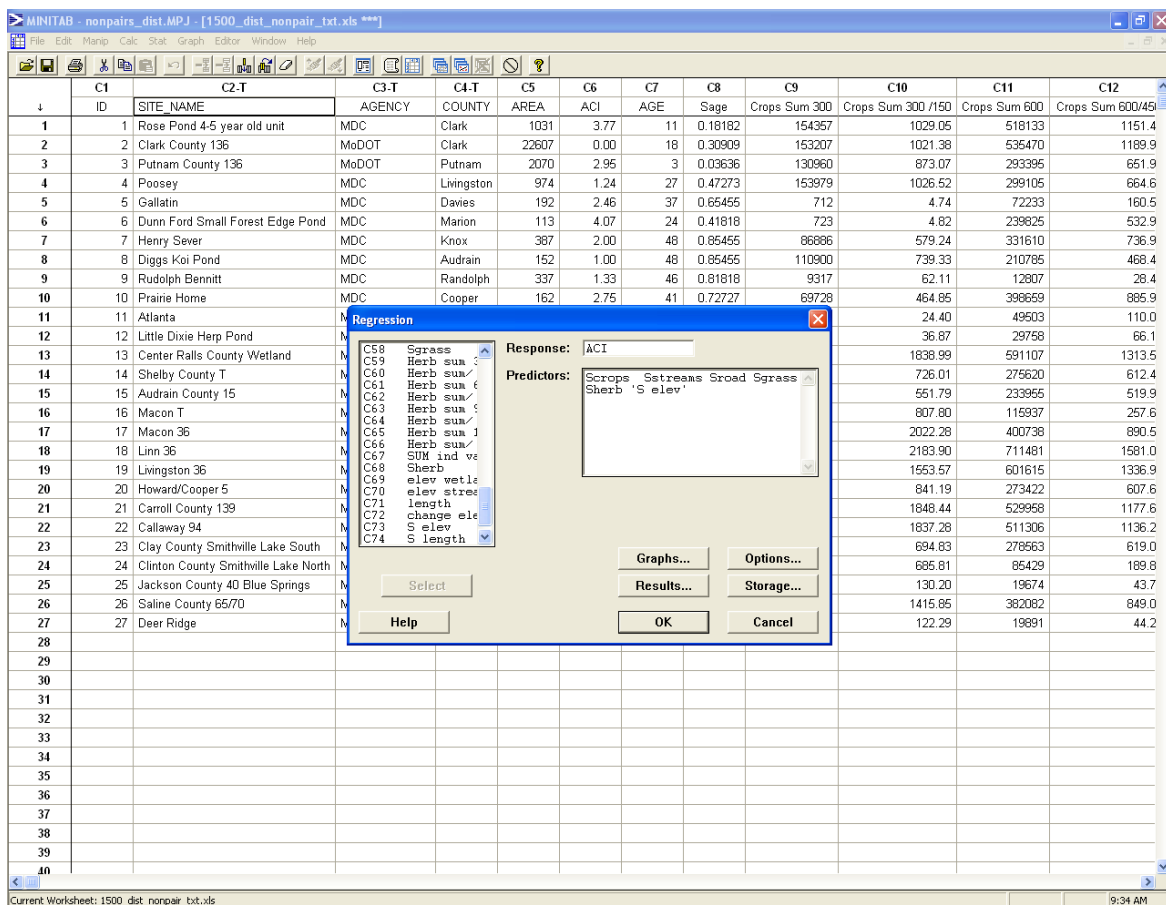


Figure A.3. Regression dialog box.

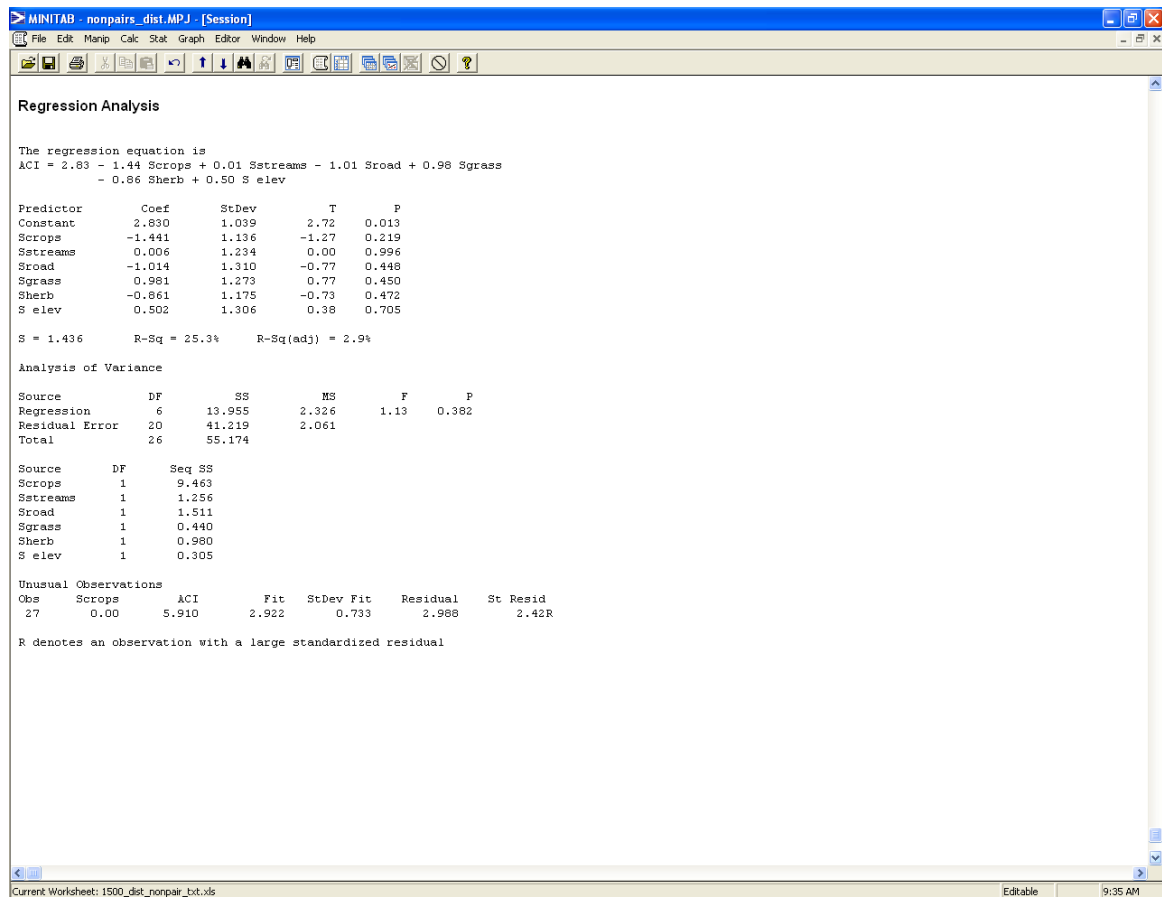


Figure A.4. Results for linear regression equation.

Regression Analysis

The regression equation is

$$\text{ACI} = 2.83 - 1.44 \text{ Scrops} + 0.01 \text{ Sstreams} - 1.01 \text{ Sroad} + 0.98 \text{ Sgrass} - 0.86 \text{ Sherb} + 0.50 \text{ S elev}$$

Predictor	Coef	StDev	T	P
Constant	2.830	1.039	2.72	0.013
Scrops	-1.441	1.136	-1.27	0.219
Sstreams	0.006	1.234	0.00	0.996
Sroad	-1.014	1.310	-0.77	0.448
Sgrass	0.981	1.273	0.77	0.450
Sherb	-0.861	1.175	-0.73	0.472
S elev	0.502	1.306	0.38	0.705

S = 1.436 R-Sq = 25.3% R-Sq(adj) = 2.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	13.955	2.326	1.13	0.382
Residual Error	20	41.219	2.061		
Total	26	55.174			

Source	DF	Seq SS
Scrops	1	9.463
Sstreams	1	1.256
Sroad	1	1.511
Sgrass	1	0.440
Sherb	1	0.980
S elev	1	0.305

Unusual Observations

Obs	Scrops	ACI	Fit	StDev Fit	Residual	St Resid
27	0.00	5.910	2.922	0.733	2.988	
2.42R						

R denotes an observation with a large standardized residual

Figure A. 5.Readable view of results for linear regression equation.

APPENDIX B. MINITAB 15 PROCEDURE PEARSON CORRELATION

1. Start Minitab.
2. Go to file>Open> Worksheet
3. Choose the file of interest and Figure 1 will appear.
4. Go to Stat>Basic Statistics>Correlation (Figure B.1).

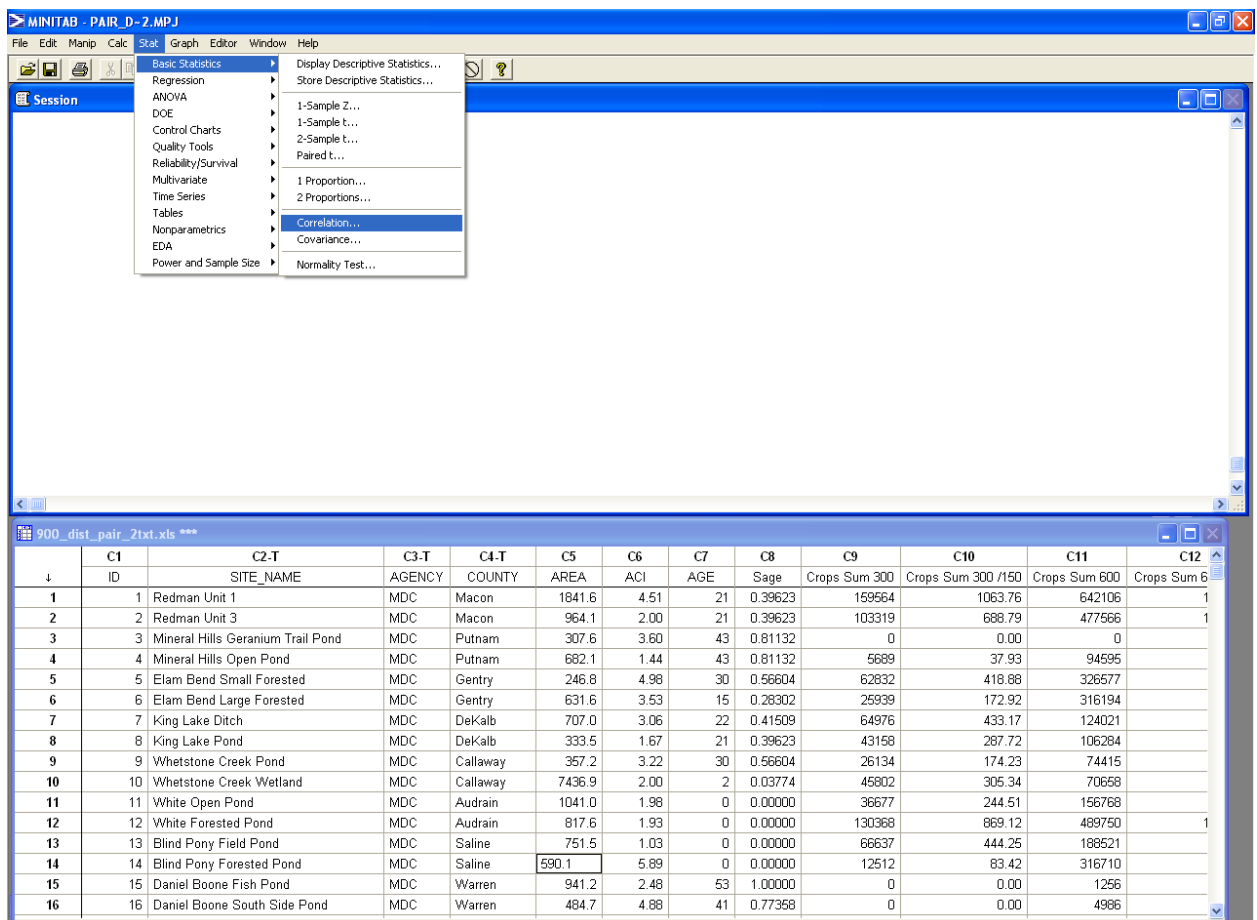


Figure B.1. Basic statistic options.

5. Specify the variables and press OK (Figure B.2).

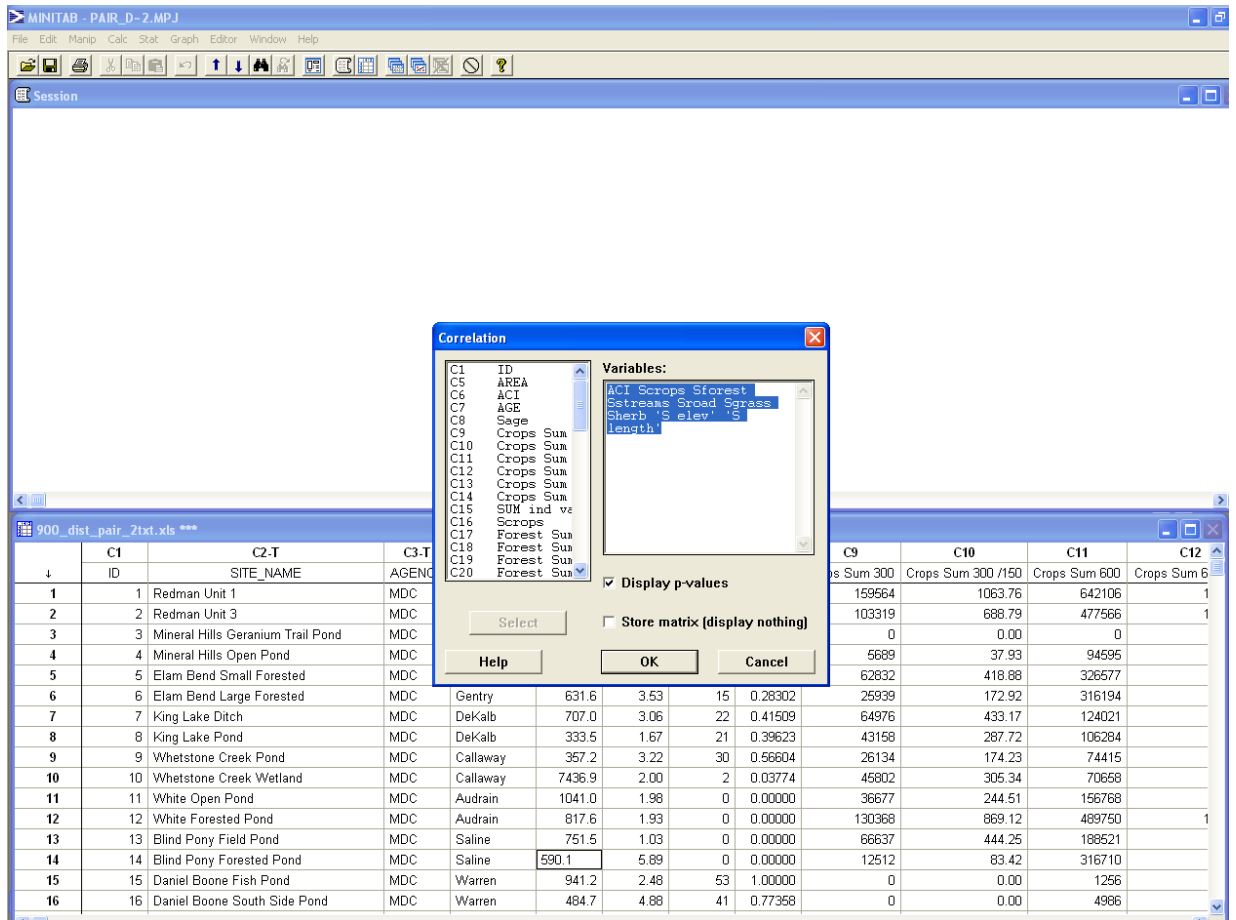


Figure B. 2. Correlation dialog box.

6. Correlation results (Figure B.3).

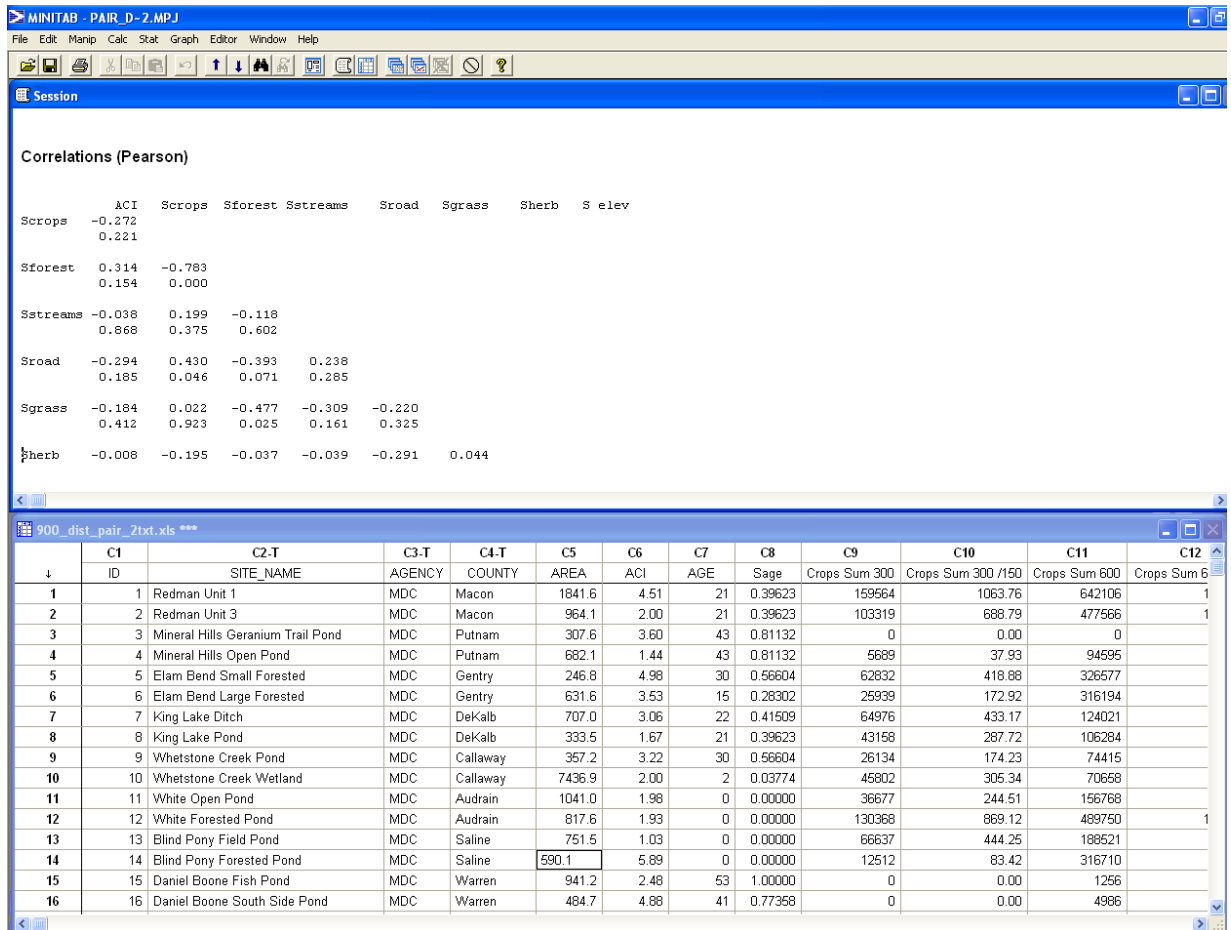


Figure B. 3. Correlation results.

APPENDIX C. NORMALIZATION WITH DISTANCE EXAMPLE.

Table C.1. Complete set of normalization with distance component applied for non-pairs wetlands at a scale of 600 m.

ID	SITE_NAME	AGENCY	COUNTY	AREA (m ²)	ACI	Crop area 300 m ring (m ²)
1	Rose Pond 4-5 year old unit	MDC	Clark	1031.356	3.77	154357.0000
2	Clark County 136	MoDOT	Clark	22607.218	0	153206.5000
3	Putnam County 136	MoDOT	Putnam	2069.803	2.95	130960.2400
4	Poosey	MDC	Livingston	973.771	1.24	153978.6000
5	Gallatin	MDC	Davies	192.028	2.46	711.7000
6	Dunn Ford Small Forest Edge Pond	MDC	Marion	113.024	4.07	722.9100
7	Henry Sever	MDC	Knox	386.897	2	86885.6300
9	Rudolph Bennitt	MDC	Randolph	337.246	1.33	9316.9400
10	Prairie Home	MDC	Cooper	162.259	2.75	69728.1800
11	Atlanta	MDC	Macon	654.223	1.09	3660.2100
12	Little Dixie Herp Pond	MDC	Callaway	279.358	6	5530.1500
13	Center Ralls County Wetland	MoDOT	Ralls	15935.771	2.27	275848.3100
14	Shelby County T	MoDOT	Shelby	244.938	3	108902.1700
15	Audrain County 15	MoDOT	Audrain	6188.866	1.9	82768.3500
16	Macon T	MoDOT	Macon	784.187	2.7	121170.5700
17	Macon 36	MoDOT	Macon	73931.388	2.48	303341.7900
18	Linn 36	MoDOT	Linn	53792.127	2.04	327585.2200
19	Livingston 36	MoDOT	Livingston	4620.178	0	233034.7500
20	Howard/Cooper 5	MoDOT	Howard	3026.394	1.97	126178.3000
21	Carroll County 139	MoDOT	Carroll	185869.99	2	277266.0500
22	Callaway 94	MoDOT	Callaway	3696.938	0	275592.3500
23	Clay County Smithville Lake South	MoDOT/USACE	Clay	21632.651	2.31	104224.5400
24	Clinton County Smithville Lake North	MoDOT/USACE	Clinton	37571.13	1.99	102871.8100
25	Jackson County 40 Blue Springs	MoDOT	Jackson	16296.253	1.99	19530.2500
26	Saline County 65/70	MoDOT	Saline	19078.72	2.48	212377.3000
27	Deer Ridge	MDC	Lewis	499.911	5.91	18343.0000

Table C.1. Complete set of normalization with distance component applied for non-pairs wetlands at a scale of 600 m (cont.).

ID	Crop area independent variable 300 m ring/150 m (m ² /m)	Crop area 600 m ring(m ²)	Crop area independent variable 600 m ring/450 m (m ² /m)	Sum independent variable (m ² /m)	Scrops	Forest area 300 m ring (m ²)
1	1029.0467	518133.2665	1151.4073	2180.4539	0.5688	0.0000
2	1021.3767	535470.2902	1189.9340	2211.3106	0.5772	46189.5920
3	873.0683	293395.3935	651.9898	1525.0580	0.3904	18164.5452
4	1026.5240	299104.7841	664.6773	1691.2013	0.4356	487.4855
5	4.7447	72233.4581	160.5188	165.2635	0.0203	111299.4900
6	4.8194	239825.3051	532.9451	537.7645	0.1217	0.0000
7	579.2375	331609.6600	736.9104	1316.1479	0.3335	45284.6794
8	739.3333	210784.8691	468.4108	1207.7441	0.3040	36140.0526
9	62.1129	12806.6769	28.4593	90.5722	0.0000	240451.3147
10	464.8545	398658.8973	885.9087	1350.7632	0.3430	78884.5408
11	24.4014	49502.9034	110.0065	134.4079	0.0119	198915.4905
12	36.8677	29757.8790	66.1286	102.9963	0.0034	83406.8970
13	1838.9887	591107.3091	1313.5718	3152.5605	0.8333	762.0208
14	726.0145	275619.7200	612.4883	1338.5027	0.3396	6432.1734
15	551.7890	233955.4933	519.9011	1071.6901	0.2670	93892.9546
16	807.8038	115936.8396	257.6374	1065.4412	0.2653	48141.1337
17	2022.2786	400737.7700	890.5284	2912.8070	0.7681	72262.5663
18	2183.9015	711481.3868	1581.0697	3764.9712	1.0000	19565.2754
19	1553.5650	601614.8513	1336.9219	2890.4869	0.7620	0.0000
20	841.1887	273421.6737	607.6037	1448.7924	0.3696	0.0000
21	1848.4403	529957.7400	1177.6839	3026.1242	0.7989	77635.3370
22	1837.2823	511306.3772	1136.2364	2973.5187	0.7846	15753.2900
23	694.8303	278563.1027	619.0291	1313.8594	0.3329	62657.6600
24	685.8121	85428.9071	189.8420	875.6541	0.2137	0.0000
25	130.2017	19674.4880	43.7211	173.9228	0.0227	26433.7310
26	1415.8487	382081.6928	849.0704	2264.9191	0.5918	76930.2100
27	122.2867	19891.0883	44.2024	166.4891	0.0207	125343.8100

Table C.1. Complete set of normalization with distance component applied for non-pairs wetlands at a scale of 600 m (cont.).

ID	Forest area independent variable 300 m ring/150 m (m ² /m)	Forest area 600 m ring(m ²)	Forest area independent variable 600 m ring/450 m (m ² /m)	Sum independent variable (m ² /m)	Sforest	Stream length 300 m ring (m ²)
1	0.0000	23506.6000	52.2369	52.2369	0.0165	0.0000
2	307.9306	72622.0000	161.3822	469.3128	0.1480	1167.8981
3	121.0970	31114.0000	69.1422	190.2392	0.0600	623.6087
4	3.2499	17411.7000	38.6927	41.9426	0.0132	0.0000
5	741.9966	205792.6000	457.3169	1199.3135	0.3781	0.0000
6	0.0000	248007.8000	551.1284	551.1284	0.1738	111.4591
7	301.8979	38079.6600	84.6215	386.5193	0.1219	0.0000
8	240.9337	311858.7000	693.0193	933.9530	0.2944	0.0000
9	1603.0088	706001.0000	1568.8911	3171.8999	1.0000	0.0000
10	525.8969	236645.9000	525.8798	1051.7767	0.3316	0.0000
11	1326.1033	330457.2000	734.3493	2060.4526	0.6496	0.0000
12	556.0460	150814.3500	335.1430	891.1890	0.2810	0.0000
13	5.0801	4702.3000	10.4496	15.5297	0.0049	0.0000
14	42.8812	69764.3000	155.0318	197.9129	0.0624	0.0000
15	625.9530	261154.4600	580.3432	1206.2963	0.3803	0.0000
16	320.9409	159487.2400	354.4161	675.3570	0.2129	685.6806
17	481.7504	208102.7366	462.4505	944.2010	0.2977	841.3324
18	130.4352	26789.0000	59.5311	189.9663	0.0599	973.6717
19	0.0000	5400.0000	12.0000	12.0000	0.0038	633.8523
20	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	517.5689	54053.3473	120.1185	637.6875	0.2010	0.0000
22	105.0219	15753.2992	35.0073	140.0293	0.0441	0.0000
23	417.7177	62657.6699	139.2393	556.9570	0.1756	0.0000
24	0.0000	137560.1251	305.6892	305.6892	0.0964	723.5559
25	176.2249	26433.7486	58.7417	234.9665	0.0741	0.0000
26	512.8681	76930.2306	170.9561	683.8241	0.2156	757.9044
27	835.6254	486102.0000	1080.2267	1915.8521	0.6040	0.0000

Table C.1. Complete set of normalization with distance component for non-pairs wetlands at a scale of 600 m (cont.).

ID	Stream length independent variable 300 m ring/150 m (m ² /m)	Stream length 600 m ring(m ²)	Stream length independent variable 600 m ring/450 m (m/m)	Sum Stream length independent variable (m/m)	Sstream
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	7.7860	1530.6328	3.4014	11.1874	1.0000
3	4.1574	724.0820	1.6091	5.7665	0.5154
4	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.7431	1511.2976	3.3584	4.1015	0.3666
7	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	123.7769	0.2751	0.2751	0.0246
12	0.0000	0.0000	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000
16	4.5712	846.2333	1.8805	6.4517	0.5767
17	5.6089	670.4062	1.4898	7.0987	0.6345
18	6.4911	647.2078	1.4382	7.9294	0.7088
19	4.2257	1461.8427	3.2485	7.4742	0.6681
20	0.0000	1063.8630	2.3641	2.3641	0.2113
21	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000	0.0000	0.0000
24	4.8237	971.6800	2.1593	6.9830	0.6242
25	0.0000	0.0000	0.0000	0.0000	0.0000
26	5.0527	824.0700	1.8313	6.8840	0.6153
27	0.0000	0.0000	0.0000	0.0000	0.0000

Table C.1. Complete set of normalization with distance component for non-pairs wetlands at a scale of 600 m (cont.).

ID	Road length 300 m ring (m ²)	Road length independent variable 300 m ring/150 m (m ² /m)	Road length 600 m ring(m ²)	Road length independent variable 600 m ring/450 m (m/m)	Sum road length independent variable variable (m/m)
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	1014.4300	6.7629	596.0016	1.3244	8.0873
3	0.0000	0.0000	815.3942	1.8120	1.8120
4	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000
13	769.1385	5.1276	617.6358	1.3725	6.5001
14	0.0000	0.0000	0.0000	0.0000	0.0000
15	736.4148	4.9094	630.9265	1.4021	6.3115
16	0.0000	0.0000	0.0000	0.0000	0.0000
17	1069.3690	7.1291	595.7179	1.3238	8.4529
18	1710.5993	11.4040	1221.5160	2.7145	14.1185
19	1798.2589	11.9884	1199.1176	2.6647	14.6531
20	920.6292	6.1375	926.2257	2.0583	8.1958
21	1177.1570	7.8477	604.0200	1.3423	9.1900
22	738.7890	4.9253	614.1670	1.3648	6.2901
23	0.0000	0.0000	0.0000	0.0000	0.0000
24	0.0000	0.0000	0.0000	0.0000	0.0000
25	1561.9920	10.4133	1256.4323	2.7921	13.2054
26	0.0000	0.0000	1560.0700	3.4668	3.4668
27	0.0000	0.0000	0.0000	0.0000	0.0000

Table C.1. Complete set of normalization with distance component for non-pairs wetlands at a scale of 600 m (cont.).

ID	Sstream	elevation wetland centroid (m)	elevation stream stream (m)	length of flowpath (m)	change elevation (m)	S change elevation	S length of flowpath	Slandscape
1	0.0000	497.0000	480.0000	11229.9066	17.0000	0.0591	0.5146	0.2868
2	0.5519	521.0000	518.0000	1331.5739	3.0000	0.0039	0.0591	0.0315
3	0.1237	903.0000	886.0000	359.1227	17.0000	0.0591	0.0143	0.0367
4	0.0000	820.0000	790.0000	834.5974	30.0000	0.1102	0.0362	0.0732
5	0.0000	872.0000	708.0000	18053.3009	164.0000	0.6378	0.8286	0.7332
6	0.0000	621.0000	579.0000	306.3140	42.0000	0.1575	0.0119	0.0847
7	0.0000	721.0000	629.0000	4620.4259	92.0000	0.3543	0.2104	0.2824
8	0.0000	787.0000	583.0000	21777.5333	204.0000	0.7953	1.0000	0.8976
9	0.0000	820.0000	730.0000	1779.1727	90.0000	0.3465	0.0797	0.2131
10	0.0000	870.0000	614.0000	9592.6273	256.0000	1.0000	0.4392	0.7196
11	0.0000	856.0000	793.0000	1893.9662	63.0000	0.2402	0.0849	0.1626
12	0.0000	837.0000	718.0000	7148.3412	119.0000	0.4606	0.3268	0.3937
13	0.4436	711.0000	559.0000	8942.5201	152.0000	0.5906	0.4093	0.4999
14	0.0000	658.0000	630.0000	8116.3962	28.0000	0.1024	0.3713	0.2368
15	0.4307	722.0000	720.0000	1730.5447	2.0000	0.0000	0.0774	0.0387
16	0.0000	726.0000	720.0000	48.0796	6.0000	0.0157	0.0000	0.0079
17	0.5769	748.0000	741.0000	1264.9600	7.0000	0.0197	0.0560	0.0378
18	0.9635	723.0000	720.0000	431.9036	3.0000	0.0039	0.0177	0.0108
19	1.0000	697.0000	669.0000	360.5449	28.0000	0.1024	0.0144	0.0584
20	0.5593	586.0000	575.0000	824.7586	11.0000	0.0354	0.0357	0.0356
21	0.6272	651.0000	630.0000	11425.6056	21.0000	0.0748	0.5236	0.2992
22	0.4293	521.0000	515.0000	1192.6197	6.0000	0.0157	0.0527	0.0342
23	0.0000	867.0000	810.0000	11001.0564	57.0000	0.2165	0.5041	0.3603
24	0.0000	885.0000	859.0000	542.2882	26.0000	0.0945	0.0227	0.0586
25	0.9012	768.0000	750.0000	3657.6166	18.0000	0.0630	0.1661	0.1146
26	0.2366	619.0000	608.0000	208.1734	11.0000	0.0354	0.0074	0.0214
27	0.0000	726.0000	579.0000	4698.0311	147.0000	0.5709	0.2140	0.3924

APPENDIX D. NORMALIZATION IGNORING DISTANCE EXAMPLE.

Table D.1. Complete set of normalization ignoring distance component applied for non-pairs wetlands at a scale of 600 m.

ID	SITE_NAME	AGENCY	COUNTY	AREA (m ²)	ACI	Crops area 300 m ring (m ²)	Crops area 600 m ring(m ²)
1	Rose Pond 4-5 year old unit	MDC	Clark	1031.3560	3.77	154357.0000	518133.2665
2	Clark County 136	MoDOT	Clark	22607.2180	0.00	153206.5000	535470.2902
3	Putnam County 136	MoDOT	Putnam	2069.8030	2.95	130960.2400	293395.3935
4	Poosey	MDC	Livingston	973.7710	1.24	153978.6000	299104.7841
5	Gallatin	MDC	Davies	192.0280	2.46	711.7000	72233.4581
6	Dunn Ford Small Forest Edge Pond	MDC	Marion	113.0240	4.07	722.9100	239825.3051
7	Henry Sever	MDC	Knox	386.8970	2.00	86885.6300	331609.6600
8	Diggs Koi Pond	MDC	Audrain	152.3190	1.00	110899.9900	210784.8691
9	Rudolph Bennitt	MDC	Randolph	337.2460	1.33	9316.9400	12806.6769
10	Prairie Home	MDC	Cooper	162.2590	2.75	69728.1800	398658.8973
11	Atlanta	MDC	Macon	654.2230	1.09	3660.2100	49502.9034
12	Little Dixie Herp Pond	MDC	Callaway	279.3580	6.00	5530.1500	29757.8790
13	Center Ralls County Wetland	MoDOT	Ralls	15935.7710	2.27	275848.3100	591107.3091
14	Shelby County T	MoDOT	Shelby	244.9380	3.00	108902.1700	275619.7200
15	Audrain County 15	MoDOT	Audrain	6188.8660	1.90	82768.3500	233955.4933
16	Macon T	MoDOT	Macon	784.1870	2.70	121170.5700	115936.8396
17	Macon 36	MoDOT	Macon	73931.3880	2.48	303341.7900	400737.7700
18	Linn 36	MoDOT	Linn	53792.1270	2.04	327585.2200	711481.3868
19	Livingston 36	MoDOT	Livingston	4620.1780	0.00	233034.7500	601614.8513
20	Howard/Cooper 5	MoDOT	Howard	3026.3940	1.97	126178.3000	273421.6737
21	Carroll County 139	MoDOT	Carroll	185869.9860	2.00	277266.0500	529957.7400
22	Callaway 94	MoDOT	Callaway	3696.9380	0.00	275592.3500	511306.3772
23	Clay County Smithville Lake South	MoDOT/USACE	Clay	21632.6510	2.31	104224.5400	278563.1027
24	Clinton County Smithville Lake North	MoDOT/USACE	Clinton	37571.1300	1.99	102871.8100	85428.9071
25	Jackson County 40 Blue Springs	MoDOT	Jackson	16296.2530	1.99	19530.2500	19674.4880
26	Saline County 65/70	MoDOT	Saline	19078.7200	2.48	212377.3000	382081.6928
27	Deer Ridge	MDC	Lewis	499.9110	5.91	18343.0000	19891.0883

Appendix D.1. Complete set of normalization ignoring distance component for non-pairs wetlands at a scale of 600 m (cont.).

ID	Sstreams	Roads 300m ring (m)	Roads 600m ring (m)	Sum Road 300 m+ 600 m rings(m)	Sroad	elevation wetland centroid (m)	elevation stream stream (m)	length of flowpath (m)	change elevation (m)
1	0.0000	0.0000	0.0000	0.0000	0.0000	497.0000	480.0000	11229.9066	17.0000
2	1.0000	1014.4300	596.0016	1610.4316	0.5373	521.0000	518.0000	1331.5739	3.0000
3	0.4994	0.0000	815.3942	815.3942	0.2720	903.0000	886.0000	359.1227	17.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000	820.0000	790.0000	834.5974	30.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000	872.0000	708.0000	18053.3009	164.0000
6	0.6013	0.0000	0.0000	0.0000	0.0000	621.0000	579.0000	306.3140	42.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000	721.0000	629.0000	4620.4259	92.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	787.0000	583.0000	21777.5333	204.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	820.0000	730.0000	1779.1727	90.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	870.0000	614.0000	9592.6273	256.0000
11	0.0459	0.0000	0.0000	0.0000	0.0000	856.0000	793.0000	1893.9662	63.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	837.0000	718.0000	7148.3412	119.0000
13	0.0000	769.1385	617.6358	1386.7743	0.4627	711.0000	559.0000	8942.5201	152.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	658.0000	630.0000	8116.3962	28.0000
15	0.0000	736.4148	630.9265	1367.3413	0.4562	722.0000	720.0000	1730.5447	2.0000
16	0.5677	0.0000	0.0000	0.0000	0.0000	726.0000	720.0000	48.0796	6.0000
17	0.5602	1069.3690	595.7179	1665.0869	0.5555	748.0000	741.0000	1264.9600	7.0000
18	0.6007	1710.5993	1221.5160	2932.1153	0.9782	723.0000	720.0000	431.9036	3.0000
19	0.7766	1798.2589	1199.1176	2997.3765	1.0000	697.0000	669.0000	360.5449	28.0000
20	0.3942	920.6292	926.2257	1846.8549	0.6162	586.0000	575.0000	824.7586	11.0000
21	0.0000	1177.1570	604.0200	1781.1770	0.5942	651.0000	630.0000	11425.6056	21.0000
22	0.0000	738.7890	614.1670	1352.9560	0.4514	521.0000	515.0000	1192.6197	6.0000
23	0.0000	0.0000	0.0000	0.0000	0.0000	867.0000	810.0000	11001.0564	57.0000
24	0.6282	0.0000	0.0000	0.0000	0.0000	885.0000	859.0000	542.2882	26.0000
25	0.0000	1561.9920	1256.4323	2818.4243	0.9403	768.0000	750.0000	3657.6166	18.0000
26	0.5862	0.0000	1560.0700	1560.0700	0.5205	619.0000	608.0000	208.1734	11.0000
27	0.0000	0.0000	0.0000	0.0000	0.0000	726.0000	579.0000	4698.0311	147.0000

Appendix D.1. Complete set of normalization ignoring distance component for non-pairs wetlands at a scale of 600 m (cont.)

ID	S change elevation	S length of flowpath	Slandscape
1	0.0591	0.5146	0.2868
2	0.0039	0.0591	0.0315
3	0.0591	0.0143	0.0367
4	0.1102	0.0362	0.0732
5	0.6378	0.8286	0.7332
6	0.1575	0.0119	0.0847
7	0.3543	0.2104	0.2824
8	0.7953	1.0000	0.8976
9	0.3465	0.0797	0.2131
10	1.0000	0.4392	0.7196
11	0.2402	0.0849	0.1626
12	0.4606	0.3268	0.3937
13	0.5906	0.4093	0.4999
14	0.1024	0.3713	0.2368
15	0.0000	0.0774	0.0387
16	0.0157	0.0000	0.0079
17	0.0197	0.0560	0.0378
18	0.0039	0.0177	0.0108
19	0.1024	0.0144	0.0584
20	0.0354	0.0357	0.0356
21	0.0748	0.5236	0.2992
22	0.0157	0.0527	0.0342
23	0.2165	0.5041	0.3603
24	0.0945	0.0227	0.0586
25	0.0630	0.1661	0.1146
26	0.0354	0.0074	0.0214
27	0.5709	0.2140	0.3924

VITA

Miriam Romero was born in Mayaguez, Puerto Rico in 1975. She graduated from high school in 1993. She attended the University of Puerto Rico, where she received her BSCE and MSCE in 1999 and 2002, respectively. After this, she attended the University of Missouri at Columbia, where she earned her Ph.D. in Civil and Environmental Engineering in 2010. She lives with her husband, José J. Rodriguez and her son, Iván Andrés Rodríguez Romero, who was born in 2009, while she was finishing her Ph.D.