MODELING ECOSYSTEM FUNCTIONS TO PRIORITIZE POTENTIAL WETLAND MITIGATION SITES IN GEORGIA

by

STEPHEN MOORE CARPENEDO

(Under the Direction of Elizabeth Kramer)

ABSTRACT

Compensatory wetland mitigation in the United States has been used as a means to achieve no-net-loss of wetland acreage and functions resulting from impacts to wetlands. Current methods employed in mitigation site selection may satisfy the no-net-loss of wetland acreage, but not the loss of wetland functions. The functions provided by wetlands are dependent upon their size, structure, spatial location and configuration within the landscape. The National Research Council recognized this, and identified the need for watershed-based planning tools to increase the effectiveness of wetland mitigation. Following their recommendations, I developed a GIS watershed-based planning tool for increasing the effectiveness of wetland mitigation in Georgia. The watershed-based planning tool identifies and ranks the spatial location and configuration of wetlands based on the ecosystem functions they provide. Identifying and ranking priority areas gives resource managers a more effective tool to select mitigation sites that will achieve the objectives of no-net-loss.

INDEX WORDS: Wetlands, Compensatory Mitigation, Ecosystem Functions, Amphibian Conservation, Connectivity, GIS, Spatial Analysis Modeling, Spatial Location and Configuration of Wetlands

MODELING ECOSYSTEM FUNCTIONS TO PRIORITIZE POTENTIAL WETLAND MITIGATION SITES IN GEORGIA

by

STEPHEN MOORE CARPENEDO

B.A., Gustavus Adolphus College, 1996

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTERS OF SCIENCE

ATHENS, GEORGIA

2008

MODELING ECOSYSTEM FUNCTIONS TO PRIORITIZE POTENTIAL WETLAND MITIGATION SITES IN GEORGIA

by

STEPHEN MOORE CARPENEDO

Major Professor: Elizabeth Kramer

Committee: John Maerz
Rhett Jackson

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
May 2008

DEDICATION

To my wife, Dorota, for all of her help, support and understanding.

ACKNOWLEDGEMENTS

I would like to thank the members of the Technical Steering Committee for their contributions during of this project. They include but are not limited to: Mike Gleaton from DCA, Brent Dykes Georgia Soil and Water Conservation Commission, Tom Welborn - USEPA; Jennifer Derby - USEPA; Mark Nuhfer – USEPD; Keith Parsons GAEPD; David Crosby US Army COE; Tim Lowrimore GA Forestry Assoc.; Malcolm Hodges - TNC; Mara Lindsley from DOT; Frank Green from GFC; Jon Ambrose and Matt Elliot from WRD; Jan MicKinnon and Dom Guadganoli – CRD, Kathy Chapman USFWS, Keith Wooster – USDA NRCS. To the staff of the EPD who coordinated this project, Alice Miller Keyes and Bennett Weinstein. Carol Couch, director of the EPD, for her help and comments on the many drafts and papers associated with my thesis. Dr. Jeff Hepinstall for reviewing my simulation modeling chapter. Kevin Samples for the invaluable amount of help he provided throughout this project. To my committee members, Rhett Jackson and John Maerz for their time, effort, expertise and guidance they provided to me in this project. And finally and most importantly, Liz Kramer, for giving me this opportunity and all of the guidance and support she provided.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

This thesis is structured in five different chapters. Chapters 1 – 3 introduce the background, methods and preliminary results of the Potential Wetland Restoration Site Index that was developed to identify wetland mitigation sites that would have the greatest benefit. Chapter 4 is a standalone manuscript that takes one of the methods from the Potential Wetland Restoration Site Index, and conducts a more in-depth analysis of the methods and potential management implications. Chapter 5 concludes with a discussion of the major results from chapters 3 and 4 and their implications on wetland mitigation in the State of Georgia.

LITERATURE REVIEW

Wetlands in the United States play a vital role in the health not only of our ecosystems but also the health of the population in general. In the past, the ecosystem services provided by wetlands went largely unappreciated and as a result many of our wetlands were converted to other land uses. In general, wetlands have been considered as unproductive lands that should be converted to "profitable" land uses such as agriculture or silviculture. In fact, through the Swamp Land Act of 1850, the federal government encouraged states to reclaim wetlands and make them suitable for agriculture (Somerville & Pruitt 2006). Wetlands have also been considered as breeding sites of disease and thus landscapes to be eradicated (Mitsch & Gosselink 1993; Zimmerman 2001). This has particularly evident in the case of draining wetlands to control mosquitoes which are the vector of malaria (Kitron & Spielman 1989). That is not to say that historically all wetlands were considered worthless.

Tangible values of a wetland or any habitat help to ensure its protection. The tangible values of wetlands are as not easily seen as in other habitat types. Only in a few instances where wetlands provided food stuffs were these visible. Many of the wetlands and shallow rivers in the upper Midwest produced wild rice, a staple of the Native Americans and early settlers (Oelke 1993). Until more intensive and advanced forms of agriculture were introduced these wetlands remained "protected" as a vital resource. Less tangible, yet most important, are the benefits that wetlands provide, such as protecting water quality, flood abatement and maintain flows in streams and rivers. Costanza et al. (1997) estimated that these functions provided by wetlands are equivalent to 14.9 trillion dollars worldwide, and that wetlands in general provide a greater dollar per acre benefit to society than almost any other landcover (USEPA 2006a). Regardless of their tangible values, wetlands were not seen as vital resources and protecting them was not commonly practiced.

As a result of this prevailing attitude, it is estimated that 53% of our wetland acreage was lost in the continental United States from 1780 – 1980. 21 out of 48 states lost at least 50% of their wetlands with two states, California and Ohio, losing 90% or more. Only one state, New Hampshire, lost less then 20% of its original wetland acreage in 200 years. During this time period only three states converted less wetland acreage to other landcovers than did Georgia. Georgia converted approximately 1.5 million acres or 23% of its wetlands in this period (Dahl 1990). Kramer et al. (2007) reported that from 1974 to 1998 Georgia converted an additional 16.2% of its remaining freshwater wetlands at a rate six times greater than the historical rate. Agriculture has generally been considered the main culprit in wetland conversion, for this 24 year period in Georgia it accounted for only 5.4% of the change in wetland acreage (*unpublished data*). The majority of converted wetlands (66.1%) were as a result of silviculture (Figure 1.1). The protection of wetlands in the United States, while in only more recent times formally enacted into law, has its roots in legislation dating back more than a century.

Starting in 1899 with Section 10 of the Rivers and Harbors Act (33 U.S.C § 403) (RHA), the U.S. Army Corps of Engineers (USACE) began regulating dredging and fill activities that impacted navigable waters. The protection of wetlands was only taken under consideration when dredge and fill activities would negatively impact navigable waterways (NRC 2001). During this period, and today, rivers and harbors were extensively used as interstate transportation corridors for commerce. At the time, most states had little to no regulations regarding the destruction of wetlands, or modification of hydrological systems. In fact, the governmental system in the United States was designed so that the federal government had few means to regulate the land use activities within a state. It was realized that the impact to navigable waterways within one state may impede the flow of commerce from upstream states and thus infringe upon their basic rights, giving the federal government jurisdiction over navigable waterways. It was under this pretext of commerce that the protection of wetlands in the United States was first passed in to law.

While a limited form of protection of wetlands, as it related to commerce, was enacted in 1899, it was not until 35 years later with the 1934 Fish and Wildlife

Coordination Act (16 U.S.C § 661-667e; March 10, 1934; Ch. 55; 48 Stat. 401) (FWCA) that impacts to fish and wildlife were considered from wetland conversion. This Act did not enact laws regarding wetland impacts, but required that consultations on dredge and fill activities be undertaken to determine the impacts on fish and wildlife. The FWCA did not require the USACE to incorporate these consultations, only to consider them. As a result, only in extraordinary circumstances were impacts other than those to navigation considered (NRC 2001). In the intervening years between the passage of the Fish and Wildlife and Coordination Act and the late 1960's no legislation was passed that substantial impacts on the regulation of wetlands. Starting in the late 1960's, the environmental legislation regulating the impacts to wetlands increased rapidly.

In 1967 through a Memorandum of Understanding (*Fed.-Reg.* 33(Dec18):18671) between the USACE and United States Fish and Wildlife Service (USFWS), the USACE agreed to evaluate impacts from pollution and dredge and fill activities on navigation, fish and wildlife, conservation areas, aesthetics, ecology and in the general interest of the health of the public (NRC 2001). The evaluation of impacts to these functions received further strength from the 1969 National Environmental Policy Act (42 U.S.C. § 4321 et seq.) (NEPA). Section 101 of NEPA requires that any action taken by a federal agency or funded with federal dollars show that impacts to the environment have been minimized and all feasible alternatives considered. The NEPA also requires federal agencies consider mitigation as measures for reducing the impact to natural resources (NRC 2001). The consideration of mitigation mentioned in NEPA, as defined by the Council on Environmental Quality (CEQ), formed the basis for current wetland mitigation practices (NRC 2001). By this point, regardless of the legislation already enacted, the waters of the United States had become increasingly polluted. So much so, that on June 22, 1969 the Cuyahoga River in Cleveland, Ohio caught fire from the industrial pollutants being dumped into it. In response to the degradation of our waters, the 1972 Federal Water Pollution Control Act (FWPCA) (33 U.S.C § 1251) was passed and with it ways to regulate impacts to wetlands when their destruction would negatively affect waters of the United States. During the same year, the Coastal Zone Management Act (16 U.S.C. § 1452[1],[2a]) was enacted with the explicit intent to protect and restore coastal wetlands.

Under the FWPCA, the waters of the United States were not clearly defined (Somerville & Pruitt 2006) and was interpreted by the USACE based on the limited definition given in the 1899 Rivers and Harbors Act. This limited definition and the USACE mandate to regulate waters of the United States was challenged in Natural Resources Defense Council (NRDC) v. Callaway (392 F. Supp. 685(D.D.C). 1975). The U.S. District Court for the District of Columbia sided with NRDC that waters of the state defined in the FWPCA included those not defined as traditionally navigable under the 1899 Rivers and Harbors Act (Somerville & Pruitt 2006). The major impact of this ruling was a change in the definition of waters of the state to specifically include tributaries of navigable waters and the wetlands adjacent to them as areas regulated by the USACE. Adjacent wetlands included those "bordering, contiguous [to] or neighboring" waters of the United States, even when wetlands are "separated from [such] waters…by man-made dikes…and the like" (33 C.F.R. § 328.3(c)). In another pivotal case involving the regulation of wetlands, the U.S. Supreme Court (United States v. Riverside Bay View Homes, 474 U.S. 121(1985)) upheld the USACE usage of the definition from Callaway as to what could be regulated as waters of the state (Macdonald

2007). Two other legal cases that have had impacts on the regulations of wetlands have come in much more recent times.

In 2001, Solid Waste Authority for Northern Cook County (SWANCC) v. USACE challenged the Army Corps of Engineers establishment of jurisdiction over isolated constructed wetlands based on their use by migratory birds (NRC 2001). The U.S. Supreme Court ruled that the "Migratory Bird Rule" was not a valid form of determining adjacency to navigable waters (Macdonald 2007). This ruling had the effect that the definition of what constitutes jurisdictional determinations of wetlands became one that is more legal than one that is hydrologically and ecologically relevant (Downing et al. 2003; van der Valk & Pederson 2003). The most current legal case are the consolidated cases of Rapanos v. United States and Carabell v. USACE (126 S. Ct. 2208 (2006)). Both Rapanos and Carabell challenged the after the fact penalizations for filling wetlands next to man-made, intermittent streams and flood control structures. The U.S. Supreme Court over turned the penalizations in both of these cases, but due to the lack of a majority ruling the outcomes have not had as much effect as originally anticipated (Macdonald 2007). The effect the Rapanos and Carabell cases have had is on how the USACE determines jurisdiction, and that they now have to on a case-by-case basis prove that a "significant nexus" exists between wetlands and navigable waters. Whereas before Rapanos and Carabell, jurisdictional designations of wetlands could be made by the class of wetlands and their likely impact on navigable waters of the state (Downing et al. 2003; Macdonald 2007). The legal challenges and precedents of the FWPCA have helped to define the role of the U.S. Army Corps of Engineers in wetland protection. The Federal

Water Pollution Control Act also outlines the steps necessary to mitigate the effects of impacts to wetlands on lost wetland functions and values.

The FWPCA was amended in 1977 and today is commonly known as the Clean Water Act. In 1977 when the Clean Water Act, 33 U.S. C. § 1344, (CWA) was enacted, one of its provisions was Section 404 which helped to regulate and mitigate for the dredging and filling of waters of the United States, including wetlands. Section 404 of the Clean Water Act, regulates only dredging and filling of wetlands, and has no jurisdiction over other activities that impact wetlands, such as agriculture and silviculture (NRC 2001). Section 404 also does not regulate activities that indirectly impact wetlands (NRC 2001). This is important as 56 % of wetlands loss from 1986 – 1997 in the conterminous United States were as a result of agriculture and forestry (Dahl 2000). During similar time periods, Kramer et al. (2007) found the percentage of wetlands converted to agricultural and silviculture in Georgia was even greater, 71% (Figure 1.1). Section 404 of the 1977 Clean Water Act does though provide regulatory mechanisms to mitigate the effects of impacts to wetlands on waters of the state.

The CEQ definition of mitigation requires that impacts to natural resources first be avoided and minimized is the premises in Section 404(b) and 403(c) for all decisions regarding wetland regulation and permitting. Originally the U.S. Environmental Protection Agency (USEPA) was charged with regulating impacts to wetlands but in 1989 through a Memorandum of Agreement the U.S. Army Corps of Engineers took over administration of the wetland regulatory program (USEPA 1989). Incorporated into the regulatory program, through Section 404b[1], is a permitting framework with the possibility of compensatory wetland mitigation to "help offset authorized losses of wetlands and other waters [of the state] by restoring, enhancing or creating wetlands and other waters to replace those lost acres and functions and values" (USEPA 2004). Prior to issuing any wetland impact permit the USACE evaluates three criteria: 1) Were all reasonable attempts to avoid impacts to wetlands taken; 2) Were all unavoidable impacts minimized to the greatest extent possible; and 3) For unavoidable impacts, have the necessary mitigation steps to compensate for wetland impacts been undertaken or planned. The purpose of my project deals only with mitigation and not the minimization of impacts [to], avoidance or preservation of wetlands. Creating new wetlands to mitigate for the loss of existing wetlands may not completely restore all wetland functions and values lost. Created wetlands, depending on their landscape position (NRC 2001), may also replace lost wetland functions and values with a completely different set of wetland functions and values, a trade off of ecosystem services (Rodŕiguez et al. 2006). While avoiding and minimizing impacts wetlands to maintain the functions and values they provide within a watershed is preferable, mitigation is an important tool to offset the loss of wetland functions and values from unavoidable impacts to wetlands.

One of the goals of Section 404 permitting and regulation is to satisfy the "no-net-loss" of wetland acreage and function. "No-net-loss" was proposed by the Conservation Fund in 1988 and officially established through the Water Resources Development Act of 1990 (P.L. 102-580, Nov. 28th, 1990) (NRC 2001). Mitigation is one of the tools the U.S. Army Corps of Engineers has to accomplish "no-net-loss" of wetland functions and values within a watershed. The National Research Council (2001) defines wetland functions as including "water quality, water retention which helps to ameliorate flood peaks and desynchronizes high flows in streams and rivers, ground water recharge, shore stabilization, and provision of a unique environment, part aquatic and part terrestrial, that supports a diversity of plants and animals." Mitigation is "the restoration, creation, enhancement or in exceptional cases preservation of wetlands and/or other aquatic resources expressly for the purpose of compensating for adverse impacts that remain after all appropriate and practicable avoidance and minimization have been achieved" (USEPA 2003). There are three main types of mitigation that are possible under the creation of wetlands; 1) Project specific, 2) Mitigation banking and 3) In-Lieu Fee. My project, while it may be applicable to the other mitigation types, deals mainly with the creation and restoration of wetlands for mitigation purposes.

Project specific mitigation is undertaken by a permittee in order to compensate for wetland impacts resulting from a specific project (USEPA 2003). Project specific mitigation can be broken down into two categories, on-site and off-site. On-site is currently the preferred type of mitigation and is defined as areas adjacent or contiguous to an impacted wetland site. Off-site mitigation is mitigation placed in close proximity to and, to the extent possible, in the same watershed as the impacted wetland site (USEPA 2003). On-site and off-site mitigation can be broken down even further into two subcategories, in-kind and out-of-kind mitigation. The physical and functional type of a wetland is determined by its hydroperiod, soils, vegetation, size and its position in the landscape (Dunne & Leopold 1978; Gergel 2005; Jackson 2006; Johnston et al. 1990; Kolka & Thompson 2006; Mitsch & Gosselink 1993; NRC 2001; Sharitz & Pennings 2006; Zedler 2003; Zedler 2006). In-kind mitigation is the replacement of an impacted wetland with a wetland of the same physical and functional type; whereas, out-of-kind mitigation is the replacement of an impacted wetland with a wetland of a different physical and functional type (NRC 2001; USEPA 2002). Out-of-kind mitigation results in the trade off of ecosystem services, in that as a result of a management decision the function provided by the impacted wetland is reduced in the watershed in favor of another (Rodŕiguez et al. 2006). The trade off of ecosystem services as a result of out-of-kind mitigation can have unintended negative consequences. For this reason, out-of-kind mitigation is in generally not preferred, and used only when it would provide a greater ecological or watershed benefit. Project specific mitigation is still the most common undertaken; yet, mitigation baking is increasing becoming a viable alternative as more banks are being developed.

Mitigation banks are "a site where wetlands and/or other aquatic resources are restored, created, enhanced or in exceptional cases preserved expressly for the purpose of providing compensatory mitigation in advance of authorized impacts to similar resources" (*Fed. Reg.* 60(Nov. 28):58605) (NRC 2001). Mitigation banks generally fall under two types, single user and commercial. Commercial mitigation banking generates "credits" that can be sold for profit to any permittee in need of compensating for wetland impacts (Somerville & Pruitt 2006; USEPA 2006b). A mitigation credit is "a unit of measure representing the accrual or attainment of aquatic functions at a mitigation bank: the measure of function is typically indexed by the number of acres restored, created, enhanced or preserved" (*Fed. Reg.* 60(Nov. 28):58605) (NRC 2001). The third type of mitigation is in-lieu fee mitigation where the permittee pays a fee in lieu of permittee responsible mitigation to a third party (NRC 2001). In-lieu fee mitigation is the least common of the three principal types of compensatory wetland mitigation. Mitigation of wetlands is important because it has only been in the last 50 years that we have begun to understand the effects of the loss and conversion of wetlands into other land uses on ecosystem services.

The wetland functions previously defined by the NRC (2001) are only some of the ecosystem services provided by wetlands. It is important to remember, that not all wetlands provide all identified wetland functions and values, and that similar wetland types, depending on their position in the landscape may not provide similar functions (NRC 2001). The wetland functions as defined by the National Research Council (2001) are also not all of the functions and values provided by wetlands. Some of the unmentioned functions and values include the production of food stuffs such as wild rice in the Midwest or cranberries in the Northeast, and various forms of recreational and educational opportunities. The most common wetland functions and values identified by resource managers when determining the impact to ecosystem services from the destruction of wetlands though are water quality, flood control and conservation of plants and animals (Cedfeldt et al. 2000; Zedler 2006).

The protection and mitigation of wetlands, including riparian areas, are an important aspect in protecting the quality of our waters, providing flood attenuation, maintaining adequate flows and for the conservation of biodiversity. Numerous research projects have shown the link between the proportion of human altered landscapes (urban, agriculture, etc.) in a watershed and an increase of pollutants in the waters (Berka et al. 2001; Gergel et al. 2002; Herlihy et al. 1998; Mattikalli & Richards 1996; Meador & Goldstein 2003; Mitsch & Gosselink 1993; Wang 2001), increases in peak flood levels and synchronization of flows (McAllister et al. 2000; Mitsch 1992; Potter 1994), and impacts to fish and wildlife populations (Gibbons 2003; Meador & Goldstein 2003;

Semlitsch 1998; Semlitsch 2002; Semlitsch & Bodie 2003; Wang 2001). Many of the studies have mentioned the potential for identifying altered landcovers, i.e. low and high intensity urban areas, agriculture and silviculture, and creating or restoring wetlands to decrease these impacts. Identification of where these human altered landscapes are having the greatest negative impact is paramount to mitigating their effects and maximizing the functions provided by wetlands. For example, White and Fennessy (2005) found substantial benefits to water quality in watersheds that contained only a small proportion of wetlands. While their findings do not constitute a rule for restoration, their results show that the amount that wetlands contribute to the ecosystem services in a watershed are out of proportion with the percentage of the watershed they comprise. This suggests that by restoring only small amounts of wetlands in a watershed may have substantial benefits. Newbold (2005) notes though that mitigating the effects of altered landscapes is more than strictly identifying landcovers and restoring wetlands to a certain percentage. The unique properties of wetlands and the effect they have on ecosystem services are dictated by their spatial location and configuration in the landscape, not by the percentage of the landscape they occupy.

Depending on the spatial location and configuration of wetlands within a watershed, the functions and values provided wetlands play different roles in protecting the health of our ecosystems and the human population in general. Numerous researches have shown the importance of spatial location and configuration of wetlands in determining their effect on water quality (Gergel 2005; Gergel et al. 2002; Houlahan & Findlay 2004; Johnston et al. 1990; McAllister et al. 2000), flood attenuation (Johnston et al. 1990; McAllister et al. 2000) and biodiversity conservation (Mitsch 1992; Mitsch & Gosselink

1993; Zedler 2003). For example, ephemeral depressional wetlands in forested landscapes and those lacking hydrologic surface connections to permanent water that remain fishless which are located in suitable dispersal corridors are critical locations and configurations for the persistence of numerous threatened and endangered amphibian species (Marsh & Trenham 2001; Mazerolle et al. 2005; Semlitsch & Bodie 1998). A diversity in wetland type, size, location and configuration is important for the conservation of biodiversity because 53% of all species listed as threatened or endangered under the U.S. Endangered Species Act rely upon wetlands for at least one stage of their life cycle (USEPA 2006a). The spatial location and configuration are also important when considering mitigation in watershed planning objectives. Mitigation of headwater wetlands may be more effective for flood attenuation (McAllister et al. 2000), while riparian wetlands and forests may be more beneficial for water quality and reducing impacts to stream biota (Johnston et al. 1990; Wang 2001). The spatial location and configuration of wetland, though, have been largely ignored though through the Section 404 mitigation process.

McAllister et al. (2000) stated that "unfortunately this process [mitigation] does not ensure the benefits of wetland functions and values are optimized throughout the landscape". McAllister et al. (2000) further states that the spatial location and configuration of compensatory wetland mitigation, and hence the functions they provide, is largely one of opportunity and economic viability. In response to criticism about the Section 404 process, the National Research Council (NRC) evaluated the effectiveness of compensatory wetland mitigation. In their 2001 report "Compensating for Wetland Losses under the Clean Water Act" NRC identified several shortcomings in the compensatory mitigation process. One example was the lack of tracking the progress of mitigation projects. They stated that for every 100 acres of wetlands degraded, 178 acres of wetlands were required to be mitigated for (NRC 2001). In looking strictly at numbers the USACE reported that they were accomplishing the goals of "no-net-less". What was not taken into consideration was the type of mitigation and even if the mitigation was initiated or successful. Brown and Veneman (2001) in their study of the effectiveness of compensatory wetland mitigation found that 54.4% of all mitigation projects in Massachusetts were not in compliance, 21.9% of which were never initiated. In their review of compensatory mitigation projects the NRC (2001) found an even higher percentage of required mitigation was never initiated, approximately 34%. This is only one of many shortcomings the NRC report highlights. In response, the Department of Interior, Department of Army, U.S. Environmental Protection Agency, U.S. Department of Commerce, U.S. Department of Agriculture and U.S. Department of Transportation formed an interagency team to develop the National Wetlands Mitigation Action Plan in 2001.

The National Wetlands Mitigation Action Plan (NWMAP) outlined a set of objectives to "further achievement of the goal of no-net-loss by undertaking a series of actions to improve the ecological performance and results of wetlands compensatory mitigation" (USEPA 2002). In their objectives they identified (USEPA 2002): 1) Clarifying Recent Mitigation Guidance, 2) Integrating Compensatory Mitigation into a Watershed Context, 3) Improving Compensatory Mitigation Accountability, 4) Clarifying Performance Standards and 5) Improving Data Collection and Availability. Wetland restoration and mitigation can be costly and time consuming for all parties involved and are often opportunity driven (McAllister et al. 2000). With the limited resources available it is necessary to develop proactive approaches (Randhir et al. 2001) for focusing mitigation to areas most likely to provide the desired wetland functions and values in a cost efficient manner (Wang 2001; Zedler 2004). Using GIS to assess and prioritize the potential functions of mitigation sites can also increase the cost efficiency of wetland restoration and mitigation (Cedfeldt et al. 2000; Russell et al. 1997). Wetland mitigation can be used as a tool to meet watershed planning objectives for protecting water quality, providing flood control, flow regulation, conservation of biodiversity, recreation and other desired functions and values. The NWMAP addressed this and encouraged agencies to "develop guidance to encourage placement of mitigation where it would have the greatest benefit and probability for long term sustainability. The guidance will help decision makers utilize watershed-based planning tools and resources available" (USEPA 2002). In working within this framework, I developed a model identifying and ranking the spatial location and configuration of wetlands based on their effect on ecosystem services to develop a watershed-based planning tool for increasing the effectiveness of compensatory wetland mitigation. Identifying and ranking priority areas for compensatory wetland mitigation gives resource managers more effective tools to choose mitigation sites that will achieve the objectives no-net-loss of wetland acreage and functions (McAllister et al. 2000).

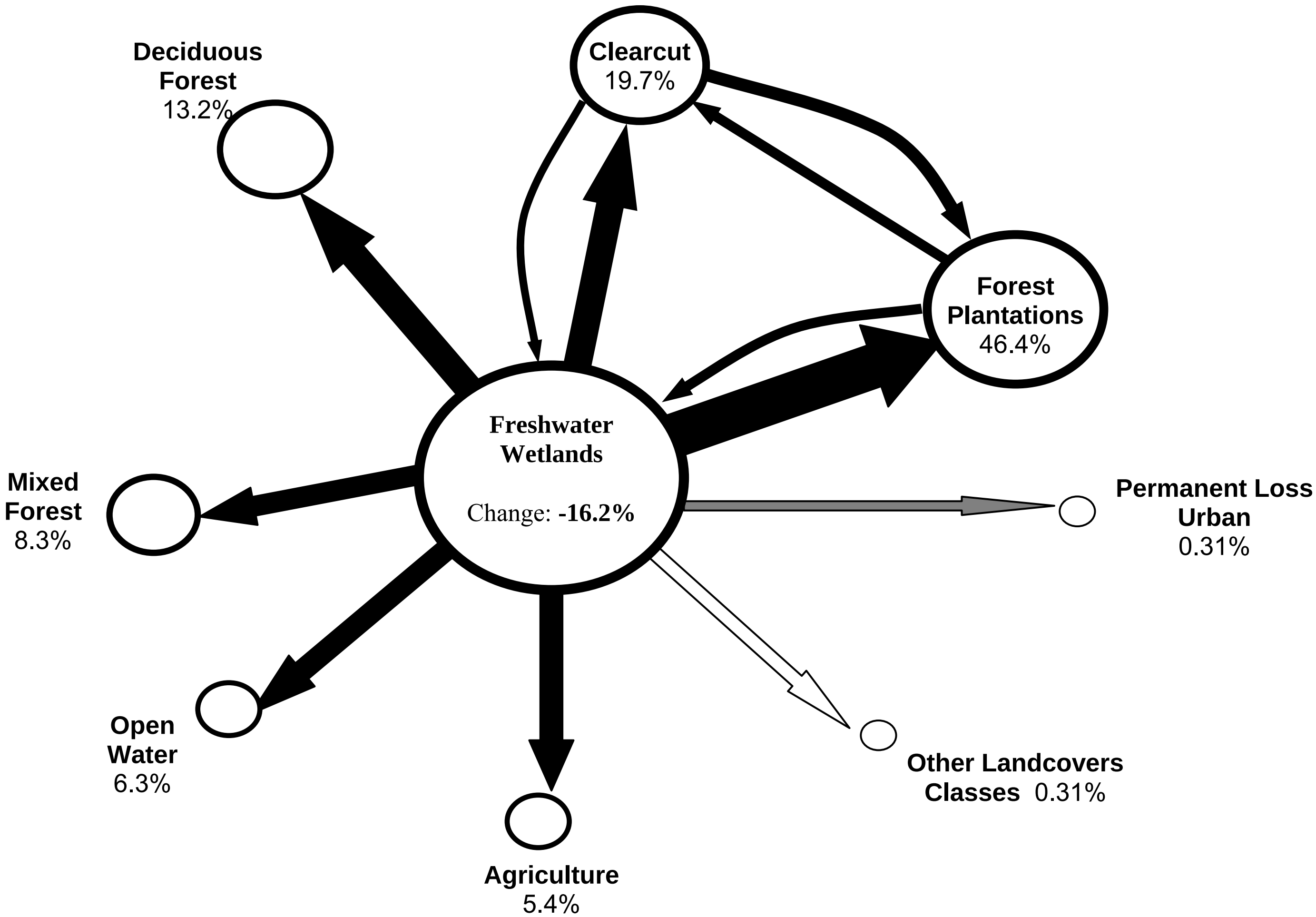


Figure 1.1: Circle diagram outlining the conversion of freshwater wetlands to other landcover classes in Georgia from 1974 – 1998 using the Georgia Land Use Trends Database.

CHAPTER 2

A LANDSCAPE MODEL IDENTIFYING PRIOTRIZED POTENTIAL WETLAND MITIGATION SITES

Under the direction of Georgia Environmental Protection Division (GAEPD) and a technical steering committee I developed a GIS watershed-based planning tool to identify where wetland mitigation will have the greatest impact on assessed wetland functions and values. The product is a GIS based map identifying prioritized potential wetland restoration sites that is usable at multiple spatial scales, statewide to local watersheds. The prioritized potential wetland restoration sites represent a landscape level assessment (White & Fennessy 2005) of the spatial location and configuration where compensatory wetland mitigation sites may provide most of the ecosystem services desired by resource managers.

The ecosystem services modeled to identify and prioritize potential wetland restoration sites were decided upon by a technical advisory committee during initial project planning meetings in January 2006. The technical steering committee was formed by the Georgia Environmental Protection Division with the mission to guide the process of developing a watershed based planning tool that will help increase the effectiveness of compensatory wetland mitigation in Georgia. The technical steering committee included participants from state and federal governmental agencies, non-governmental organizations and forest product industry groups that either participate in the development of compensatory wetlands mitigation projects or are responsible for regulating wetlands impacts under the Clean Water Act. The first charge given to the technical steering committed was to develop a list of ecosystem functions provided by wetlands. Each participant was asked to state which ecosystem functions were most important to their organization when considering wetland restoration or creation. After a list of all wetland functions and values were compiled the list was narrowed to only those wetland functions and values that a majority consensus of the participants felt are important when considering wetland mitigation. The functions and values that were not selected in this majority list were then discussed amongst the technical steering committee until a consensus was reached as to whether or not they should be included in the final list of wetland functions and values. The list of ecosystem functions, that were decided upon are a combination of tangible ecosystem services, desired compensatory mitigation site attributes and the perceived social benefits of wetlands. Ecosystem functions include:

- Biodiversity conservation
- Connectivity
- Ease of restoration
- Ecological services
- Education
- Flood control and flow regulation
- Recreation
- Scenic Value
- Water quality and quantity
- Wildlife habitat

Following the completion of the list of identified ecosystem functions, myself and the Natural Resources Spatial Analysis Laboratory (NARSAL) were given the responsibility of determining how and whether it was feasible to model these ecosystem functions using GIS and the best available data. An initial review consisted of a through literature search of how wetlands function and dictate each of the identified wetland functions and values. A review of similar projects being undertaken in other states, especially those in the Southeast, were also evaluated to determine how they modeled wetland functions and if their methodology was applicable and could be modified for use in our models. A literature review of research projects was also conducted to determine how other scientists dealt with similar problems. This review was specifically to identify potential methods that have proven to model ecosystem functions provided by wetlands and those methods that have proven ineffective or unreliable. Background was also obtained on the methods regulatory agencies use to evaluate wetland mitigation sites, and how we may incorporate these into a model to identify and prioritize potential wetland restoration sites. After these reviews, we selected methods and the best available datasets that would identify and prioritize potential wetland mitigation sites in Georgia. These methods were then presented to the technical steering committee for their inputs and suggestions. The final product that best identified and prioritized potential wetland restoration sites was a two component multi-metric landscape analysis model.

The prioritized potential wetland restoration sites model was developed using two different components. The first component, Potential Wetland Restoration Site Index (PWRS), is an additive multi-layer model that represents the potential of a site for wetland mitigation based on its ability to increase the desired ecosystem functions within its watershed. Modeling ecosystem functions and selecting sites for wetland restoration projects requires consideration of the effect of landscape position, hydrology, morphology, soils, topographical variability and the surrounding land use on the functions provided by wetlands (Bedford 1996; Russell et al. 1997). The individual layers in Component One, 9 total, were developed using specific methodology to model these variables and their influence one of the main identified wetland function and value provided by wetlands. And by targeting sites identified as having high potential for wetland restoration the main wetland function and value identified will be most positively impacted. The second component, not discussed in this thesis, is an additive multi-layer model that prioritizes 12 digit Hydrologic Unit Codes (HUCs) based on their past, present and future development and the threats they pose to the ecosystem functions provided by wetlands at a watershed scale.

Aside from the unique methods used in the development of each layer, all Component One layers received the same post-processing steps. First, each layer is reclassified on a scale from one to nine with nine indicating sites with the highest potential to improve, Component One, or are detrimental to, Component Two, ecosystem functions. Reclassification was done by using a choropleth classification approach known as Jenks Optimization (Dent 1999) which minimizes the within group variance while maximizing the variance between groups. This approach identifies the range of values which maximizes group homogeneity (Murray & Shyy 2000). After reclassifying, the layers were then added together to get a non-classified map identifying potential sites for wetland mitigation. The non-classified map was once again reclassified on a scale of one to nine using Jenks Optimization (Dent 1999) to produce a final map identifying the potential sites for compensatory wetland mitigation that would have the greatest positive benefit on the ecosystem functions provided by wetlands.

NON-RESTORABLE LANDCOVER CLASSES (LAYER 1.1)

Main Wetland Function

- Restorability

Component One is based on a hierarchical structure starting with the identification of all landcover classes that are considered as potentially restorable. Berman et al. (2002) and North Carolina's Department of Environment, Health and Natural Resources (1995) noted in the development of similar wetland restoration models that not all landcover classes have the same potential to be restored as a functioning wetland. We chose to classify restorable landcover classes into three separate groups, (ranked 9) as high potential for restoration, (ranked 6) potentially restorable, and (ranked 1) landcover classes considered as non-restorable. The classification values were chosen to spread the data and aid in identifying high priority areas in subsequent steps. All of the restorable and non-restorable landcover classes were derived from a combination of the 1974 and 2005 Georgia Land Use Trends (GLUT) database which identifies 13 general landcover classes (NARSAL 2006). GLUT was developed through remote sensing of LandSat MSS (1974, 1985, 90 meter spatial resolution) and LandSat TM data (1992-2005) at a 30 meter spatial resolution (NARSAL 2006).

Landcover classes that are considered as high potential for restoration must have been considered as wetlands (i.e. forested wetlands, freshwater emergent marshes, or saltwater / brackish marsh) in the 1974 GLUT database and converted to a non-wetland landcover class in the 2005 GLUT database (Zedler 2006). Regardless of whether an area was classified as high potential for restoration, if it was designated as low or high intensity urban, open water greater than 5 acres (White & Fennessy 2005), forested wetlands, freshwater emergent marsh or saltwater brackish marsh in the 2005 GLUT database it was considered as a non-restorable. See Figure 2.1 for decision analysis chart for determining restoration potential of GLUT landcover classes.

The three GLUT wetland classes are included in the non-restorable landcover classes for two reasons. First, the scope of this project was to identify areas where creating wetlands for compensatory mitigation would have the greatest positive influence on ecosystem functions, not through the restoration of wetlands to satisfy compensatory mitigation. Second, the GLUT database does not include a measure of the current condition of a site. It is a pixel by pixel analysis of the spectral identity of the landscape and thus the probability of a landcover class type at a given location (NARSAL 2006). As a result, we have no way to conduct a functional assessment of current wetlands and have assumed that if they are mapped in the 2005 GLUT database they are fully functioning and not in need of restoration. The potentially restorable areas, rank = 6, are all other areas not classified into high potential for restoration or non-restorable landcovers.

HYDRIC SOILS (LAYER 1.2)

Main Wetland Function

- Restorability

Secondary Wetland Functions

- Jurisdiction

One of the three primary components used to delineate wetlands for federal jurisdiction is whether or not hydric soils are present. The presence of hydric soils is also important when considering the potential restorability of a site's wetland functions (Zedler 2006). In addition, the presence of hydric soils reflects the underlying geomorphology of the area and the ability of the system to maintain a prolonged hydroperiod necessary for a functioning wetland (Jackson 2006).

Potential wetland restoration sites were categorized based on their intersection with low conductivity / hydric soils identified in the US General Soils Map for Georgia (STATSGO) (USDA 2006). To account for the different soil characteristics in each physiographic region in Georgia, the STATSGO soils database was queried based on generalized EPA Level 3 Ecoregion (Wharton 1977) separately. The GLUT 1974 database (NARSAL 2006) was used to determine which attributes in the STATSGO database encompassed the majority of identified wetlands in each ecoregion. Four major attributes in the STATSGO database were common to all ecoregions in the state and used in various combinations to select low conductivity / hydric soils (Table 2.1). Selecting multiple attributes was necessary because STATSGO polygons represent soil associations rather than single soil types. And the attributes include inclusions found within certain soils that make up an association (USDA 2006).

STATSGO soils that meet the requirements were given a value of nine and considered as primary potential wetland restoration sites. All other soils were classified as a six, secondary restoration sites, except those that corresponding with non-restorable landcover classes identified in Layer 1.1 which received a value of one (Table 2.2). The hydric soils layer is not part of the additive model but combined with Layer 1.1 to create a final masking layer that is used to constrain potential wetland restoration sites prior to reclassifying the data in Layers 1.4 - 1.9.

MASKING LAYER

A masking layer combining the datasets developed in Layers 1.1 and 1.2 is used to constrain potentially restorable sites identified in Layers 1.4 - 1.9, using ArcINFO AMLs (Appendix C), to those areas considered as highly restorable (White & Fennessy 2005). Layers 1.1 and 1.2 were combined in a fashion so that all areas with the highest ranking (9) retain that value. If these areas were identified as natural upland vegetation in "A Comprehensive Wildlife Conservation Strategy for Georgia" (GADNR 2005) they were given a rank of eight. Non-restorable landcover classes identified in Layer 1.1 retained a value of one and the remaining areas were given a value of six (Figure 2.3). These values were chosen to spread the data and aid in reducing the within group variance and maximizing the variance between groups.

The masking layer was then used at the end of Layers 1.4 to 1.9 to remove non-restorable landcover classes from influencing the grouping of potential wetland restoration sites, outlined in the methods introduction, and to prioritize highly restorable areas. Masking was done on a pixel by pixel analysis using ArcINFO AMLs to relate each of the model layers to the masking layer. Layers 1.4 to 1.9 were masked using the following rules:

1. If the masking layer = 9, the corresponding location in the specified layer retains its original value.
2. If the masking layer = 8, the corresponding location in the specified layer retains 89% of its original value.

3. If the masking layer = 6, the corresponding location in the specified layer retains 66% of its original value.
4. If the masking layer = 1, the corresponding location in the specified layer equals the minimum value calculated for the specified layer.

JURISDICTIONAL DESIGNATION (LAYER 1.3)

Main Wetland Function

- Jurisdiction

Compensatory wetland mitigation sites by definition should be developed where they would be ensured permanent protection under Section 404 of the Clean Water Act. Each US Army Corps of Engineers District develops a working definition of jurisdiction, as long as it is at least as restrictive as the federal jurisdictional wetland designation. The Savannah District, which is responsible for Georgia, defines jurisdiction as within 100 feet of navigable waters or within the 100 year floodplain, whichever is greater (*D. Crosby, pers. Comm.*). The jurisdictional designation layer is a ranked combination of data sources that identify sites that may potentially be jurisdictional based on the Savannah District definition. Unlike the remaining layers in component one which rank potential sites on a scale of one to nine, Layer 1.3 is divided into four categories that specify their potential for jurisdictional designation (Table 2.3).

Sites that received a rank of nine are either adjacent to navigable waters or within the 100 year floodplain. To determine adjacency, a subset of the 1:100,000 National Hydrography Dataset (NHD) (USGS 2002) identifying navigable waters was selected (Table 2.4) and buffered using the ArcINFO EXPAND command at 30 meters (one pixel). The most recent Federal Emergency Management Agency (FEMA) Q3 flood data

(FEMA 1996) for each county in Georgia was used to identify sites that lie within the 100 year floodplain. The FEMA Q3 flood data was used because it identifies the floodplain at a scale of 1:24000 and is the accepted legal document for determining flood hazards.

Using a 30 meter pixel resolution for the NHD and expanding the data 1 pixel produces a buffer less than 100 ft (30 meters = 98.4 ft.). To account for this, and other potential inaccuracies in NHD and the FEMA Q3 flood data, all sites that received a value of nine were again buffered by one pixel and given a value of eight. All other sites are given a value of six unless associated with a landcover class identified in Layer 1.1 as non restorable, which are then given a value of one.

WATER QUALITY AND QUANTITY INDEX (LAYER 1.4)

Main Wetland Function

- Water Quality and Quantity

Secondary Wetland Functions

- Flood control and flow regulation
- Wildlife habitat
- Recreation
- Scenic value

The protection and mitigation of wetlands and riparian buffers are an important aspect in protecting water quality. Numerous researchers have proven the link between increased runoff and the proportion of human altered landscapes (urban, agriculture, etc.) in a watershed with increased levels of non-point source pollutants (Berka et al. 2001; Gergel et al. 2002; Herlihy et al. 1998; Mattikalli & Richards 1996; Meador & Goldstein 2003; Wang 2001). Constructed wetlands placed directly below source habitats, in areas of high runoff accumulation or at the ends of drainage tiles are effective in removing nutrients and sediments from non-point source and agriculture runoff (Mitsch 1992; Mitsch & Day 2006; van der Valk & Jolly 1992).

The water quality and quantity index (WQQI) is used to evaluate where potential wetland restoration sites may have the greatest positive effect on non-point source impairments to water quality. By identifying the positions in the landscape where saturated variable source runoff accumulates and restoring wetlands and riparian buffers in these areas, we can use compensatory wetland mitigation as a tool to improve water quality (Zedler 2006) and potentially flood control and flow regulation (Cedfeldt et al. 2000). The water quality and quantity index is the product of two separate indices, a Potential Runoff Index (PRI) and a Distance to Impairment Index (DII). Both indices were created using Arc Marco Language (AML) scripts (Appendix C) in ArcINFO (ESRI, Redlands, California) with the final data processing done in ArcGIS 9.2.

Potential Runoff Index

The Potential Runoff Index was designed to calculate the potential proportion of saturated variable source runoff entering open waterbodies after a two year 24 hour storm event. To accomplish this I incorporated into the PRI; landcover classification, hydrologic soil groups (HSG), hydrologic conditions and antecedent runoff conditions. We used the 2005 Georgia Land Use Trends database for our landcover classification. All 13 identified landcover classes were used in development of this model: beaches/sand, open water, low and high intensity urban, clearcut, barren ground, deciduous forests, evergreen forests, mixed forests, agriculture, forested wetlands, brackish marshes and emergent marshes (NARSAL 2006). All GLUT forests were lumped into one cover type, woods, to obtain a Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service (SCS)) curve number.

The potential runoff index was calculated using the SCS runoff curve number (USDA 1986) method. To identify the hydrologic soil groups of each landcover classes, I related each pixel in the 2005 GLUT database to its corresponding STATSGO hydrologic soils group (USDA 2006). The HSG is included because it defines the water holding potential in the watershed and can be used to separate the amount of rainfall received during a storm event that contributes to over land flow from that which enters the groundwater. The inclusion of HSG and SCS curve number in the potential runoff index is similar to the 3rd variation for calculating runoff in the wetland restoration model developed by White and Fennessy (2005). They found that in their model the inclusion of the water storage capacity of soils increased the amount of areas defined as suitable for wetland restoration but did not change the spatial location and configuration of suitable sites. Russell et al. (1997) also found that including soils in similar runoff models increased the accuracy of model when used to identify and prioritize areas for wetland and riparian restoration. I then assigned an appropriate curve number (CN) by relating landcover class/HSG to the values in Table 2.2 in TR-55 (USDA 1986). The landcover types in Table 2.2 in TR-55 differ from those used in the GLUT database. To assign appropriate curve numbers, landcover classes were associated by TR-55 definition and evaluation by NARSAL staff responsible for developing the GLUT database.

Gergel (2005) noted that during large storms a significant proportion of annual nutrient input occurs for many watersheds from saturated variable source runoff. Based on this, we chose to base runoff on precipitation received during a two year 24 hour storm event. The two year 24 hour storm event was determined using isopluvial maps for the state of Georgia (Dunne & Leopold 1978). The precipitation ranged from 3.5 inches in the Piedmont to five inches in the coast and southern Appalachians (Figure 2.7). Runoff was calculated using the NRCS runoff equation (eq. 1) (USDA 1986).

$$Q_i = \frac{\left(P - 0.2\left(\frac{1000}{CN_i} - 10\right)\right)^2}{P + 0.8\left(\frac{1000}{CN_i} - 10\right)} \quad \text{(eq. 1)}$$

Where:

Q_i = Runoff (in)

P = Rainfall (in)

CN_i = Curve number of pixel i

After calculating the runoff from each pixel we needed to know the potential amount of runoff from each watershed. This was accomplished through running un-weighted and weighted flow accumulation models. An un-weighted flow accumulation model (*FA*) calculates the accumulated flow of all upstream pixels assuming that there is no initial abstraction (ESRI 2007). The weighted flow accumulation (*WFA*) model takes into account initial abstraction by incorporating Q_i, calculated in equation 1, as the weighted value. Groundwater which is influenced by initial abstraction, undoubtedly influences the hydrological processes [of] and nutrient inputs to wetlands (Jackson 2006). The potential runoff index was limited to evaluating saturated variable source runoff because of the limited availability and difficulty in determining the influences of groundwater on potential wetland restoration sites at a statewide spatial scale. The potential runoff index is calculated using equation 2.

$$PRI = \frac{FA - WFA}{FA} \qquad \text{(eq. 2)}$$

The potential runoff index represents the proportion of saturated variable source runoff generated from the two year 24 hour storm event that may enter an open waterbody. PRI is an inverse index between 0-1, with 0 exhibiting greatest potential amount of non-point source runoff. The potential runoff index is then reclassified from 1 - 9 (PRI_{rcls}) using Jenks Optimization (Dent 1999) with nine corresponding to the greatest potential amount of non-point source runoff entering an open waterbody.

Distance to Impairment Index

The distance to impairment index (DII) was developed to rank individual landcover class pixels contribution to nonpoint source pollution based on their hydrologic flow distance to all streams, rivers and lakes. The distance to impairment index is a measure of a potential wetland restoration sites position in the landscape (White & Fennessy 2005), and thus their potential effect on limiting nonpoint source pollution. Streams and rivers were calculated using 30 meter digital elevation models (DEM) instead of the National Hydrography Dataset. Merrill (2001) reported that using NHD, approximately 6500 km of streams were found in their study area while digital elevation models showed approximately 15,000 km. The 8,500 km increase in mainly associated with small 1st order and ephemeral streams (Figure 2.8). It is important to account for the small 1st order and ephemeral streams missed in NHD because as Gilliam et al. (1996) noted, riparian wetlands and buffers on small streams are considered as the most important for controlling non-point source pollution (*as reported in* (NRC 2001)). Lakes and large rivers were incorporated by adding these attributes from the National Hydrography Dataset and the 2005 Georgia Land Use Trends Database. DII is used to incorporate the spatial relationship, i.e. landscape position, of an individual landcover class pixel to an open waterbody and thus its potential influence on water quality (Johnston et al. 1990; McAllister et al. 2000). To calculate DII we used an AML (Appendix C) to run a series of ArcINFO cost allocation and flow length models. Cost allocation uses the aspect derived from DEMs to determine the path water would travel down a slope after saturation has been reached. Flow length models use the product of the cost allocation model and flow accumulation models to calculate the distance a landcover class pixel lies from an open waterbody and thus its relative position in the landscape and influence on water quality. This is similar to White and Fennessy's (2005) topographic saturation index which is an adaptation of TOPMODELS Wetness Index, and their assumption that as distance from a saturated site to open water increased the benefit of restoring that site decreases. The distance to impairment index differs from the topographical saturation index in that I did not use the stream order as a measure of position in the landscape. Both White and Fennessy (2005) and Russell et al. (1997) found that stream order did not accurately reflect the position of a potential wetland or restoration site in the landscape.

The distance to Impairment Index is an unbounded inverse index from 0 - ∞, with 0 implying that a landcover class pixel drains directly into an open waterbody. Location is important as it has been noted that riparian wetlands and those directly below source habitats are the most important wetlands for protecting water quality and minimizing flow directly in to open water (Cedfeldt et al. 2000; Johnston et al. 1990). We did not limit the distance that beyond which an individual landcover pixel would have no contributing effect on water quality. Houlahan and Findlay (2004) detected sediment and water nutrients in wetlands originating up to 2000 meters away. The distance to impairment index is then reclassified from 1 - 9 (DII_{rcls}) using Jenks Optimization (Dent 1999) with nine corresponding to the areas with the shortest flow distance to open waterbodies.

Water Quality and Quantity Index

The water quality and quantity index (WQQI) is a ranked set of areas that have the highest potential to directly input the greatest amount of saturated variable source runoff to an open waterbody. The ranking is distance, saying that areas located closest to open waterbodies and contribute the highest potential proportion of saturated variable source runoff have a greater potential negative effect on water quality than areas further away and should be considered as priority for mitigation. WQQI is calculated using equation 3.

$$WQQI = PRI_{rcls} * DII_{rcls} \quad \text{(eq. 3)}$$

Where:

PRI_{rcls} = Reclassified Potential Runoff Index

DII_{rcls} = Reclassified Distance to Impairment Index

WQQI is scaled from 1 - 81, with 81 signifying areas where potential wetland mitigation sites would potentially reduce the most non-point source inputs to open waterbodies. The WQQI index is then scaled by the masking layer and reclassified using the steps outlined in the methods introduction.

CONNECTIVITY TO EXISTING CONSERVATION AREAS (LAYER 1.5)

Main Wetland Function

- Connectivity

Secondary Wetland Functions

- Recreation

- Education
- Wildlife habitat

Increasing the connectivity of compensatory wetland mitigation sites to existing conservation lands increases the recreational and educational opportunities of the general public. In addition connectivity to an existing conservation lands expand the ecosystem functional capacity of that land and enhances its economic value. Whether recreation is in the form of hunting, nature trails or bird watching an increase in recreational opportunities generally has a positive impact on the economy of the surrounding communities (Costanza et al. 1997; USEPA 2006a). Mitsch and Gosselink (1993) point out that in urban areas constructed wetlands may also provide excellent educational opportunities. The reader is cautioned that the term connectivity is used often and the definition is relative to the layer being discussed. Connectivity in Layer 1.5 is used strictly in the sense of increasing existing conservation areas through connecting them to compensatory wetlands mitigation sites. In subsequent layers connectivity is also referred to and is used to define the ability of compensatory wetland mitigation sites to increase tangible ecosystem functions of wetlands.

The Georgia Conservation Lands Database (GADNR 2005) is used to evaluate where potential wetland restoration sites would increase the connectivity, size and identified ecosystem functions of existing conservation areas. Conservation areas include local, state and federal land holdings, existing US Army Corps of Engineers wetland restrictive covenants, and privately held conservation easements. Connectivity (S_i) to existing conservation areas was calculated using an area weighted connectivity function (Möilanen & Nieminen 2002). This connectivity function is used because it decreases the importance of a potential restoration site as its distance from an existing conservation area increases. Hanski (1994) originally developed the connectivity function for use in metapopulation models, but it has been applied a variety of ecological applications (Möilanen & Hanski 2001). Connectivity was calculated using equation 4 in an ArcINFO AML (Appendix C) (Möilanen & Nieminen 2002):

$$S_i = \sum_{j \neq i}^{n} \left(e^{-\alpha d_{ij}} \right) A_j \quad \text{(eq. 4)}$$

Where:

S_i is the connectivity of potential wetland restoration site *i* to conservation area *j*.

D_{ij} is the distance between a potential wetland restoration site *i* and conservation area *j*.

A_j is the area of conservation area *j*.

α negatively scales distance based on the inverse of the mean dispersal distance of an amphibian ($\frac{1}{r}$). For consistency in our connectivity measurements *r* is based on the mean migration distance of *Rana clamitans*, 500 meters (Gray et al. 2004; Lamoureux & Madison 1999; NatureServe 2006).

The connectivity to existing conservation areas is a dimensionless index from 0 - ∞. Potential wetland restoration sites with a value of zero have no connectivity to existing conservation areas. The connectivity function calculates connectivity both internally and externally to existing conservation areas. As I was interested in increasing the area of conservation lands, the internal areas were masked out and given a value of zero. Connectivity is calculated for each conservation area individually and then summed to get a final grid of connectivity to existing conservation areas. Adding the connectivity of individual conservation areas highlights areas that would bridge connections between multiple conservation areas. The connectivity to existing conservation areas is scaled using the masking layer and then reclassified following the steps outlined in the methods introduction. The final layer represents the position in the landscape where potential wetland restoration sites may have the greatest benefit to the stated wetland functions and values.

TERRESTRIAL DISPERSAL CORRIDORS BETWEEN WETLANDS (LAYER 1.6)

Main Wetland Function

- Wildlife Habitat

Secondary Wetland Functions

- Connectivity

The terrestrial dispersal corridors between wetlands layer is used to rank potential wetland restoration sites based their ability to positively influence the metapopulation dynamics of facultative wetland species. Constructing wetlands as part of wetland mitigation may influence the metapopulation dynamics of amphibians through a change in connectivity between source habitats. Connectivity has a role in metapopulation theory in that it impacts the rescue of extirpated populations from source populations, the colonization of newly created suitable habitats and the maintenance of the genetic diversity of a population (Hanski 1994). As connectivity decreases and wetlands become increasingly isolated the threat to the persistence of populations increases (Hanski 1997). By mapping and determining where wetland mitigation sites would be the most connected within a wetlands complex, we can identify ways by which "population isolation can be broken" (Joly et al. 2003).

The terrestrial dispersal corridors between wetlands layer does not use the 2005 GLUT database to identify the wetlands by which connectivity is determined. In this layer wetlands are determined by the average weighted species richness model (AWSR) developed for the "Comprehensive Wildlife Conservation Strategy for Georgia" (GADNR 2005). The average weighted species richness model identifies and ranks areas of natural vegetation by the number of potential species present, their federal status and their global and state Natural Heritage ranking. This model was developed to identify natural vegetation habitat patches in the landscape that may be most important for species of conservation concern and thus higher priority for protection (GADNR 2005). The AWSR model is used because it does not prioritize only areas that contain individual species of high conservation value, but is cumulative so that areas with multiple species of lower conservation value are also identified as priority areas for protection. The average weighted species richness model was developed by combining the distribution maps from GAP vertebrate species models which identifies suitable habitats for a species, given their natural history traits (Kramer & Elliott 2005). To minimize possible negative effects to upland species, all natural vegetation patches that did not intersect with 1974 GLUT wetlands were removed, resulting in natural wetland vegetation patches.

The connectivity of wetlands was calculated using a two step process. The first step was the development of a grid of habitat resistance to the dispersal and migration of *Rana clamitans* using general resistance coefficients. Habitat resistance is important in that the landscape structure defines the physiological costs of an amphibian dispersing through a landscape and the behavioral response of the organism to that cost (Mazerolle & Desrochers 2005; Wiens 1997). The second step ranks the connectivity between wetlands based on the non-random movement of juvenile and adult amphibians during dispersal and migration by the potential value of a given wetland for species of conservation concern. The gird of habitat resistance is incorporated into connectivity as it defines the path of least resistance, or dispersal corridors, an amphibian may follow when dispersing between source habitats.

Habitat Resistance

The gird of habitat resistance was created using an ArcINFO AML (Appendix C) to reclassify all landcover classes identified in an 18 class 2005 GLUT database (NARSAL 2006), roads from the Tiger Roads Database (USCB 2007) and streams calculated using flow accumulation models. The values of resistance coefficients were taken from multiple peer reviewed literature sources and expert opinion, Table 2.5. Habitat resistance coefficients ranged from 0 – 100, with 100 considered as an absolute barrier to movement (Joly et al. 2003). In cases where reported scales differed, they were normalized to be equivalent to Joly et al. (2003). For example, Compton et al. (2007) reports a scale where 40 was considered as an absolute barrier for *Ambystoma opacum* dispersing through a landscape in Massachusetts. In this instance when their reported values were used, they were multiplied by a factor of 2.5 to make comparable.

The landcover classes in the Georgia Land Use Trends database, with the exception of open water and edge effects, were not divided into smaller partitions. Each landcover class received individual resistance coefficients regardless of the patch size or location in the state. Based on capture data, a significant effect of edge on dispersing amphibian species was found by both deMaynadier and Hunter (1999) and Gibbs (1998) for six different amphibian species. Gibbs (1998) found that dispersing amphibians were 2.5

times more likely to be captured in forest interiors than in forest edges. deMaynadier and Hunter (1999) found that juveniles use of forested habitat > 20 meters from a forest edge was 2.6 times greater. To incorporate their findings a 30 meter forest edge resistance coefficient was incorporated into all forest landcover classes and forested wetland classes. Open water was divided into three separate categories, less than one acre, between one and five acres and greater than five acres (Compton et al. 2007; Joly et al. 2003). Only open water greater than five acres in size were considered as an absolute barrier to movement (Joly et al. 2003).

Streams were calculated using 30 meter digital elevation models (DEM) to incorporate small 1st order and ephemeral streams missed when mapped at 1:100,000 in NHD, Figure 2.8 (Merrill 2001) (Figure 2.8). Streams were divided into four different categories based on Strahler stream order, 1, 2, 3 and $\geq$ 4, and given resistance coefficients identified by Compton et al. (2007). Roads were also divided into four categories identified in the 2007 Tiger Roads database by road type (USCB 2007). The Tiger database is in a vector format that was incompatible with the wetlands model. To make comparable, we created a gird based on the road type attributes identifying local roads, state highways, US highways and interstates. Resistance coefficients were then taken from Compton et al. (2007) where local roads were given the value of minor street or road, state highways - major road, US highways - major highways and Interstates the value of expressways.

Connectivity Analysis

The connectivity between wetlands was calculated using a ranked connectivity function ((Hanski 1994) as reported in (Möilanen & Nieminen 2002)). A connectivity function is commonly used because a negative exponential distribution accounts for the inverse relationship between increasing distance and decreasing area of neighboring wetlands on connectivity (Compton et al. 2007). The connectivity function sums the values of a wetland's connectedness to all of its neighbors. It is then ranked by the average AWSR rank of all wetland neighbors to determine the relative importance of a potential wetland restoration site for species of conservation concern. A ranked connectivity value, S_i, of a single wetland within a landscape mosaic is the final product. The ranked connectivity function is as follows (Möilanen & Nieminen 2002):

$$S_i = \frac{R}{N} \sum_{j \neq i}^{n} \left(e^{-\frac{1}{r} d_{ij}} \right) A_j^b \quad \text{(eq. 5)}$$

Where:

S_i is the ranked connectivity of natural wetland vegetation patch i to natural wetland vegetation patch j.

D_{ij} is the distance between natural wetland vegetation patches i and j.

A_j is the area of natural wetland vegetation patch j.

b is the emigration rate of juvenile *R. clamitans* .

R is sum of all natural wetland vegetation patches AWSR rankings that are connected to natural wetland vegetation are i.

N is the number of natural wetland vegetation patches within 3168 meters of natural wetland vegetation patch i.

r is the mean migration distance of *R. clamitans*.

The terrestrial connectivity of wetlands layer was based on *R. clamitans* natural history traits because it is considered a habitat generalist and found in all regions of

Georgia (Lannoo 2005). Semlitsch (2002) noted that by choosing a habitat generalist the connectivity model may be applicable to a wider range of amphibian species then by choosing a species with very specific habitat requirements and limited dispersal distances. Connectivity was modeled using both adult and juvenile life history traits. Juvenile life history traits are included; because, changes in juvenile life history traits due to habitat alteration and restoration may have more impact on metapopulation dynamics than changes in adult life history traits (Green 2003).

Using mean dispersal distance (Hilty et al. 2007) and emigration rates based on juvenile life history stages is also more appropriate than migration distances for adults because of the reported site fidelity in adult *R. clamitans* (Martof 1953; Rothermel & Semlitsch 2002; Wiens 1997). Pope et al. (2000) also found that the landscape complementation near the maximum reported dispersal distance was a significant indicator of the probability of occurrence and metapopulation structure in *Rana pipens.* The emigration rate is used to model a species-area relationship where larger wetlands have higher relative abundances and potentially larger number of emigrants (Möilanen & Nieminen 2002). Gray et al. (2004) found a species-area relationship in their research of amphibians, Lehtinen and Galatowitsch (2001) noted that the species-area relationship may not applicable to amphibians. Martof (1953) found that 23% of juvenile *R. clamitans* emigrated from their natal ponds. The emigration rate (b = 0.23) is used to scale the area of a neighboring wetland j and determine its relative importance in colonizing or rescuing focal wetland patch i. The mean migration distance of adult *R. clamitans*, r, was set at 500 meters (Gray et al. 2004; Lamoureux & Madison 1999; NatureServe 2006). The connectivity is not limited to wetlands within 500 meters of the focal wetland patch, but calculated to encompass all wetlands within 3168 meters. 3168 meters is 66% (Gray et al. 2004) of the maximum reported dispersal distance, 4.8 km, of juvenile *R. clamitans* (Schroeder 1976) which is relevant to the probability of colonization of wetland mitigation sites (Pulliam 1988) and thus the probability of occurrence within a given habitat patch.

Rothermel and Semlitsch (2002) showed that amphibians are perceptive of their habitats and actively seek habitats that offer less resistance to movement. When modeling terrestrial movements of amphibians it is therefore impractical to use linear distances. To model non-random movement of emigrating or migrating *R. clamitans* (Cole 2006; deMaynadier & Hunter 1999; Hilty et al. 2007; Mazerolle & Desrochers 2005; Patrick et al. 2006; Regosin et al. 2005; Rothermel 2004; Wiens 2001) we calculated the cost distance (Compton et al. 2007; Joly et al. 2003) from focal wetland patches to all wetlands within 3168 meters. The resistance coefficients from the grid of habitat resistance were used as the physiological costs of movement (Mazerolle & Desrochers 2005; Patrick et al. 2006; Wiens 2001). The cost distance to a potential wetland restoration site is then used in the ranked connectivity function as d_{ij}. Cost distance is best explained by the following example. An emigrating or migrating *R. clamitans* starts with 0 "credits" in a movement budget before leaving its natal pond. As it traverses the landscape pixel by pixel, the cost of the associated habitat resistance grid is added to its movement budget. Once the movement budget has reached 500, *R. clamitans* has reached its maximum migration capability. Each pixel surrounding a source wetland is given the value of the smallest movement budget to that point, thus its effective cost distance, d_{ij}.

The terrestrial dispersal corridors between wetlands is a dimensionless index from 0 - ∞. Potential wetland restoration sites with a value of zero lie beyond the maximum reported dispersal and migratory capabilities of *R. clamitans* and are considered as biologically isolated for amphibians. Connectivity is individually calculated for each natural wetland vegetation patch and their values summed with all neighboring natural wetland patches. Summing the connectivity values highlight corridors between wetlands that lie within the dispersal and migration capabilities of *R. clamitans,* exhibit the least resistance to dispersal and may act as "stepping stones" in the landscape for rescuing extirpated populations in existing wetlands. In a final step the terrestrial dispersal corridors between wetland are scaled using the masking layer and then reclassified using the steps outlined in the methods introduction. The final layer represents the landscape position of potential wetland restoration sites where they have the highest probability of colonization and potentially increasing the stability of metapopulations of amphibians.

Statistical Analysis of Non-Random Movement

To determine whether cost-distance was the appropriate method for modeling non-random movement, neutral landscape models were constructed to test whether calculated non-random cost-distances to known wetlands significantly differed from the same wetlands in randomly generated landscapes. Neutral models are useful because they generate grids that are "comparable to raster-based representations of real landscapes commonly used in landscape structure analysis" (Neel et al. 2004). Neutral models were used because they provided a null hypothesis against which non-random movement could be tested (Turner et al. 2001).

Non-random movement was tested in eight randomly selected analysis areas in the Southeast Coastal Plain (Wharton 1977). Within each analysis area one 10 ha focal wetland patch was constructed in a random position in the landscape. Focal wetlands were only constrained so that they could not be constructed in an area considered as non-restorable in Layer 1.1. After a focal wetland was constructed, the minimum cost-distance, using the original grid of habitat resistance was calculated from all natural wetland vegetation patches to the focal wetland patch. A random uniformly distributed grid of habitat resistance was then created in ArcINFO and the cost-distance recalculated for all natural wetland vegetation patches to the focal wetland. The random cost-distance was run 100 times for each focal wetland patch and the minimum cost-distance averaged. The wetland construction process was repeated 50 times in each of the eight analysis areas. The non-random cost-distance to 388 focal wetland patches, 12 focal wetland patches were removed because of corrupt files, were evaluated against 38,800 runs of random cost-distance.

Significant differences between non-random and random cost distance was tested using Wilcoxon Signed Ranks Tests (SPSS 1999). Initially, I tested whether each variable was normally distributed using a Shapiro-Wilks Test (SPSS 1999) and whether a paired T-test was appropriate to determine the difference between random and non-random movements. The data did not meet the assumption of normal distributions, so a non-parametric test was chosen. Wilcoxon Signed Ranks Test is a non-parametric test that determines whether the difference between non-random and random cost significantly differs from zero (Anderson et al. 1994). All data analysis was conducted using Statistical Packages for the Social Sciences Version 11.0 (SPSS 1999).

HYDROLOGIC CONNECTIVITY OF WETLANDS (LAYER 1.7)

Main Wetland Function

- Flood control and flow regulation

Secondary Wetland Functions

- Connectivity
- Wildlife habitat
- Water quality and quantity

The hydrologic connectivity of wetlands is used to evaluate the position in the landscape where potential wetland restoration sites may have the greatest impact on flood control and flow regulation through increased storage capacity of wetlands. A wetlands water budget is useful in describing this relationship, showing that by keeping the hydrologic inputs to a wetland constant, an increase in the storage capacity reduces outflows (Cedfeldt et al. 2000; Jackson 2006; Ogawa & Male 1983) and potentially mitigates flood hazards. Jackson (2006) also notes that an increase in storage capacity may increase the residence time of wetlands, positively influencing nutrient cycling capacity, pollution reduction and a decrease of sediment in the outflow. The hydrologic connectivity of wetlands via surface waters is also important for the conservation of biodiversity by allowing for the colonization and/or rescue of vacant wetlands by species that require hydrologic connections for dispersal. Hydrologically connected wetlands are also more likely to support a greater diversity and abundance of fish, macroinvertebrates and birds (Cedfeldt et al. 2000).

The hydrologic connectivity of wetlands was developed in two steps using ArcINFO AMLs and Python Scripts (Appendix C). The first step was creating a binary gird of all wetlands in the 2005 Georgia Land Use Trends Database (NARSAL 2006). The binary grid was used to determine hydrologic connectivity and the patch and neighborhood based spatial configuration statistics (Gustafson 1998) of wetlands. The size and spatial configuration and location of wetland are a determinant factor in flood attenuation within a watershed (Zedler 2003). Landscape metrics are frequently used to determine spatial configuration and assess the effects of habitat loss and fragmentation on connectivity (Neel et al. 2004). Patch-based metrics may also be useful as coarse filters when evaluating ecosystem functions (Gustafson 1998). I used two of three spatial configuration metrics identified by Li and Reynolds (1994) to evaluate the potential ability of current wetlands to perform our identified wetland functions.

Two separate patch level metrics, contiguity and proximity, were calculated using Fragstats 3.3 (McGarigal et al. 2003) for each wetland. Ritters et al. (1995) found that the average patch shape was one of 6 factors that explain 87% of the variation in landscape metrics. Contiguity is used because it is an indicator of shape (Gustafson 1998) and describes the spatial connectedness or cohesiveness (McGarigal et al. 2003) of an existing wetland. Contiguity is also an indicator of the relative size of a wetland (McGarigal et al. 2003) and thus its potential for flood storage and flow regulation. In Georgia where many of the wetlands are linear floodplain wetlands, contiguity is a better indicator of shape and size than more frequently used metrics like core area (Gustafson 1998; McGarigal et al. 2003). Contiguity is calculated as follows:

$$CONTIGUITY = \left(\frac{\left[\frac{\sum_{r-1}^{z} C_{ijr}}{a_{ij}} \right] - 1}{v - 1} \right) \quad \text{(eq. 6 (McGarigal et al. 2003))}$$

Where:

C_{ijr} is the contiguity value for pixel r in patch ij.

v is the sum of the values in a 3-by-3 cell template.

a_{ij} equals the area of patch ij in terms of number of cells.

Proximity of existing wetlands is used because it is a simple measure of connectivity between wetlands in a binary landscape. It is a neighborhood analysis that is based on island biogeography theory (Gustafson 1998) and identified by Li and Reynolds (1994) as another method to represent the spatial configuration of wetlands in a landscape. McGarigal et al. (2003) notes that proximity takes into account size and proximity of all wetlands to a focal wetland patch within a specified radius. To maintain consistency with other layers in Component One, a 500 meter radius surrounding the focal wetland was set. Proximity is calculated as follows:

$$PROXIMITY = \sum_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}^2} \quad \text{(eq. 7 (McGarigal et al. 2003))}$$

Where:

a_{ijs} is the area (m^2) of patch ijs within specified neighborhood of patch ij.

h_{ijs} is the distance (m) between patch ijs and patch ijs, based on patch edge-to-edge distance, computed from cell center to cell center.

The contiguity and proximity were reclassified on a scale of one to nine using Jenks Optimization (Dent 1999). These ranks were then summed (max = 18) to give an index of the spatial configuration (ISC) of each wetland. The index of spatial configuration details the potential for a wetland to provide the primary and secondary wetland functions. In determining the location for potential wetland restoration sites it is important to evaluate all of the wetlands in a surrounding neighborhood. The relationship of the spatial configuration of all wetlands was accomplished by calculating the percent of the maximum index of spatial configuration in relation to the maximum number of wetlands observed within 500 meters of a focal wetland patch, high quality wetlands index (HQWI). The high quality wetlands index is calculated as follows:

$$HQWI = \frac{N}{g_{\max}} + \left(\frac{\sum_{j \neq i}^{n} ISC_j}{N(18)} \right) \quad \text{(eq. 8)}$$

Where:

N equals the number of existing wetlands potentially connected to potential wetland restoration site *i*.

gmax equals the maximum number of connections possible between a potential wetland restoration site and existing wetlands.

ISC_j equals the index of spatial configuration of existing wetland *j*.

The habitat quality index is scaled from zero to two, with two being the highest quality existing wetlands with the global maximum number of connections. The second step in determining the hydrologic connectivity of potential wetland restoration sites to existing wetlands was calculating the connectivity of wetlands using a ranked connectivity function (Möilanen & Nieminen 2002). The ranked connectivity function used in Layer 1.7 is similar in form to that used in Layer 1.6. In this layer the emigration rate is removed, distance between a focal wetland patch and neighboring patches is calculated using Euclidean distance. The connectivity function is then ranked by HQWI. The ranked connectivity function is calculated as follows:

$$S_i = HQWI * \left[\sum_{j \neq i}^{n} \left(\exp\left(\frac{1}{r} d_{ij} \right) \right) A_j \right] \quad \text{(eq. 9)}$$

Where:

Aj is the area of existing wetland *j*.

dij is the Euclidean distance between wetland *j* and focal wetland patch *i*.

r is the radius surrounding focal wetland patch *i*.

HQWI is the high quality wetlands index.

The connectivity function is ranked by HQWI to determine position in the landscape with the highest connectivity and the greatest potential to provide the main and secondary wetland functions listed. Increasing the connectivity of existing wetlands may have a greater positive cumulative effect on flood storage than restoring wetlands with little or no connectivity to existing wetlands (McAllister et al. 2000; Mitsch 1992; Mitsch & Gosselink 1993; Ogawa & Male 1983; Potter 1994; Zedler 2003). Although it has also been found that smaller wetlands in headwater positions and isolated wetlands are important in regulating flow and desychronizing flood peaks (Cedfeldt et al. 2000; McAllister et al. 2000; Mitsch 1992; Potter 1994). In a final step connectivity to existing wetlands is scaled using the masking layer and then reclassified using Jenks Optimization (Dent 1999). The final layer represents the position in the landscape where potential wetland restoration sites may have the greatest effect on reducing flood volumes and maintaining flows.

NATURAL UPLAND HABITAT SURROUNDING WETLANDS (LAYER 1.8)

Main Wetland Function

- Wildlife habitat

Secondary Wetland Functions

- Connectivity
- Water quality and quantity

The natural upland habitat surrounding wetlands layer is used to determine the where in the landscape potential wetland restoration sites will provide the greatest benefit to wildlife. When evaluating wetlands for restoration or jurisdiction the importance of adjacent upland habitat is often ignored or given a diminutive status (Gibbons 2003). From a jurisdictional standpoint, the only connectivity evaluated is hydrologic connectivity. Hydrologic connectivity is not just the distance a wetland lies from a navigable waterbody. Jackson (2006) notes that uplands impact the hill slope hydrological processes important in determining the hydropattern of wetlands, and the reduction of detrimental inputs directly into wetlands. Terrestrial habitats and its connectivity to wetlands are also essential for maintaining the persistence of many species in the landscape (Gibbons 2003).

Terrestrial habitat plays different yet equally important roles in the persistence and metapopulation structure of amphibians during different life history stages (Gibbons 2003; Semlitsch & Bodie 2003). As I have discussed in Layer 1.6 the connectivity between wetlands is dependent in part on the intervening upland habitat. Juveniles are the primary dispersers for many herptofauna species and during this life history stage the terrestrial habitat can affect the rescue or colonization of unoccupied habitats (Green 2003). During the adult life history stage, terrestrial habitats are critical for foraging locations, reservoirs for adults between breeding seasons and overwintering habitat (Lamoureux & Madison 1999; Lamoureux et al. 2002; Patrick et al. 2006; Semlitsch & Bodie 2003).

The fact that the importance of terrestrial habitats is often overlooked could have devastating effects on the persistence of amphibian populations. Semlitsch (1998) reports that six different species of *Ambystoma* salamanders spent a minimum of 85.9% of the year in upland habitats. Lamoureux et al. (2002) studied terrestrial foraging forays of *Rana clamitans*. They found significant increases in the weight of individuals captured after foraging events into terrestrial habitat. As they discuss, these forays are essential to build lipid reservoirs that will help them survive to the next breeding season. The proportion of terrestrial habitat surrounding wetlands is not the only factor affecting amphibian populations. The scale and spatial configuration of terrestrial habitat impacts amphibians differently in each life history stage.

Price et al. (2004) tested the ability of different landscape metrics at varying spatial scales to determine the probability of a wetland being occupied by selected species. They found that the landscape metrics describing the presence or absence of a species was dependent upon the scale at which it was analyzed. Their results support those found by Pope et al. (2000) who also found the spatial scale at which a landscape mosaics were evaluated affect the probability of occurrence of breeding *R. pipiens* in core wetlands. Furthermore, Price et al. (2004) results indicated that at scales generally associated with dispersing juveniles, 1000 - 3000 meters, landscape metrics that directly affected dispersal were most correlated with presence or absence. At local scales, 100 - 500 meters, presence or absence of a species was correlated to terrestrial habitat characteristics important during the adult life history stage (Guerry & Hunter 2002; Price et al. 2004; Semlitsch 1998; Semlitsch & Bodie 2003). Their results are further supported by Marsh and Trenham (2001) who state that pond occupancy may be more a result of the spatial configuration of terrestrial habitat then the distance between wetlands.

I used ArcINFO AMLs (Appendix C) to model the position in the landscape potential wetland restoration sites would most impact the persistence of amphibians in the adult life history stage. Our methods are based on the findings of Price et al. (2004), Semlitsch and Bodie (2003) and Guerry and Hunter (2002). The position in the landscape where potential wetland restoration sites would have the most impact on adult amphibians was calculated by determining the percent of natural upland vegetation within a 500 meter radius.

The amount of natural upland vegetation was found to have a positive association with the presence of *R. clamitans* (Guerry & Hunter 2002; Price et al. 2004). The natural vegetation patches were developed for the "Comprehensive Wildlife Conservation Strategy for Georgia" (GADNR 2005). They are the same patches that are used in the average weighted species richness model used to calculate connectivity in Layer 1.6. Natural vegetation patches were developed by combining the distribution maps from the GAP vertebrate species models which identifies suitable habitats for a species, given their natural history traits (Kramer & Elliott 2005). To isolate natural upland vegetation patches, all natural vegetation that intersected with 1974 GLUT wetland classes were removed. Semlitsch (1998) reports that a 164 meter buffer around a wetland encompassed 95% of the maximum distance surveyed species moved into terrestrial habitat. I chose a radius of 500 meters to encompass more vagile species (Semlitsch 1998; Semlitsch & Bodie 2003) and to represent the local scale that affected presence and absence as found by Price et al. (2004) and others (Guerry & Hunter 2002; Pope et al. 2000; Semlitsch 1998; Semlitsch & Bodie 2003).

The natural upland habitat surrounding a wetland is a bounded index from 0 - 100 with higher values indicating sites with a higher probability of occupancy and greater diversity of amphibian species (Price et al. 2004). As the percent of natural upland vegetation surrounding wetlands increases, populations become less dependent on metapopulation dynamics and are increasingly stable and the local scale (Kareiva et al. 1997). The final step is to scale the natural upland habitat surround a wetland using the masking layer. This is then reclassified using the steps outlined in the methods introduction. The final layer represents the landscape position where potential wetland restoration sites, following colonization, may support the most stable and thus the most persistent amphibian populations.

MAINTENANCE OF HIGH WATER QUALITY STREAMS (LAYER 1.9)

Main Wetland Function

- Water Quality and Quantity

Secondary Wetland Functions

- Aquatic Wildlife habitat
- Flood control and flow regulation
- Recreation

- Scenic value

The maintenance of high water quality streams layer is used to evaluate where potential wetland restoration sites may have the greatest positive effect on minimizing non-point source impairments to high priority streams. The high priority streams were identified by the Georgia Natural Heritage Program as streams that support aquatic species of conservation concern for the "Comprehensive Wildlife Conservation Strategy for Georgia" (GADNR 2005). By identifying the positions in the landscape where saturated variable source runoff accumulates and restoring wetlands and riparian buffers in these areas, we can use compensatory wetland mitigation as a tool to protect aquatic biodiversity.

The maintenance of high water quality streams uses the exact methodology as Layer 1.4 water quality and quantity index. The only change is in the stream datasets evaluated. Whereas, Layer 1.4 evaluated all streams 1st order and greater, the maintenance of high water quality streams only uses streams identified as high priority for aquatic biodiversity conservation. The maintenance of high water quality streams was developed using AMLs in ArcINFO (Appendix C). The final layer represents locations where potential wetland restoration sites would minimize impairments to streams and rivers and increase the likelihood that populations of aquatic species of conservation concern continue to persist.

POTENTIAL WETLAND RESTORATION SITE INDEX

The final output of the landscape model is the potential wetland restoration site index (PWRS). As stated in the methods introduction, the potential wetland restoration site index is an additive model used to highlight areas where restoration of wetlands would have the greatest benefit on the identified ecosystem functions and values. To obtain the PWRS index several final processing steps were necessary, see Figure 2.15.

First, the final outputs of Layers 1.3 to 1.9 were added together using ArcINFO to obtain a non-classified PWRS index. The maximum value attainable (63) of the non-classified PWRS index signifies sites with the highest potential to positively impact identified wetland functions and values. During the development of the model, each individual layer was masked in a final processing step to remove non-restorable landcover classes identified in Layer 1.1. As a precautionary check, the non-classified PWRS index was masked using Layer 1.1 and all non-restorable sites given a value of one, effectively separating these areas from all sites with some potential of restoration value. The final potential wetland restoration site index was obtained by reclassifying the masked non-classified PWRS index using Jenks Optimization (Dent 1999) on a scale of one to nine. Identified restoration sites with a value of nine have the highest potential to provide the desired wetland functions and values, while values of one are areas that are considered as non-restorable.

SENSITIVITY ANALYSIS

The potential wetland restoration site index was developed by adding Layers 1.3 - 1.9 together in a one to one fashion. Intuitively, it would seem that each layer in the potential wetland restoration site index is equally weighted and has an equal impact on the final output of the model. The underlying data, including errors and uncertainty, technical methods and assumptions we introduce at each layer has substantial effects on the areas identified as priority for restoration and the usefulness of our model for informing natural resource management decisions (Rae et al. 2007). A sensitivity analysis is a useful model evaluation technique that helps us understand how the structure of the data and methods impacts the final output of the model and the relative importance of each layer to the final priority wetland restoration sited index (Turner et al. 2001).

A one at-a-time sensitivity analysis technique was used to determine the direct and indexed effect each layer has on the total area and mean patch area of high value (7, 8, or 9) potential wetland restoration sites. The one at-a-time sensitivity analysis technique alters each input layer one layer at a time to create a weighted output and then compares it to a standard output (Compton et al. 2007; Crosetto et al. 2000). The standard output for my model is the potential wetland restoration site index described in the previous section without any modifications. The differences in the weighted output for each individual layer and the standard output can then be compared to determine the direct and indexed effect each layer has on the potential wetland restoration site index (Crosetto et al. 2000).

The sensitivity analysis was conducted by multiplying one input layer (Layer 1.4 - 1.9) that comprise the potential wetland restoration site index, one at a time by a factor of five. This weighted input layer is then added together with the remaining unweighted layers that comprise the PWRS Index, to receive a weighted output. The weighted output, based on the weighted individual layer, was then reclassified using Jenks Optimization (Dent 1999) on a scale of one to nine to make it comparable to the standard output of the potential wetland restoration site index. Both the weighted output and the standard output from the PWRS index were then reclassified into three classes, low (1, 2, and 3), medium (4, 5, and 6) and high (7, 8, and 9) potential for wetland restoration. The effect of each layer on the PWRS may be different at different spatial scales and regions

(Turner et al. 2001). To test for this I evaluated the direct and relative effects of each layer at two separate spatial scales, statewide and by generalized EPA Level 3 ecoregion as defined by Wharton (1977) (Figure 2.17) on the total area and mean patch area of high value potential wetland restoration sites.

The generalized ecoregions I evaluated were Blue Ridge, Ridge and Valley, Appalachian Plateau, the Piedmont, Southeast Coastal Plain and the Coastal Plain. The indexed effect of each layer on the standard output of the priority wetland restoration site index was determined by indexing the total area or mean patch size of high value PWRS for each weighted output to the weighted output that had the least effect on the standard output of the priority wetland restoration site index. The direct effect on the potential wetland restoration site index was calculated by determining the number of times the total area or mean patch size of high value PWRS in each input layer's weighted output increased in relation to the standard output. Understanding the direct and indexed effects of the input layers is important to understand how the model identifies sites and the impact restoring a particular site would have on the identified wetland functions and values.

The potential wetland restoration site index is most sensitive to the methods and parameters used in the development of layers that show the greatest direct effect. Sites identified as high value for wetland restoration are more likely to result in the potential improvements to wetland functions and values indentified by layers that have the greatest indexed effect on the PWRS index as compared to the layers having the least effect. For example, at the statewide spatial scale, high value potential wetland restoration sites are 183.65 times more likely to impact flood control and flow regulation then they are to impact wildlife habitat (Table 3.3). A Sensitivity analysis is useful in evaluating whether the model performs as anticipated and desired. By understanding the effects of each layer at a statewide and ecoregional spatial scale, layer outputs in the additive model can be adjusted, through weighting or reclassifying schemes, to identify potential wetland restoration sites where mitigation would have the highest probability in benefiting the desired wetland functions and values.

SURVEY ANALYSIS

Surveys were sent out to the technical advisory committee on October 18th, 2006 to evaluate the perceived acceptance of the model and how it can be tailored to be a more usable product by people involved in wetland mitigation (Appendix D). The survey consisted of three parts. The first section dealt with the different methods of reclassifying the final output of each layer before they were added together to receive the potential wetland restoration site index. This was a graphical interpretation of the data that dealt with how each reclassifying method highlighted different positions of high value potential wetland restoration sites in the landscape. Each respondent was asked which method identifies areas of high value potential wetland restoration sites that correspond to areas they felt would most positively influence the identified wetland functions and values. A brief explanation of reason for choosing a particular method was also requested. The written response was used to gauge what each respondent deemed important when evaluating a site for restoration based on a particular wetland function and value.

The second section of the survey was used to determine the importance each technical steering committee member ascribed to the individual layers within Component One of the model. Respondents were asked to rank the importance, to their organization, of the information represented by each layer as either, low, medium or of high when considering wetland mitigation. The second section of the survey was then used in conjugation with the results of the sensitivity analysis to evaluate whether the model performs as desired.

During periodic reviews of the model by the technical steering committee, concern was expressed that too much weight was being given to biodiversity conservation and wildlife habitat. The third section of the survey was used to determine what wetland function and value is most important to members of the technical steering committee when evaluating sites for wetland mitigation. Respondents were asked to rank the importance of each wetland function and value as either, low, medium or of high when considering site for wetland mitigation. The ranks of each wetland function and value were then compared to the main wetland function and value identified in each layer to see if the model was in fact biased and how closely the model reflects the order identified through the survey results.

Table 2.1. Attributes and values selected from STATSGO database used to determine hydric soils

Attribute	Definition	Values
ANFLOOD	The likelihood of flooding in a given year.	Occasionally = 5-50% Frequently = >50%
DRAINAGE	Natural drainage condition of the soil.	MW = Moderately well SP = somewhat poorly P = Poorly VP = Very poorly
HYDRIC	Soil meets the requirements for a hydric soil	Y = soil meets hydric definition
WTDEPH	Maximum value for the range in depth to the seasonally high water table	0 - 2.5 meters

Table 2.2. Ranking scheme for hydric soils identified in Layer 1.2

Rank	Definition
9	Low conductivity \ hydric soils present - Primary wetland restoration site.
6	Low conductivity \ hydric soils not present - Secondary restoration sites.
1	Non restorable landcovers identified in Layer 1.1.

Table 2.3: Ranking scheme for potentially jurisdictional wetlands identified in Layer 1.3

Rank	Definition
9	Sites that meet the Savannah District definition of jurisdictional wetlands
8	100 foot buffer of sites designated as jurisdictional (Rank = 9)
6	Secondary sites that are outside of the 100 foot buffer on jurisdictional wetlands (Rank = 8) yet still considered as potentially restorable.
1	Non restorable landcovers identified in Layer 1.1

Table 2.4: Attributes selected from the National Hydrography Dataset to determine potentially jurisdictional wetlands.

Attribute (FType)	Definition (USGS 2002)	Special Notes
Connector (334)	A known, but nonspecific connection between two nonadjacent network segments.	
Canal or Ditch (336)	An artificial open waterway constructed to transport water, to irrigate or drain land, to connect two or more bodies of water, or to serve as a waterway for water craft.	Canal or ditch was used because it may represent navigable waterways and adjacent wetlands would be considered as jurisdictional.
Playa (361)	The flat area at the lowest part of an un-drained desert basin, generally devoid of vegetation.	Playa was used because several Carolina Bays and other wetland systems in Georgia were classified as Playas.
Lake or pond (390)	A standing body of water with a predominantly natural shoreline surrounded by land.	
Inundation Area(403)		Inundation area was chosen because it encompasses habitat for migrating waterfowl, percolation basins and other areas affecting water quality
Reservoir (436)	A constructed basin formed to contain water or other liquids.	Reservoir was chosen because it includes area that affect water quality; for example filtration ponds and sewage treatment ponds. Reservoirs in NHD also encompass water storage which has an effect on flood control.
Stream and Rivers (460)	A body of flowing water.	
Swamp or Marsh (466)	A non-cultivated, vegetated area that is inundated or saturated for a significant part of the year. The vegetation is adapted for life in saturated soil conditions.	

Table 2.5: Resistance coefficients used to calculate the grid of habitat resistance. NR signifies that no range was reported.

Landcover Class	Size	Resistance Value	Range	Species	Location Studied	Citation
Beaches	N/A	45.0	NR	*Bufo bufo*	France	(Joly et al. 2003)
Open Water	<1 ac	2.3	2.3 - 2.3	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007)
Open Water	1<x<5 ac	50.0	23.3 - 100	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007)
Open Water	>5 ac	100.0	23.3 - 100	*Bufo bufo*	France	(Joly et al. 2003)
Low Intensity Urban	N/A	59.1	23.3 - 100	*Ambystoma opacum; Bufo americanus, Hyla versicolor, Pseudacris crucifer, Rana clamitans, P. triseriata*	Massachusetts, Michigan & Ohio	(Compton et al. 2007; Price et al. 2004)
High Intensity Urban	N/A	80.0	23.3 - 100	*Bufo bufo*	France	(Joly et al. 2003; Price et al. 2004)
Clearcuts	N/A	63.5	4.6 - 77.0	*Rana clamitans;* multiple species*; Ambystoma maculatum, A. texanum, Bufo americanus*	Maine; Maine; Missouri	(Cole 2006; Patrick et al. 2006; Rothermel & Semlitsch 2002)
Barren Ground	N/A	80.0	50.0 - 100	*Bufo bufo; Rana clamitans, R. pipens*	France; New Brunswick Canada	(Joly et al. 2003; Mazerolle & Desrochers 2005)
Deciduous Forests	N/A	2.3	2.3 - 2.3	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007)
Evergreen Forests	N/A	2.3	2.3 - 2.3	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007)
Mixed Forests	N/A	2.3	2.3 - 2.3	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007)
Agriculture, Pasture	N/A	20.9	11.5 - 46.0	*Ambystoma opacum; Bufo bufo*	Massachusetts ; France	(Compton et al. 2007; Joly et al. 2003)
Agriculture, Row Crops	N/A	45.0	NR	*Bufo bufo*	France	(Joly et al. 2003)
Forested Wetlands	N/A	2.3	2.3 - 2.3	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007)

Table 2.5 continued

Forests and Forested Wetland	Edge (30 meters)	8.5	2.3 - 21.5	*Ambystoma opacum;* multiple species*; A. opacum, Notophthalmus viridescens, Rana palustris; Bufo bufo;* Multiple species	Massachusetts; Maine; Connecticut; France; Maine	(Compton et al. 2007; deMaynadier & Hunter 1999; Gibbs 1998; Joly et al. 2003; Patrick et al. 2006)
Saltwater/ Brackish Marsh	N/A	92.0	63.0- 100	*Rana sphenocephala, R. clamitans*	Florida; Georgia, Georgia, California	(Christman 1974; Jenson 2007 *Pers Comm;* Maerz 2007 *Pers. Comm.;* Ruibal 1959)
Freshwater Emergent Marsh	N/A	6.8	4.6 - 11.5	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007)
Road 4	Interstate	88.6	69.0 - 100	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USCB 2007)
Road 3	US Highway	74.1	46.0 - 100	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USCB 2007)
Road 2	State Highway	37.3	23.0 - 80.5	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USCB 2007)
Road 1	Local	16.4	4.6 - 46.0	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USCB 2007)
Stream Order	1	3.0	2.3 - 6.9	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USGS 2002)
Stream Order	2	6.4	4.6 - 11.5	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USGS 2002)
Stream Order	3	28.6	18.4 - 69.0	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USGS 2002)
Stream Order	$\geq$4	75.0	34.5 - 100	*Ambystoma opacum*	Massachusetts	(Compton et al. 2007; USGS 2002)

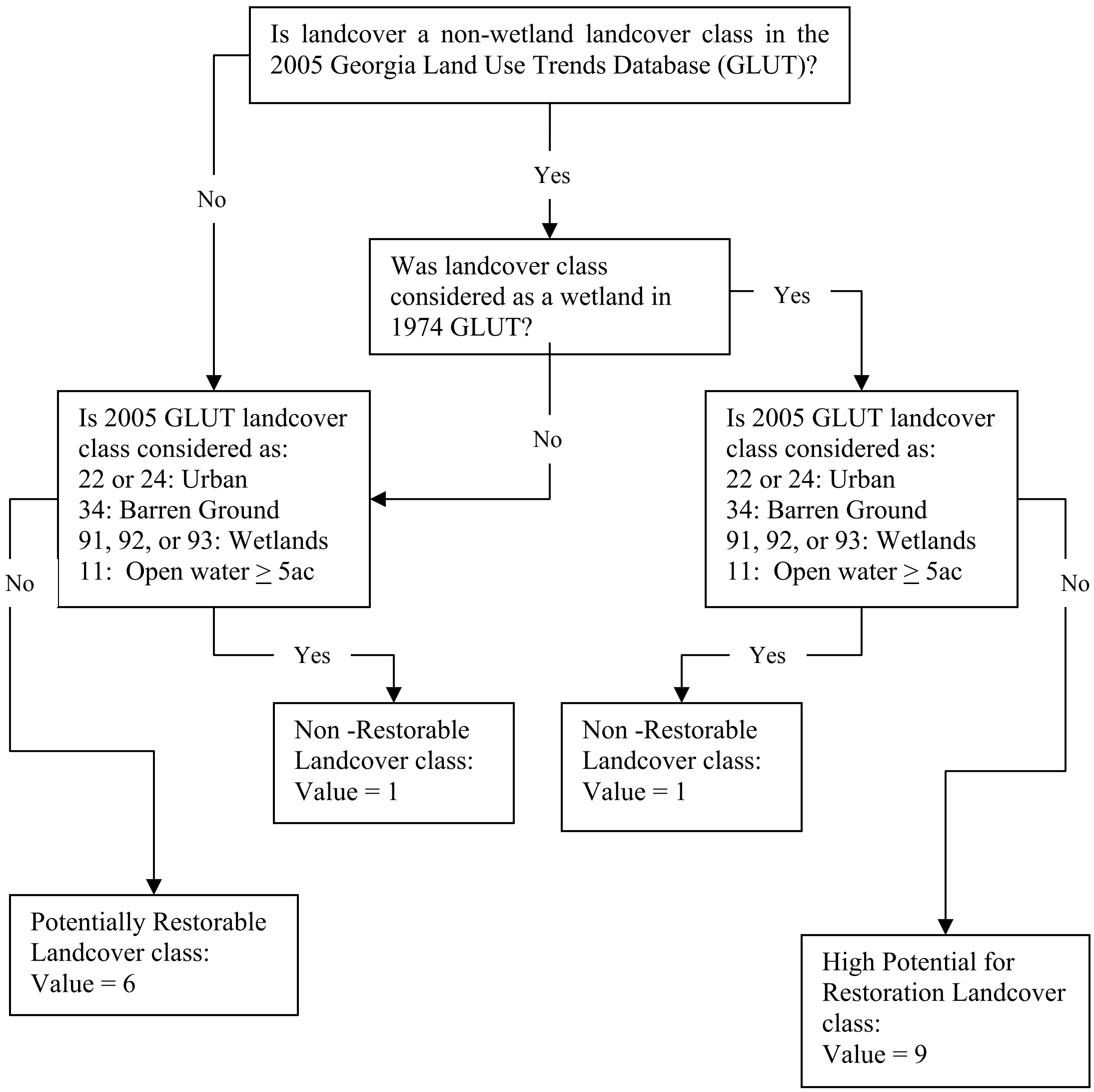


Figure 2.1: Decision analysis chart for determining whether a landcover class in the 2005 Georgia Land Use Trends database is considered as potentially restorable to a wetland state.

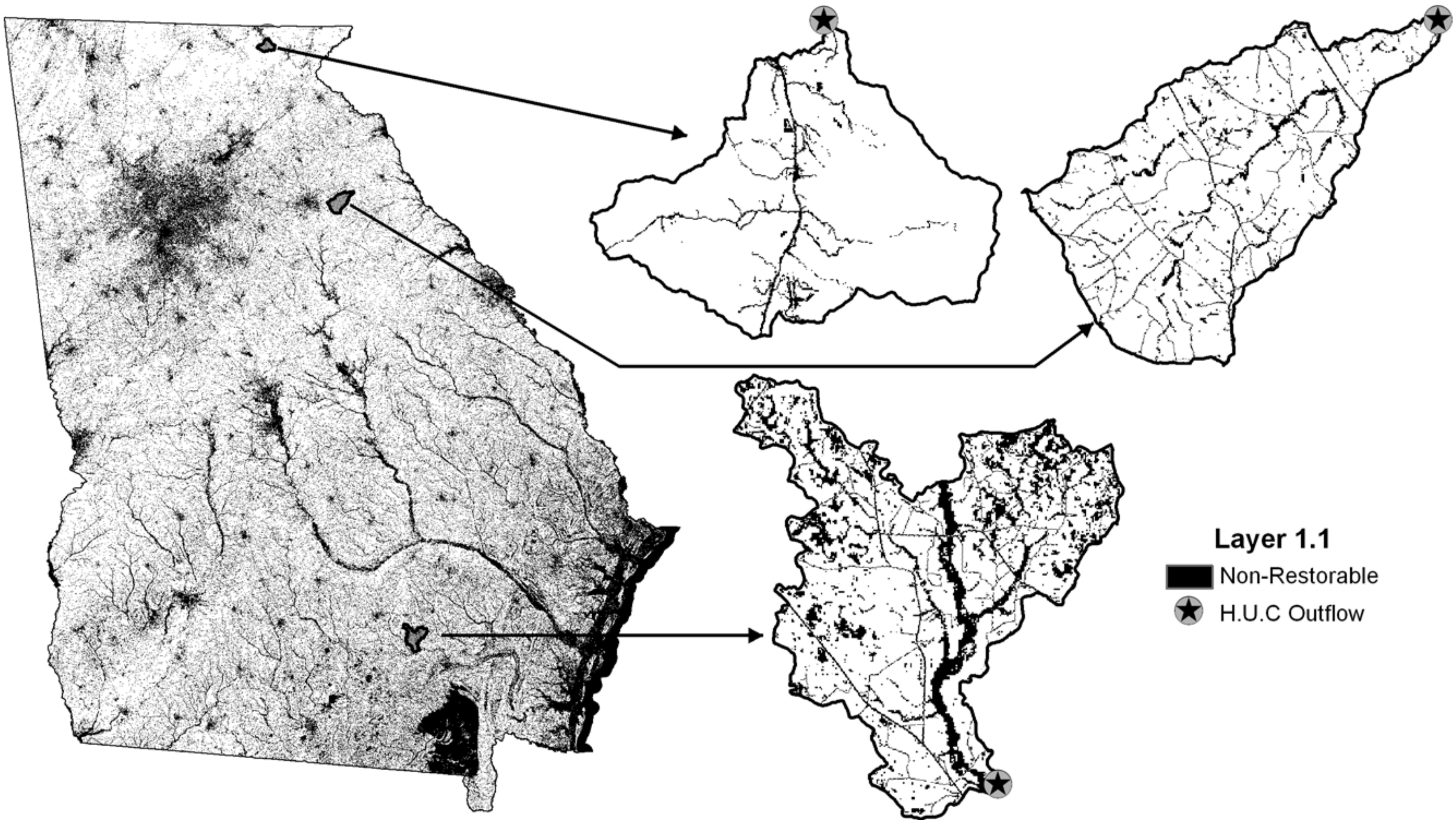


Figure 2.2: Layer 1.1 Non-restorable landcover classes identified using the 2005 Georgia Land Use Trends database with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

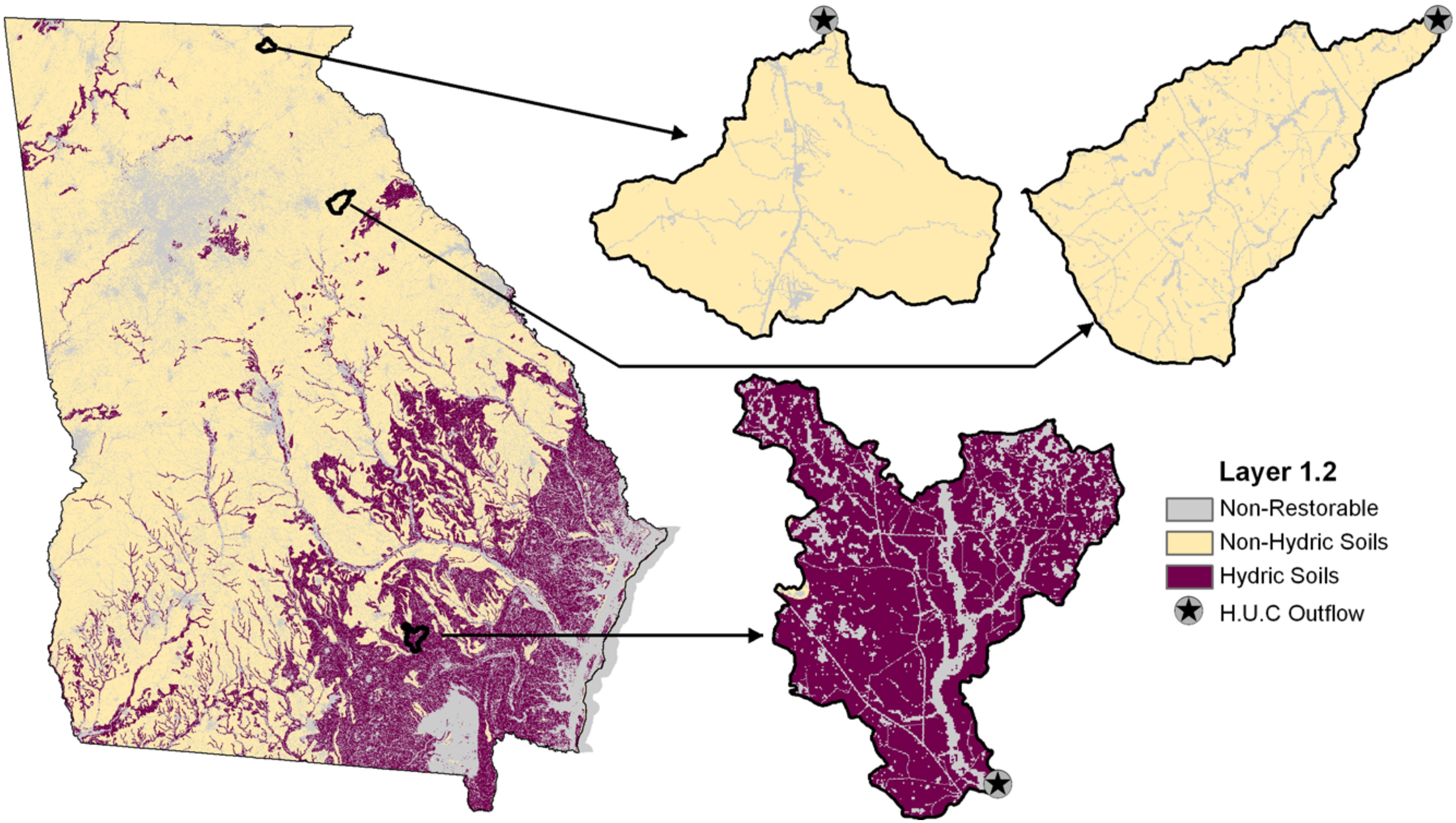


Figure 2.3: Layer 1.2 Hydric soils identified using the STATSGO database with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

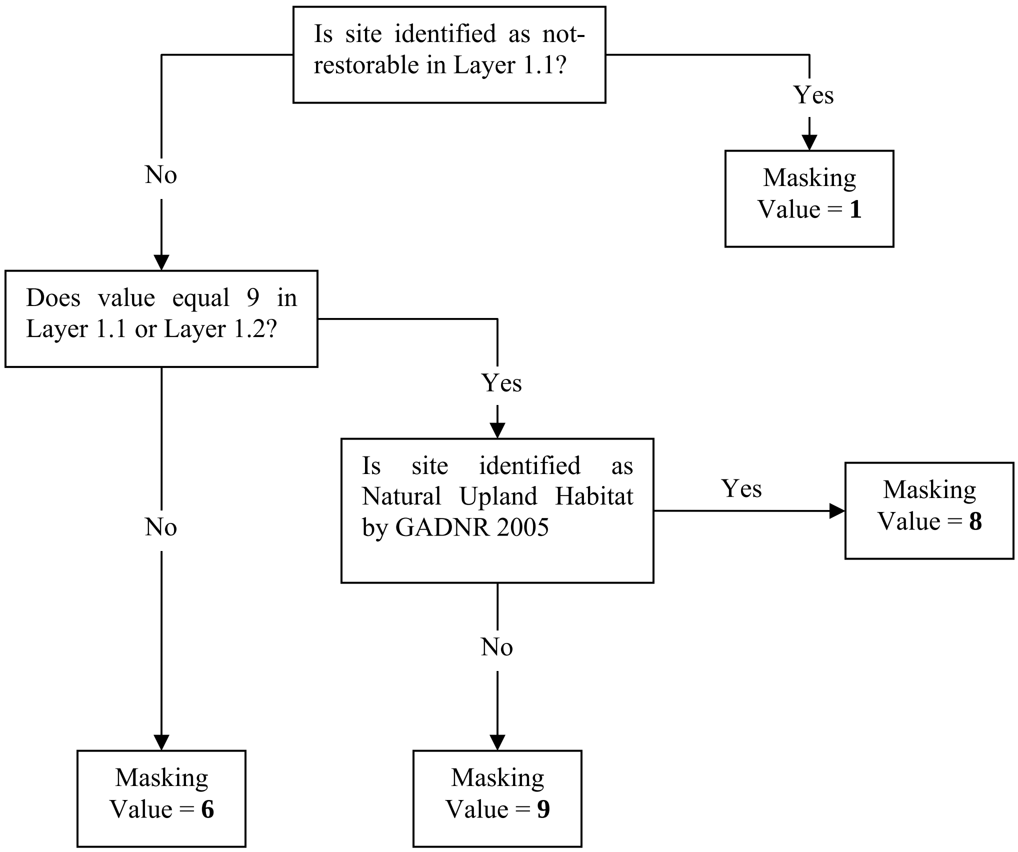


Figure 2.4: Decision analysis chart used to construct the Masking Layer from Layers 1.1 and 1.2 in Component One of the potential wetland restoration site index.

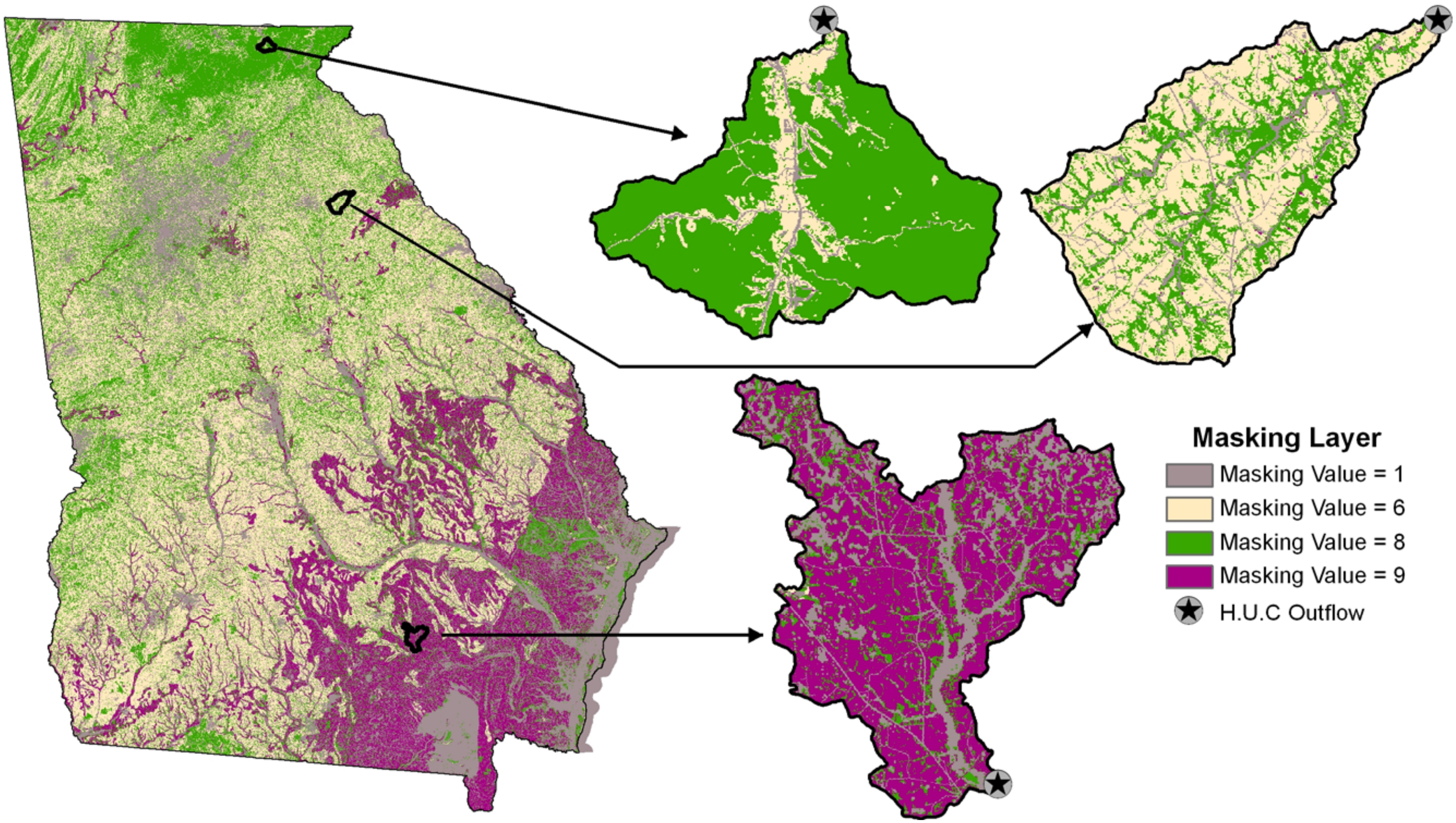


Figure 2.5: Masking layer constructed by combining Layers 1.1, non-restorable landcover classes, and 1.2, hydric soils, with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

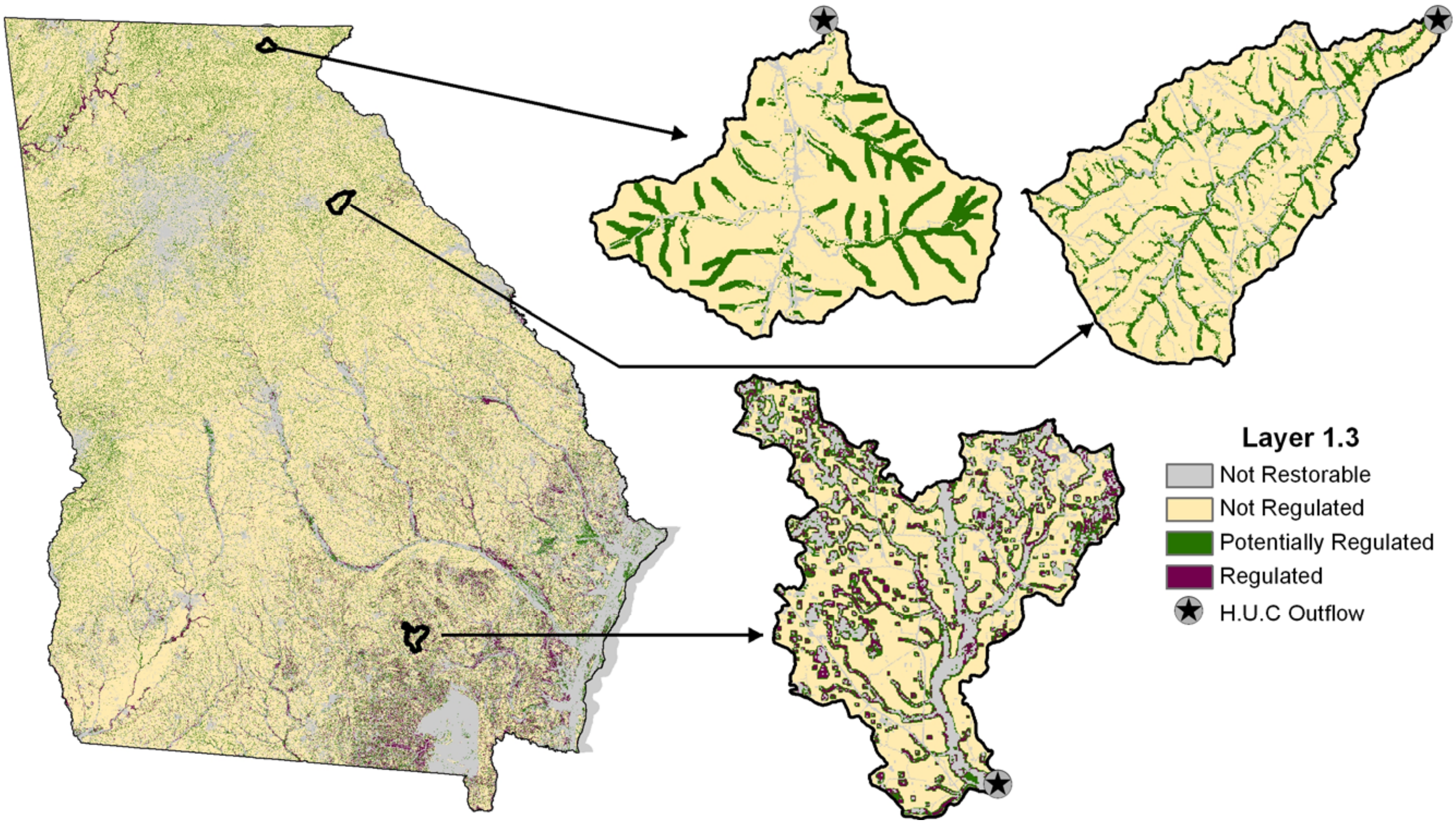


Figure 2.6: Layer 1.3 Jurisdictional designation used as part of the potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

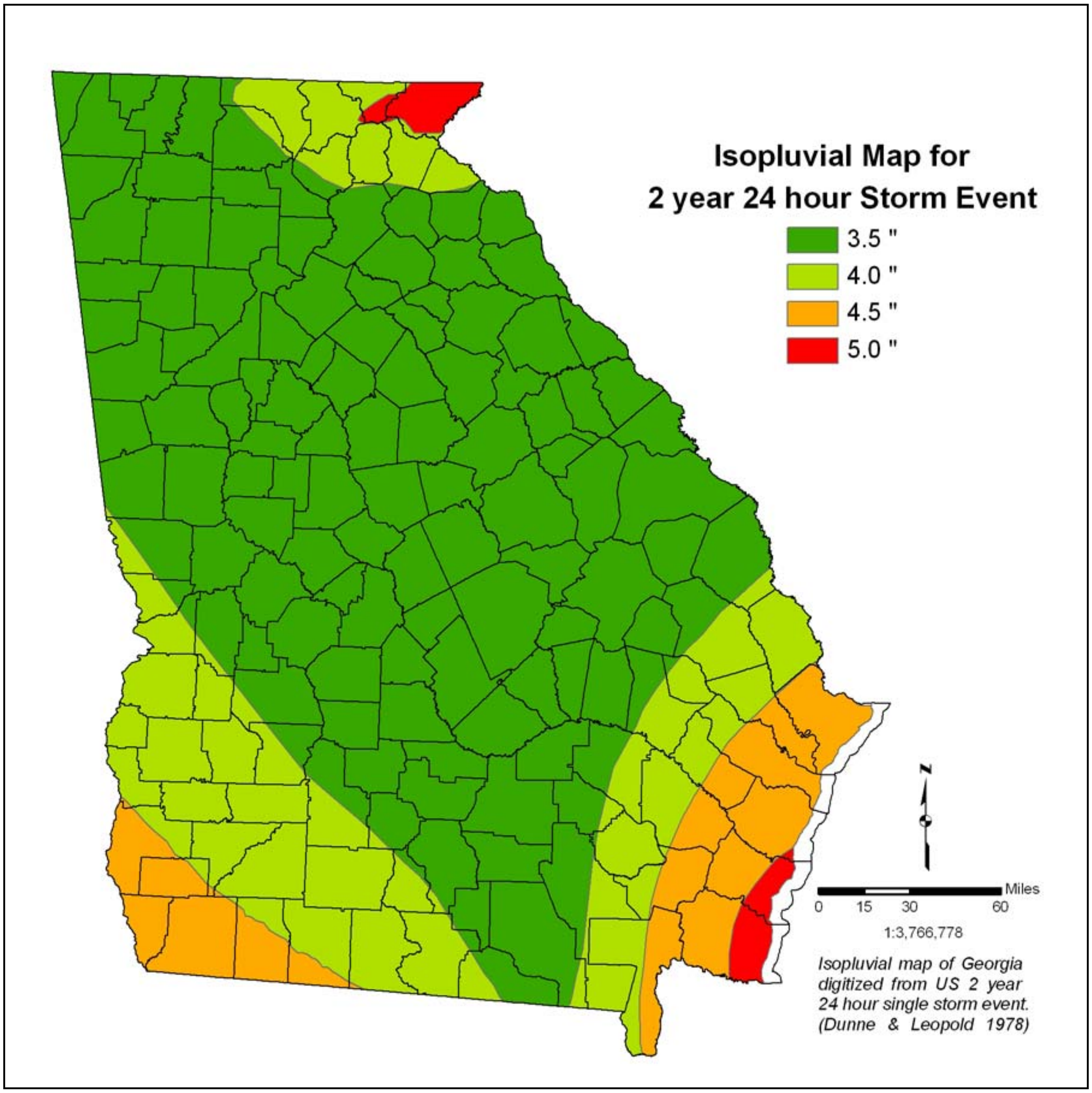


Figure 2.7: Isopluvial map depicting the two year 24 hour single storm event for all regions in Georgia.

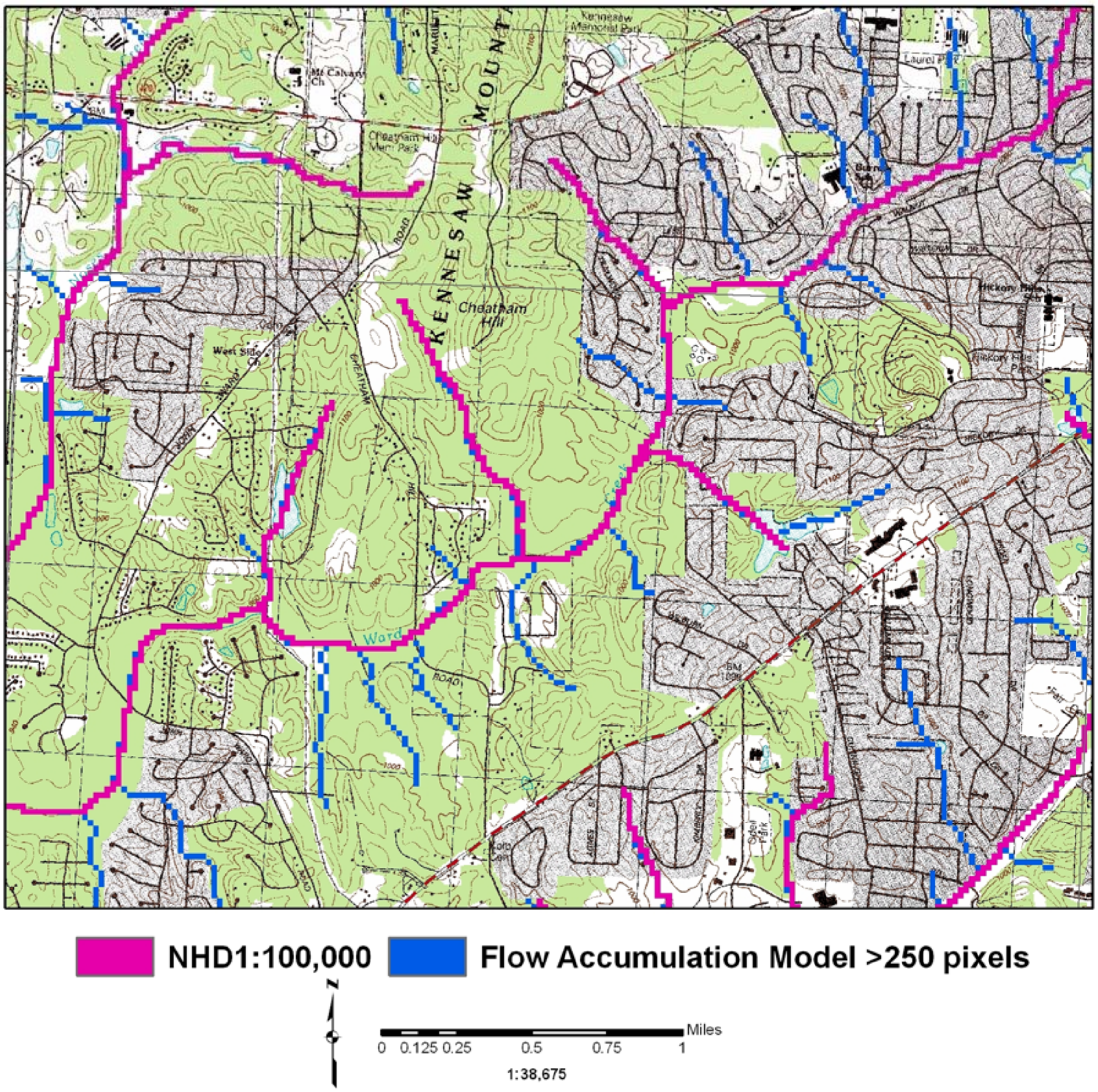


Figure 2.8. Example of the differences in stream lengths mapped in the National Hydrography Dataset at 1:100,000 and stream lengths mapped using digital elevation models in ArcINFO.

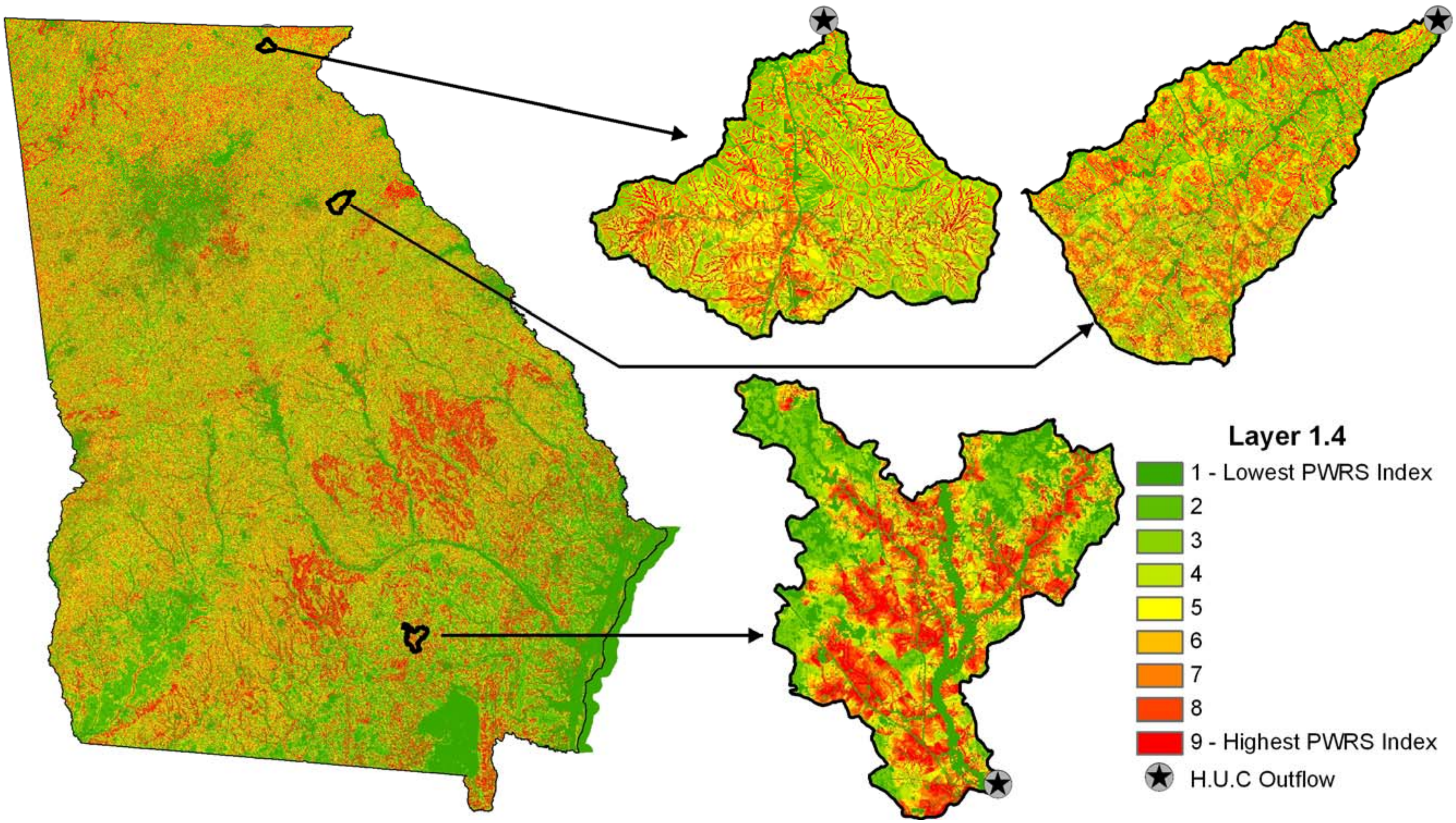


Figure 2.9: Layer 1.4 Water quality and quantity index used as part of the potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

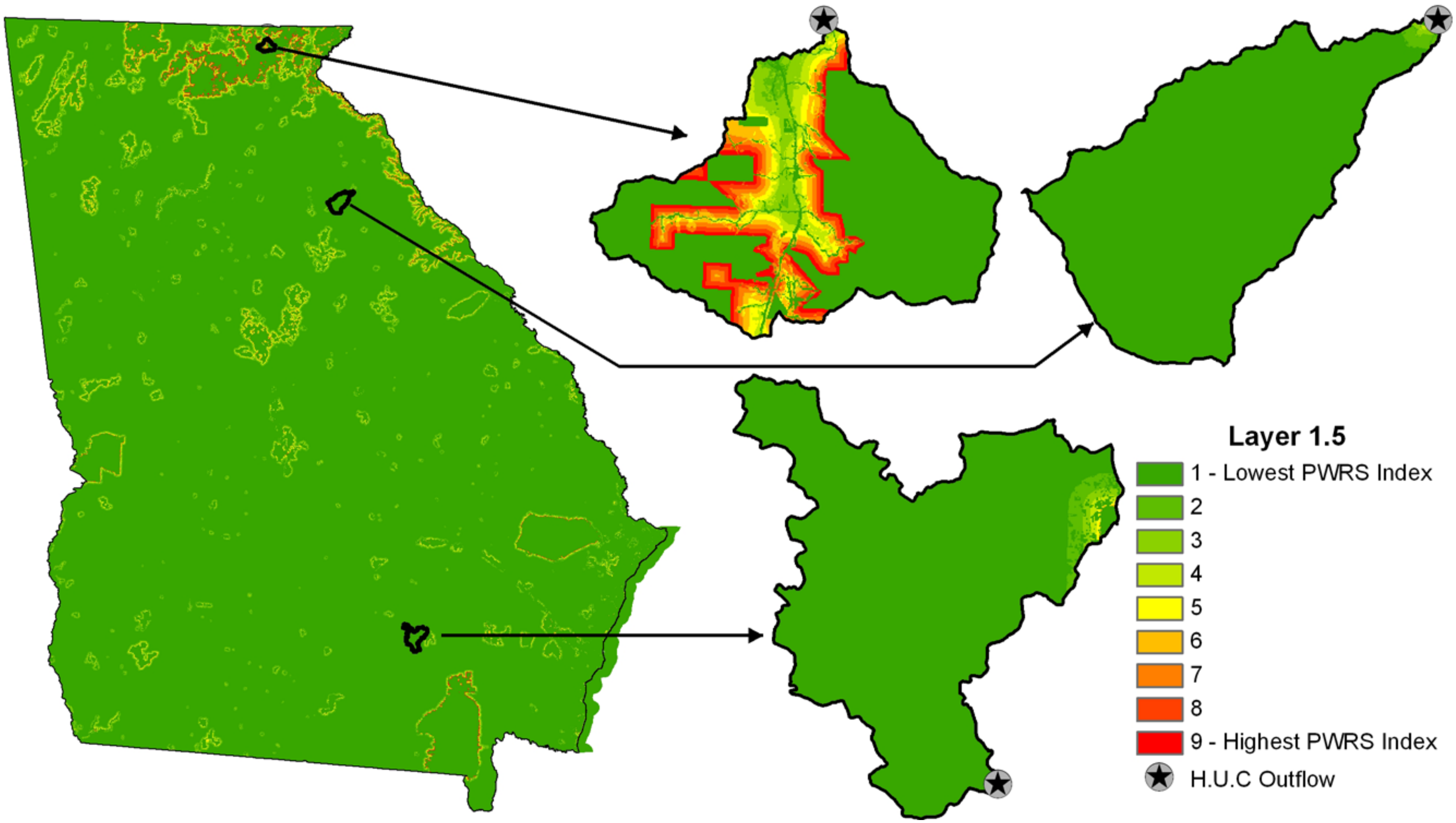


Figure 2.10: Layer 1.5 Connectivity of existing conservation areas used as part of the potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

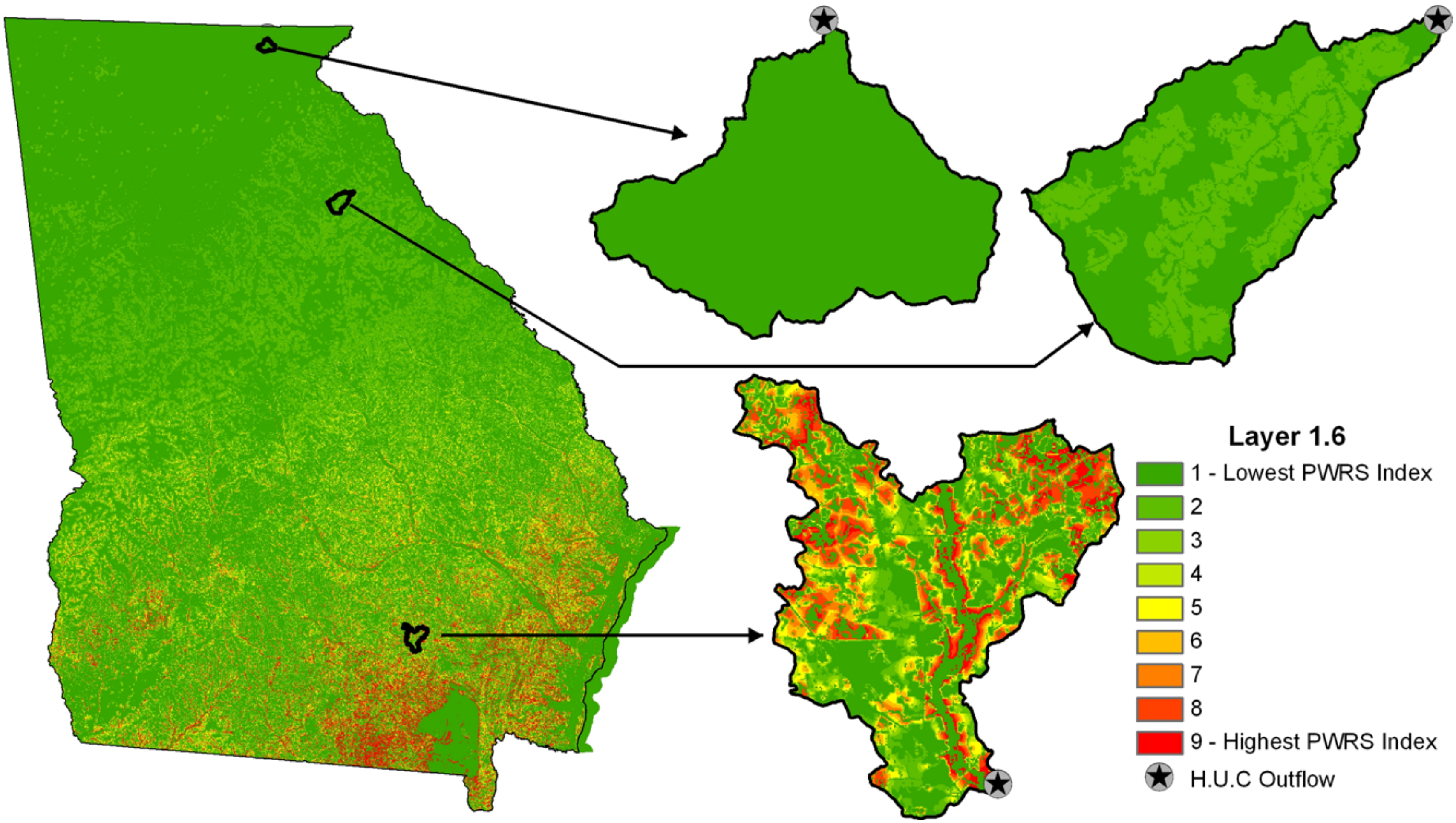


Figure 2.11: Layer 1.6 Terrestrial dispersal corridors between wetlands used as part of the potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

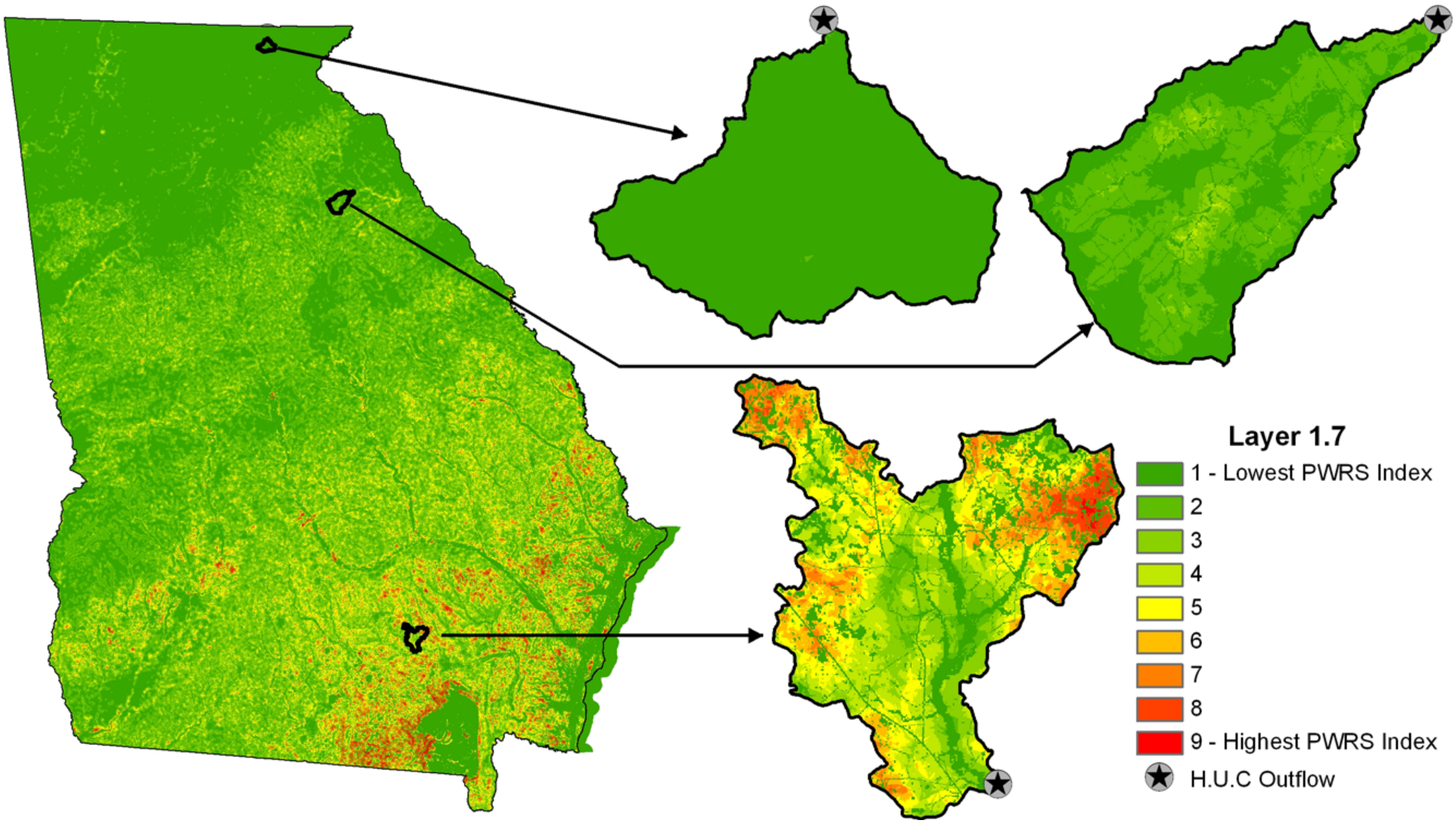


Figure 2.12: Layer 1.7 Hydrologic connectivity of wetlands used as part of the potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

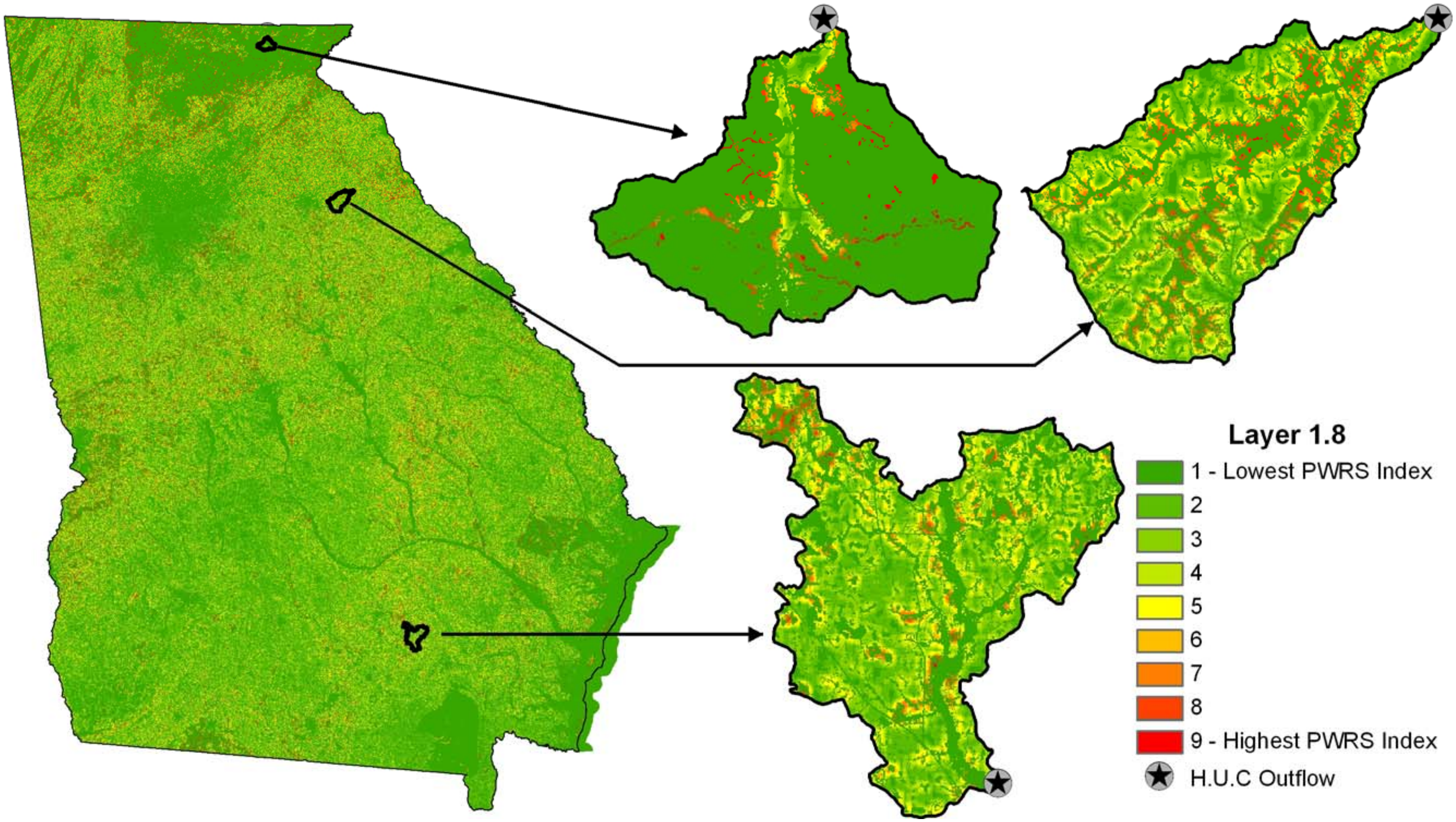


Figure 2.13: Layer 1.8 Natural upland habitat surrounding wetlands used as part of the potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

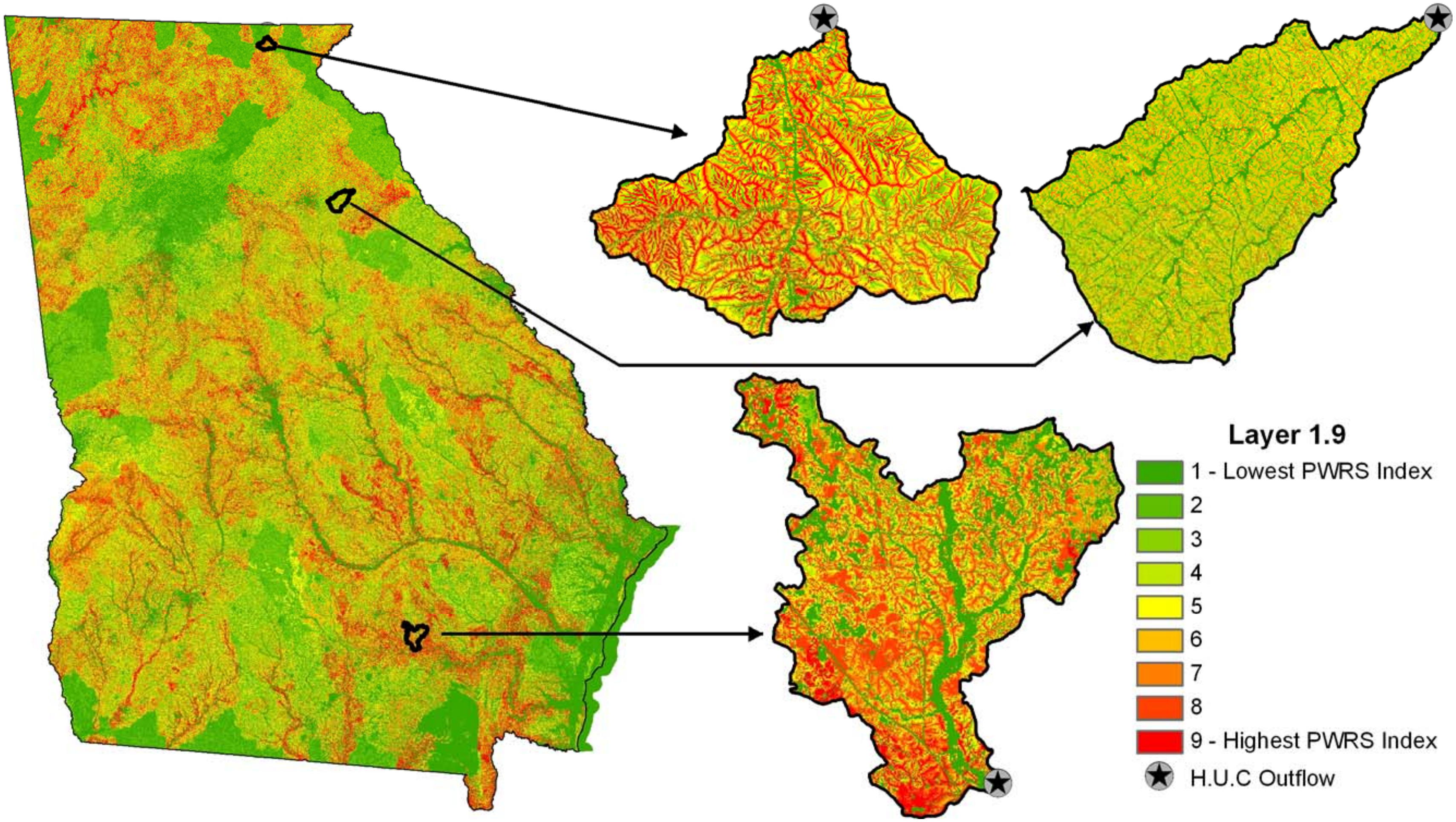


Figure 2.14: Layer 1.9 Maintenance of high water quality streams used as part of the potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

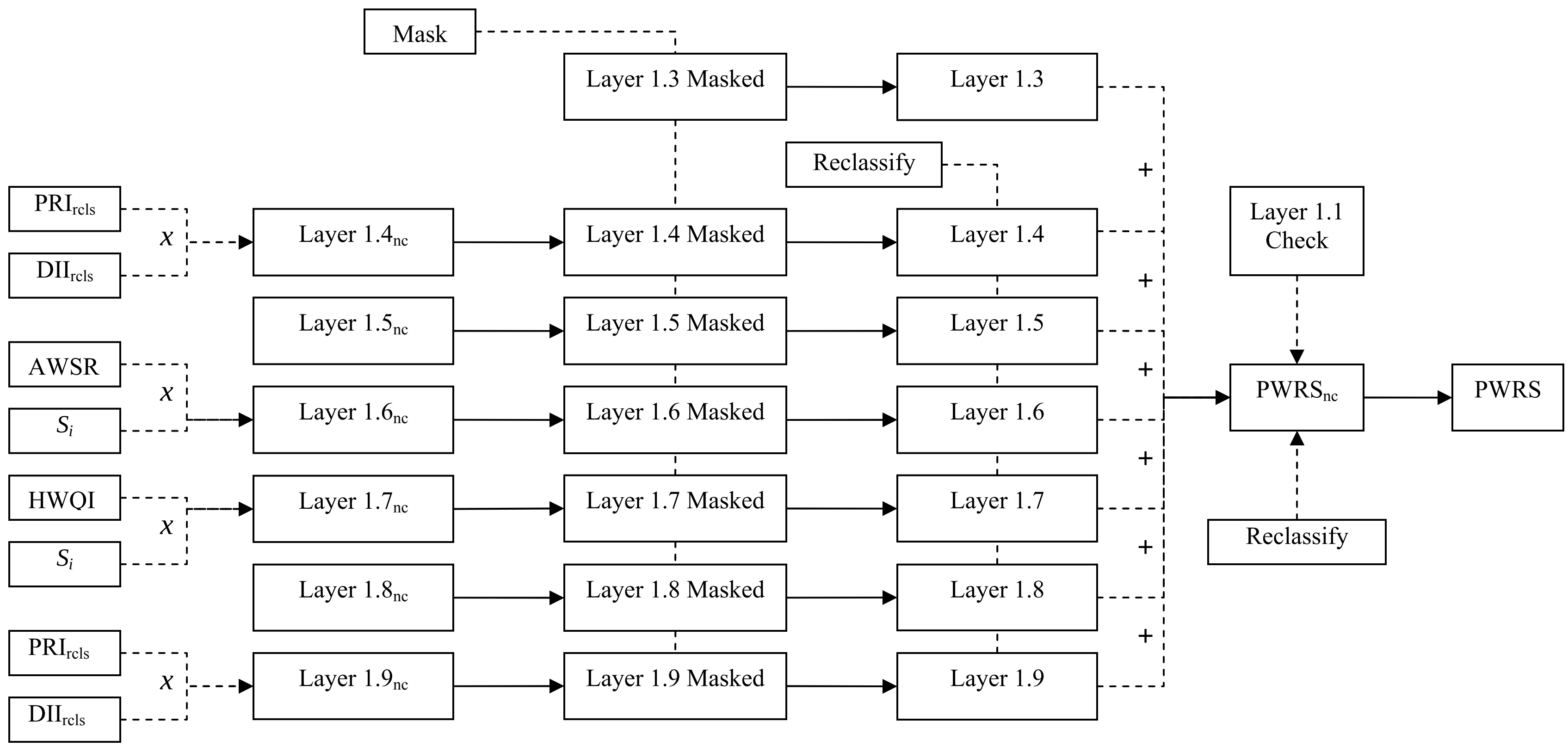


Figure 2.15: Flowchart describing how the potential wetland restoration site index is constructed by combining the layers in Component One. Dashed lines (- - -) signify processes in the model; solid lines (——) signify progression of each layer; *nc* signifies a layer has not yet been reclassified using Jenks Optimization. Mask is created using conditional statements in Figure 2.3.

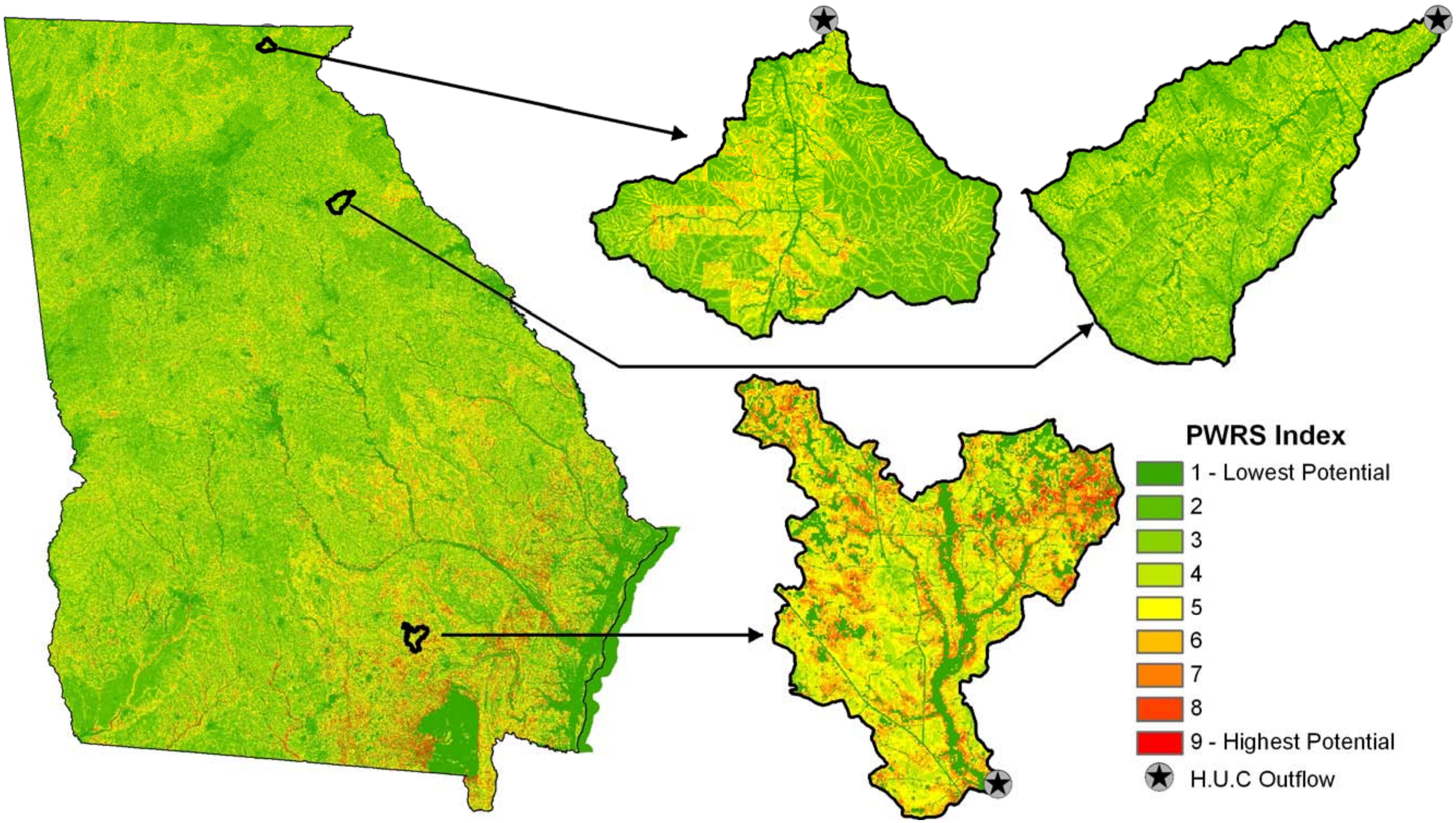


Figure 2.16: The potential wetland restoration site index with representative 12 Digit Hydrologic Unit Codes in the North, South and Piedmont regions of Georgia.

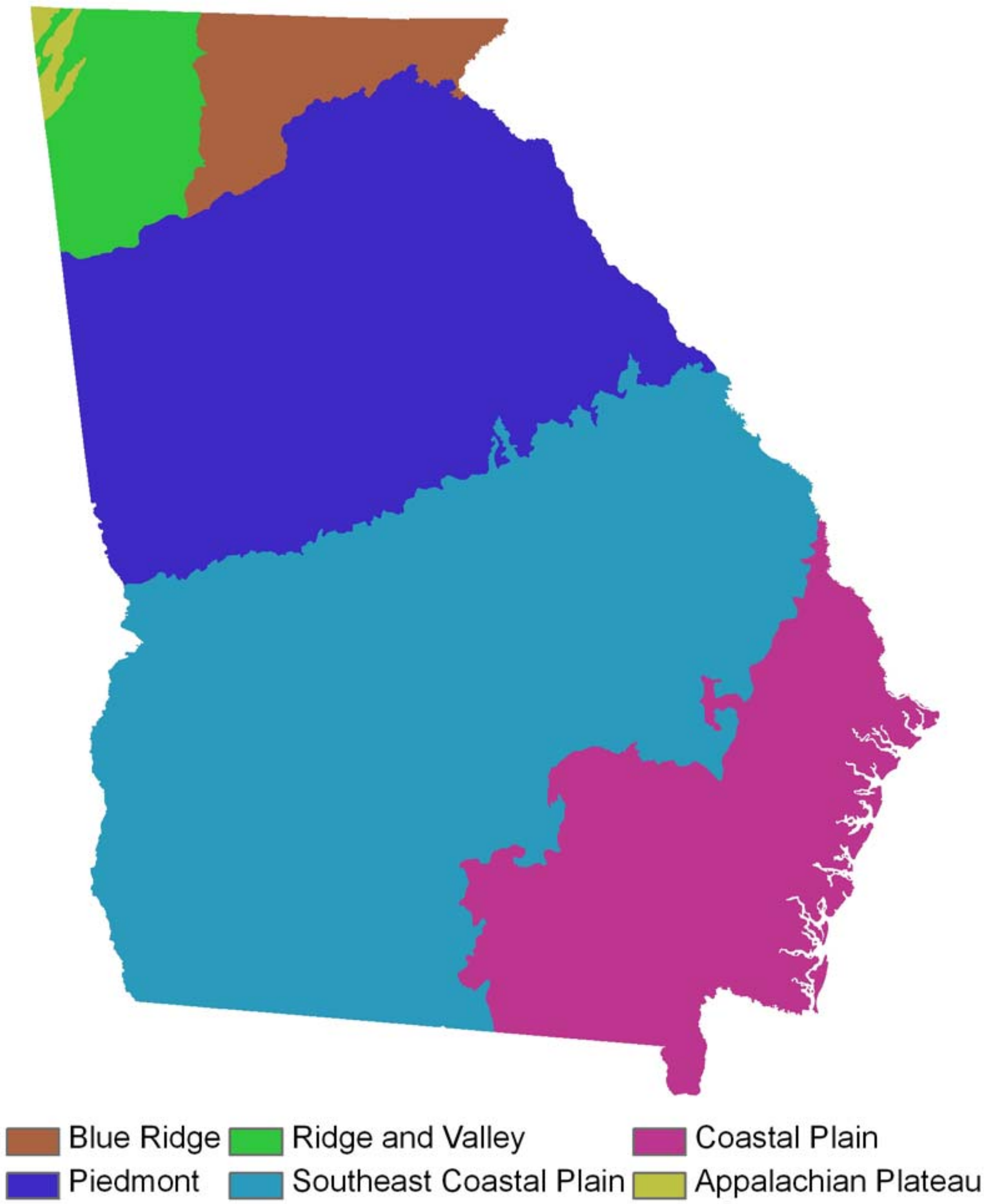


Figure 2.17: Generalized ecoregions (Wharton 1977) used to evaluate the sensitivity of the potential wetland restoration site index to the individual input layers of Component One.

CHAPTER 3

SENSITIVITY AND SURVEY ANALYSIS RESULTS

The potential wetland restoration index indentified that of all lands having some potential to benefit ecosystem services through wetland restoration, only 2.9% of them are considered as high value potential wetland restoration sites (Table 3.1). The 2.9% identified as high potential for restoration constitutes only 391,188 ha of the total area of the state (15,406,024 ha) that is considered as potentially restorable. Based on the 2005 GLUT database, wetlands constitute 12.4% (1,916,797 ha) of the total area of the state. Restoring these high value sites would increase this proportion 1.8% to 14.2% of the total area of the state. This is still less than the percentage of wetlands that existed in 1974, 15.6% (2,398,532 ha). The majority of the state, 60.0%, has little potential to be restored to a wetland state. The coastal plain exhibits the highest percent, 9.8%, of its area as high value for restoration while the Blue Ridge Ecoregion the least, 0.06%. The largest number of hectares that were identified as high priority for wetland restoration are located in the Southeast Coastal Plain ecoregion, 152426 ha.

NON-RANDOM MOVEMENT

The Shapiro-Wilks Test for normal distributions indicated that neither non-random cost-distance (Shapiro-Wilks statistic = 0.908, $n = 388$, $p < 0.001$) nor random cost distance (Shapiro-Wilks statistic = 0.871, $n = 388$, $p < 0.001$) are normally distributed (Table 3.2, Figure 3.1). Based on these results it was determined that parametric tests were not appropriate for our data and a non-parametric Wilcoxon Signed Ranks Test was most appropriate. Results from the Wilcoxon Signed Ranks Tests (Table 3.3a) indicate that difference between non-random and random cost-distance are significantly different from zero ($n = 388$, $z = -9.773$, $p < 0.001$, Table 3.3b). The results of these statistics are not biologically relevant to the movement of amphibians in a landscape mosaic. The significant results only indicate that the model does perform in a non-random fashion, and that the methods chosen are appropriate to spatially evaluate the non-random movement of amphibians.

SENSITIVITY ANALYSIS

The sensitivity analysis indicates that the additive layers affect the total area and mean patch size of potential wetland restoration sites differently depending upon the spatial scale and ecoregion in which they are evaluated. At a statewide spatial scale, Layer 1.7, the Hydrologic connectivity of wetlands, has 183.65 times more indexed effect on the mean patch size of high potential wetland restoration sites than does Layer 1.8, Natural upland habitat surrounding wetlands (Table 3.5, Figure 3.2). The mean patch size of the high value potential wetland restoration sites is also 2.69 times more sensitive to the methods and parameters used in Layer 1.7 than it is to Layer 1.5. The methods and parameters that comprise the natural upland habitat surrounding wetlands layer have a negative effect on the mean patch size of high value potential wetland restoration sites (-0.73 times). When evaluating the sensitivity of the total area of high value potential wetland restoration sites, in relation to mean patch size, the order of the layers that have the most direct and indexed effect on the model changes. Restoring high value potential wetland restoration sites is 11.25 times more likely to result in benefits to wetland functions and values identified in Layer 1.4 than those identified in Layer 1.5 (Table 3.6).

The PWRS index is also most sensitive to methods and parameters used in Layer 1.4; though, only slightly more so than Layer 1.9 (1.17 times). As with the mean patch size, the methods and parameters from the layer that has the least effect on the PWRS index has a direct negative effect on the total area of high value potential wetland restoration sites.

The sensitivity of the model and the evaluation of the effects at a statewide spatial scale can be misleading. By mapping and analyzing the data at a statewide scale, the wetland functions and values that the technical steering committee deemed most important when evaluating possible sites for mitigation are not those highlighted by the PWRS index. Therefore, it is important to evaluate the model using the same datasets by ecoregion to determine if the highlighted wetland functions and values are consistent at all spatial scales.

Evaluating the model at the ecoregional scale shows that depending on the ecoregion of interest the direct and indexed effects of the input layers on the total area and mean patch size of high value potential wetland restoration sites varies. In the piedmont ecoregion Layer 1.5, connectivity to existing conservation areas, has the most indexed effect on the potential wetland restoration site index. This layer has 606.40 times more indexed effect on mean patch size than does Layer 1.6, terrestrial dispersal corridors between wetlands (Table 3.7, Figure 3.3). The mean patch size of high value PWRS are also 2.07 and 5.16 times more likely to benefit connectivity to existing conservation areas than benefit either of the water quality models, Layer 1.4 and Layer 1.9 respectively, which are the most important layers to the technical steering committee. The two water quality indices do have the most effect on the total area of high value potential wetland restoration site in the Piedmont ecoregion. Water quality is 1804 times more likely to benefit from restoring high values sites than is wildlife habitat based on terrestrial dispersal corridors (Table 3.8). In the Piedmont ecoregion, as at the statewide spatial scale, the PWRS index is most sensitive to the methods and parameters used to calculate Layer 1.4.

The mean patch size of high value potential wetland restoration sites in the Blue Ridge ecoregion are also most affected by Layer 1.5. The effect, though, is much greater. Layer 1.5 has 3,433.52 times more indexed effect on the PWRS index than does Layer 1.6 and 1.7 (Table 3.9). Due to the geographical makeup of the Blue Ridge ecosystem which limits the number and size of wetlands, both Layers 1.6 and 1.7 have no direct or indexed effect on the PWRS index. The mean patch size of high value PWRS in the standard output indicates that there are only relatively small patches in the Blue Ridge ecoregion that are of high value for restoration (0.7 ha). The total area of high value potential wetland restoration sites shows that 1424 ha of high value sites are located in the Blue Ridge ecoregion (Table 3.10). Based on the comparison of the mean patch size and total area, most of the high value sites in the Blue Ridge ecoregion are small or single pixel patches that highly influence the sensitivity of the mean patch size.

The water quality and quantity index has the most effect on the mean patch size of high value PWRS in the Ridge and Valley ecosystem. It has 68.55 times more indexed effect than does Layer 1.6, 1.7 or 1.8 (Table 3.11, Figure 3.5). As in the Blue Ridge ecoregion, in the Ridge and Valley ecoregion Layers 1.6 and 1.7 have no effect on the PWRS index. Layer 1.8, natural upland vegetation surrounding wetlands, also shows almost no effect, 1.01 times, on mean patch size of high value potential wetland restoration sites. Layer 1.8 does have a substantial effect on the total area of high value potential wetland restoration sites. The total area of high value sites increased 43,726 ha as a result of increasing the importance of Layer 1.8 (Table 3.12). Based on the results for Layer 1.8 for total area, the number of patches of high value potential wetland restoration sites increased while the mean size of these patches remained similar to those in the standard output (8 ha).

The total area of high value potential wetland restoration sites in the Appalachian Plateau is most sensitive to Layer 1.9. The PWRS index is only 1.2 times more sensitive to the parameters in Layer 1.9 than it is to Layer 1.4 (Table 3.14). The similar direct effect reflects that Layer 1.9 and 1.4 use the same methodology on different stream datasets. And that a high percentage of the streams in the Appalachian Plateau are considered as high priority for conservation by the Georgia Natural Heritage Program (GADNR 2005).

In the Coastal Plain ecoregion the PWRS index is most sensitive to Layer 1.7, hydrologic connectivity to wetlands. It has 433.22 times more indexed effect on mean patch size than does Layer 1.8, natural upland habitat surrounding wetlands (Table 3.15, Figure 3.7). The Coastal Plains ecoregion is similar to the statewide spatial scale, in that the Natural upland vegetation surrounding wetlands has a direct negative effect (-0.89) on the mean patch size of high value potential wetland restoration sites. The direct effect between each input layer on the total area of high value PWRS is fairly similar. The maximum difference in the direct effect between Layer 1.7 and 1.5 is only 2.5 times (Table 3.16), where as in the Appalachian Plateau ecoregion the maximum difference between layers is 145.68 times (Table 3.14). The similar direct effects on total area suggest that in the Coastal Plain the methods for each layer come closest to desired outcome of a one to one relationship between the input layers in the potential wetland restoration index.

The mean patch size of high value restoration sites in the Southeastern Coastal Plains ecoregion most closely resembles the importance of layers the technical steering committee deemed important for prioritizing potential sites for wetland mitigation (Tables 3.16 and 3.18). Both of the layers dealing with water quality and quantity, Layers 1.4 and 1.9, have the most effect on the mean patch size. Layer 1.9, Maintenance of high water quality streams has 55.54 times more indexed effect on high value potential wetland restoration sites than does Layer 1.8 (Table 3.17, Figure 3.8). The importance of the layers and their effect on the PWRS index changes when evaluated based on the total area. Layer 1.4 and 1.9 remain the most influential on the model; now though, Layer 1.4 has the greatest indexed effect (Table 3.18). Even though the two water quality models remain the most influential, the order of the layers for total area change and the Southeast Coastal Plain no longer reflects the order of layers deemed most important by the technical steering committee.

In the surveys provided to the technical steering committee, Layer 1.9 and 1.4 ranked as the two most important layers in the model. While the importance of the each layer on the mean patch size of high value restoration sites in the Southeast Coastal Plain closely reflect the importance ascribed by the technical steering committee. The sensitivity analysis results differ from the survey results in two ways. First, in the sensitivity analysis Layer 1.8, natural upland habitat surrounding wetlands, has the least effect on the standard output, while the survey results indicate that the least important layer should be Layer 1.6. The second difference is in the effect each layer has over the next most important. For example, based on the mean patch size, Layer 1.9 has 1.973 times more direct effect on the standard output than does Layer 1.4 (Table 3.18). The technical steering committee determined that in the potential wetland restoration site index the direct effect of Layer 1.9 should only be 1.036 times greater than Layer 1.4 (Table 3.21).

SURVEY RESULTS

Nine of the thirty one participants from the technical steering committee returned surveys. All of the state and federal agencies directly involved in the wetland mitigation process, as well as one non-governmental organization, responded. The results from the first section of the survey indicated that most of the respondents felt that the method of reclassification was not as important as that the method used was scientifically justifiable. There was also a general consensus that using the original Layer 1.6 Biodiversity conservation - Weighted density model heavily biased the data to regions of the state that had adequate survey records for species of conservation concern and this layer should be removed in favor of the current Layer 1.6 Terrestrial dispersal corridors between wetlands. Based on these recommendations we chose Jenks Optimization (Dent 1999) to reclassify final layer outputs because of its grouping algorithm and ability to set the desired number of classes and removed the original Layer 1.6 from the potential wetland restoration site index.

Results from the second section of the survey indicated that the two layers with water quality and quantity as their main wetland functions and values were most important. Layer 1.9, Maintenance of high water quality streams had an average rank (2.78) only slightly higher than did layer 1.4, Water quality and quantity index (2.56) (Table 3.19).

Layer 1.6 terrestrial dispersal corridors between wetland was given the least importance in the potential wetland restoration site index (1.67). The results of third section of the survey indicated that the effect wetland mitigation has on water quality and quantity is the most important wetland function and value. The average rank of water quality and quantity was three (Table 3.20). This was followed by ecosystem services which received an average rank of 2.56. Flood control and flow regulation and connectivity were both equally ranked (2.33) followed by wildlife habitat (2.22), ease of restoration (2.0), education (1.56), scenic value (1.32) and recreation (1.22).

Table 3.1: Total area in hectares statewide and by ecoregion of low (1, 2 and 3), medium (4, 5 and 6) and high (7, 8 and 9) value potential wetland restoration sites. Parenthesizes signify percent of the total area of each class of potential wetland restoration sites by ecoregion.

Ecoregion	High Value PWRS	Medium Value PWRS	Low Value PWRS	Total Area
Southeast Coastal Plain:	152426 (2.3%)	2619539 (39.8%)	3817207 (57.9%)	6589172
Piedmont:	14988 (0.34%)	1396041 (31.3%)	3051182 (68.4%)	4462211
Coastal Plain:	262574 (9.8%)	1137834 (42.5%)	1274994 (47.7%)	2675402
Ridge and Valley:	3962 (0.54%)	256011 (34.7%)	477430 (64.8%)	737403
Blue Ridge:	1424 (0.06%)	221882 (32.4%)	461424 (67.4%)	684730
Appalachian Plateau:	38 (0.21%)	13693 (21.3%)	50421 (78.6%)	64152
Total Area in State:	435413 (2.9%)	5645000 (37.1%)	9132657 (60.0%)	15213070

Table 3.2. Shapiro-Wilks Tests to determine whether non-random and random movement are normally distributed. Significance ($p < 0.05$) indicates that the variable is not normally distributed.

	Shapiro-Wilk Statistic	df	p <
Non-Random Distance	0.908	388	0.000
Random Distance	0.871	388	0.000

Table 3.3. Wilcoxon Signed Ranks Test to determine whether non-random cost distance significantly differs from random cost distance.

		N	Mean Rank	Sum of Ranks
Random Distance - Non-Random Distance	Negative Ranks	107 [a]	150.74	16129.00
	Positive Ranks	281 [b]	211.16	59337.00
	Ties	0 [c]		
	Total	388		

[a] Random Distance < Non-Random Distance
[b] Random Distance > Non-Random Distance
[c] Non-Random Distance = Random Distance

Table 3.4: Z score used to determine significance in the Wilcoxon Signed Ranks Tests.

	Random Distance - Non-Random Distance
z	-9.773 [a]
Asymp. Sig. (2-tailed)	0.000

[a] Based on negative ranks

Table 3.5: Sensitivity of the potential wetland restoration site index to the individual layers at a statewide spatial scale. All area measurements are hectares of the mean patch size of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.7	188	9023	9211	183.65	47.84
Layer 1.5	188	3359	3548	70.74	17.81
Layer 1.6	188	2560	2748	54.80	13.57
Layer 1.4	188	1664	1852	36.93	8.82
Layer 1.9	188	1347	1535	30.62	7.14
Layer 1.8	188	-138	50	1.00	-0.73

Table 3.6: Sensitivity of the total area of high value potential wetland restoration sites to the individual layers at a statewide spatial scale. All area measurements are hectares of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.4	435412	1508364	1943776	11.25	3.46
Layer 1.9	435412	1285141	1720554	9.96	2.95
Layer 1.7	435412	446062	881474	5.10	1.02
Layer 1.6	435412	424659	860072	4.98	0.98
Layer 1.8	435412	369933	805346	4.66	0.85
Layer 1.5	435412	-262631	172782	1.00	-0.60

Table 3.7: Sensitivity of the potential wetland restoration site index to the individual layers in the Piedmont ecoregion of Georgia. All area measurements are hectares of the mean patch size of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.5	3	272	274	606.40	100.98
Layer 1.4	3	129	132	292.63	48.21
Layer 1.9	3	50	53	117.47	18.75
Layer 1.7	3	17	19	43.67	6.34
Layer 1.8	3	3	5	12.87	1.17
Layer 1.6	3	-2	0.5	1.00	-0.83

Table 3.8: Sensitivity of the total area of high value potential wetland restoration sites to the individual layers in the Piedmont ecoregion of Georgia. All area measurements are hectares of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.4	14988	381943	396931	1,804.23	25.48
Layer 1.9	14988	271369	286358	1,301.63	18.11
Layer 1.8	14988	215423	230412	1,047.33	14.37
Layer 1.5	14988	35263	50251	228.41	2.35
Layer 1.7	14988	-5989	8999	40.90	-0.40
Layer 1.6	14988	-14767	220	1.00	-0.99

Table 3.9: Sensitivity of the potential wetland restoration site index to the individual layers in the Blue Ridge ecoregion of Georgia. All area measurements are hectares of the mean patch size of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.5	0.7	2547	2548	3,433.52	3,432.52
Layer 1.4	0.7	17	18	24.46	23.46
Layer 1.9	0.7	3	4	5.74	4.74
Layer 1.8	0.7	2	4	5.00	4.00
Layer 1.6	0.7	0	0.7	1.00	0.00
Layer 1.7	0.7	0	0.7	1.00	0.00

Table 3.10: Sensitivity of the total area of high value potential wetland restoration sites to the individual layers in the Blue Ridge ecoregion of Georgia. All area measurements are hectares of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.9	1424	76159	77584	54.48	53.48
Layer 1.4	1424	68860	70284	49.36	48.36
Layer 1.5	1424	47860	49284	34.61	33.61
Layer 1.8	1424	41639	43063	30.24	29.24
Layer 1.6	1424	0	1424	1.00	0.00
Layer 1.7	1424	0	1424	1.00	0.00

Table 3.11: Sensitivity of the potential wetland restoration site index to the individual layers in the Ridge and Valley ecoregion of Georgia. All area measurements are hectares of the mean patch size of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.4	8	536	543	68.55	67.55
Layer 1.9	8	364	372	47.00	46.00
Layer 1.5	8	100	108	13.72	12.72
Layer 1.8	8	0.1	8	1.01	0.01
Layer 1.7	8	0	8	1.00	0.00
Layer 1.6	8	0	8	1.00	0.00

Table 3.12: Sensitivity of the total area of high value potential wetland restoration sites to the individual layers in the Ridge and Valley ecoregion of Georgia. All area measurements are hectares of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.9	3962	88656	92619	23.38	22.38
Layer 1.4	3962	80533	84496	21.33	20.33
Layer 1.8	3962	43726	47688	12.04	11.04
Layer 1.5	3962	3236	7199	1.82	0.82
Layer 1.6	3962	0	3962	1.00	0.00
Layer 1.7	3962	0	3962	1.00	0.00

Table 3.13: Sensitivity of the potential wetland restoration site index to the individual layers in the Appalachian Plateau ecoregion of Georgia. All area measurements are hectares of the mean patch size of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.4	1	5	6	6.17	5.17
Layer 1.5	1	3	5	4.60	3.60
Layer 1.8	1	2	3	3.06	2.06
Layer 1.9	1	1	2	2.17	1.17
Layer 1.6	1	0	1	1.00	0.00
Layer 1.7	1	0	1	1.00	0.00

Table 3.14: Sensitivity of the total area of high value potential wetland restoration sites to the individual layers in the Appalachian Plateau ecoregion of Georgia. All area measurements are hectares of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.9	38	5536	5574	146.68	145.68
Layer 1.4	38	4667	4705	123.82	122.82
Layer 1.8	38	3926	3964	104.32	103.32
Layer 1.5	38	313	350	9.21	8.24
Layer 1.7	38	0	38	1.00	0.00
Layer 1.6	38	0	38	1.00	0.00

Table 3.15: Sensitivity of the potential wetland restoration site index to the individual layers in the Coastal Plain ecoregion of Georgia. All area measurements are hectares of the mean patch size of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.7	160	7415	7575	433.22	46.36
Layer 1.6	160	1083	1243	71.11	6.77
Layer 1.4	160	646	806	46.12	4.04
Layer 1.5	160	368	528	30.18	2.30
Layer 1.9	160	278	438	25.03	1.74
Layer 1.8	160	-143	17	1.00	-0.89

Table 3.16: Sensitivity of the total area of high value potential wetland restoration sites to the individual layers in the Coastal Plain ecoregion of Georgia. All area measurements are hectares of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.7	262574	371775	634349	14.36	1.42
Layer 1.6	262574	328295	590868	13.37	1.25
Layer 1.9	262574	274221	536795	12.15	1.04
Layer 1.4	262574	230698	493272	11.16	0.88
Layer 1.8	262574	-69249	193325	4.37	-0.26
Layer 1.5	262574	-218384	44190	1.00	-0.83

Table 3.17: Sensitivity of the potential wetland restoration site index to the individual layers in the Southeast Coastal Plains ecoregion of Georgia. All area measurements are hectares of the mean patch size of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.9	16	649	665	55.54	39.90
Layer 1.4	16	329	345	28.81	20.22
Layer 1.7	16	168	184	15.34	10.29
Layer 1.5	16	67	84	6.98	4.14
Layer 1.6	16	56	72	6.02	3.43
Layer 1.8	16	-4	12	1.00	-0.26

Table 3.18: Sensitivity of the total area of high value potential wetland restoration sites to the individual layers in the Southeast Coastal Plains ecoregion of Georgia. All area measurements are hectares of high value PWRS (value = 7, 8, and 9).

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Layer 1.4	152426	741663	894089	41.57	4.87
Layer 1.9	152426	569200	721626	33.55	3.73
Layer 1.8	152426	134468	286895	13.34	0.88
Layer 1.6	152426	116557	268984	12.51	0.76
Layer 1.7	152426	85254	237680	11.05	0.56
Layer 1.5	152426	-130919	21508	1.00	-0.86

Table 3.19: Results from Section 2 of the October 18th, 2006 survey. Ranking layers by their perceived importance to the Technical Steering Committee when evaluating sites for potential wetland mitigation. Weight is based on rounding the average result of nine surveys with ranks of low (1), medium (2) and high (3).

Layer	Total Score	Average Score	Rank	Weight	Main Function	Secondary Wetland Functions Identified
Layer 1.9 - Maintenance of high water quality streams	25	2.78	1	3.00	Water Quality / Quantity	• Flood control and Flow regulation • Aquatic biodiversity conservation • Recreation • Scenic value
Layer 1.4 - Water quality and quantity index	23	2.56	2	3.00	Water Quality / Quantity	• Flood Control / Flow regulation • Wildlife Habitat • Recreation • Scenic value
Layer 1.7 - Hydrologic connectivity of wetlands	21	2.33	3	2.00	Flood Control / Flow Regulation	• Water Quality / Quantity • Wildlife Habitat • Connectivity
Layer 1.5 - Connectivity to existing conservation areas	18	2.00	4	2.00	Connectivity	• Wildlife Habitat • Education • Recreation
Layer 1.8 - Natural upland vegetation surrounding wetlands	16	1.78	5	2.00	Wildlife Habitat	• Connectivity • Water Quality / Quantity
Layer 1.6 - Terrestrial dispersal corridors between wetlands	15	1.67	6	2.00	Wildlife Habitat	• Connectivity

Table 3.20: Results from Section 3 of the October 18th, 2006 survey. Ranking the wetland function and values most important to members of the technical steering committee when evaluating sites for compensatory wetland mitigation.

Wetland Function and Value	Total Score (max = 27)	Average Score	Rank	Weight	Layer Identifying	# of Times Covered	# of Times Main Function
Water Quality / Quantity	27	3.00	1	3.00	Layer **1.4**, 1.7, 1.8, **1.9**	4	2
Ecological Services	23	2.56	2	3.00	--	0	0
Flow Regulation/ Flood Control	21	2.33	3	2.00	Layer 1.4, 1.9, **1.7**	3	1
Connectivity	21	2.33	3	2.00	Layer **1.5**, 1.6, 1.7, 1.8	4	1
Wildlife Habitat	20	2.22	5	2.00	Layer 1.5, **1.6**, 1.7, **1.8**, 1.9	5	2
Ease of Restoration	18	2.00	6	2.00	Layer **1.1**, **1.2**	2	2
Education	14	1.56	7	2.00	Layer 1.5	1	0
Scenic Value	12	1.33	8	1.00	Layer 1.4, 1.9	2	0
Recreation	11	1.22	9	1.00	Layer 1.4, 1.5, 1.9	3	0

Table 3.21: Comparison of the effect and change in importance between layers in the potential wetland restoration site index using the results from the sensitivity analysis for the Southeast Coastal Plain and Section 2 of the October 18th, 2006 surveys.

Layer order from survey results	Times change in importance	Layer order from sensitivity analysis	Times change in effect
1.9	--	1.9	--
1.4	1.036	1.4	1.973
1.7	1.099	1.7	1.965
1.5	1.165	1.5	2.486
1.8	1.124	1.6	1.20
1.6	1.066	1.8	13.192

* Note: The switch in the order of Layer 1.6 and 1.8 in the sensitivity analysis results make the times change in importance and effect between layers 1.5 and 1.8 and Layers 1.8 and 1.6 incomparable.

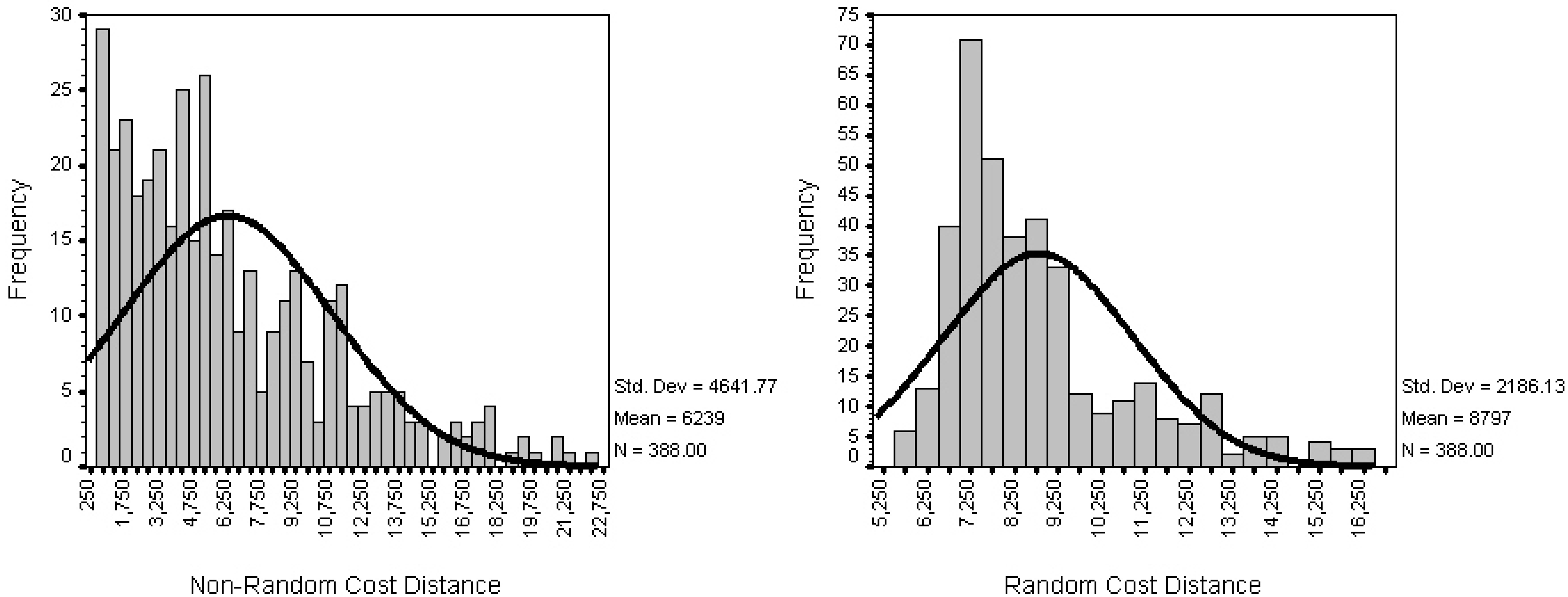


Figure 3.1: Histograms of non-random and random cost distance with normally distributed curves fitted for comparison.

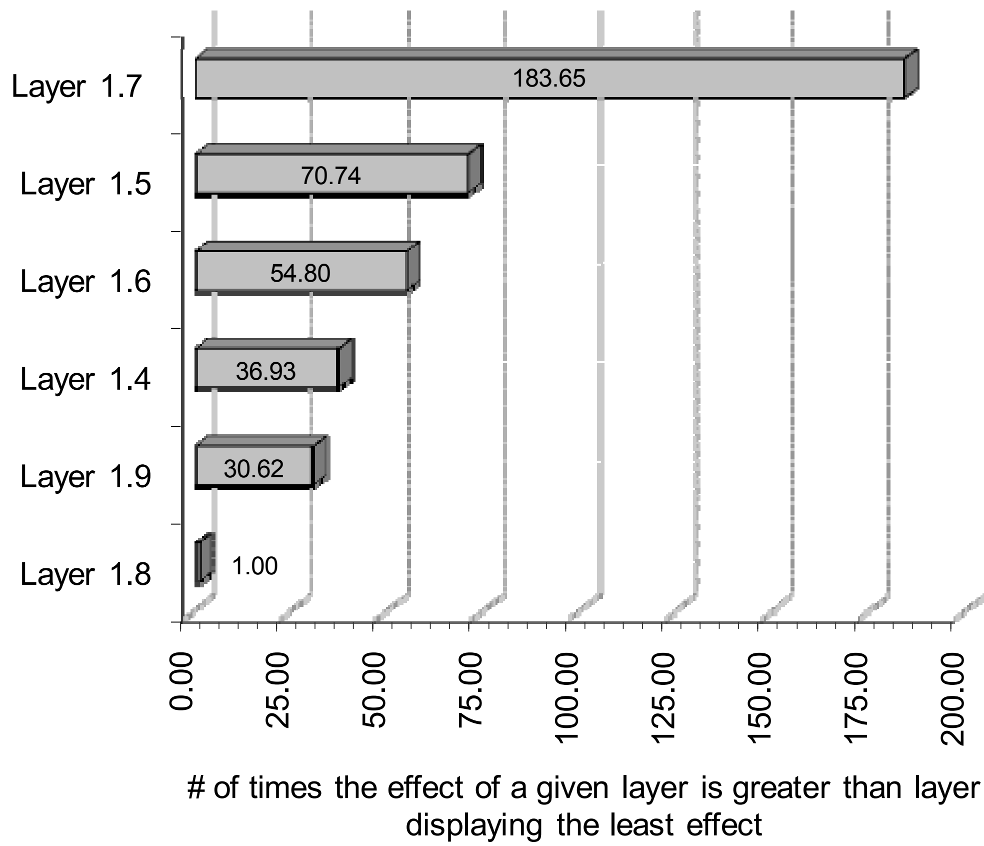


Figure 3.2: The indexed effect of each layer on the potential wetland restoration site index at a statewide spatial scale. See Table 3.3.

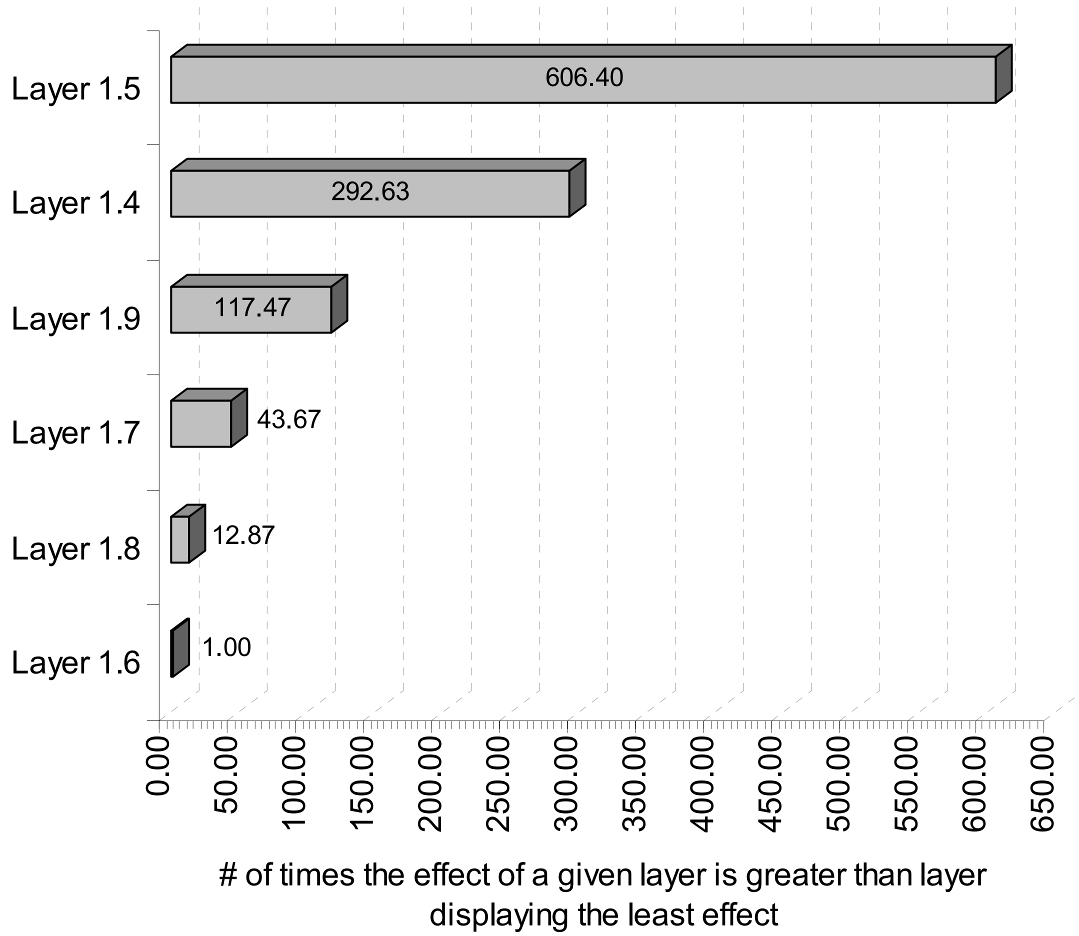


Figure 3.3: The indexed effect of each layer on the potential wetland restoration site index in the piedmont ecoregion of Georgia. See Table 3.5.

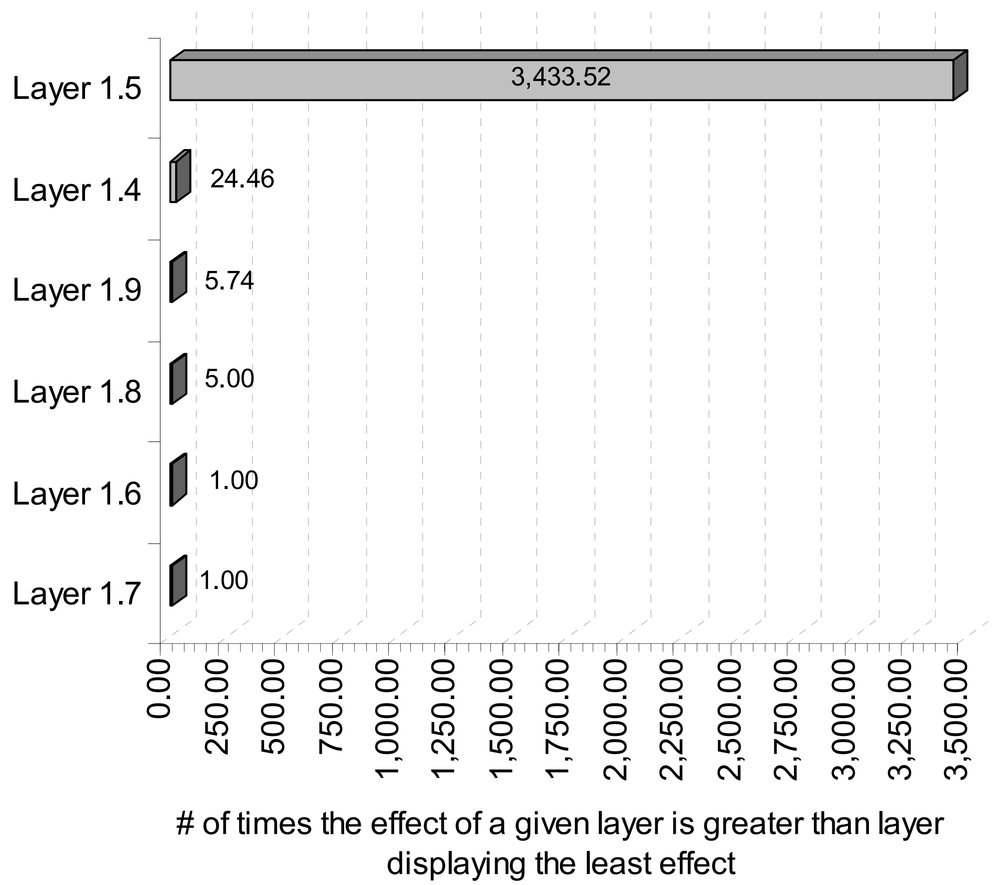


Figure 3.4: The indexed effect of each layer on the potential wetland restoration site index in the Blue Ridge ecoregion of Georgia. See Table 3.6.

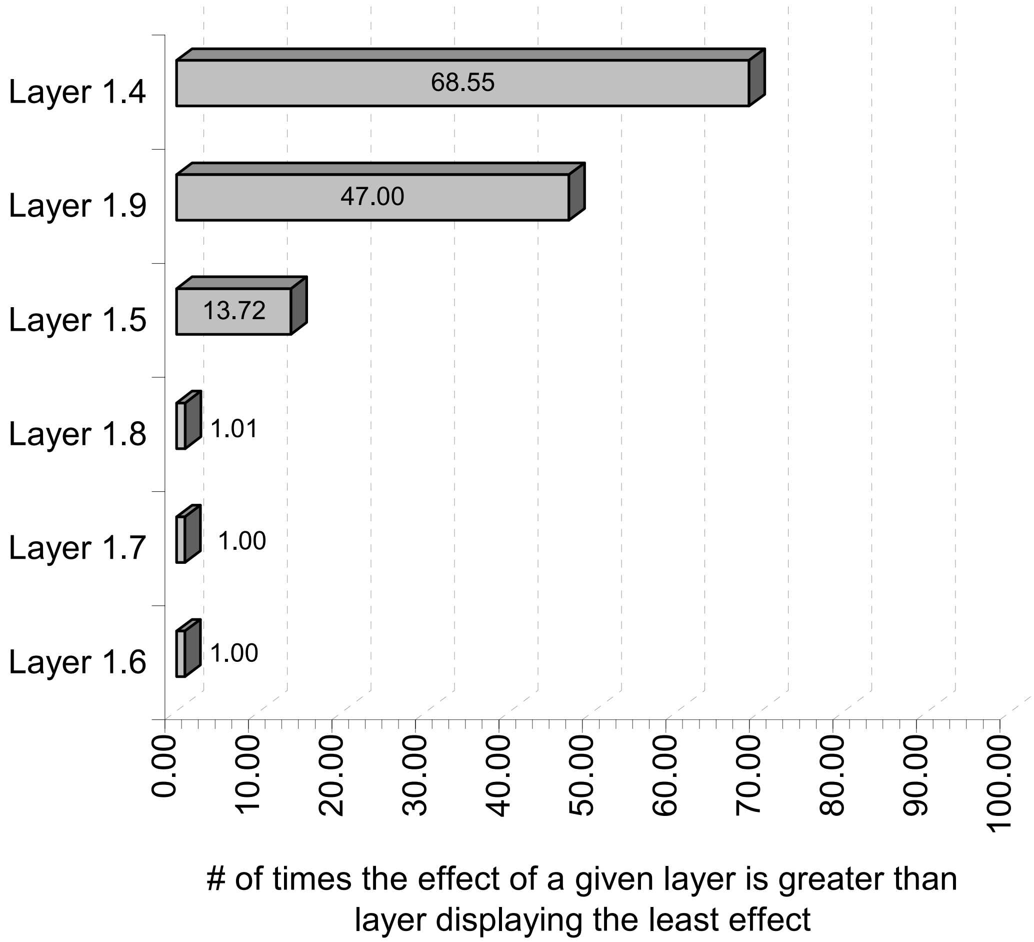


Figure 3.5: The indexed effect of each layer on the potential wetland restoration site index in the Ridge and Valley ecoregion of Georgia. See Table 3.7.

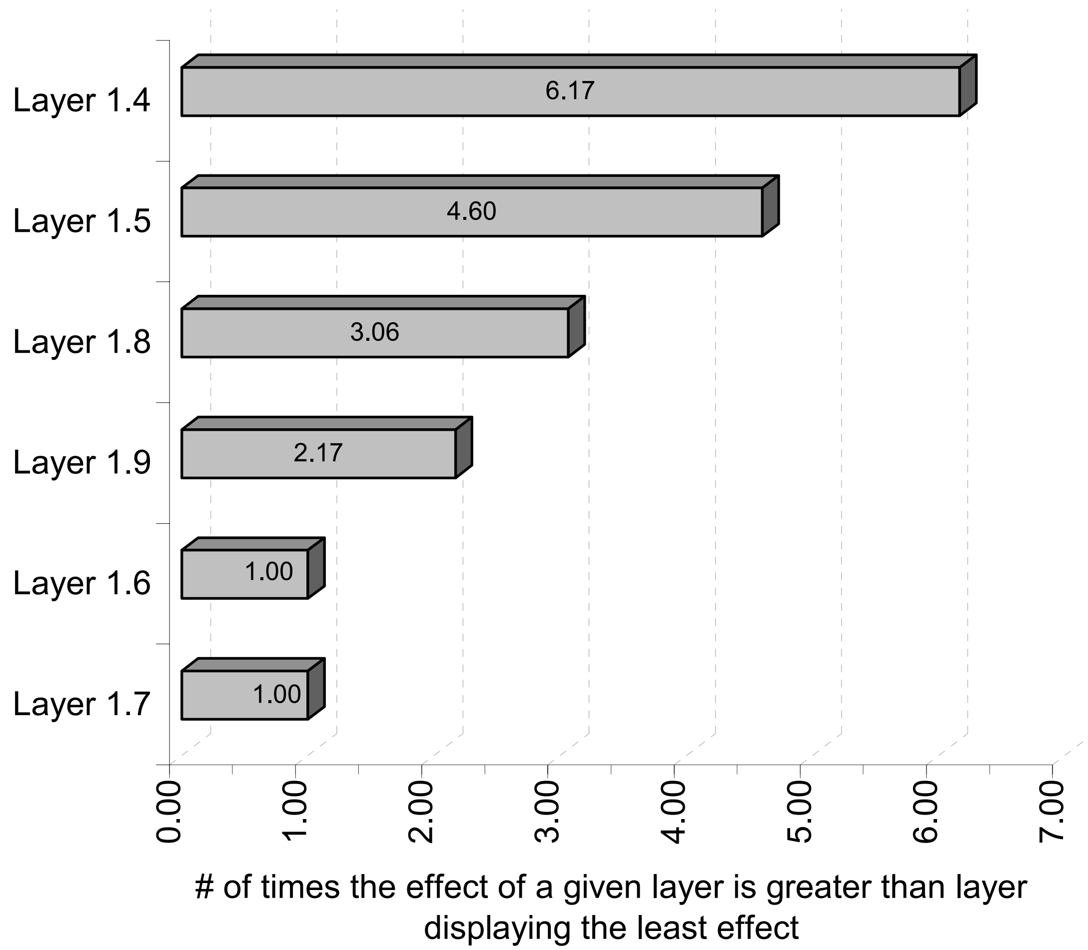


Figure 3.6: The indexed effect of each layer on the potential wetland restoration site index in the Appalachian Plateau ecoregion of Georgia. See Table 3.8.

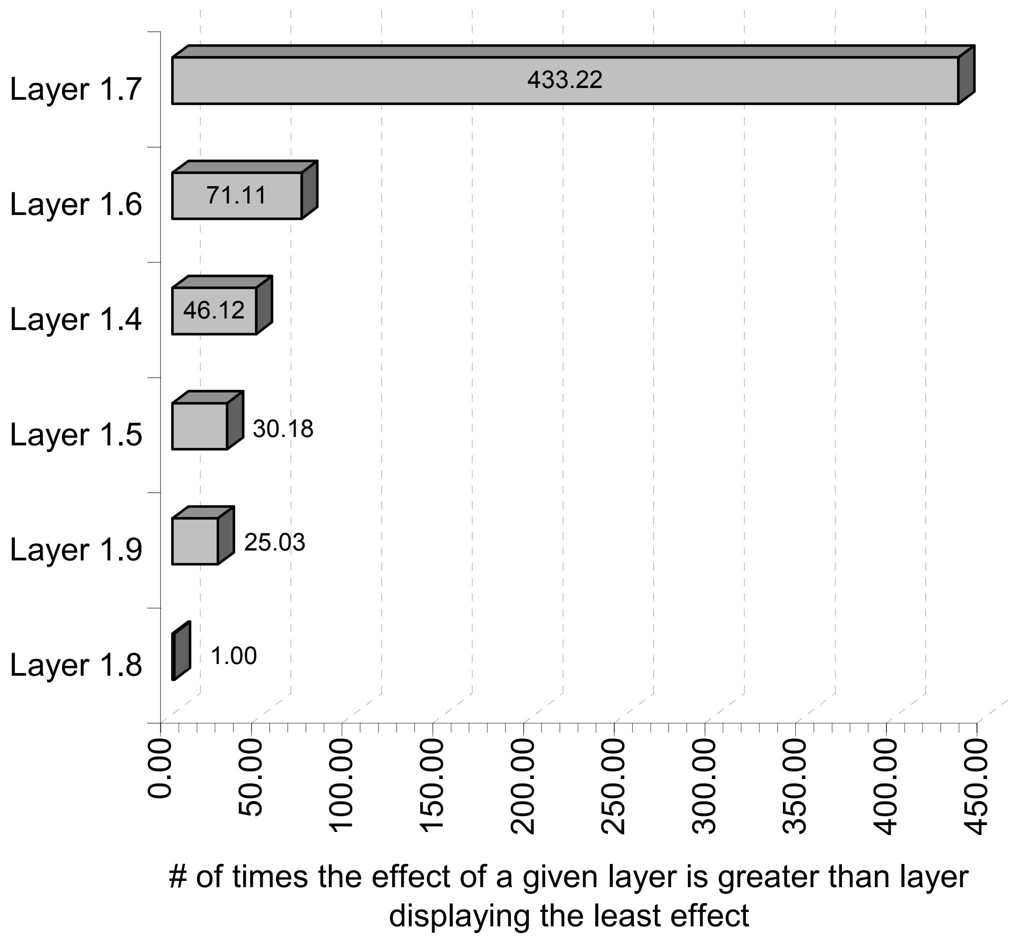


Figure 3.7: The indexed effect of each layer on the potential wetland restoration site index in the Coastal Plain ecoregion of Georgia. See Table 3.9.

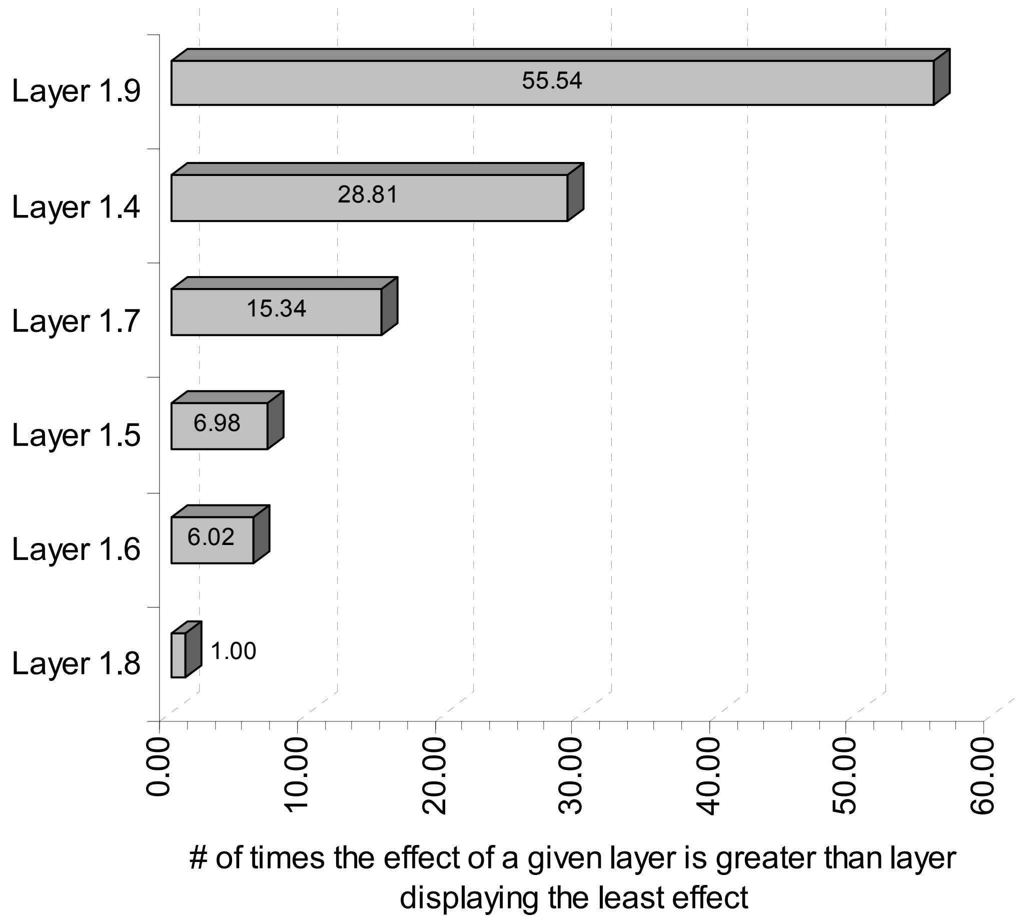


Figure 3.8: The indexed effect of each layer on the potential wetland restoration site index in the Southeast Coastal Plains ecoregion of Georgia. See Table 3.10.

CHAPTER 4

SIMULATING THE EFFECTS OF SIZE AND LOCATION OF COMPENSATORY WETLAND MITIGATION SITES ON CONNECTIVITY OF WETLANDS FOR DISPERSING AND MIGRATING AMPHIBIANS[1]

[1]Carpenedo S. M. To be submitted to *The Journal of Wildlife Management*

ABSTRACT

Amphibians may be suitable species to evaluate the effects wetland mitigation sites have on the metapopulation dynamics within an existing wetlands complex. The size and location of wetland mitigation sites affect the connectivity between a constructed wetland and existing wetlands, as well as the connectivity between existing wetlands. The effect of changing the connectivity within a wetlands complex may impact metapopulation dynamics through the colonization probability and rescue effect. By determining the landscape position for wetland mitigation sites that will have the greatest positive effect on the probability of colonization and rescue, compensatory wetland mitigation may be used as a more effective tool to manage wildlife populations. Simulation models in GIS were developed to determine whether there is an optimal position in the landscape at which constructing wetlands would have the greatest effect on the connectivity within an existing wetlands complex. Thus, having the greatest effect on metapopulation dynamics of amphibians within existing wetland complexes. The size and landscape position of simulated wetlands and the surrounding landscape mosaic were evaluated for their effects on the change in connectivity of existing wetland complexes using Akaike's Information Criteria. The results of the simulation modeling suggest that there is a range of optimal positions in the landscape at which constructing wetlands would have the greatest effect on the connectivity of existing wetland complexes. It also suggests that from the stand point of dispersing and migrating amphibians the construction of several smaller wetlands within a wetlands complex may have more effect on the persistence of amphibian populations than would the construction of one large wetland. The simulation models show that choosing wetland mitigation sites based on opportunity and economic

feasibility may not be the most effective use of compensatory mitigation. And that by targeting optimal positions in the landscape compensatory wetland mitigation sites can be more effective at ensuring the continued persistence of amphibian populations.

INTRODUCTION

For Landscape Ecologists the development of metapopulation theory is an excellent opportunity to research the dynamics between spatial ecology and conservation biology. Classic metapopulation theory as proposed by Levins (1969; 1970) details that the persistence of a population within a landscape depends on the species population parameters and the number and connectivity of suitable patches. While classic metapopulation theory has been a major step forward in the understanding of population dynamics, several assumptions make it somewhat impractical in application of natural resources management (Hilty et al. 2007). These assumptions include but are not limited to: 1) All habitat patches are considered equivalent in size, 2) There is no dispersal among occupied patches and 3) The landscape mosaic between patches has a uniform effect on connectivity. Advances in dynamics of metapopulation models through the inclusion of more spatially realistic population parameters (Hanski 1994; Hanski & Gilpin 1991; Hanski 2004; Pulliam 1988) have made this theory more pertinent to natural resources management.

Connectivity has a role in metapopulation theory in that it impacts the rescue of extirpated populations from source populations, the colonization of newly created suitable habitats, and the maintenance of the genetic diversity of a population. By definition connectivity is a measure of the ability of organisms to move among separated patches of suitable habitat (Hilty et al. 2007). The success of dispersal and migration is dependent in part upon the connectivity between suitable habitats (Wiens 1997). In the classic Levins model connectivity is a function of the Euclidean distance between patches. The persistence of metapopulations is threatened as the distance between suitable habitats increases, regardless of the number and size of patches within a landscape (Hanski 1997). While distance has been proven to have an effect on connectivity and the probability of successful dispersal and migration (Hanski 1997; Patrick et al. 2006), linear distance does not taking into account the affect of the landscape mosaic on species movement.

The physiological cost of traversing a landscape mosaic has an effect on the connectivity and successful dispersal and migration of organisms. The heterogeneity of a landscape mosaic influences the response of organisms, their mechanisms of dispersal and migration and their use of corridors (deMaynadier & Hunter 1999; Marsh & Trenham 2001; Rothermel & Semlitsch 2002; Wiens 1997, 2001). This response is most noticeable in the non-random movements of species moving through a landscape mosaic (Cole 2006; Hilty et al. 2007; Mazerolle & Desrochers 2005; Patrick et al. 2006; Regosin et al. 2005; Rothermel 2004; Wiens 2001). Through the incorporation of the effect of the landscape mosaic into metapopulation theory (Price et al. 2004) and subsequent models, we are able to include spatial explicit processes into metapopulation analysis and simulations. Hanski (1994) developed a simple connectivity measure using a negative exponential distribution for his Incidence Function Model (IFM). Möilanen and Nieminen (2002) modified this connectivity function to include area of source habitats and metapopulation parameters. This combined with current geographical information system (GIS) analysis techniques allows us to begin to look at the spatially realistic models of connectivity in a landscape mosaic for use in natural resource management.

Wetlands and the species that use them as natal habitats may be good candidates for spatially realistic models that evaluate the effect of landscape parameters on connectivity and its implications for biodiversity conservation (Kareiva et al. 1997). Many amphibian species, including Green Frogs, *Rana clamitans,* use wetlands as breeding habitats and then migrate to uplands to forage and over-winter (Birchfield & Deters 2005; Hecnar & M'Closkey 1997). Zedler (2003) noted that "connected habitats are essential for the dispersal and recolonization of restored [wetland] sites [and] for migrating species that require different habitats during nesting, spawning or other seasons". In *R. clamitans* the juveniles produced in a breeding season do not always return to their natal pond, but instead disperse through the landscape mosaic in search of new breeding grounds (Hilty et al. 2007; Schroeder 1976). The distance and landscape mosaic that juvenile amphibians traverse affect their probability of survival and finding suitable habitat (Hanski 1994; Wiens 1997). Increases in the isolation of wetlands or the landscape transitioning into a more inhospitable mosaic can have implications on metapopulation dynamics through changes in movement, (Green 2003; Noon et al. 1997; Patrick et al. 2006), survival probabilities (Mazerolle & Desrochers 2005) and subsequently recolonization of available habitats after localized extinction events (Hanski 1997; Pope et al. 2000).

In the coastal plain of Georgia this effect of increasing isolation of wetland habitats and the transition of wetlands and upland buffers to unsuitable habitats is very pronounced and may have severe consequences. Kramer (2007) reported that from 1974 to 1998 Georgia has seen a 16.2% decrease in wetland acreage, a rate of decrease six times greater than reported for 1750-1980 by Dahl (1990). The loss of wetlands has many negative impacts on wildlife populations. Wetlands and the landscape mosaic surrounding them are critical habitat for 20% of the species listed as threatened or endangered under the Endangered Species Act, (16 U.S.C. 1531-1544, 87 Stat. 884) (USEPA 2006a). Under the Section 404 of the 1972 Clean Water Act, 33 U.S.C. 1344, the destruction of wetlands was set into a regulatory framework, where by wetland mitigation was required for permitted wetland destruction. While the evaluation of impacts to fish and wildlife is required under Section 404, the NRC (2001) found that the current practice of compensatory wetland mitigation gave little importance to wildlife and their habitat requirements. Having positive impacts on fish and wildlife populations requires that compensatory wetland mitigation sites be located in suitable landscape positions where they will most positively influence the stability of wildlife populations. The current practice of deciding on the landscape position of compensatory wetlands and thus their effect on the connectivity of the landscape mosaic is one of opportunity and economic viability (GADOT, *pers. comm.*; (McAllister et al. 2000)).

The purpose of this paper was to demonstrate that targeting compensatory wetland mitigation in optimal landscape positions will have a greater impact on connectivity of wetlands within a landscape mosaic and the stability of amphibian populations, then by constructing them in locations of opportunity. By mapping connectivity and determining where compensatory mitigation sites will have the greatest effect on the change in connectivity, we can identify ways by which "population isolation can be broken" (Joly et al. 2003). Hanski (1997) noted that a good use of metapopulation models was to determine the effects of removing or fragmenting habitats on extinction probability. The reverse can also be true, by simulating random construction of wetlands of different sizes at random landscape positions and determining their effect on connectivity in relation to the landscape mosaic, we can determine an optimal position in the landscape at which constructed wetlands will have the greatest influence on the colonization probability and potentially the persistence of populations (Kareiva et al. 1997).

METHODS

Constructing wetlands as part of compensatory wetland mitigation may influence the stability of metapopulation dynamics of amphibians through a change in connectivity between source habitats. I wanted to evaluate whether there is an optimal position in the landscape at which construction of wetlands would most positively influence the dispersal and migration opportunities and subsequently the metapopulation dynamics of *Rana clamitans*. To evaluate the optimal position of constructed wetlands in the landscape I developed a simulation model in GIS to test the mean change in connectivity of eight survey sites after the construction of wetlands. I evaluated the effect of 751 randomly created wetlands of three different size classes, 2.25 ha, 10 ha and 40 ha, the landscape position of constructed wetlands and the landscape mosaic on the mean change in connectivity.

Model Development

The original connectivity of a survey site was calculated using the exact methodology outlined in Chapter 2 - Layer 1.6 with one generalizing modification. Instead of using natural wetland vegetation patches to test connectivity, I used all wetlands identified by the 2005 Georgia Land Use Trends database (GLUT) for each of the eight survey sites. Using the GLUT database meant that there are no associated rankings to determine the potential value of a wetland for all species of conservation concern. The original connectivity between wetlands within survey sites were therefore calculated using an unranked connectivity function described by Hanski (1994) for use in the colonization probabilities of metapopulation models and modified by Möilanen & Nieminen (2002). The gird of habitat resistance and all other parameters used to calculate original connectivity remained the same.

The original connectivity of the survey site was used to determine the mean connectivity value of our randomly constructed wetlands, C_{cw}, and the mean connectivity of a 36 km^2 sample site centered on the centroid of a constructed wetland, C_{orig}. The mean connectivity, C_{cw}, signifies the landscape position of a constructed wetland within the landscape. The mean connectivity of a 36 km^2 sample site, $C_{orig,}$ is a description of the landscape mosaic, with low value, little connectivity, landscape mosaics potentially less permeable for dispersing and migrating amphibians (Wiens 1997). For example, sample sites that have a high proportion of existing wetlands within a deciduous forest matrix will have higher C_{orig} values than predominately agricultural sample sites with few existing wetlands (Figure 4.1).

To evaluate the effect of the size, landscape position, and landscape mosaic surrounding constructed wetlands on connectivity, I randomly constructed one wetland from our chosen size classes in a survey site and recalculated the gird of habitat resistance and connectivity. This simulation was run 751 times in eight randomly selected survey sites in the Southeast Coastal Plain of Georgia (Wharton 1977). The difference between the mean connectivity of the post-wetland construction landscape and the connectivity of the original landscape mosaic was calculated to determine the mean change in connectivity.

Statistical Analysis

Logistic regression models, using SAS Version 9.1.3 (SAS 2005), were used to fit a set of candidate models to evaluate which model best explains the mean change in connectivity by size class. I was most interested in the effect of our parameter estimates on connectivity and how this may be used to evaluate the function of constructed wetlands in regard to their landscape position. A goodness of fit test run to determine whether our variables fit the assumptions of normal distributions. To avoid multicollinearity in the candidate models, Pearson's correlations were conducted on the global model and all parameters that had an $r^2 > 0.49$ were not included in the same candidate model.

Akaike's Information Criteria (Akaike 1973) adjusted for small sample biases (AICc) (Hurvich & Tsai 1989) was used to evaluate the relative fit of the candidate models to the mean change in connectivity. I constructed three candidate models (Table 4.1) to determine which model is the most plausible explanation for the mean change in connectivity by size class. The three models look at the cumulative effect of the landscape position and mosaic and the effect of each individual parameter on the response variable. Akaike's weights, which ranks the most plausible model based on AICc, were used to rank each candidate model. To account for model selection uncertainty a confidence set of candidate models was selected by creating a threshold value of 12% based on Royall's (1997) 1/8 rule of thumb for assessing the strength of evidence. Any candidate model with an Akaike weight greater than or equal to this threshold was retained in our confidence set of models.

Interpretation of parameters and their effect on the mean change in connectivity may be influenced by the confidence set of models selected. To account for this, I calculated model averaged parameter estimates for all variables present in the composite model (Burnham & Anderson 2002). A composite model is a model that contains all model averaged parameter estimates from the confidence set of models. Because we used a logistic regression to determine the effect of the parameters on the mean change in connectivity, odds ratios of the parameter estimates are used instead of directly interpreting the model averaged parameter estimates.

Logistic regression curves (SPSS 1999) were then fit to the composite model for each size class. The half-saturation constant was calculated for each fitted curve to determine individual landscape position and mosaic thresholds at which the greatest rate of change in connectivity occurs by size class. Constructed wetlands that were located in a landscape position and mosaic at or above the half saturation thresholds were then given a value of one and considered in an optimal position, all other data equaled zero. This binary classified data was then used to evaluate of the predictive ability of our composite model using a KNN 10 fold cross validation of the logistic regression (SAS 2005).

Connectivity, as I have calculated it, is a dimensionless measure that in the field may be impossible to measure. To make this more applicable to resource managers, I developed a general set of guidelines relating the optimal position of constructed wetlands in the landscape to easily measurable landscape variables. The variables describing landscape position are landcover type at the compensatory mitigation site (forest or non-forest) and the minimum linear distance to the nearest wetland. The majority landcover (forested or non-forested) and proportion of wetlands within a 36 km^2

area surrounding a potential compensatory mitigation site were chosen to describe the landscape mosaic.

The binomial classification for optimal position of constructed wetlands in a landscape was used to develop a binary classification tree, in CATDAT. The classification tree is useful to determine the combination of easily measurable parameters necessary to increase the probability that a wetland would be constructed in an optimal landscape position. CATDAT uses sequential binary splits of sampled data by minimizing within group variance. It is not a hierarchical classification, but chooses parameters in an order that explains the greatest proportion of the remaining variance (Peterson et al. 1999). The parameters necessary to construct the classification tree are the optimal number of nearest neighbors and the maximum number of nodes to evaluate.

RESULTS

Based on the connectivity calculations we observed that by constructing wetlands completely at random within the landscape connectivity increased on average 1.2% (n = 751, X-bar = 5.32, SD = 4.48). Regardless of the size class, targeting wetland construction at an optimal position in the landscape has 1.8 times more effect on connectivity (n = 201, X-bar = 9.63, SD = 3.00). When comparing wetlands constructed in optimal (n = 201, X-bar = 9.63, SD = 3.0) to non-optimal (n = 550, X-bar = 3.75, SD = 3.86) landscape positions the effect on the mean change in connectivity is even greater, 2.5 times (Figure 4.2). The change in connectivity by size class showed predictable trends that as size increased the mean and maximum change in connectivity increased. 40 ha wetlands in an optimal landscape position the mean and maximum increase in connectivity was greatest, 2.10% (n = 24, SD = 0.09) and 15.9 (n = 24, X-bar = 14.62, SD = 1.10) respectively, followed by 10 ha, 1.61% (n = 106, SD = 0. 24) and 12.69 (n = 106, X-bar = 10.41, SD = 1.31), and 2.25 ha constructed wetland, 0.9% (n = 71, SD = 0.33) and 8.90 (n = 71, X-bar = 6.76, SD = 2.21).

Targeting different size classes of wetlands at optimal locations in the landscape increases the mean change in connectivity 1.76 (2.25 ha) to 2.44 times (40 ha), when compared to constructing wetlands at random. The effect when comparing wetland size classes in non-optimal and optimal landscapes show similar trends (Figure 4.3). 40 ha wetlands in optimal landscape positions (n=24, X-bar= 14.62, SD= 1.10) have 5.76 times more effect on the mean change in connectivity than non-optimal locations (n=60, X-bar= 2.54, SD = 4.75). 10 ha wetland have 2.28 times more effect (optimal; n=106, X-bar=10.41, SD= 1.31: non-optimal; n=322, X-bar= 4.57, SD = 3.97), and 2.25 ha wetlands have 2.59 times more effect on the mean change in connectivity (optimal; n=106, X-bar=10.41, SD= 1.31: non-optimal; n=322, X-bar= 4.57, SD = 3.97).

Based on the logistic regression using Akaike's information criteria (Akaike 1973) and Royall's (1997) rule of thumb for assessing the strength of evidence, only the global model for each size class was included in the confidence set of models (Table 4.2, 4.4 and 4.6). The global model contains all of the parameters and thus the composite model also contains all parameters. The parameter estimates of the composite model are not model averaged parameter estimates and reflect only the parameter estimates of the global model for each size class.

The odds ratios of the parameter estimates for the most plausible models indicate that both the landscape position and the landscape mosaic have relatively little effect on the change in connectivity. An increase of one unit in the landscape position of the constructed wetland, i.e. increasing connectedness to all wetlands, the probability that maximum observed change is achieved increases from 1.008 to 1.025 times in 40 ha wetlands (Table 4.7), 1.0 - 1.005 times in 10 ha wetlands (Table 4.5) and 1.0 - 1.003 times in 2.25 ha wetlands (Table 4.3). The landscape mosaic is similar. An increase of one unit in the landscape mosaic surrounding a 40 ha wetlands corresponds to a 1.003 - 1.011 times increase (Table 4.6) in the likelihood that maximum observed change in connectivity will be achieved. For 10 ha (Table 4.4) and 2.25 ha (Table 4.2) wetlands a one unit increase in the landscape mosaic increases the probability that maximum change in connectivity is reached from 1.0 - 1.004 times.

Figures 4.4 a-f represents the logistic regression curves fitted to the data that were used to determine the half saturation constants ($\frac{k}{2}$) and the corresponding thresholds. Using the half saturation constant, the landscape position threshold was set at a mean connectivity value of 245, 310 and 650 for 40 ha, 10 ha and 2.25 ha wetlands respectively (Figure 4.5). The landscape mosaic threshold was set at an original mean connectivity value of 370, 395 and 580 for 40 ha, 10 ha and 2.25 ha wetlands respectively (Figure 4.6). Combining the landscape position and mosaic thresholds indicated that 201 of the randomly constructed wetlands were in an optimal location, 550 in non-optimal locations. Figure 4.7 represents the optimal position to construct wetlands of a given size class within a landscape mosaic. In Figure 4.7 large wetlands, 40 ha in size, are considered in an optimal location when constructed in any location other than the non optimal landscape position (blue). Whereas 2.25 ha wetlands the range of optimal locations is much narrower, encompassing only those areas represented in dark purple. This is especially prominent in more hostile, low connectivity, landscape mosaics. The evaluation of model performance using the 10 fold cross validation indicates that the best fitting model for all size classes correctly predicted the optimal landscape position of constructed wetlands 98.5% of the time (Table 4.8).

The binary classification tree using the simulated data shows that there are only three combinations of easily measurable landscape variables at which optimal positions may be achieved (Figure 4.8). These represent only 33% of the total number of possible outcomes. All of these combinations resulted from constructing wetlands at sites that were originally represented by forested landcover class in the 2005 Georgia Land Use Trends database.

DISCUSSION

Based on the incidence function model formulas from Hanski (1994) the mean change in connectivity as a result of simulated constructed wetlands corresponds to a mean change in the probability of colonization for all wetlands within $36km^2$. Holding the extinction probability of existing wetlands constant, this increase in connectivity affects the rescue effect for existing wetlands. It also increases the probability of occurrence of a given species for any wetland within the dispersal or migration distance of a compensatory wetland mitigation site. By having a positive effect on the rescue effect and probability of occurrence, constructing wetlands in optimal landscape positions positively impact the persistence of populations within a wetlands complex.

Currently the majority of site selection of compensatory wetland mitigation projects is driven by the opportunity (McAllister et al. 2000; Zedler 2006) and size of available lands with only cursory regard to all ecosystem functions provided by wetlands. The results show that the mean change in the connectivity is affected by the position in the landscape at which a wetland is constructed. My data suggests that the closer compensatory wetlands are developed to existing wetlands the more affect on the mean change in connectivity. Similarly, I observed that the larger the compensatory wetland the greater the mean change in connectivity of all wetlands in a 36 km^2 analysis area. This is similar to Zedler (2003), who noted that "the greatest biodiversity should result from restoring large wetlands that have mixed terrain and dispersal corridors and are close to natural wetlands."

The data also suggests that similar results in the mean change in connectivity can be achieved by constructing wetlands in landscape positions that are less connected than those closest to existing wetlands. The mean change in connectivity follows the microeconomic principle of the Law of Diminishing Returns, in that as position in the landscape at which a wetland is constructed increases in connectivity, the mean change in connectivity of a sample site increases by smaller and smaller increments. For example, the change in connectivity as a result of constructing 10ha wetlands at a landscape position with connectivity of 950 is only 5% less than if constructed at a landscape position with a connectivity of 1400. Whereas for the same interval width from 500 - 950 the mean change in connectivity increases 25%. While this does not show that constructing further from existing wetlands is necessarily better, it does show that there is some leeway in the optimal position in the landscape for constructing wetlands. And that by staying within an optimal range of connectivity (Figure 4.7) the most suitable site for restoration can be chosen in a location that can act as a stepping stone between wetlands in an existing complex. This is similar to Hanski (1998) in that the optimal spacing of suitable habitats is a compromise between locating them close enough to allow for colonization yet far enough apart to reduce the impact of localized stochasticity.

The maximum change in connectivity that I calculated through the simulation models seem to support Zedler's (2003) statement that constructing large wetlands may be best. The 40 ha constructed wetlands did show a 1.78 times increase in maximum change over 2.25 ha wetlands. This is also in line with the current practices of "no-net-loss" compensatory wetland mitigation where larger mitigation sites are preferred to replace lost wetland acreage and functions (NRC 2001). The National Research Council (2001), though, suggests that the area of compensatory wetland mitigation sites should be proportional to the area required to replace the functions lost. And that the area of a required mitigation is not a good surrogate for replacing lost functions (Zedler 2003). My data suggests that by restoring multiple smaller wetlands at optimal positions in the landscape, a greater cumulative effect on the connectivity of wetland complexes will be achieved. This supports Semlitsch and Bodie (2003; Zedler 2006) that restoring a large wetland may not compensate for the functions lost when impacting many small ones, especially when restoring wetlands that are needed by amphibians. This idea of restoring smaller wetlands within wetland complexes to increase the overall connectivity is supported by wetland restoration scientists such as Mitsch and Gosselink (1993). Mitsch (1992) cautions though that one small wetland should not be expected to restore lost wetland functions and values by itself.

Constructing smaller wetlands may have a greater cumulative effect on the connectivity within a wetland complex, yet, it may also have undesirable consequences. In species that exhibit a species area effect, populations are generally more extinction prone in smaller patches of suitable habitat (Simberloff 1976). The stability of metapopulations may also be impacted whereby increasing the connectivity of a landscape mosaic more individuals may occur in sink habitats because of the increase in the colonization probability from source habitats (Pulliam 1988). Suitable habitat patches, though, may remain unoccupied due to the limited dispersal capabilities of a species through a landscape mosaic (Pulliam 2000). By constructing compensatory wetland mitigation sites in optimal positions in the landscape, species that are dispersal limited may potentially colonize previously unconnected suitable habitat patches thereby positively impacting the persistence of amphibian populations.

The classification tree is useful as general guidelines to quickly assess whether a potential wetland mitigation site lies in an optimal position in the landscape. It should be noted that these guidelines are based on simulation and not field collected data. Understanding the final outcomes, optimal or non optimal landscape positions, is important to understanding the effect of constructed wetlands on the mean change in connectivity of wetland complexes. Based on our simulation data, any constructed wetland that was constructed in a non-forested habitat was not in an optimal position in the landscape (Figure 4.8 **(A)**). The habitat in which a wetland is constructed impacts the effect it has on the mean connectivity of the surrounding wetlands as well as its probability of colonization. Constructing wetland in hostile landscape such as former agricultural fields and in urban areas impede the movement of amphibians affecting their probability of colonization and lessen their potential impact on metapopulations dynamics (Lehtinen & Galatowitsch 2001).

The distance a constructed wetland is from its nearest neighbor has an effect on its probability of colonization and its affect on the change in connectivity of wetland complexes. A potential wetland restoration site in a forested landcover with less than 9.9% of wetlands within a 36km^2 area and is less than 390.0 meters from its nearest wetland neighbor has a higher likelihood of being in an optimal position in the landscape (Figure 4.8 **(B))**. The distance is important in that as a wetlands become increasing isolated, regardless of the hostility of the landscape mosaic, the probability of colonization and the persistence of metapopulations decreases (Hanski 1997; Mazerolle et al. 2005).

The hostility of the landscape mosaic between suitable habitat patches and the proportion of suitable habitat in a 36 km^2 area has what may be considered as a threshold effect. Kareiva et al. (1997) noted that as the proportion of suitable habitat within a landscape mosaic increased connectivity and its effect on dispersal became less relevant. This is similar to what is seen in the final output of Figure 4.8 **(C)**, where there is a range of suitable habitat within 36 km^2 at which constructing wetlands will be in optimal landscape positions. Above this range any constructed wetland, regardless of size, is considered as being located in a non optimal landscape position because it has relatively little effect on the mean change in connectivity between wetlands.

In more hostile non-forested landscape mosaics the size of constructed wetlands is an important determinant as to whether they will be located in optimal or non optimal landscape positions. Based on our simulations, small 2.25 ha wetlands in more hostile landscape mosaics have little effect on the mean change in connectivity. For this reason when using easily measurable landscape variables, constructing 2.25 ha wetlands in hostile landscape mosaics will result in non optimal landscape positions (Figure 4.8 **(D)**). This may be misleading, as the low connectivity landscape mosaic in Figure 4.7 demonstrates, 2.25 ha wetlands can be constructed in optimal landscape positions in hostile landscape mosaics. The range, though, is narrow and close to existing suitable habitat patches. In more hostile landscape mosaics larger, 10 and 40 ha, wetlands may also have little effect on the mean change in connectivity depending upon the proportion of suitable habitat within 36 km^2. Above a threshold of 13% suitable wetland habitat within 36 km^2, the probability increases that 10 and 40 ha wetlands are constructed in optimal landscape positions (Figure 4.8 **(E)**). Below this threshold, the existing suitable wetland habitat may be too isolated and, regardless of size, constructed wetlands will have little effect on the connectivity of existing wetland complexes.

Management Implications

The ability to measure spatially explicit connectivity has other applications besides locating wetland restoration in the optimal position in the landscape for increasing the probability of colonization. The connectivity of existing wetlands can be determined for specific species, by developing species specific habitat resistant grids. By calculating and locating wetlands that are highly connected at multiple degrees to several other wetlands, resource managers can make more informed decisions regarding species reintroductions or conservation strategies. Reintroduced species have a higher probability of colonizing unoccupied habitats when reintroduced into highly connected existing suitable habitats; thereby, increasing the probability of successful reintroductions. When faced with limited means to protect habitats for biodiversity conservation, the ability to identify priority landscapes is imperative (Randhir et al. 2001; Wang 2001; Zedler 2004). By identifying and conserving landscapes with high connectivity between critical habitats of at risk species the existing populations have a higher probability of long term persistence. By incorporating connectivity measures into targeted conservation and management approaches, resource managers can better use the limited conservation dollars with more assurance of increasing the desired ecosystem functions of restored habitats and achieving their conservation goals.

Table 4.1: Candidate models evaluating the effect of landscape parameters of randomly constructed wetlands on the mean change in connectivity, for all size classes.

Candidate Model	Equation
H1: Global Model - The change in connectivity due to wetland construction and its impacts on dispersing amphibians is best explained by the landscape position of the constructed wetland and the landscape mosaic in which it is constructed.	Landscape Position + Landscape Mosaic
H2: The change in connectivity due to wetland construction and its potential impact on dispersing amphibians is best explained by the original connectivity of the site to all surrounding wetlands.	Landscape Position
H3: The change in connectivity between wetlands and its potential impact on dispersing amphibians is best explained by the landscape mosaic and its resistance to dispersal.	Landscape Mosaic

Table 4.2: Akaike's Information Criteria and Akaike Weights used to evaluate the most plausible models explaining the mean change in connectivity as a result of constructing 2.25 ha wetlands.

Candidate Model	K	AICc	Δi	exp(-0.5*Δi)	Wi
H1: Global Model	3	3.39	0.00	1.00	0.9999
H2: Landscape Position	2	21.28	17.89	0.00	0.0001
H3: Landscape Mosaic	2	74.57	71.18	0.00	0.0000

Table 4.3: Model average parameter estimates of the composite model explaining the mean change in connectivity as a result of constructing 2.25 ha wetlands.

Parameter	Parameter Estimate	Standard Error	Upper 95%	Lower 95%	Odds Ratio	Odds Ratio Upper 95%	Odds Ratio Lower 95%
INTERCEPT	-2.26955	0.232	-1.815	-2.724			
Landscape Position	0.00223	0.000	0.003	0.002	1.00223	1.000	1.003
Landscape Mosaic	0.00208	0.000	0.003	0.001	1.00208	1.000	1.003

Table 4.4: Akaike's Information Criteria and Akaike Weights used to evaluate the most plausible models explaining the mean change in connectivity as a result of constructing 10 ha wetlands.

Candidate Model	K	AICc	Δi	exp(-0.5*Δi)	Wi
H1: Global Model	3	-166.706	0	1.00	1.00
H2: Landscape Position	2	-63.552	103.154	0.00	0.00
H3: Landscape Mosaic	2	-8.597	158.109	0.00	0.00

Table 4.5: Model average parameter estimates of the composite model explaining the mean change in connectivity as a result of constructing 10 ha wetlands.

Parameter	Parameter Estimate	Standard Error	Upper 95%	Lower 95%	Odds Ratio	Odds Ratio Upper 95%	Odds Ratio Lower 95%
INTERCEPT	-2.07156	0.127	-1.823	-2.320			
Landscape Position	0.00414	0.000	0.005	0.003	1.004	1.000	1.005
Landscape Mosaic	0.00306	0.000	0.004	0.002	1.003	1.000	1.004

Table 4.6: Akaike's Information Criteria and Akaike Weights used to evaluate the most plausible models explaining the mean change in connectivity as a result of constructing 40 ha wetlands.

Candidate Model	K	AICc	Δi	exp(-0.5*Δi)	Wi
H1: Global Model	3.000	-39.069	0.000	1.000	1.000
H3: Landscape Mosaic	2.000	26.524	65.593	0.000	0.000

Table 4.7: Model average parameter estimates of the composite model explaining the mean change in connectivity as a result of constructing 40 ha wetlands.

Parameter	Parameter Estimate	Standard Error	Upper 95%	Lower 95%	Odds Ratio	Odds Ratio Upper 95%	Odds Ratio Lower 95%
INTERCEPT	-4.1822	1.89127	-0.47531	-7.88909			
Landscape Position	0.01008	0.00749	0.02477	-0.0046	1.010	1.008	1.025
Landscape Mosaic	0.00526	0.0028	0.01074	-0.00022	1.005	1.003	1.011

Table 4.8: Results of the KNN 10 fold cross validation evaluating the predictive ability of the global model to correctly determine whether constructed wetlands are located at an optimal position in the landscape.

		Predicted		
		1	0	
Observed	1	200	1	201
	0	3	547	550
		203	548	704

Omission error rate percent:	0.50
Commission error rate percent:	1.48
Classification error rate percent:	0.55

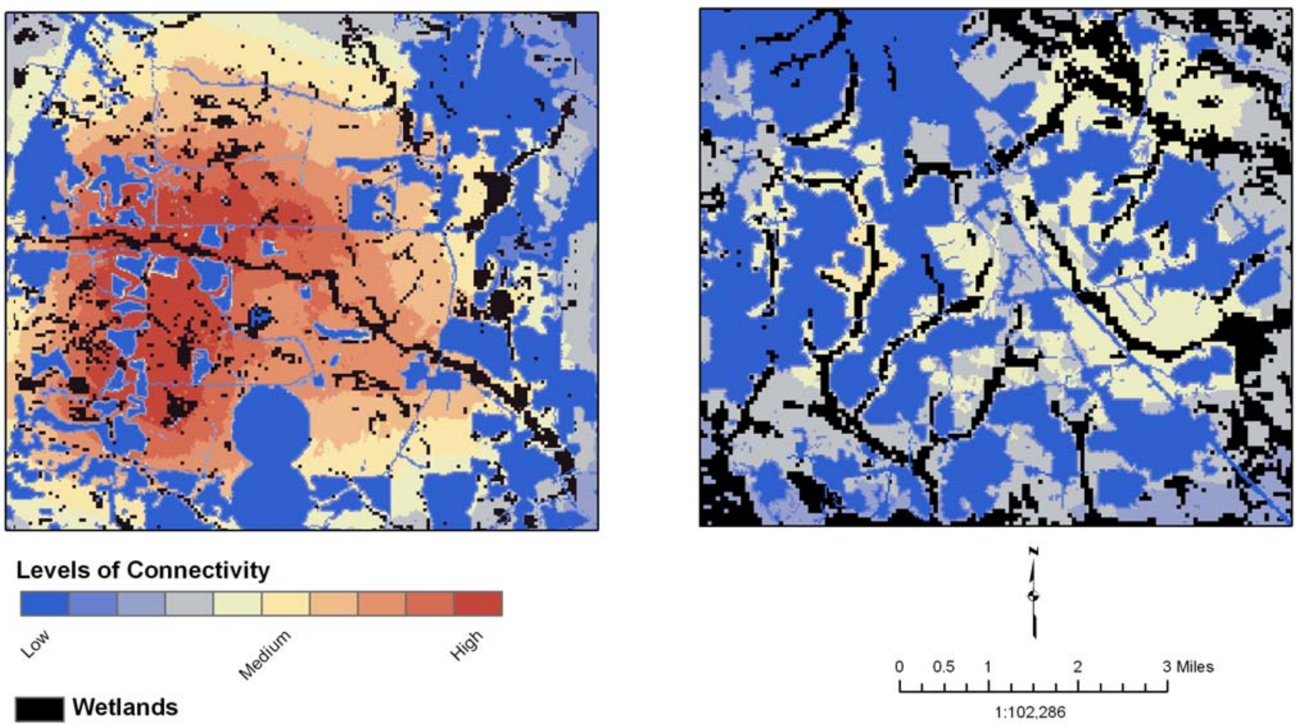


Figure 4.1: Examples of high (left map) and low (right map) levels of connectivity between wetlands within a landscape mosaic.

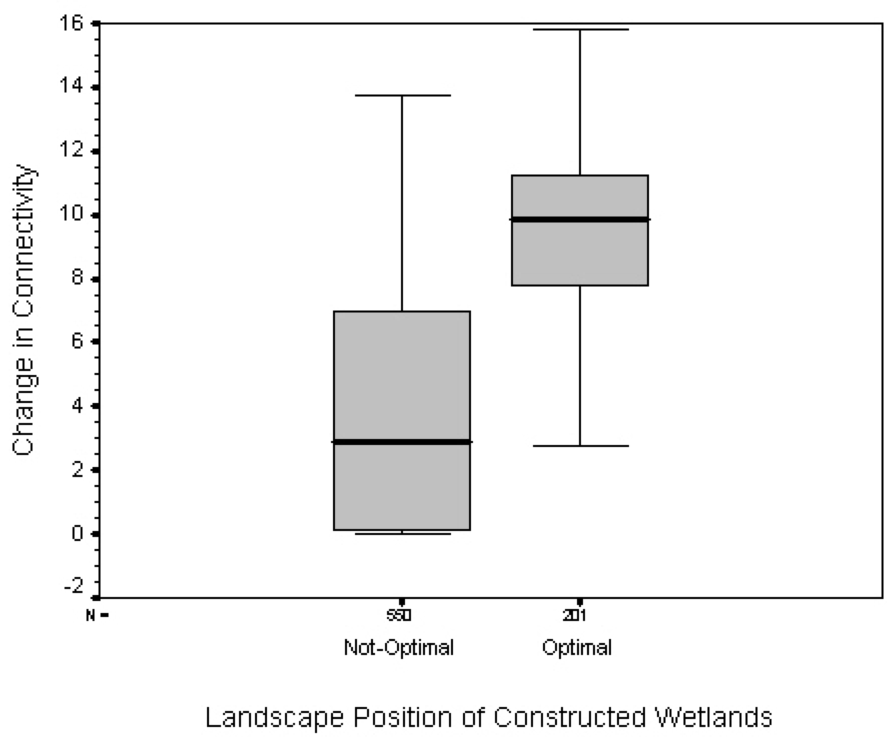


Figure 4.2: Box plot comparing the change in connectivity as a result of constructing wetlands in optimal versus non-optimal landscape positions. Heavy bar signifies the median value.

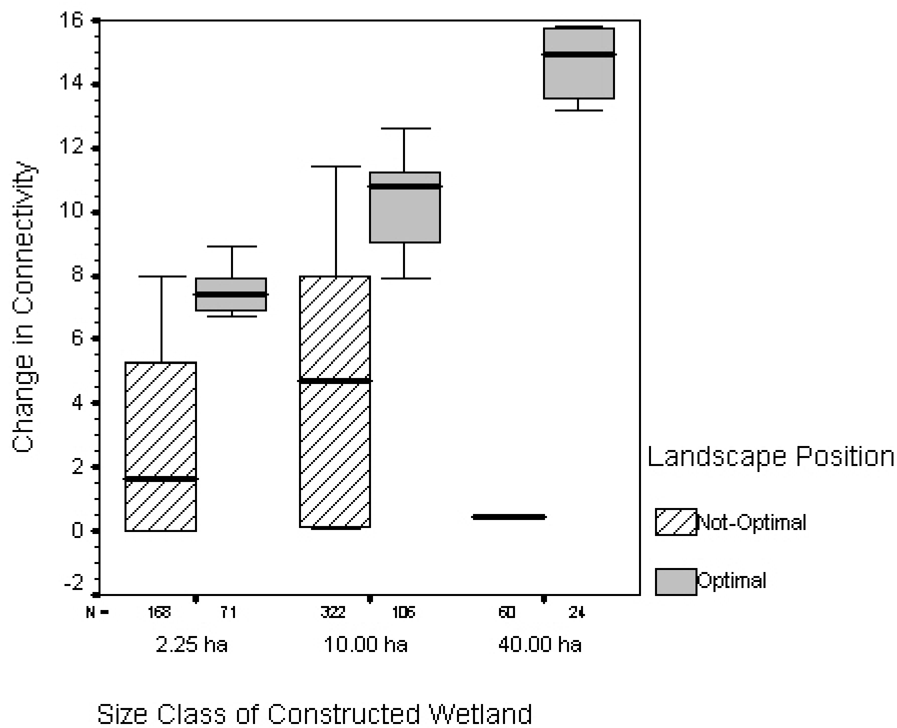
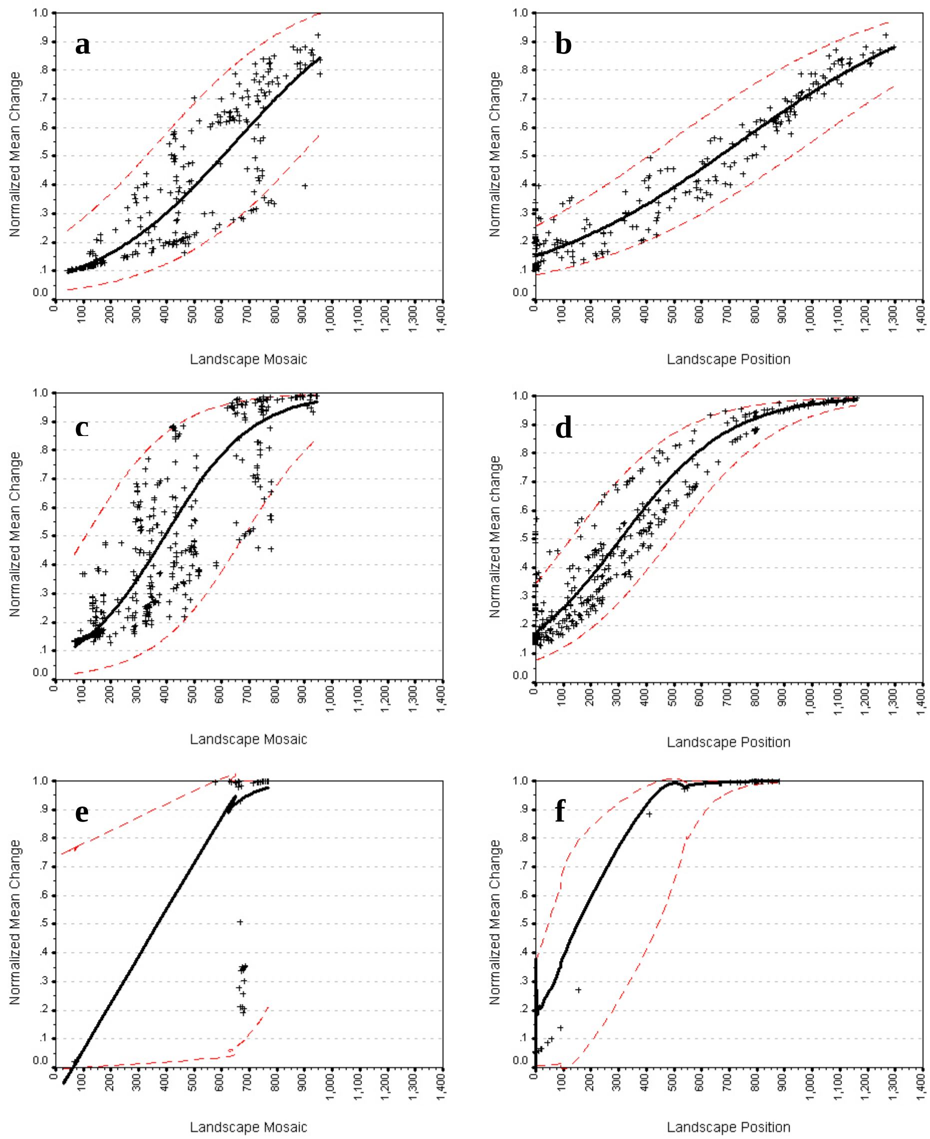


Figure 4.3: Box plot comparing the change in connectivity as a result of constructing wetlands in optimal versus non-optimal landscape positions by size class. Heavy bar signifies the median value.



Figures 4.4: Fitted logistic regression curves for the landscape position and landscape mosaic of each size class in relation to normalized mean change. a - b represent 2.25 ha wetlands, c - d 10 ha wetlands and e - f 40 ha wetlands.

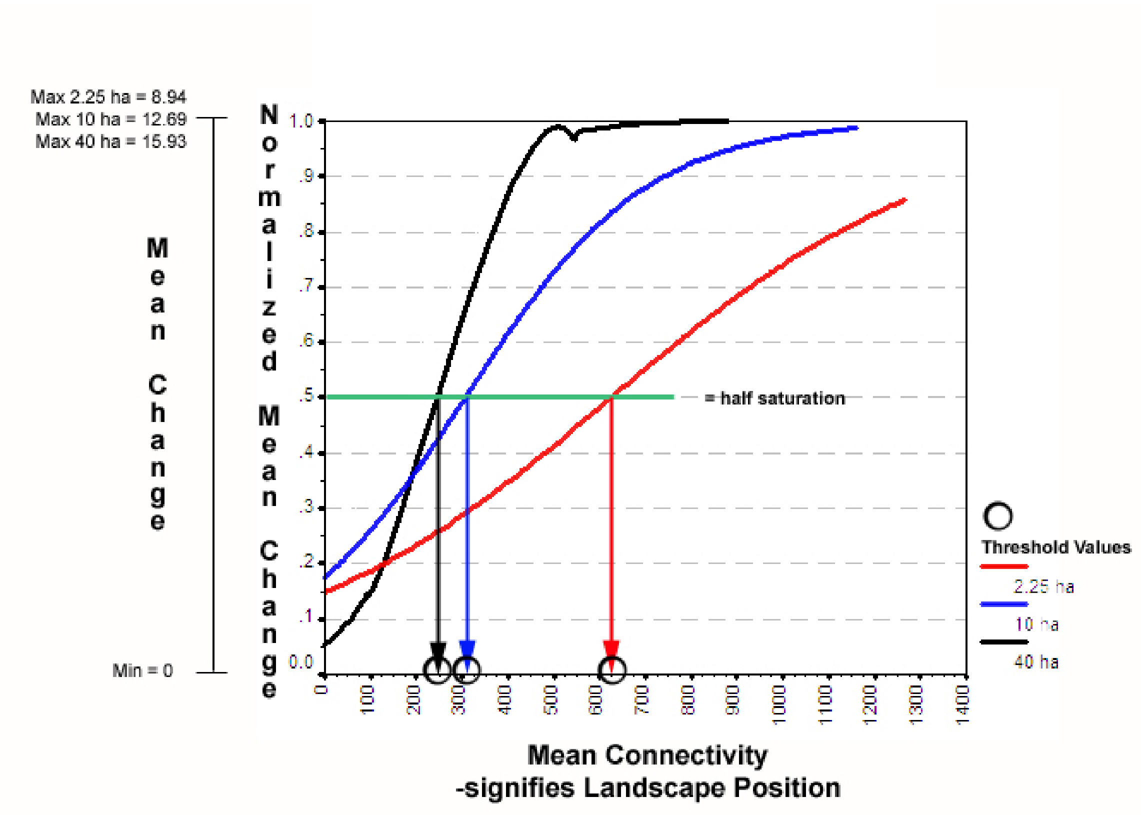


Figure 4.5: Using the fitted logistic regression curves to determine half-saturation constant identifying the landscape position threshold of constructed wetlands for each size class.

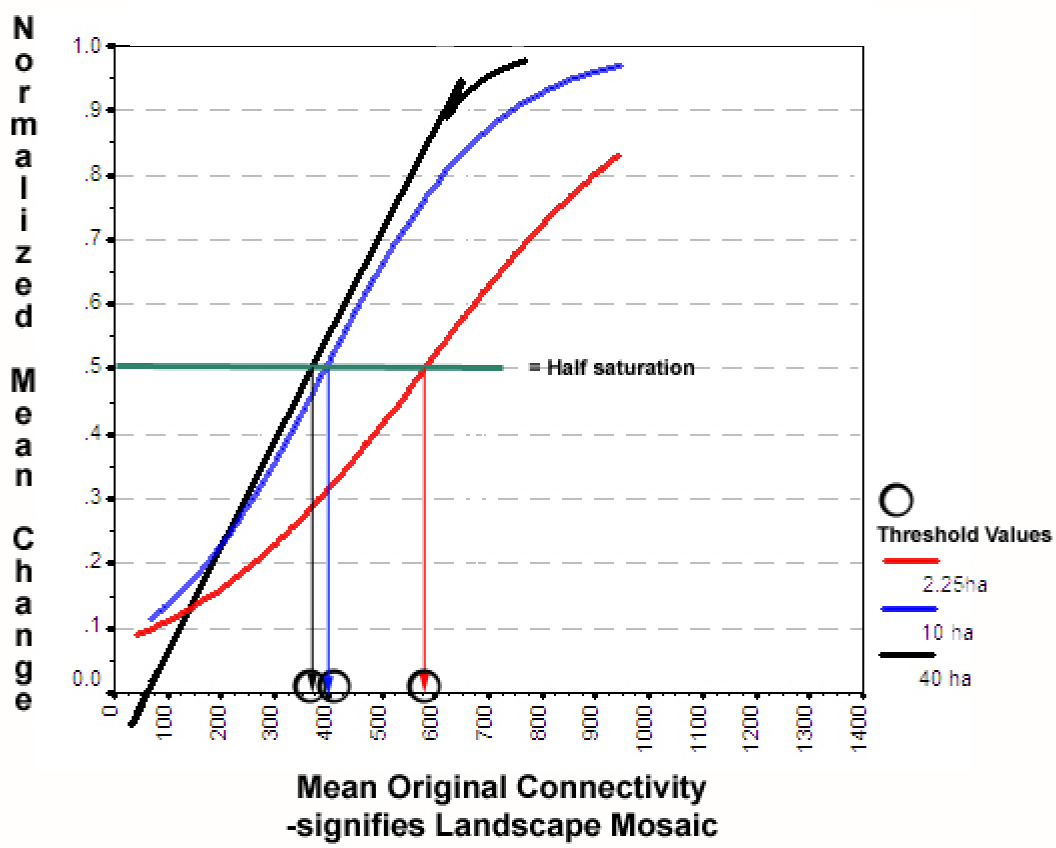
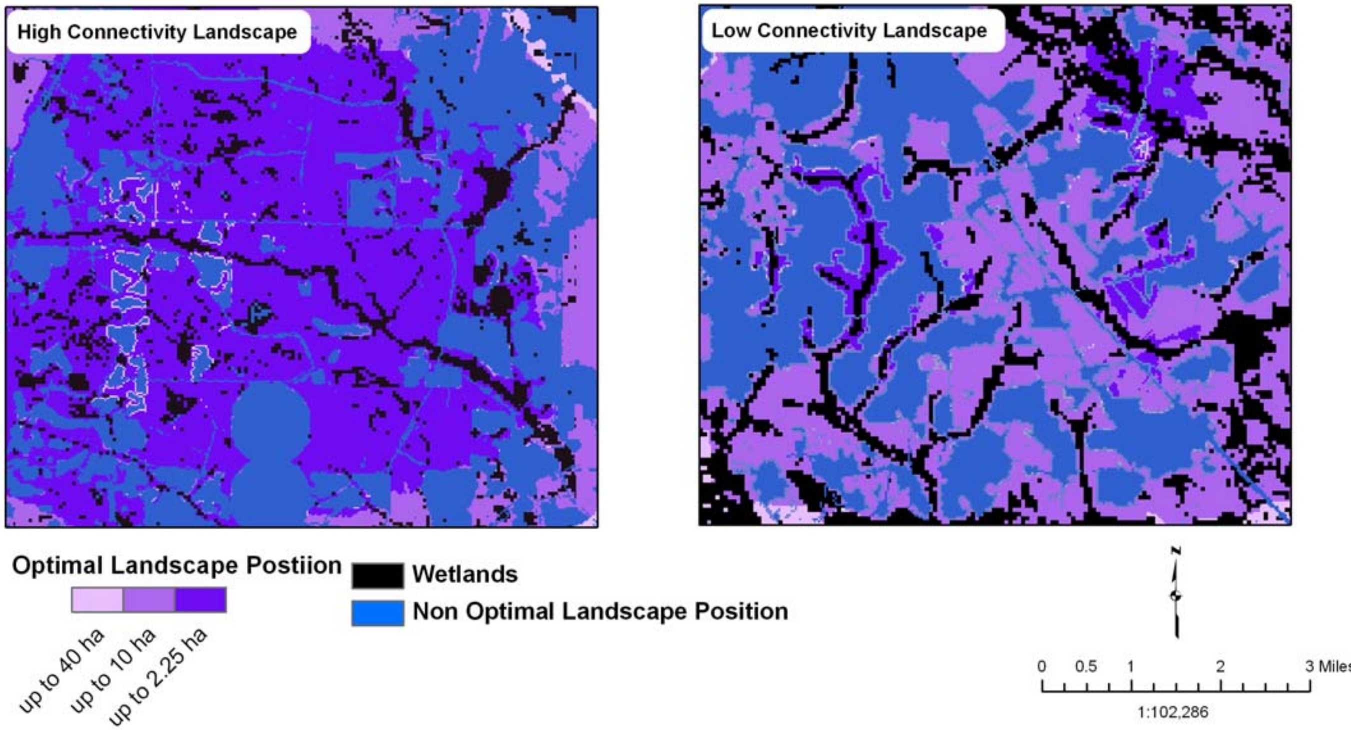


Figure 4.6: Using the fitted logistic regression curves to determine half-saturation constant identifying the landscape mosaic threshold of constructed wetlands for each size class.

Figure 4.7: Optimal position for constructing wetlands in high and low connectivity landscapes. Dark purple represents where 2.25 ha wetlands would be considered as located in an optimal position in the landscape, dark and medium purple for 10 ha wetlands and dark and medium purple and pink for 40 ha wetlands.


High Connectivity Landscape
Low Connectivity Landscape
Optimal Landscape Postiion
up to 40 ha
up to 10 ha
up to 2.25 ha
Wetlands
Non Optimal Landscape Position
N
0 0.5 1 2 3 Miles
1:102,286

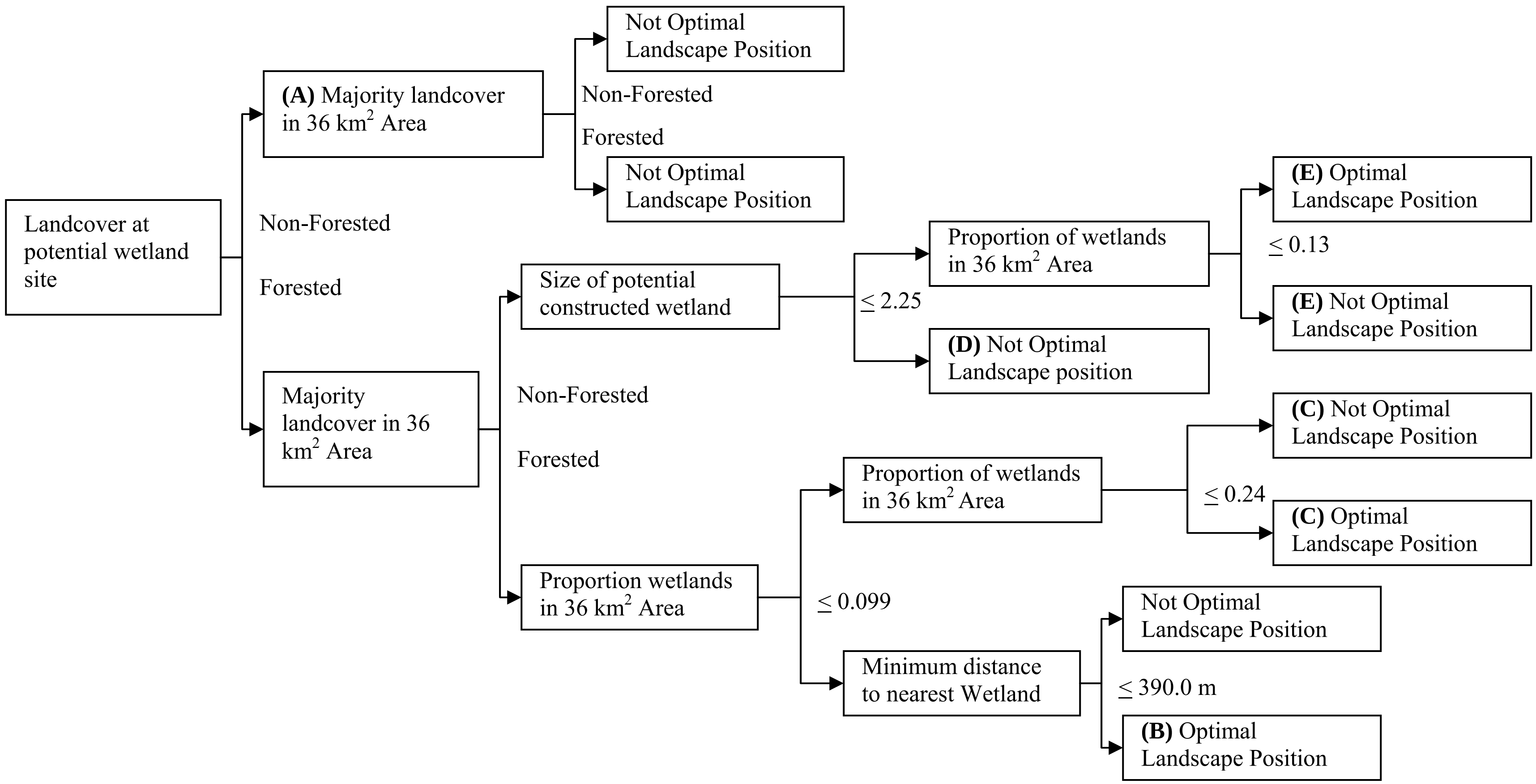


Figure 4.8: General guidelines for locating constructed wetlands in an optimal landscape position using easily measured landscape variables. Classification tree was developed using simulated wetland construction data in CATDAT. Table is read so that if the answer to the box is “true” then the lower box is applicable; if “false” the upper box is applicable.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Ecosystem functions provided by wetlands are out of proportion to the percentage of the landscape in which they occupy (NRC 2001). This is reflected by the small percentage of the state and ecoregions identified by the potential wetland restoration index as having high potential to benefit ecosystem functions provided by wetlands. Restoring the 2.9% of lands identified as high value potential wetland restoration sites may have significant impacts on the ecosystem services provided by wetlands and the health of our watersheds. The distribution of sites identified as high priority for wetland restoration is similar to the current distribution of wetlands in the state. In the Southeast Coastal Plains and Coastal Plains ecoregions where the majority of existing wetlands are located, as well as the majority of impacts to wetlands (*unpublished data)*. The most opportunities for restoring potential wetland restoration sites identified as high value, 95%, are in the Coastal Plain ecoregions. Only 5% of high value sites for restoration are located above the Fall Line, but this does not signify that suitable sites for restoration are not available.

The methods employed in developing the potential wetland restoration site index make all sites relative to each other regardless of their location in the state. Because of the topography in Georgia with most wetlands located in the Southern half of the state, the PWRS index is heavily skewed to this area. Being relative, though, sites in North Georgia that have potential to positively affect the identified wetland functions and values may be classified only as having medium value for restoration. It is important to understand the relative nature of the model, and when using the PWRS index to evaluate sites, choosing first sites with the highest rankings with respect to the watershed, ecoregion or USACE service area of interest. By not taking into account the relative nature of the potential wetland restoration site index, the applicability and effectiveness of the PWRS index may decrease. Understanding the sensitivity of the PWRS index to the methods employed and the outcomes desired clarifies what wetland functions and values the PWRS index is highlighting and how they should be evaluated and prioritized.

The sensitivity analysis for the mean patch size at the statewide spatial scale shows that restoring wetlands in a landscape position and configuration identified as high value potential wetland restoration sites are most likely to affect flood control and flow regulation. The large patch size, 188 ha, of these high value sites reflect that flood control is a function of the size, or storage capacity, of a wetland. The same relationship is seen in the coastal plain where the mean patch size is 160 ha and most influenced by flood control and flow regulation. The large mean patch size is found only when the model was evaluated at the statewide spatial scale and in the coastal plain. These are also the only two scales where flood control and flow regulation have the most effect on the potential wetland restoration site index.

The landscape position and configuration of the total area of high value potential wetland restoration sites at the statewide spatial scale indicate that the PWRS index is most sensitive to water quality and quantity and then to flood control and flow regulation. In the initial planning meetings concerning the methodology for Component One, concern was expressed that wildlife habitat (biodiversity conservation) was given too much importance. While the results from Section 3 of the surveys, Table 3.13, does show that wildlife habitat is equally weighted based on the number of times it is represented as a main function. The sensitivity analysis results show it has much less influence when compared to either of the water quality and quantity (Layers 1.4 and 1.9) or flood control and flow regulation models (Layer 1.7). This is also reflected in all ecoregions except for water quality and quantity in the Coastal Plain and flood control and flow regulation in the Blue Ridge ecoregions. This suggests that at the current method of classifying the potential wetland restoration site index at a statewide spatial scale accurately reflects the top three priority layers identified through the survey results. The effect in the coastal plain where flood control and flow regulation has the most effect is likely influenced by the large proportion of saltwater/brackish marshes and the interconnectedness of the hydrologic systems. It has also been observed in other Southeastern states developing similar models that due to the uniqueness of the abiotic and biotic processes in saltwater/brackish marshes, one restoration model may not be feasible (DEHNR 1995). The Blue Ridge differs in that because it is highly influenced by the large area of the Chattahoochee National Forest on the connectivity function, connectivity to existing conservation areas has more effect than flood control and flow regulation.

The mean patch size of high value restoration sites is also a function of the type of wetland that is identified. In the Piedmont, Appalachian Plateau, Ridge and Valley and Blue Ridge ecoregions, the potential wetland restoration site index identifies riparian areas for restoration. In general, these are topographically constrained and small, and as a result the mean patch size reflects this. The small mean patch size may also be a result of single pixels influencing the model and inferences about the performance of the PWRS index should be made using the total area of high value potential wetland restoration sites. The Coastal Plain does reflect the larger wetlands that are typical of the expansive bottomland hardwoods and saltwater/brackish marshes. The mean patch size in the Southeast Coastal Plain ecoregion, while two times larger than those located above the fall line, are much smaller than the Coastal Plain. The most likely cause of this is that the Southeast Coastal Plain was combined with Southwest Georgia which has a karst geomorphology. Wetlands in Southwest Georgia are mainly riparian with few large bottomland hardwoods. While the Southeast Coastal Plain has large expansive bottomland hardwood forests in the Satilla, Altamaha and other drainage basins.

The potential wetland restoration site index for mean patch size of wetland is affected by the north-south topographical gradient in Georgia. The mean patch size of potential wetland restoration sites below the fall line are 10 times larger than above the fall line and reflect the flat topography and characteristics of the existing wetlands. The topographical and geomorphological differences on a north to south gradient are also transmitted through the methods and affect both the total area and mean patch size of the model. Layer 1.6, terrestrial dispersal corridors between wetlands and Layer 1.7 hydrologic connectivity between wetland both have as base data layers existing wetlands. As previously mentioned, in North Georgia most mitigation is riparian mitigation and the few natural wetlands that exist have little influence on the PWRS index. Except in a few instances, those wetlands that do exist in North Georgia are generally below the minimum mapping unit of the Georgia Land Use Trends database which is used as the base wetlands layer. For this reason, in the Blue Ridge, Appalachian Plateau, Ridge and

Valley Layers 1.6 and 1.7 have no effect on the sites identified as high value potential wetland restoration sites.

The effect of natural upland vegetation also follows a north-south gradient. In the Coastal Plain, Southeast Coastal Plain and to a lesser extent the piedmont, natural upland vegetation has a direct negative effect on the mean patch size of potential wetland restoration sites. The effect of the north-south gradient in natural upland vegetation is more a function of current land uses than topographical constraints. The dominant land uses below the fall line are agriculture and silviculture. Compared to North Georgia, relatively little natural upland vegetation exists in South Georgia outside of existing conservation and military lands. As a result wetlands in South Georgia are less likely to be surrounded by natural upland vegetation when compared to North Georgia where the dominant land use is development. Thus, prioritizing natural upland vegetation drives mitigation out of South Georgia to the northern sections of the state. The total area of high value potential wetland restoration sites does not exhibit a geographical gradient as a result of increasing the importance of natural upland vegetation. The results of the sensitivity analysis are used in combination with the results of the surveys to evaluate alternatives for finalizing the model structure.

The October 18th, 2006 survey given to the technical steering committee involved three separate sections. From section 2 of the surveys the technical steering committee felt that both layers whose main function is improving / maintaining water quality are the most important, followed by flood control and flow regulation. The order of the layers and the functions they identify are consistent with discussions amongst the technical advisory committee during initial planning meetings. While the results from Section 2 do not necessarily suggest a bias against including wildlife habitat in mitigation plans. It is consistent with the results from the National Research Councils' report on compensatory wetland mitigation. They found that none of the compensatory wetland mitigation projects reviewed for their report included design and evaluation criteria for wildlife and any benefits experienced were most likely the result of chance (NRC 2001). Connectivity to existing conservation areas was also given more importance in Section 2 than was wildlife habitat. The reason for this maybe that compensatory wetland mitigation sites constructed adjacent to existing conservation areas have a higher rate of success due to increase exposure and likelihood of remaining protected in perpetuity.

The prioritized order of the layers and their associated functions from Section 2 are the same as the prioritized order of wetland functions and values in Section 3. This suggests that, as the NRC stated, wildlife habitat is of less importance when planning wetland mitigation projects than other wetland functions and values. Comparing the results of Section 3 of the survey to the main wetland functions and values of each layer in Component One shows that the PWRS index does not reflect the desired output (Table 3.20). Ecosystem services which are the 2^{nd} most important wetland function and value are not mentioned as a main or secondary function of any layer in the PWRS index. By definition ecosystem services are the conditions and processes of natural ecosystems that provide some ecological or societal value (Groom et al. 2006). Thus all of the other identified wetland functions and values are more specific aspects of ecosystem services provided by wetlands (Zedler 2006). The results also indicate that wildlife habitat was given equal weight in the PWRS index to water quality and quantity based on the number of times it was identified as a main wetland function and value. Wildlife habitat, when based on the number of times it was identified as a main and secondary function, is given the most importance in the potential wetland restoration site index.

The results from Section 3 of the surveys can be misleading. Even though wildlife habitat does appear most often in the model, the sensitivity analysis shows that in most ecoregions it has relatively little influence on the total area or mean patch size of high value potential wetland restoration sites. This effect varies, as does the effect for all of the wetland functions and value. The results from Section 3 of the survey can be looked at to determine how often each wetland function and value is identified in the PWRS index. It cannot be used to evaluate weighting schemes so that the layers in Component One will reflect the wetland function and value rankings. Weighting schemes can be evaluated by comparing the results of Section 2 of the survey to the results of the sensitivity analyses.

As shown, the spatial scale chosen for finalizing the potential wetland restoration site index influences the location in the landscape of high value potential restoration sites and the wetland functions and values prioritized. As discussed in the sensitivity analysis methods, the methods used to construct the final potential wetland restoration site index also affects the spatial location and configuration of high value potential restoration sites and the wetland functions and values prioritized. By using the results of the sensitivity analysis and the surveys, we can choose the methods and appropriate spatial scale at which the potential wetland restoration index should be finalized. Thereby ensuring that the spatial location and configuration of high value potential wetland restoration sites identify locations where restoration would have the most effect on the desired wetland functions and values.

I have identified three different alternatives that can be used to finalize the potential wetland restoration site index: 1) Base-model, 2) Regional Separation / Independence Model, 3) Regional Weighted Average Model. Each alternative has its advantages and disadvantages. The first alternative, “base-model”, keeps the already employed methods of a one to one additive model at a statewide spatial scale. Couple this with field validation at randomly located sites in all ecoregions to evaluate the performance of the model to determine how to manipulate the model so that the proper weights of the wetland functions and values are achieved. The main advantage of this alternative is that by using field validation techniques a more accurate picture develops of the current performance of the model and the sites it prioritizes as high potential for restoration. Having a more complete picture makes it easier to manipulate the model so that it performs to the satisfaction of all parties involved.

There are also several disadvantages of the first alternative. The first is that the functional wetland assessment necessary to evaluate a potential wetland restoration site is time consuming (Cedfeldt et al. 2000) and costly. Rapid wetland assessment tools, such as the Hydrogeomorphic approach (HGM) and the Index of Biological Integrity (IBI), exist to evaluate the impact on the ecosystem services and biological integrity lost in a watershed as a result of impacts to a particular wetland (USEPA 1998). The ability of these approaches to quantify a priori a potential increase in ecosystem services resulting from compensatory wetland mitigation is not stated (Berman et al. 2002). Regardless, even with in-depth functional assessments of a site, determining the effect of restoration on wetland functions and values and the performance of the model are difficult to determine (NRC 2001).

The second disadvantage of this approach is the disconnect between current practices and preferences for selecting mitigation sites and the ecological equivalence of these sites for replacing lost wetland functions and values. Site that generate the most mitigation credits possible are preferred by resource managers. In general, mitigation sites that have severely altered hydrology generate more mitigation credits than do less degraded sites. These sites may support more wetland functions and values and be easier to restore (NRC 2001; Zedler 2006). When evaluating the potential wetland restoration site index in this context the results will not be truly indicative of the performance of the model. This is because the potential wetland restoration site index was developed to determine locations in a watershed where wetland mitigation would have the most effect on wetland functions and values, regardless of the size, current condition or ability of a site to generate mitigation credits.

As the potential wetland restoration site index is currently constructed, South Georgia is more heavily weighted than North Georgia because geographically the majority of the wetlands are located below the Fall Line. The second alternative, Regional Separation / Independence Model, might even out this disparity by reclassifying each input layer (Layers 1.4 - 1.9). This could be done by reclassifying each layer with respect to ecoregion or U.S. Army Corp of Engineers service areas. One advantage of this alternative is that it would prioritize potential wetland restoration sites within ecoregions or service area, making them independent of one another. This would potentially identify more stream mitigation sites in North Georgia. It is important to identify stream mitigation sites because it accounts for the majority of compensatory mitigation currently taking place in Georgia (GADOT *pers. comm.*). Another advantage is that by reclassifying the data by service area it identifies potential sites specific to a primary service area that should be evaluated for compensatory mitigation before considering sites in secondary or tertiary service areas.

The disadvantage of alternative two is identifying how each layer once divided into ecoregions or service areas will influence the output of the potential wetland restoration site index. To determine the influence, the sensitivity analysis would have to be redone on a regional basis since it was initially calculated using data reclassified at the statewide scale. It would also be necessary to resend surveys since they asked questions based on the statewide data and general priorities and not at an ecoregional or service area scale. It is also unknown how each input layer will change and what information it will convey once divided. This problem arises because all of the input layers were developed with methodology specifically to be evaluated at a statewide spatial scale.

The Piedmont ecoregion was reclassified as an example of Regional Separation / Independence Model and the effects it has on the potential wetland restoration site index. The performance of the model for reflecting the desired prioritization of layers improves when reclassified by ecoregion. The effect of each layer on the model, which was highly skewed when using data reclassified at the statewide spatial scale, shows much less spread in the indexed effects between layers (Table 5.1). While this suggests that alternative two may be preferable to the base model, all ecoregions should be evaluated to determine the effects of partitioning the state into ecoregions, and whether the performance of the PWRS index improves enough to justify the added time and steps necessary to finalize the model.

The third alternative, Regional Weighted Average Model, for developing the potential wetland restoration index is to weight each layer by ecoregion before it is combined with the other layers in Component One of the model. Weighting of each layer would be accomplished by multiplying the direct effect of each layer on the total area of high value potential wetland restoration sites calculated by a factor so that it accurately reflects the average rank in Section 2 of the survey results. See Table 5.2 as an example in the Southeast Coastal Plain. The advantage of this method is that sites identified as high value for potential wetland restoration, regardless of location in the state, should highlight the wetland functions and values deemed most important for the area of interest.

There are a couple of disadvantages with weighting each layer by ecoregion. As noted in the sensitivity analysis methods, depending on the data and methods used, errors are introduced into the model. By weighting individual layers, any associated errors would also be magnified; thereby, increasing the uncertainty in the potential wetland restoration site index. Secondly, each individual layer was developed using methodology specifically for testing data at the statewide spatial scale. While the methods do break the state into smaller parcels for analysis, this analysis was not done with respect to ecoregion. By weighting each layer by ecoregion it is possible to induce added bias in the potential wetland restoration index through edge effects between the ecoregions.

The result of modeling multiple wetland functions and values in an additive model is that sites identified as high priority for restoration in the potential wetland restoration index are found in many different spatial locations and configurations. Depending on the spatial location and configuration, sites may prioritize one wetland function and value over another. Regardless of the methods used to finalize the PWRS index, it was not developed to specifically highlight one function over another but to equally weight the identified functions and values. The model was specifically developed this way so resource managers with an understanding of the effects of landscape position and configuration on wetland functions could select and evaluate sites identified as high value for restoration to optimize one or potentially many desired wetland functions and values. This requires that prior to undertaking wetland restoration goals are clearly defined to compensate for the loss functions provided by existing wetlands. This should be done using the current available wetland assessment techniques to determine the wetland functions and values that will be most impacted (NRC 2001). And using the potential wetland restoration site index as a watershed-based planning tool to aid in choosing sites for evaluation based on their spatial location and configuration and the effects they have on ecosystem services provided by wetlands.

There are proper and improper ways in which the PWRS index can be used as a watershed-based planning tool to increase the effectiveness of compensatory wetland mitigation. Using wetland mitigation as a tool for targeting protection of resources is more than maximizing the area of wetlands within a watershed or restoring sites identified as high value in the potential wetland restoration index. Even though, White and Fennessy (2005) found an area relationship between wetlands and water quality, more important might be the contribution of spatial location and configuration of these wetlands. Targeting specific functions provided by wetland for restoration requires an understanding of the relationship between the size, spatial location and configuration of wetlands and the functions they provide. Through the identification of the spatial location and configuration we can be more effective at using compensatory wetland mitigation to meet watershed planning objectives such as protecting water quality, providing flood control, flow regulation and conservation of biodiversity.

Numerous research projects have concentrated on the effect of the spatial location and configuration of wetlands within a watershed on the functions they provide. The improvement of water quality was found to be mainly a function of wetlands in the headwaters of streams and rivers or those directly below source habitats (Brinson 1988; Mitsch 1992; Mitsch & Day 2006; Mitsch & Gosselink 1993; van der Valk & Jolly 1992; Weller et al. 1996; Zedler 2003; Zedler 2006). This is contrary to Johnston et al. (1990) who found that wetlands lower in the watershed at stream junctions have the most effect on water quality. In the initial planning of this project, the technical steering committee lumped flood control and flow regulation into one class of wetland functions and values. The spatial location and configuration of wetlands may affect these two differently. Headwater wetlands have been found to have the most effect on flow regulation through recharge and desynchronizing flows (Cedfeldt et al. 2000; McAllister et al. 2000; Mitsch 1992; Potter 1994), whereas wetlands in the lower reaches of streams and rivers tend to have more effect on flood control (Johnston et al. 1990; Mitsch & Gosselink 1993; Ogawa & Male 1983; Zedler 2003). The size of a wetland has the same confounding effect on the wetland functions and values as does their spatial location and configuration.

The NRC in their 2001 report on the effectiveness of compensatory wetland mitigation stated that replacing impacted wetlands with large mitigation sites may not adequately compensate for the lost wetland functions and values. For example, in Sweden Hansson et al. (2005) found that restored wetlands with larger areas supported a greater diversity of macroinvertebrates, fish and plants (Mitsch & Wilson 1996). Yet, if one of the goals of restoration is the conservation of amphibian populations the ability of larger wetlands to support a greater diversity of fishes may have a negative consequences (White & Fennessy 2005). Snodgrass et al. (2000) states that due to the confounding effects of wetland area on conservation of biodiversity, instead of requiring mitigation wetlands of a certain size, a diversity of wetland sizes and locations in the landscape may be more beneficial to accomplish the goal of biodiversity conservation. This is further supported by the cumulative effect on connectivity of smaller simulated wetlands and its effect on metapopulation dynamics of *Rana clamitans* in Chapter 4.

The same is true in protecting water quality and quantity, while larger wetlands do have the ability to treat larger quantities of water (Hansson et al. 2005), the NRC (2001) pointed out that the area of a compensatory wetland designed to benefit water quality need only be large enough to handle the inputs from its drainage basin. Mitsch and Gosselink (1993) lend support to this by stating that "multiple smaller wetlands could be very effective in controlling certain types of nonpoint source pollution while creating needed [wildlife] habitat." Hansson et al (2005) though, found that large wetlands have more ability to assimilate nitrogen while small wetlands have more effect on phosphorous loading. As they noted though, this is more likely a cause of structure of the wetland than actual size of the wetland. When looking at the size of wetlands for flood control and flow regulation the same problem arises, large wetland have more impact on flood control (Mitsch & Gosselink 1993; Ogawa & Male 1983; Zedler 2003) while smaller wetland have more impact on flow regulation (McAllister et al. 2000; Mitsch 1992; Potter 1994). Resource manager also need to understand that targeting specific functions provided by one type of wetland may come at the expense of another (Rodŕiguez et al. 2006).

As has been noted the main functions that are desired from wetland restoration are generally water quality, flood abatement, and the conservation of biodiversity. To some extent all wetland perform all of these functions, yet depending on their size, spatial location and configuration the main functions vary by type and degree (NRC 2001). The management decision to compensate for impacts to wetlands by requiring replacement with larger wetlands involves a trade off of ecosystem services. The trade off of ecosystem services can either be involuntary, as might be seen from supposedly in-kind mitigation, or by design in out-of-kind mitigation. It is important to realize that by selecting sites based on availability and economic feasibility and requiring the amount of area replaced to be greater than lost, compensatory wetland mitigation may optimize one function at the expense of others (Rodŕiguez et al. 2006). For example, while the development of tertiary waste water treatment wetlands provide substantial benefits to water quality (Mitsch & Gosselink 1993) and may provide suitable habitat for wildlife. In Pennsylvania, Laposata and Dunson (2000) found though that wetlands optimized or created to treat waste water, the amphibian populations using these sites experienced decreased reproductive fitness and larval survival potentially creating "sink" populations within the landscape (Pulliam 1988). The NRC recognized the importance of size, spatial location and configuration of wetland on ecosystem function and recommended a more comprehensive approach to evaluating potential mitigation sites and their effects on ecosystem functions.

The potential wetland restoration index was developed to follow the recommendations laid forth in the National Research Council's "Compensating for Wetland Losses under the Clean Water Act." In following their recommendations, the potential wetland restoration site index can be incorporated into a larger framework that will help develop a comprehensive wetland protection program in Georgia that satisfies the goal of no-net-losses of wetland acreage and functions. The PWRS index was developed as a science-based tool using the best available data to model the position in the landscape and the configuration of wetlands that would be most likely to provide the main wetland function and value identified by each layer. The PWRS index was not developed to specifically highlight the large areas where the development of project specific mitigation sites or mitigation banks would earn the most possible "credits". If the goal of wetland restoration remains restoring the largest and most degraded area possible without regard to the effects of landscape position and configuration, the potential wetland restoration index will not and cannot be used as an effective watershed-based planning tool.

Used properly with an understanding of how the methods employed, size and spatial location of potential wetland restoration sites influence the ecosystem services provided by wetlands. The potential wetland restoration site index can be an effective watershed-based planning tool to help resource managers achieve the objective of no-net-loss of wetland acreage and functions. Modeling and evaluating the ecosystem services of wetlands based on their spatial location and configuration in the landscape can help resource managers identify appropriate sites to mitigate for impacts to existing wetlands. As recommended by the NRC (2001), using a science-based approach for identifying compensatory wetland mitigation sites based the effects of their position in the landscape on recognized functions will increase the performance of a site in mitigating impacts to existing wetlands. By using the potential wetland restoration site index as a tool to aid in selecting mitigation sites, instead of selecting them based on economic feasibility or opportunity, we can increase the effectiveness of compensatory wetland mitigation.

Table 5.1: Example of the sensitivity of the potential wetland restoration site index using alternative two, regional separation / independence model, on the total area of high value restoration sites in the Piedmont Ecoregion.

Layer	Standard Output (ha)	Change (ha)	Weighted Output (ha)	Indexed Effect	Direct Effect
Layer 1.4	71716	695701	767417	12.70	9.70
Layer 1.9	71716	316249	387966	6.42	4.41
Layer 1.8	71716	169371	241088	3.99	2.36
Layer 1.7	71716	129118	200835	3.32	1.80
Layer 1.5	71716	15796	87512	1.45	0.22
Layer 1.6	71716	-11303	60414	1.00	-0.16

Table 5.2: Example of Alternative three for the Southeast Coastal Plain in the final model weighting; Factor necessary to weight the direct effect of each input layer on the total area of high value restoration sites to reflect the average weight of each layer from Section 2 of the October 18th, 2006 surveys.

Layer	Standard Output (ha)	Change (ha)	Weighted Output (ha)	Direct Effect	Desired effect	Factor
Layer 1.9	152426	569200	721626	3.73	2.78	0.74
Layer 1.4	152426	741663	894089	4.87	2.56	0.53
Layer 1.7	152426	85254	237680	0.56	2.33	4.17
Layer 1.5	152426	-130919	21508	-0.86	2.00	-2.33
Layer 1.8	152426	134468	286895	0.88	1.78	2.02
Layer 1.6	152426	116557	268984	0.76	1.67	2.18

REFERENCES

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 in B. N. Petrov, and F. Csake, editors. Second International Symposium on Information Theory. Akademiai Kiado, Budapest, Hungary.

Anderson, D. R., D. J. Sweeney, and T. A. Williams 1994. Introduction to statistics: Concepts and applications. West Publishing Company, Minneapolis/St. Paul.

Bedford, B. L. 1996. The need to define hydrologic equivalence at the landscape scale for freshwater wetland mitigation. Ecological Applications **6**:57-68.

Berka, C., H. Schreier, and K. Hall. 2001. Linking water quality with agricultural intensification in a rural watershed. Water Air and Soil Pollution **127**:389-401.

Berman, M. R., T. Rudnicky, H. Berquist, and C. Hershner. 2002. Protocols for implementation of a GIS-based model for the selection of potential wetlands restoration sites in Southeastern Virginia. Center for Coastal Resources Management, Virginia Institute of Marine Science.

Birchfield, G. L., and J. E. Deters. 2005. Movement paths of displaced Northern Green Frogs (*Rana clamitans melanota*). Southeastern Naturalist:63-76.

Brinson, M. M. 1988. Strategies for assessing the cumulative effects of wetland alteration on water quality. Environmental Management **12**:655-662.

Brown, S. C., and P. L. M. Veneman. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, USA. Wetlands **21**:508-518.

Burnham, K. P., and D. R. Anderson 2002. Model selection and multimodel inference: A practical information-theoretic approach. Springer-Verlag, New York, New York.

Cedfeldt, P. T., M. C. Watzin, and B. D. Richardson. 2000. Using GIS to identify functionally significant wetlands in the Northeastern United States. Environmental Management **26**:13-24.

Christman, S. P. 1974. Geographic variation for salt-water tolerance in the frog *Rana sphenocephala*. Copeia:773-778.

Cole, C. A. 2006. HGM and wetland functional assessment: Six degrees of separation from the data? Ecological Indicators **6**:485-493.

Compton, B. W., K. McGarigal, S. A. Cushman, and L. R. Gamble. 2007. A resistant-kernel model of connectivity for amphibians that breed in vernal pools. Conservation Biology **21**:788-799.

Costanza, R., R. dArge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. Oneill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature **387**:253-260.

Crosetto, M., S. Tarantola, and A. Saltelli. 2000. Sensitivity and uncertainty analysis in spatial modeling based on GIS. Agriculture, Ecosystems and Environment **81**:71-79.

Dahl, T. E. 1990. Wetland Losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/wetlands/wetloss/index.htm (Version 16 JUL97).

Dahl, T. E. 2000. Status and trends of wetlands in the counterminuous United States 1986 - 1997. Department of the Interior, Fish and Wildlife Service, Washington D.C. 82 pp.

DEHNR. 1995. Fourth version, guidance for rating the values of wetlands in North Carolina. North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management, Water Quality Section, Raleigh, NC.

deMaynadier, P. G., and M. L. Hunter. 1999. Forest canopy closure and juvenile emigration by pool-breeding amphibians in Maine. Journal of Wildlife Management **63**:441-450.

Dent, B. D. 1999. Cartography: Thematic map design. WCB/McGraw-Hill, New York.

Downing, D. M., C. Winer, and L. D. Wood. 2003. Navigating through Clean Water Act jurisdiction: A legal review. Wetlands **23**:475-493.

Dunne, T., and L. B. Leopold 1978. Water in Environmental Planning. W. H. Freeman and Company, New York.

ESRI. 2007. ArcGIS and ArcINFO Help Documentation. Environmental Systems Research Institute, Redlands, California {Available Online}.

FEMA. 1996. Q3 flood data specifications. Draft March 1996. Federal Emergency Management Agency, Washington, D.C.

GADNR. 2005. A Comprehensive Wildlife Conservation Strategy for Georgia. Georgia Department of Natural Resources, Wildlife Resources Division, Social Circle, GA.

Gergel, S. E. 2005. Spatial and non-spatial factors: When do they affect landscape indicators of watershed loading? Landscape Ecology **20**:177-189.

Gergel, S. E., M. G. Turner, J. R. Miller, J. M. Melack, and E. H. Stanley. 2002. Landscape Indicators of Human Impacts to Riverine Systems. Aquatic Sciences **64**:118-128.

Gibbons, J. W. 2003. Terrestrial habitat: A vital component for herptofauna of isolated wetlands. Wetlands **23**:630-635.

Gibbs, J. P. 1998. Amphibian movements in response to forest edges, roads, and streambeds in southern New England. Journal of Wildlife Management **62**:584-589.

Gilliam, J. W., J. E. Parsons, and R. L. Mikkelsen. 1996. Water quality benefits of riparian wetlands. Pages 61-65. *in* Solutions: A technical conference on water quality. Conference proceedings, March 19-21, 1996., N.C. State University, Raleigh.

Gray, M. J., L. M. Smith, and R. I. Leyva. 2004. Influence of agricultural landscape structure on a Southern High Plains, USA, amphibian assemblage. Landscape Ecology:719-729.

Green, D. M. 2003. The ecology of extinction: population fluctuation and decline in amphibians. Biological Conservation **111**:331-343.

Groom, M. J., G. K. Meffe, and C. R. Carroll 2006. Principles of conservation biology. Sinauer Associates, Inc., Sunderland, MA.

Guerry, A. D., and M. L. Hunter. 2002. Amphibian distributions in a landscape of forests and agriculture: An examination of landscape composition and configuration. Conservation Biology **16**:745-754.

Gustafson, E. J. 1998. Quantifying landscape spatial pattern: What is the state of the art? Ecosystems **1**:143-156.

Hanski, I. 1994. A practical model of metapopulation dynamics. Journal of Animal Ecology **63**:151-162.

Hanski, I. 1997. Habitat destruction and metapopulation dynamics in S. T. A. Pickett, R. S. Ostfeld, M. Shachak, and G. E. Likens, editors. The ecological basis of conservation: heterogeneity, ecosystems and biodiversity. Chapman & Hall, New York, NY.

Hanski, I. 1998. Metapopulation dynamics. Nature **395**:41-49.

Hanski, I., and M. E. Gilpin. 1991. Metapopulation dynamics: a brief history and conceptual domain. Biological Journal of Linnean Society **42** 3-16.

Hanski, L. 2004. Metapopulation theory, its use and misuse. Basic and Applied Ecology **5**:225-229.

Hansson, L.-A., C. Brönmark, P. A. Nilsson, and K. Åbjörnsson. 2005. Conflicting demands on wetland ecosystem services: nutrient retention, biodiversity or both? Freshwater Biology **50**:705-714.

Hecnar, S. J., and M'Closkey. 1997. Spatial scale and determination of species status of the green frog. Conservation Biology **11**:670-682.

Herlihy, A. T., J. L. Stoddard, and C. B. Johnson. 1998. The relationship between stream chemistry and watershed land cover data in the Mid-Atlantic Region, U.S. Water, Air, and Soil Pollution **105**:337-386.

Hilty, J. A., W. Z. Lidicker, and A. M. Merenlender 2007. Corridor Ecology: The science and practice of linking landscapes for biodiversity conservation. Island Press, Washington D.C.

Houlahan, J. E., and C. S. Findlay. 2004. Estimating the 'critical' distance at which adjacent land-use degrades wetland water and sediment quality. Landscape Ecology **19**:677-690.

Hurvich, C. M., and C. L. Tsai. 1989. Regression and time-series model selection in small samples. Biometrika **76**:297-307.

Jackson, C. R. 2006. Wetland hydrology. Pages 43 -78 in D. P. Batzer, and R. R. Sharitz, editors. Ecology of freshwater and estuarine wetlands. University of California Press, Berkeley, CA.

Jenson, J. 2007 *Pers Comm*. Discussion on the effects of brackish marshes on *Rana clamitans* movement.

Johnston, C. A., N. E. Detenbeck, and G. J. Niemi. 1990. The cumulative effect of wetlands on stream water quality and quantity - a landscape approach. Biogeochemistry **10**:105-141.

Joly, P., C. Morand, and A. Cohas. 2003. Habitat fragmentation and amphibian conservation: building a tool for assessing landscape matrix connectivity. Comptes Rendus Biologies **326**:S132-S139.

Kareiva, P., D. Skelly, and M. Ruckelshaus. 1997. Reevaluating the use of models to predict the consequences of habitat loss and fragmentation in S. T. A. Pickett, R. S. Ostfeld, M. Shachak, and G. E. Likens, editors. The ecological basis of conservation: heterogeneity, ecosystems and biodiversity. Chapman & Hall, New York, NY.

Kitron, U., and A. Spielman. 1989. Suppression of transmission of malaria through source reduction: antianopheline measures applied in Israel, the United States and Italy. Review of Infectious Diseases **11**:391-406.

Kolka, R. K., and J. A. Thompson. 2006. Wetland geomorphology, soils and formative processes. Pages 7-42 in D. P. Batzer, and R. R. Sharitz, editors. Ecology of freshwater and estuarine wetlands. University of California Press, Berkeley, CA.

Kramer, E., S. M. Carpenedo, J. Lee, and K. Samples. 2007. Monitoring Georgia's Wetland Trends Using Remote Sensing. Proceedings of the 2007 Georgia Water Resources Conference, University of Georgia.

Kramer, L., and M. Elliott. 2005. Identification of conservation opportunity areas in Georgia. GAP Analysis Bulletin **13**:14-20.

Lamoureux, V. S., and D. M. Madison. 1999. Overwintering habitat of radio-implanted green frogs. Journal of Herpetology **33**:430-435.

Lamoureux, V. S., J. C. Maerz, and D. M. Madison. 2002. Premigratory autumn foraging forays in the green frog, *Rana clamitans*. Journal of Herpetology **36**:245-254.

Lannoo, M., editor. 2005. Amphibian declines: the conservation status of United States Species. University of California Press, Berkeley.

Laposata, M. M., and W. A. Dunson. 2000. Effects of spray-irrigated wastewater effluent on temporary pond-breeding amphibians. Ecotoxicology and Environmental Safety **46**:192-201.

Lehtinen, R. M., and S. M. Galatowitsch. 2001. Colonization of restored wetlands by amphibians in Minnesota. American Midland Naturalist **145**:388-396.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bulletin of the Entomological Society of America **15**:237-240.

Levins, R. 1970. Extinction. Lectures in Mathematical Life Sciences **2**:75-107.

Li, H. B., and J. F. Reynolds. 1994. A simulation experiment to quantify spatial heterogeneity in categorical maps. Ecology **75**:2446-2455.

Macdonald, M. A. 2007. Rapanos v. United States and Carabell v. United States Army Corps of Engineers. Harvard Environmental Law Review **31**:321-332.

Maerz, J. C. 2007 *Pers. Comm.* Discussion on the resistance of brackish marshes on the movement of *Rana clamitans*.

Marsh, D. M., and P. C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. Conservation Biology **15**:40-49.

Martof, B. 1953. Home range and movements of the green frog, *Rana clamitans*. Ecology **34**:529-543.

Mattikalli, N. M., and K. S. Richards. 1996. Estimation of surface water quality changes in response to land use change: Application of the export coefficient model Using remote sensing and geographical information system. Journal of Environmental Management **48**:263-282.

Mazerolle, M. J., and A. Desrochers. 2005. Landscape resistance to frog movements. Canadian Journal of Zoology-Revue Canadienne De Zoologie **83**:455-464.

Mazerolle, M. J., A. Desrochers, and L. Rochefort. 2005. Landscape characteristics influence pond occupancy by frogs after accounting for detectability. Ecological Applications **15**:824-834.

McAllister, L. S., B. E. Peniston, S. G. Leibowitz, B. Abbruzzese, and J. B. Hyman. 2000. A synoptic assessment for prioritizing wetland restoration efforts to optimize flood attenuation. Wetlands **20**:70-83.

McGarigal, K., B. J. Marks, C. Holmes, and E. Ene. 2003. Fragstats Version 3.3 User Guidelines. University of Massachusetts, Amherst, Mass.

Meador, M. R., and R. M. Goldstein. 2003. Assessing water quality at large geographic scales: Relations among land use, water physicochemistry, riparian condition, and fish community structure. Environmental Management **31**:504-517.

Merrill, M. D. 2001. Local and watershed influences on stream fish biotic integrity in the Upper Oconee watershed, Georgia, USA. Institute of Ecology. University of Georgia, Athens.

Mitsch, W. J. 1992. Combining Ecosystem and Landscape Approaches to Great-Lakes Wetlands. Journal of Great Lakes Research **18**:552-570.

Mitsch, W. J., and J. W. Day. 2006. Restoration of wetlands in the Mississippi-Ohio-Missouri (MOM) River Basin: Experience and needed research. Ecological Engineering **26**:55-69.

Mitsch, W. J., and J. G. Gosselink 1993. Wetlands, 2nd Edition. John Wiley & Sons, New York, NY.

Mitsch, W. J., and R. F. Wilson. 1996. Improving the success of wetland creation and restoration with know-how, time and self design. Ecological Applications **6**:77-83.

Möilanen, A., and I. Hanski. 2001. On the use of connectivity measures in spatial ecology. Oikos **95**:147-151.

Möilanen, A., and M. Nieminen. 2002. Simple connectivity measures in spatial ecology. Ecology **83**:1131-1145.

Murray, A. T., and T. K. Shyy. 2000. Integrating attribute and space characteristics in choropleth display and spatial data mining. International Journal of Geographical Information Science **14**:649-667.

NARSAL. 2006. Georgia Land Use Trends. University of Georgia, Institute of Ecology, Natural Resources Spatial Analysis Laboratory, Athens, GA.

NatureServe. 2006. An Online Encyclopedia of Life. NatureServe.

Neel, M. C., K. McGarigal, and S. A. Cushman. 2004. Behavior of class-level landscape metrics across gradients of class aggregation and area. Landscape Ecology **19**:435-455.

Newbold, S. C. 2005. A combined hydrologic simulation and landscape design model to prioritize sites for wetlands restoration. Environmental Modeling & Assessment **10**:251-263.

Noon, B., K. Mckelvey, and D. Murphy. 1997. Developing an analytical context for multispecies conservation planning in S. T. A. Pickett, R. S. Ostfeld, M. Shachak, and G. E. Likens, editors. The ecological basis of conservation: heterogeneity, ecosystems and biodiversity. Chapman & Hall, New York, NY.

NRC 2001. Compensating for Wetland Losses Under the Clean Water Act. National Academy of Science, National Research Council, Board of Environmental Studies and Toxicology. National Academy Press, Washington DC.

Oelke, E. A. 1993. Wild Rice: Domestication of a native North American genus. Pages 235-243 in J. J. a. J. E. Simons, editor. New Crops. Wiley, New York.

Ogawa, H., and J. W. Male. 1983. The flood mitigation potential of inland wetlands. University of Massachusetts, Amherst, Water Resources Research Center Publication **138**:p. 164.

Patrick, D. A., M. L. Hunter, and A. J. K. Calhoun. 2006. Effects of experimental forestry treatments on a Maine amphibian community. Forest Ecology and Management:323-332.

Peterson, J. T., T. C. Haas, and D. C. Lee. 1999. CATDAT-A Program for parametric and nonparametric categorical data analysis, user's manual version 1.0, Annual report 1999 to Bonneville Power Administration, Portland, OR, Contract No. 92AI25866, Project No. 92-0302-00, 98 electronic pages (BPA Report DOE/BP-25866-3).

Pope, S. E., L. Fahrig, and N. G. Merriam. 2000. Landscape complementation and metapopulation effects on leopard frog populations. Ecology **81**:2498-2508.

Potter, K. W. 1994. Estimating potential reduction flood benefits of restored wetlands. Water Resource Update **97**:34-38.

Price, S. J., D. R. Marks, R. W. Howe, J. M. Hanowski, and G. J. Niemi. 2004. The importance of spatial scale for conservation and assessment of anuran populations in coastal wetlands of the western Great Lakes, USA. Landscape Ecology **20**:441-454.

Pulliam, H. R. 1988. Sources, sinks and population regulation. American Naturalist **132**:652-661.

Pulliam, H. R. 2000. On the relationship between niche and distribution. Ecology Letters **2000**:349-361.

Rae, C., K. Rothley, and S. Dragicevic. 2007. Implications of error and uncertainty for an environmental planning scenario: A sensitivity analysis of GIS-based variables in a reserve design exercise. Landscape and Urban Planning **79**:210-217.

Randhir, T. O., R. O'Connor, P. R. Penner, and D. W. Goodwin. 2001. A watershed-based land prioritization model for water supply protection. Forest Ecology and Management **143**:47-56.

Regosin, J. V., B. S. Windmiller, R. N. Homan, and J. M. Reed. 2005. Variation in terrestrial habitat use by four pool breeding amphibian species. Journal of Wildlife Management:1481-1493.

Riitters, K. H., R. V. Oneill, C. T. Hunsaker, J. D. Wickham, D. H. Yankee, S. P. Timmins, K. B. Jones, and B. L. Jackson. 1995. A factor-analysis of landscape pattern and structure metrics. Landscape Ecology **10**:23-39.

Rodŕiguez, J. P., T. D. B. Jr., E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time and ecosystem services. Ecology and Society **11**:28-41.

Rothermel, B. B. 2004. Migratory success of juveniles: A potential constraint on connectivity for pond-breeding amphibians. Ecological Applications **14**:1535-1546.

Rothermel, B. B., and R. D. Semlitsch. 2002. An experimental investigation of landscape resistance of forest versus old-field habitats to emigrating juvenile amphibians. Conservation Biology **16**:1324-1332.

Royall, R. M. 1997. Statistical evidence: a likelihood paradigm. Chapman and Hall/CRC, New York, New York.

Ruibal, R. 1959. The ecology of a brackish water population of *Rana pipiens*. Copia **1959**:315-322.

Russell, G. D., C. P. Hawkins, and M. P. O'Neill. 1997. The role of GIS in selecting sites for riparian restoration based on hydrology and land use. Restoration Ecology **5**:56-68.

SAS. 2005. SAS 9.1.3 Help and Documentation. SAS Institute Inc., Cary, NC.

Schroeder, E. E. 1976. Dispersal and movement of newly transformed green frogs, *Rana clamitans*. American Midland Naturalist **95**:471-474.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology **15**:1113-1119.

Semlitsch, R. D. 2002. Critical elements for biologically based recovery plans of aquatic breeding amphibians. Conservation Biology **16**:619-629.

Semlitsch, R. D., and J. R. Bodie. 1998. Are small, isolated wetland expendable? Conservation Biology **12**:1129-1133.

Semlitsch, R. D., and J. R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology **17**:1219-1228.

Sharitz, R. R., and S. C. Pennings. 2006. Development of wetland plant communities. Pages 177-241 in D. P. Batzer, and R. R. Sharitz, editors. Ecology of freshwater and estuarine wetlands. University of California Press, Berkeley, CA.

Simberloff, D. 1976. Species turnover and equilibrium island biogeography. Science **194**:572-578.

Snodgrass, J. W., M. J. Komoroski, A. L. Bryan, and J. Burger. 2000. Relationships among isolated wetland size, hydroperiod and amphibian species richness: Implications for wetland regulations. Conservation Biology **14**:414-419.

Somerville, D. E., and B. A. Pruitt. 2006. United States wetland regulation and policy. Pages 313-347 in D. P. Batzer, and R. R. Sharitz, editors. Ecology of freshwater and estuarine wetlands. University of California Press, Berkley, CA.

SPSS. 1999. SPSS Base 11.0 for Windows User's Guide. SPSS, Inc, Chicago, IL.

Turner, M. G., R. H. Gardner, and R. V. O'Neill 2001. Landscape ecology in theory and practice: Pattern and process. Springer Science+Business Media, New York.

USCB. 2007. Topologically Integrated Geographic Encoding and Referencing System (TIGER). U.S. Census Bureau, Washington, D.C. {available online} http://www.census.gov/geo/www/tiger/index.html.

USDA. 1986. Technical Report 55, Urban Hydrology for Small Watersheds, 2nd Edition. Page 162. US Department of Agriculture, National Resources Conservation Services, Conservation Engineering Division, Washington, DC.

USDA. 2006. US General Soils Map (STATSGO) for Georgia. Soil Survey Staff, National Resources Conservation Service, US Department of Agriculture.

USEPA. 1989. Memorandum Between The Department of the Army and The Environmental Protection Agency: Federal Enforcement for the Section 404 Program of the Clean Water Act. United States Environmental Protection Agency, Washington, D.C. http://www.epa.gov/owow/wetlands/regs/enfmoa.html. [*Available Online*].

USEPA. 1998. Wetland biological and HGM functional assessments. EPA834-F-98-001f. United States Environmental Protection Agency, Office of Water, Office of Wetlands, Oceans and Watersheds (4502-f). Washington D.C.

USEPA. 2002. National Wetlands Mitigation Action Plan, http://www.mitigationactionplan.gov/map1226withsign.pdf. Page 12.

USEPA. 2003. Wetland Compensatory Mitigation. EPA-843-F-03-002. United States Environmental Protection Agency, Washington, D.C.

USEPA. 2004. Wetland Regulatory Authority. EPA843-F-04-001. United States Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA. 2006a. Economic Benefits of Wetlands. EPA843-F-06-004. United States Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA. 2006b. Mitigation Banking Factsheet: Compensating for Impacts to Wetlands and Streams. United States Environmental Protection Agency. http://www.ega.goc/cgi-bin/epaprintonly.cgi. [*Online Accessed 11/22/06*].

USGS. 2002. The National Hydrography Dataset. U.S. Department of Interior, United States Geological Survey, Lakewood, CO {available online} http://nhd.usgs.gov/chapter1/index.html#_Toc474479772.

van der Valk, A., and R. W. Jolly. 1992. Recommendations for Research to Develop Guidelines for the Use of Wetlands to Control Rural Nonpoint Source Pollution. Ecological Engineering **1**:115-134.

van der Valk, A. G., and R. L. Pederson. 2003. The SWANCC decision and its implications for prairie potholes. Wetlands **23**:590-596.

Wang, X. 2001. Integrating water-quality management and land-use planning in a watershed context. Journal of Environmental Management **61**:25-36.

Weller, C. M., M. C. Watzin, and D. Wang. 1996. Role of wetlands in reducing phosphorus loading to surface water in eight watersheds in the Lake Champlain basin. Environmental Management **20**:731-739.

Wharton, C. H. 1977. The natural environments of Georgia. Georgia Department of Natural Resources, Office of Planning and Research, Resource Planning Section, Atlanta, Ga.

White, D., and S. Fennessy. 2005. Modeling the suitability of wetland restoration potential at the watershed scale. Ecological Engineering **24**:359-377.

Wiens, J. A. 1997. The emerging role of patchiness in conservation biology. Pages 93-107 in S. T. A. Picketts, editor. The ecological basis of conservation: heterogeneity, ecosystems and biodiversity.

Wiens, J. A. 2001. The landscape context of dispersal in J. Clobert, E. Danchin, A. A. Dhondt, and J. D. Nichols, editors. Dispersal. Oxford University Press, Oxford, England.

Zedler, J. B. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. Frontiers in Ecology and the Environment **1**:65-72.

Zedler, J. B. 2004. Compensating for wetland losses in the United States. Ibis **146 (suppl. 1)**:92-100.

Zedler, J. B. 2006. Wetland restoration in D. P. Batzer, and R. R. Sharitz, editors. Ecology of freshwater and estuarine wetlands. University of California Press, Berkeley, CA.

Zimmerman, R. H. 2001. Wetlands and infectious diseases. Cad. Saúde Pública **17**:127-131.

APPENDIX A

LIST OF EQUATIONS

APPENDIX B

LIST OF ACRONYMS

AIC	Akaike's Information Criteria
AML	Arc Macro Language
AWSR	Average Weighted Species Richness
CEQ	Council on Environmental Quality
CN	Curve Number
CWA	Clean Water Act of 1972
DEM	Digital Elevation Model
DII	Distance to Impairment Index
FA	ArcINFO un-weighted flow accumulation model
FEMA	Federal Emergency Management Agency
FWCA	Fish and Wildlife Coordination Act
FWPCA	Federal Water Pollution Control Act
GA DNR	Georgia Department of Natural Resources
GA DOT	Georgia Department of Transportation
GA EPD	Georgia Environmental Protection Division
GA NHP	Georgia Natural Heritage Program
GIS	Geographical Information Systems
GLUT	Georgia Land Use Trends Database
HDI	Human Development Index

HQWI	High Quality Wetlands Index
HSG	Hydrologic Soils Group
HUC	Hydrologic Unit Codes
IFM	Incidence Function Model
ISC	Index of Spatial Configuration
KNN	K Nearest Neighbor
NARSAL	Natural Resources Spatial Analysis Laboratory
NEPA	National Environmental Policy Act
NHD	National Hydrography Dataset
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRDC	National Resources Defense Council
NWI	National Wetlands Inventory
NWMAP	National Wetlands Mitigation Action Plan
PWRS	Potential Wetland Restoration Site
RHA	Rivers and Harbors Act of 1899
RPI	Runoff Potential Index
SCS	Soil Conservation Service
STATSGO	United States General Soils Map for Georgia
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Division
USFWS	United States Fish and Wildlife Service

USGS	United States Geological Survey
WFA	ArcINFO weighted flow accumulation model
WQQI	Water Quality and Quantity Index

APPENDIX C

COMPUTER SCRIPTS USED TO DEVELOP THE POTENTIAL WETLAND RESTORATION SITE INDEX

MASKING LAYER AML

```
--------------------------------------------------------------------------------------------
This aml designates the masking layer that combines the landcover classes that are
   considered restorable in Layer 1.1 and the hydric soils in Layer 1.2 and the natural
   upland habitat identified by the Georgia Natural Heritage Department.

S:\GLUT_wetlands\wetland_model\amls\layer1_1.aml

Created 4/5/2007
          Stephen M. Carpenedo
          Natural Resources Spatial Analysis Laboratory
          Athens, GA 30606

  Criteria is that    1)  Landcover classes were wetlands in 1974
                      2)  Landcover classes are not, Low/ High intensity urban or barren
ground
                      3)  Open water of less than 5 acres
                      4)  STATSGO SOILS that are considered hydric

Input Files:
   .layer2 = This is the finished product of Layer 1.2 Hydric soils.  This must be
completed before Layer 1.1 can be run
   .out = This is the name and location of the output file

WORKSPACE:  S:\GLUT_wetlands\wetland_model\layer1_1\base_files.  All files
   generated are in the base_files folder.
 --------------------------------------------------------------------------------------------

&args .wrk .out .layer2
&severity &error &warning
&echo &on

cw %.wrk%
w %.wrk%

&sv glut74 = S:\GLUT_wetlands\wetland_model\Library\glut_1974
&sv glut05 = S:\GLUT_wetlands\wetland_model\Library\glut_2005
```

```
grid

setwindow S:\GLUT_wetlands\wetland_model\Library\mask
S:\GLUT_wetlands\wetland_model\Library\mask

/*  Extracts all wetlands from GLUT 1974 to develop a mask
wet74 = con((%glut74% eq 91 OR %glut74% eq 92 OR %glut74% eq 93), 1, 0)

/*  Removes land covers from GLUT 2005 that are considered not restorable
lcc05 = con(%glut05% eq 11 OR %glut05% eq 22 OR %glut05% eq 24 or %glut05% eq
34 OR %glut05% eq 91 OR %glut05% eq 92 OR %glut05% eq 93, 0, 1)

/*  Extracts all open water from 2005
water05 = con(%glut05% eq 11, 1)

/*  Groups open water for subsequent area calculations
wtrgrp = regiongroup(water05, #, eight, #, #, nolink)

/*  Calculates the area of each body of open water (sq. meters)
wtrarea = zonalarea(wtrgrp)

/*  Selects only bodies of water that are less than 5 acres in size and considers them
   restorable
wtr = con(wtrarea lt 20234.13, 1, 0)
wtr2 = con(isnull(wtr) eq 1,0,wtr)

/*  Selects only open water less than 5 acres that were wetlands in 1974
pot_water = con(wet74 gt 0, wtr2, 0)

/* Selects only landcovers that were wetlands in 1974 as potentially restorable
pot_lcc = con(wet74 gt 0, lcc05, 0)

/*  Combines potentially restorable landcovers and open water
temp_rest = con(pot_lcc gt 0, pot_lcc, pot_water)

/*  Sets the potentially restorable landcovers to 9, the 1 pixel buffer to 6 and the rest of
   the state to 1
%.out% = con(temp_rest eq 1, 9, con(lcc05 eq 0, 1, 6))

/*  Includes hydric soils to the restoration potential exclusion coverage
temp = con(%.out% eq 9, 9, con(%.layer2% eq 9, 9, %.out%))
kill %.out% all
rename temp %.out%

/*  Extracts natural upland vegetation identified by the Georgia DNR from the potential
   restorable areas and effectively gives them a value of ~66% of the other areas.
```

```
temp = con(S:\GLUT_wetlands\wetland_model\Library\nat_up_veg eq 1, 8, %.out%)
kill %.out% all
rename temp %.out%

q
&stop
```

MASKING ADDITIVE LAYERS AML

```
--------------------------------------------------------------------------------------
This AML is the masks each layer prior to reclassification using Jenks Optimization so
  that all areas either considered as non-restorable or "sub-optimal" reflect these values
  before the final ranking is completed..

S:\GLUT_wetlands\wetland_model\amls\non-classify_mask.aml

Created 8/14/2007
 Created by:  Stephen M. Carpenedo
              Natural Resources Spatial Analysis Laboratory
              Odum School of Ecology, University of Georgia
              Athens, GA
--------------------------------------------------------------------------------------
&args
&severity &error &fail
&echo &on

w S:\GLUT_wetlands\wetland_model\Final_layers

&sv p = [response 'Component One Layer Number' 0]
&sv low = [response 'Low Value' 0]

&sv in = s:\GLUT_wetlands\wetland_model\Final_layers\not_classified\layer1_%p%nc
&ty %in%

&sv out = s:\GLUT_wetlands\wetland_model\Final_layers\masked\layer1_%p%mask
&ty %out%

grid

setwindow S:\GLUT_wetlands\wetland_model\Library\mask
  S:\GLUT_wetlands\wetland_model\Library\mask

%out% = con(layer1_1 eq 9, %in%, con(layer1_1 eq 8, 0.89 * %in%, con(layer1_1 eq 6,
  0.66 * %in%, con(layer1_1 eq 1, %low%, 0))))

q
&stop
```

LAYER 1.4 WATER QUALITY AND QUANTITY AML

This AML is calculates the part of Layer 1.4 Water Quality and Quantity index. This AML is divided into two separate parts. Part One calculates the potential runoff entering an open water source from the landscape. This is done using flow accumulation models that are un-weighted and weighted by the Natural Resource Conservation Service's Runoff Curve Number Method. Part Two calculates the distance of a source pixel to open water.

Further processing is necessary to complete Layer 1.4, including, reclassifying the output of the Potential Runoff and Distance to impairment indices. Reclassification is done by hand in ArcGIS 9.3. The reclassified files are then multiplied to receive the final unclassified data layer. The final unclassified data layer is then masked using Masking Additive Layers AML, and then reclassified using Jenks Optimization to receive the final output of Layer 1.4

S:\GLUT_wetlands\wetland_model\amls\layer1_4.aml

Created 4/5/2007

Stephen M. Carpenedo and Kevin Samples
Natural Resources Spatial Analysis Laboratory
Institute of Ecology, University of Georgia
Athens, GA 30606

INPUT FILES: .wrk is the workspace
S:\GLUT_wetlands\wetland_model\layer1_4\base_files
glut_2005: the 2005 Georgia land Use Trends Database located at:
S:\GLUT_wetlands\wetland_model\Library\glut_2005
for this a copy is located in the workspace folder.
hydgrp: the hydrologic soils group map created using STATSGO Soils located at
S:\GLUT_wetlands\wetland_model\layer1_4\base_files\hydgrp
.huc is the raster image containing the 8 digit HUCs located at
S:\GLUT_wetlands\wetland_model\Library\huc8
.out is the for the distance to impairment index it is located at
S:\GLUT_wetlands\wetland_model\layer1_4\base_files\DII
ISOPLUVIAL MAPS: Map calculating the potential 2 year/24 hour storm event
is located at S:\GLUT_wetlands\wetland_model\Library\iso_map
FLOW CALCULATION: All flow length and open water sources are generated using
statewide NHD coverage, variables used are identified in the report
S:\GLUT_wetlands\wetland_model\Library\NHD_finalflow
MASK: located s:\dems\mask

WORKSPACE: Workspace for this aml is
S:\GLUT_wetlands\wetland_model\layer1_4\base_files
and all files generated are in the base_files folder.

```
----------------------------------------------------------------------------------------------

&args .wrk .huc .out
&severity &error &fail
&echo &on

w %.wrk%
grid
setwindow f:\l1_4\mask f:\l1_4\mask

/*  SET 1:  POTENTIAL RUNOFF INDEX
/*        Does not reclassify data, this is done by hand!
/*  Sets the curve number to calculate the RUNOFF POTENTIAL INDEX

cn = con((glut_2005 eq 24 OR glut_2005 eq 34), 98, con((glut_2005 eq 22 OR glut_2005
  eq  31 OR glut_2005 eq 7) && hydgrp eq 4, 77, con(glut_2005 eq 22 && hydgrp eq 1,
  85, con(glut_2005 eq 22 && hydgrp eq 2, 90, con(glut_2005 eq 22 && hydgrp eq 3,
  92, con((glut_2005 eq 7 OR glut_2005 eq 31) && hydgrp eq 1, 86, con((glut_2005 eq
  7 OR glut_2005 eq 31) && hydgrp eq 2, 91, con((glut_2005 eq 7 OR glut_2005 eq 31)
  && hydgrp eq 3, 94, con(glut_2005 eq 81 && hydgrp eq 4, 72, con(glut_2005 eq 81
  && hydgrp eq 1, 81, con(glut_2005 eq 81 && hydgrp eq 2, 88, con(glut_2005 eq 81
  && hydgrp eq 3, 91, con((glut_2005 eq 41 OR glut_2005 eq 42 OR glut_2005 eq 43)
  && hydgrp eq 4, 30, con((glut_2005 eq 41 OR glut_2005 eq 42 OR glut_2005 eq 43)
  && hydgrp eq 3, 77, con((glut_2005 eq 41 OR glut_2005 eq 42 OR glut_2005 eq 43)
  && hydgrp eq 2, 70, con((glut_2005 eq 41 OR glut_2005 eq 42 OR glut_2005 eq 43)
  && hydgrp eq 1, 55, 0))))))))))))))))

&sv i = 3.5
&sv j = %i%
&sv a = 1

/* uses the isopluvial map of Georgia to calculate runoff from individual pixels as a result
  of the 2 year/24 hour storm totals

&do &while %i% lt 5.5
  cn_%a% = con(S:\GLUT_wetlands\wetland_model\Library\iso_map eq %i%, cn, 0)

  Q_%a% = con(cn_%a% eq 0, 0, pow((%i% - 0.2 * ((1000 / cn_%a%) - 10)), 2) / (%i%
  + 0.8 * ((1000 / cn_%a%) - 10)))

  &sv i = %i% + 0.5
  &sv a = %a% + 1

&end

/* Create Statewide runoff for each landcover
```

```
Q = Q_1 + Q_2 + Q_3 + Q_4

/*  Calculates the Runoff Potential Index using weighted and unweighted flow
   accumulation models.  The weighting factor comes from Q identified in the previous
   step

flow_unwght2 = flowaccumulation(f:\l1_4\flow_dir,
   S:\GLUT_wetlands\wetland_model\Library\iso_map)
flow_weighted = flowaccumulation(f:\l1_4\flow_dir, Q)

RPI = ((flow_unwght2 + 1) - (flow_weighted + 1)) / (flow_unwght2 + 1)

/* SET 2: Distance to Impairment Index
/*        Does  not reclassify data, this is done by hand

&describe %.huc%
&sv h = 71
&sv z = 71

flowlen = flowlength(f:\l1_4\flow_dir, #, downstream)

&do &while %h% gt 70

   huc_%h% = con(%.huc% eq %h%, 1)
   ws_rsmpl = resample(huc_%h%, 1000)

   &call swindow

   huc = huc_%h%
   kill huc_%h%
   rename huc huc_%h%

   dem_%h% = con(huc_%h% gt 0, f:\l1_4\ned_u17)
   flow_%h% = con(huc_%h% gt 0, f:\l1_4\nhd)
   flowacc_%h% = con(huc_%h% gt 0, f:\l1_4\flowacc)
   flowdir_%h% = con(huc_%h% gt 0, f:\l1_4\flow_dir)

   impnd = setnull(flow_%h% eq 0, flow_%h%)
   implen = con(huc_%h% gt 0 && impnd gt 0, flowlen)
   cost = costallocation(int(implen),con(dem_%h% lt 0,0,dem_%h%), #, #, #, #)

   &if %z% eq %h% &then
         &do
         %.out% = con(huc_%h% gt 0, abs(int(flowlen) - cost),0)
         &end
```

```
  &else
        &do

        reset
        &sv out = %.out%
        temp = con(huc_%h% gt 0, abs(int(flowlen) - cost),0)
        temp2 = con(isnull(temp) eq 1, 0, temp)
        output = con(isnull(%.out%) eq 1, 0, %.out%)
        disttemp = temp2 + output
        kill temp all
        kill temp2 all
        kill output all
        kill %.out% all
        rename disttemp DII_87
        &end

  /*  Kills all files
  kill huc_%h% all
  kill dem_%h% all
  kill flow_%h% all
  kill flowacc_%h% all
  kill flowdir_%h% all
  kill implen all
  kill cost all
  kill ws_rsmpl all
  kill impnd all

  &sv h = %h% - 1
  reset

&end
q
&stop

/*  This section sets the window to a smaller size to increase data processing speed

&routine swindow
  &sv minx = 0
  &sv maxx = 0
  &sv miny = 0
  &sv maxy = 0

  patch = con(ws_rsmpl gt 0,1)

  &label wredo
```

```
  resample.%h% = sample(patch,patch)
  &sv fileunit = [open resample.%h% openstatus -read]
  &sv xy = [read %fileunit% readstatus]
  &sv xy = [subst [read %fileunit% readstatus] '       ' ,]
  &do &while %readstatus% = 0
        &do
        &sv x = [extract 2 %xy%]

        &if %minx% eq 0 &then &sv minx = %x%
                &else &if %x% lt %minx% &then &sv minx = %x%
        &if %maxx% eq 0 &then &sv maxx = %x%
                &else &if %x% gt %maxx% &then &sv maxx = %x%

        &sv y = [extract 3 %xy%]

        &if %miny% eq 0 &then &sv miny = %y%
                &else &if %y% lt %miny% &then &sv miny = %y%
        &if %maxy% eq 0 &then &sv maxy = %y%
                &else &if %y% gt %maxy% &then &sv maxy = %y%

        &sv xy = [subst [read %fileunit% readstatus] '         ' ,]
        &end
  &end

  &if [close %fileunit%] eq 0 &then &type file closed
  &sys del /f /q resample.%h%

  &if %maxx% gt 0 &then &do
        &sv minx = %minx% - 4500
        &sv maxx = %maxx% + 4500
        &sv miny = %miny% - 4500
        &sv maxy = %maxy% + 4500
        setwindow %minx% %miny% %maxx% %maxy% f:\l1_4\mask
  &end

  &else &do
        setwindow f:\l1_4\mask f:\l1_4\mask
        kill patch all
        patch = con(huc_%h% gt 0,1)
        &goto wredo
  &end

  &sv killgrid patch
  kill patch all

&return
```

LAYER 1.5: CONNECTIVITY TO EXISTING CONSERVATION AREAS AML

```
-----------------------------------------------------------------------------------------
This AML tests where a potential restoration sites would have high connectivity to
  existing conservation areas.  This is the first step and produces a non-classified data
  layer.  The non-classified data layer is then masked using the Masking Additive Layer
  AML and reclassified by hand using Jenks Optimization in ArcGIS 9.3 to receive the
  final output of Layer 1.5.

S:\GLUT_wetlands\wetland_model\amls\Layer1.5.aml

 Created by: Stephen M. Carpenedo and Kevin Samples
        Natural Resources Spatial Analysis Laboratory
        Institute of Ecology, University of Georgia
        Athens, GA  30606
Input Layers:
  .wrkspc = the workspace where the necessary files are located.
S:\GLUT_wetlands\wetland_model\layer1_5\base_files
  .mr  = conservation areas database.  It is located in the workspace folder
-----------------------------------------------------------------------------------------

&args .wrkspc .mr
&severity &error &routine cleanup
&echo &on

w %.wrkspc%

grid

/*  This removes any zeros, groups the conservation areas using eight directions and then
  calculates the area in square meters
ca_rcls = setnull(%.mr% eq 0, 1)
ca_rgrp = regiongroup(ca_rcls, #, EIGHT, WITHIN, #, NOLINK)
ca_zarea = zonalarea(ca_rgrp)

/*  resamples the conservation areas to that setting the window to a buffered extent is
  quicker
group2k = resample(ca_rgrp,2000)
group1k = resample(ca_rgrp,1000)
group500 = resample(ca_rgrp,500)
group250 = resample(ca_rgrp,250)

q

&describe ca_rgrp
&sv z = %grd$zmax%
```

```
&sv x = %grd$zmax%

grid
setwindow mask mask
&sys rm -rf resample.*
&label redo
&do &while %x% gt 0

  &sv group = group2k
  &call swindow

  areatest = con(ca_rgrp eq %x%, ca_zarea)
  alloc = eucallocation(int(areatest),dist,#,4800)

  &if %z% eq %x% &then
        &do
        temp = (exp(-.002 * dist)) * (pow(alloc, 0.23))
        output = con(isnull(temp) eq 1, 0, temp)
        kill temp all
        &end
  &else
        &do
        temp = (exp(-.002 * dist)) * (pow(alloc, 0.23))
        reset
        outputtemp = con(isnull(temp) eq 1, 0, temp) + con(isnull(output) eq 1, 0, output)
        kill temp all
        kill output all
        rename outputtemp output
        &end

  kill areatest all
  kill dist all
  kill alloc all

  &if [mod %x% 20] eq 0 &then &do
        q
        &pause &seconds 5
        grid
  &end

  &sv x = %x% - 1

  &sv xminx = %minx% - 100000
  &sv xmaxx = %maxx% + 100000
  &sv xminy = %miny% - 100000
  &sv xmaxy = %maxy% + 100000
```

```
  reset
&end

&type loop exited

/*  The following commands marked as /* were not run in the AML because sections of
the state were split and run on separate computers to decrease the processing time.  This
step is accomplished using the Combining Connectivity Grids AML.

&if %x% eq 0 &then &do
  &type Begin Calculation
  /* rankave = rank / num
  /* ca_temp = rankave * output
  /* &sv killgrid output
  /* kill output all
  /* &sv killgrid rank
  /* kill rank all
  /* &sv killgrid num
  /* kill num all
  /* &sv killgrid rankave
  /* kill rankave all
  &end
&else
  &goto redo
&end

q
&stop

/*  Routine cleanup was added to because AML crashed due to file conflicts.  Artifact of
  ArcINFO.  This does nothing except reset the memory and prevent the AML from
  crashing
&routine cleanup

  &type cleanup kill
  q
  &pause &seconds 5
  &sys rm -rf %killgrid%
  grid

&return

/*  This step reduces the window size so that calculations in the first section run quicker.

&routine swindow
```

```
&sv iter = 0
&label wredo

&sv minx = 0
&sv maxx = 0
&sv miny = 0
&sv maxy = 0

patch = con(%group% eq %x%, 1)

resample.%x% = sample(patch, patch)
&sv fileunit = [open resample.%x% openstatus -read]
&sv xy = [read %fileunit% readstatus]
&sv xy = [read %fileunit% readstatus]
&do &while %readstatus% = 0
	&do
	&sv xline = [trim [substr %xy% 3 15] -both ' ']
	&if %minx% eq 0 &then &sv minx = %xline%
		&else &if %xline% lt %minx% &then &sv minx = %xline%
	&if %maxx% eq 0 &then &sv maxx = %xline%
		&else &if %xline% gt %maxx% &then &sv maxx = %xline%
	&sv y = [trim [substr %xy% 19 15] -both ' ']
	&if %miny% eq 0 &then &sv miny = %y%
		&else &if %y% lt %miny% &then &sv miny = %y%
	&if %maxy% eq 0 &then &sv maxy = %y%
		&else &if %y% gt %maxy% &then &sv maxy = %y%

	&sv xy = [read %fileunit% readstatus]
	&end
&end

&if [close %fileunit%] eq 0 &then &type file closed
&sys rm -rf resample.%x%

&if %maxx% eq 0 &then &do

	&if %iter% eq 0 &then &sv group = group1k
	&if %iter% eq 1 &then &sv group = group500
	&if %iter% eq 2 &then &sv group = group250
	&if %iter% eq 3 &then &do
		setwindow %xminx% %xminy% %xmaxx% %xmaxy% mask
		&sv group = ca_rgrp
	&end
	&if %iter% eq 4 &then &do
		setwindow mask mask
		&sv group = ca_rgrp
```

```
        &end

        &sv killgrid patch
        kill patch all
        &sv iter = %iter% + 1
        &goto wredo
  &end

  &else &do
  &sv minx = %minx% - 12000
  &sv maxx = %maxx% + 12000
  &sv miny = %miny% - 12000
  &sv maxy = %maxy% + 12000

  &sv killgrid patch
  kill patch all

  setwindow %minx% %miny% %maxx% %maxy% mask
  &end
&return
```

LAYER 1.6 TERRESTRIAL DISPERSAL CORRIDORS BETWEEN WETLANDS – HABITAT RESISTANCE AML

```
 -----------------------------------------------------------------------
```

This AML is used to create the habitat resistance grid for Layer 1.6. Resistance values are taken from three separate papers that are referenced in the comments above each section. 12 of the 13 GLUT land covers are used to create the resistance grid. Saltwater/Brackish marsh is the only landcover that does not have a section to recode the resistance grid; this is because it was determined through personal communication that its initial identification value in GLUT of 92 is an adequate representation of the resistance of saltwater/brackish marsh to amphibian dispersal.

There is one initial prep file that needs to be created. This is converting the working copy of the GLUT 18 class landcover to a grid file named GLUT_working

S:\GLUT_wetlands\wetland_model\amls\l1_7_resistance_grid.aml

Created: 8/8/2007

Stephen M. Carpenedo
Natural Resources Spatial Analysis Laboratory
Odum School of Ecology, University of Georgia
Athens, GA 30606

INPUT FILES:

   .wrk = the workspace where the necessary files are located
S:\GLUT_wetlands\wetland_model\layer1_7\base_files\resistance_grid
   .glut = S:\GLUT_wetlands\wetland_model\Library\glut_2005
   .road = This is all of the TIGER roads converted to a grid and reclassified
   so that Interstates = 4, US Highways = 3, State Highways = 2 and Local roads = 3.
S:\GLUT_wetlands\wetland_model\layer1_7\base_files\resistance_grid\roads

  OUTPUT FILE:
   S:\GLUT_wetlands\wetland_model\layer1_7\base_files\resistance_grid\resist_l1_7 (not clipped to state boundary)

   S:\GLUT_wetlands\wetland_model\layer1_7\base_files\resistance_grid\resist_grid (clipped to state boundary and should be used in layer1_7.aml)

```
&args .wrk .glut .road
&severity &error &fail
&echo &on

w %.wrk%

grid

setwindow mask mask

/*  Creates Float of Landcover map
   resist_L1_7 = float(%.glut%)

/*  Creates Stream order of NHD and resistance grid of all streams.  Are values are taken
from Compton et al. 2007.  For the Compton paper their max value was 44, values have
been modified as a % of their max value to reflect what  they would be given a maximum
value of 100.
nhd_strmorder = streamorder(S:\GLUT_wetlands\wetland_model\Library\flow_acc250,
s:\dems\flow_dir, strahler)
   temp_strmord = con(isnull(nhd_strmorder) eq 1, 0, nhd_strmorder)
   kill nhd_strmorder all
   rename temp_strmord nhd_strmorder
   nhd_resist = con(nhd_strmorder eq 1, 3, con(nhd_strmorder eq 2, 6.4,
con(nhd_strmorder eq 3, 28.6, con(nhd_strmorder ge 4, 75.0,0))))
   temp = con(nhd_resist gt 1, nhd_resist, resist_l1_7)
   kill resist_l1_7 all
   rename temp resist_l1_7

/*  Creates Pond resistance grid.  Any glut landcover class 11 lt 1 acre in size is
considered a vernal pool (Compton et al. 2007) and given a value of 2.3.  Between 1 and
5 acres it is considered as a pond/lake according  to Compton et al 2007 and given a value
```

of 50. Greater or equal to 5 acres is considered as an absolute barrier according to Joly et al. 2003 and given a value of 100.

```
ponds = con(%.glut% eq 11, 1)
pond_group = regiongroup(ponds,#,EIGHT,WITHIN,#,NOLINK)
pond_area = zonalarea(pond_group)
pond_resist = con(pond_area lt 4046.8, 2.3, con(pond_area ge 4046.8 AND pond_area lt 20234.13, 50, con(pond_area ge 20234.13, 100, 0)))
temp_pond = con(isnull(pond_resist) eq 1, 0, pond_resist)
kill pond_resist all
rename temp_pond pond_resist
temp = con(pond_resist gt 0, pond_resist, resist_l1_7)
kill resist_l1_7 all
rename temp resist_l1_7
```

/* Creates Road resistance grid. Values for resistance come from Compton et al. 2007. For road type 1 (minor street) = 16.4 for road type 2 (major road) = 37.3, for road type 3 (major hwy) = 74.1, for road type 4 (interstate) = 88.6. The other step creates the resistance grid for urban classifications GLUT 22 = 59.1 (Compton et al. 2007) GLUT 24 = 80 (Joly et al. 2003). This is setup so that a pixel will always receive the highest of the two classifications is they occur in the same area.

```
road_resist = con(%.road% eq 1, 16.4, con(%.road% eq 2, 37.3, con(%.road% eq 3, 74.1, con(%.road% eq 4, 88.6, 0))))
temp_road = con(isnull(road_resist) eq 1, 0, road_resist)
kill road_resist all
rename temp_road road_resist
temp_glut = con(%.glut% eq 22, 59.1, con(%.glut% eq 24, 80, resist_l1_7))
kill resist_l1_7 all
rename temp_glut resist_l1_7
temp = con((road_resist eq 16.4 and resist_l1_7 ne 59.1 and resist_l1_7 ne 80), road_resist, con((road_resist eq 37.3 and resist_l1_7 ne 59.1 and resist_l1_7 ne 80), road_resist, con((road_resist eq 74.1 and resist_l1_7 ne 80), road_resist, con(road_resist eq 88.6, road_resist, resist_l1_7))))
kill resist_l1_7 all
rename temp resist_l1_7
```

/* Creates a resistance grid for forest covers. All pixels that are classified as 41, 42, or 43 and are adjacent to GLUT landcovers classified as Low Intensity urban (22), High intensity urban (24), barren ground (34), AG (81) or clearcut (31) and all roads will be considered as a 30 meter forest edge. These are given a higher resistance value based on literature from deMaynadier and Hunter, 1999 and Gibbs, 1998. All pixels that are classified as 41, 42, or 43 and are adjacent to these land covers will be given a resistance value that is 70% of the forest resistance value added to itself, Gibbs, 1998, Joly et al 2003, Compton et al 2007. For example Forest resistance = 5 Forest Edge resistance = (5*0.7) +5 = 8.5. All edges are the same and given the highest value of 8.5

```
glut_open = con(%.glut% eq 22 or %.glut% eq 24 or %.glut% eq 31 or %.glut% eq 81 or %.glut% eq 34, 1, 0)
```

```
  open = con(road_resist ge 1 OR glut_open eq 1, 1, 0)
  temp_open = expand(open, 1, LIST, 1)
  temp = con(isnull(temp_open) eq 1, 0, temp_open)
  kill temp_open all
  rename temp temp_open
  temp = con((resist_l1_7 eq 41 and temp_open eq 1) OR (resist_l1_7 eq 42 and
temp_open eq 1) OR (resist_l1_7 eq 43 and temp_open eq 1) or (resist_l1_7 eq 91 and
temp_open eq 1), 8.5, resist_l1_7)
  kill resist_l1_7 all
  rename temp resist_l1_7

/*  For all remaining forests creates the resistance for Forest Cover 41, 42, 43, and 91
  temp = con(resist_l1_7 eq 41 or resist_l1_7 eq 42 or resist_l1_7 eq 43 or resist_l1_7 eq
91, 2.3, resist_l1_7)
  kill resist_l1_7 all
  rename temp resist_l1_7

/*  Recodes the resist_l1_7 for all agriculture types, the working copy of glut is used so
that agriculture can be split into pasture (80) and row crops (83).  GLUT_ag is used so
that agriculture could be split into two classes and so that there is no conflict with
resistance values = 80 created earlier for high intensity urban.
  temp = con(glut_ag eq 83, 45, con(glut_ag eq 80, 20.9, resist_l1_7))
  kill resist_l1_7 all
  rename temp resist_l1_7

/*  This cleans up slivers in the database cause by the different sampling of the statistics
and working copies of GLUT databases.  Upon visual inspection all of the slivers were
associated with glut_ag with a value of 83 therefore all remaining ag (81) is considered as
row crops and given a resistance value of 45.
  temp = con(resist_l1_7 eq 81, 45, resist_l1_7)
  kill resist_l1_7 all
  rename temp resist_l1_7

/*  Recodes resist_l1_7 for all clearcuts (31) and barren ground (34) .  Barren ground is
classified the same as a row crop while clearcuts are given a layer resistance value.  This
is an average of two surrogate values derived from Rothermel and Semlitsch ~50%
resistance; and Patrick et al 2006 (showed min 77% of Juveniles avoided clearcuts).
  temp = con(resist_l1_7 eq 31, 63.5, con(resist_l1_7 eq 34, 80, resist_l1_7))
  kill resist_l1_7 all
  rename temp resist_l1_7

/*  Recodes resist_l1_7 for beaches and sand bars.  It is classified the same as pebble beds
in Joly et al. 2003 (45).
  temp = con(resist_l1_7 eq 7, 45, resist_l1_7)
  kill resist_l1_7 all
  rename temp resist_l1_7
```

```
/*  Recodes resist_l1_7 for emergent freshwater marshes.  It is classified as Emergent
Marsh from Compton et al. 2007 (6.8).
  temp = con(resist_l1_7 eq 93, 6.8, resist_l1_7)
  kill resist_l1_7 all
  rename temp resist_l1_7

/*  Clips resist_l1_7 to state boundary.
  setwindow mask mask
  resist_grid = con(S:\GLUT_wetlands\wetland_model\Library\glut_2005 ge 1,
resist_l1_7)

q
&stop
```

LAYER 1.6: TERRESRTIAL DISPERSAL CORRIDORS BETWEEN WETLANDS – CONNECTIVITY AML

Calculates the connectivity of AWSR natural wetland vegetation patches based on the resistance of the habitat surrounding each patch.

Due to the large numbers of patches and the amount of time necessary to process natural wetland vegetation patches the complete AWSR must be put into python script S:\GLUT_wetlands\wetland_model\amls\ split_raster_by_num_attributes.py. This will divide the state so that there are an equal number of patches per file. These then need to be reclassified with nodata given a value of 1 and all non restorable lands reclassified to a value of 1. After all separate files have completed Layer 1.6: Terrestrial Dispersal Corridors between Wetlands – Add AWSR AML is used to combine all files and create a final non-classified layer. The non-classified layer is then processed using Masking Additive Layer AML and reclassified using Jenks Optimization.

S:\GLUT_wetlands\wetland_model\amls\layer1_7.aml

*Note: The original number given to this Layer was 1.7. After removal on a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.7.

Created June 2nd,2006

Created by: Stephen M. Carpenedo and Kevin Samples
Natural Resources Spatial Analysis Laboratory
Odum School of Ecology, University of Georgia
Athens, GA

INPUT FILES:

.wrkspc = the workspace where the necessary files are located.

.mr = the average weighted species richness model that has been divided into manageable files.
.rest = the resistance grid created in Layer 1.6 Terrestrial Dispersal Corridors between Wetlands – Habitat Resistance AML
.num = AWSR file number created when splitting the data into manageable files using S:\GLUT_wetlands\wetland_model\amls\ split_raster_by_num_attributes.py.

```
&args .wrkspc .mr .rest .num
&severity &error &routine cleanup
&echo &on

w %.wrkspc%

grid

aw_rcls = setnull(%.mr% eq 0,1)
aw_rgrp = regiongroup(aw_rcls,#,EIGHT,WITHIN,#,NOLINK)
aw_zarea = zonalarea(aw_rgrp)

group1k = resample(aw_rgrp,1000)
group500 = resample(aw_rgrp,500)
group250 = resample(aw_rgrp,250)

q

&describe aw_rgrp

&sv z = %grd$zmax%
&sv x = %grd$zmax%
&sv p = 0
&sv q = 0
&sv r = 0
&sv s = 0
&sv t = 0

grid
setwindow mask mask
&sys del /f /q resample.*

&label redo

&do &while %x% gt 0

  &sv group = group1k
  &call swindow
  &sv p = %p% + 1
```

/* the maximum distance (3168 m) is set at 66% of the maximum reported juvenile dispersal distance of R. Clamitans (Schroeder 1976).

```
   ranktest = con(aw_rgrp eq %x%,%.mr%)
   areatest = con(aw_rgrp eq %x%,aw_zarea)
   numtest = con(aw_rgrp eq %x%,1)
   b%p% = eucallocation(int(ranktest),#,#,3168)
   dist = costdistance(numtest, %.rest%, #, #, 3168, #)
   area_al = eucallocation(int(areatest),#,#,3168)
   c%p% = eucallocation(int(numtest),#,#,3168)
   a%p% = (exp(-.002 * dist)) * (pow(area_al,0.23))

   &if %p% eq 33 &then
          &do
          &sv q = %q% + 1
          reset
```

```
d%q% = con(isnull(a33) eq 1,0,a33) + con(isnull(a32) eq 1,0,a32) + con(isnull(a31) eq
1,0,a31) + con(isnull(a30) eq 1,0,a30) + con(isnull(a29) eq 1,0,a29) + con(isnull(a28) eq
1,0,a28) + con(isnull(a27) eq 1,0,a27) + con(isnull(a26) eq 1,0,a26) + con(isnull(a25) eq
1,0,a25) + con(isnull(a24) eq 1,0,a24) + con(isnull(a23) eq 1,0,a23) + con(isnull(a22) eq
1,0,a22) + con(isnull(a21) eq 1,0,a21) + con(isnull(a20) eq 1,0,a20) + con(isnull(a19) eq
1,0,a19) + con(isnull(a18) eq 1,0,a18) + con(isnull(a17) eq 1,0,a17) + con(isnull(a16) eq
1,0,a16) + con(isnull(a15) eq 1,0,a15) + con(isnull(a14) eq 1,0,a14) + con(isnull(a13) eq
1,0,a13) + con(isnull(a12) eq 1,0,a12) + con(isnull(a11) eq 1,0,a11) + con(isnull(a10) eq
1,0,a10) + con(isnull(a9) eq 1,0,a9) + con(isnull(a8) eq 1,0,a8) + con(isnull(a7) eq 1,0,a7)
+ con(isnull(a6) eq 1,0,a6) + con(isnull(a5) eq 1,0,a5) + con(isnull(a4) eq 1,0,a4) +
con(isnull(a3) eq 1,0,a3) + con(isnull(a2) eq 1,0,a2) + con(isnull(a1) eq 1,0,a1)

e%q% = con(isnull(b33) eq 1,0,b33) + con(isnull(b32) eq 1,0,b32) + con(isnull(b31) eq
1,0,b31) + con(isnull(b30) eq 1,0,b30) + con(isnull(b29) eq 1,0,b29) + con(isnull(b28) eq
1,0,b28) + con(isnull(b27) eq 1,0,b27) + con(isnull(b26) eq 1,0,b26) + con(isnull(b25) eq
1,0,b25) + con(isnull(b24) eq 1,0,b24) + con(isnull(b23) eq 1,0,b23) + con(isnull(b22) eq
1,0,b22) + con(isnull(b21) eq 1,0,b21) + con(isnull(b20) eq 1,0,b20) + con(isnull(b19) eq
1,0,b19) + con(isnull(b18) eq 1,0,b18) + con(isnull(b17) eq 1,0,b17) + con(isnull(b16) eq
1,0,b16) + con(isnull(b15) eq 1,0,b15) + con(isnull(b14) eq 1,0,b14) + con(isnull(b13) eq
1,0,b13) + con(isnull(b12) eq 1,0,b12) + con(isnull(b11) eq 1,0,b11) + con(isnull(b10) eq
1,0,b10) + con(isnull(b9) eq 1,0,b9) + con(isnull(b8) eq 1,0,b8) + con(isnull(b7) eq
1,0,b7) + con(isnull(b6) eq 1,0,b6) + con(isnull(b5) eq 1,0,b5) + con(isnull(b4) eq 1,0,b4)
+ con(isnull(b3) eq 1,0,b3) + con(isnull(b2) eq 1,0,b2) + con(isnull(b1) eq 1,0,b1)

f%q% = con(isnull(c33) eq 1,0,c33) + con(isnull(c32) eq 1,0,c32) + con(isnull(c31) eq
1,0,c31) + con(isnull(c30) eq 1,0,c30) + con(isnull(c29) eq 1,0,c29) + con(isnull(c28) eq
1,0,c28) + con(isnull(c27) eq 1,0,c27) + con(isnull(c26) eq 1,0,c26) + con(isnull(c25) eq
1,0,c25) + con(isnull(c24) eq 1,0,c24) + con(isnull(c23) eq 1,0,c23) + con(isnull(c22) eq
```

```
1,0,c22) + con(isnull(c21) eq 1,0,c21) + con(isnull(c20) eq 1,0,c20) + con(isnull(c19) eq
1,0,c19) + con(isnull(c18) eq 1,0,c18) + con(isnull(c17) eq 1,0,c17) + con(isnull(c16) eq
1,0,c16) + con(isnull(c15) eq 1,0,c15) + con(isnull(c14) eq 1,0,c14) + con(isnull(c13) eq
1,0,c13) + con(isnull(c12) eq 1,0,c12) + con(isnull(c11) eq 1,0,c11) + con(isnull(c10) eq
1,0,c10) + con(isnull(c9) eq 1,0,c9) + con(isnull(c8) eq 1,0,c8) + con(isnull(c7) eq 1,0,c7)
+ con(isnull(c6) eq 1,0,c6) + con(isnull(c5) eq 1,0,c5) + con(isnull(c4) eq 1,0,c4) +
con(isnull(c3) eq 1,0,c3) + con(isnull(c2) eq 1,0,c2) + con(isnull(c1) eq 1,0,c1)
        &do &while %p% ge 1
                &sv killgrid c%p%
                kill c%p% all
                &sv killgrid b%p%
                kill b%p% all
                &sv killgrid a%p%
                kill a%p% all
                &sv p = %p% - 1
        &end
  &end

  &if %q% eq 33 &then
        &do
        &sv r = %r% + 1
        reset

g%r% = con(isnull(d33) eq 1,0,d33) + con(isnull(d32) eq 1,0,d32) + con(isnull(d31) eq
1,0,d31) + con(isnull(d30) eq 1,0,d30) + con(isnull(d29) eq 1,0,d29) + con(isnull(d28) eq
1,0,d28) + con(isnull(d27) eq 1,0,d27) + con(isnull(d26) eq 1,0,d26) + con(isnull(d25) eq
1,0,d25) + con(isnull(d24) eq 1,0,d24) + con(isnull(d23) eq 1,0,d23) + con(isnull(d22) eq
1,0,d22) + con(isnull(d21) eq 1,0,d21) + con(isnull(d20) eq 1,0,d20) + con(isnull(d19) eq
1,0,d19) + con(isnull(d18) eq 1,0,d18) + con(isnull(d17) eq 1,0,d17) + con(isnull(d16) eq
1,0,d16) + con(isnull(d15) eq 1,0,d15) + con(isnull(d14) eq 1,0,d14) + con(isnull(d13) eq
1,0,d13) + con(isnull(d12) eq 1,0,d12) + con(isnull(d11) eq 1,0,d11) + con(isnull(d10) eq
1,0,d10) + con(isnull(d9) eq 1,0,d9) + con(isnull(d8) eq 1,0,d8) + con(isnull(d7) eq
1,0,d7) + con(isnull(d6) eq 1,0,d6) + con(isnull(d5) eq 1,0,d5) + con(isnull(d4) eq 1,0,d4)
+ con(isnull(d3) eq 1,0,d3) + con(isnull(d2) eq 1,0,d2) + con(isnull(d1) eq 1,0,d1)

h%r% = con(isnull(e33) eq 1,0,e33) + con(isnull(e32) eq 1,0,e32) + con(isnull(e31) eq
1,0,e31) + con(isnull(e30) eq 1,0,e30) + con(isnull(e29) eq 1,0,e29) + con(isnull(e28) eq
1,0,e28) + con(isnull(e27) eq 1,0,e27) + con(isnull(e26) eq 1,0,e26) + con(isnull(e25) eq
1,0,e25) + con(isnull(e24) eq 1,0,e24) + con(isnull(e23) eq 1,0,e23) + con(isnull(e22) eq
1,0,e22) + con(isnull(e21) eq 1,0,e21) + con(isnull(e20) eq 1,0,e20) + con(isnull(e19) eq
1,0,e19) + con(isnull(e18) eq 1,0,e18) + con(isnull(e17) eq 1,0,e17) + con(isnull(e16) eq
1,0,e16) + con(isnull(e15) eq 1,0,e15) + con(isnull(e14) eq 1,0,e14) + con(isnull(e13) eq
1,0,e13) + con(isnull(e12) eq 1,0,e12) + con(isnull(e11) eq 1,0,e11) + con(isnull(e10) eq
1,0,e10) + con(isnull(e9) eq 1,0,e9) + con(isnull(e8) eq 1,0,e8) + con(isnull(e7) eq 1,0,e7)
+ con(isnull(e6) eq 1,0,e6) + con(isnull(e5) eq 1,0,e5) + con(isnull(e4) eq 1,0,e4) +
con(isnull(e3) eq 1,0,e3) + con(isnull(e2) eq 1,0,e2) + con(isnull(e1) eq 1,0,e1)
```

```
i%r% = con(isnull(f33) eq 1,0,f33) + con(isnull(f32) eq 1,0,f32) + con(isnull(f31) eq
1,0,f31) + con(isnull(f30) eq 1,0,f30) + con(isnull(f29) eq 1,0,f29) + con(isnull(f28) eq
1,0,f28) + con(isnull(f27) eq 1,0,f27) + con(isnull(f26) eq 1,0,f26) + con(isnull(f25) eq
1,0,f25) + con(isnull(f24) eq 1,0,f24) + con(isnull(f23) eq 1,0,f23) + con(isnull(f22) eq
1,0,f22) + con(isnull(f21) eq 1,0,f21) + con(isnull(f20) eq 1,0,f20) + con(isnull(f19) eq
1,0,f19) + con(isnull(f18) eq 1,0,f18) + con(isnull(f17) eq 1,0,f17) + con(isnull(f16) eq
1,0,f16) + con(isnull(f15) eq 1,0,f15) + con(isnull(f14) eq 1,0,f14) + con(isnull(f13) eq
1,0,f13) + con(isnull(f12) eq 1,0,f12) + con(isnull(f11) eq 1,0,f11) + con(isnull(f10) eq
1,0,f10) + con(isnull(f9) eq 1,0,f9) + con(isnull(f8) eq 1,0,f8) + con(isnull(f7) eq 1,0,f7) +
con(isnull(f6) eq 1,0,f6) + con(isnull(f5) eq 1,0,f5) + con(isnull(f4) eq 1,0,f4) +
con(isnull(f3) eq 1,0,f3) + con(isnull(f2) eq 1,0,f2) + con(isnull(f1) eq 1,0,f1)
        &do &while %q% ge 1
                &sv killgrid f%q%
                kill f%q% all
                &sv killgrid e%q%
                kill e%q% all
                &sv killgrid d%q%
                kill d%q% all
                &sv q = %q% - 1
        &end
  &end
  &if %r% eq 33 &then
        &do
        &sv s = %s% + 1
        reset

j%s% = con(isnull(g33) eq 1,0,g33) + con(isnull(g32) eq 1,0,g32) + con(isnull(g31) eq
1,0,g31) + con(isnull(g30) eq 1,0,g30) + con(isnull(g29) eq 1,0,g29) + con(isnull(g28) eq
1,0,g28) + con(isnull(g27) eq 1,0,g27) + con(isnull(g26) eq 1,0,g26) + con(isnull(g25) eq
1,0,g25) + con(isnull(g24) eq 1,0,g24) + con(isnull(g23) eq 1,0,g23) + con(isnull(g22) eq
1,0,g22) + con(isnull(g21) eq 1,0,g21) + con(isnull(g20) eq 1,0,g20) + con(isnull(g19) eq
1,0,g19) + con(isnull(g18) eq 1,0,g18) + con(isnull(g17) eq 1,0,g17) + con(isnull(g16) eq
1,0,g16) + con(isnull(g15) eq 1,0,g15) + con(isnull(g14) eq 1,0,g14) + con(isnull(g13) eq
1,0,g13) + con(isnull(g12) eq 1,0,g12) + con(isnull(g11) eq 1,0,g11) + con(isnull(g10) eq
1,0,g10) + con(isnull(g9) eq 1,0,g9) + con(isnull(g8) eq 1,0,g8) + con(isnull(g7) eq
1,0,g7) + con(isnull(g6) eq 1,0,g6) + con(isnull(g5) eq 1,0,g5) + con(isnull(g4) eq 1,0,g4)
+ con(isnull(g3) eq 1,0,g3) + con(isnull(g2) eq 1,0,g2) + con(isnull(g1) eq 1,0,g1)

j%s% = con(isnull(h33) eq 1,0,h33) + con(isnull(h32) eq 1,0,h32) + con(isnull(h31) eq
1,0,h31) + con(isnull(h30) eq 1,0,h30) + con(isnull(h29) eq 1,0,h29) + con(isnull(h28) eq
1,0,h28) + con(isnull(h27) eq 1,0,h27) + con(isnull(h26) eq 1,0,h26) + con(isnull(h25) eq
1,0,h25) + con(isnull(h24) eq 1,0,h24) + con(isnull(h23) eq 1,0,h23) + con(isnull(h22) eq
1,0,h22) + con(isnull(h21) eq 1,0,h21) + con(isnull(h20) eq 1,0,h20) + con(isnull(h19) eq
1,0,h19) + con(isnull(h18) eq 1,0,h18) + con(isnull(h17) eq 1,0,h17) + con(isnull(h16) eq
1,0,h16) + con(isnull(h15) eq 1,0,h15) + con(isnull(h14) eq 1,0,h14) + con(isnull(h13) eq
```

```
1,0,h13) + con(isnull(h12) eq 1,0,h12) + con(isnull(h11) eq 1,0,h11) + con(isnull(h10) eq
1,0,h10) + con(isnull(h9) eq 1,0,h9) + con(isnull(h8) eq 1,0,h8) + con(isnull(h7) eq
1,0,h7) + con(isnull(h6) eq 1,0,h6) + con(isnull(h5) eq 1,0,h5) + con(isnull(h4) eq 1,0,h4)
+ con(isnull(h3) eq 1,0,h3) + con(isnull(h2) eq 1,0,h2) + con(isnull(h1) eq 1,0,h1)

k%s% = con(isnull(i33) eq 1,0,i33) + con(isnull(i32) eq 1,0,i32) + con(isnull(i31) eq
1,0,i31) + con(isnull(i30) eq 1,0,i30) + con(isnull(i29) eq 1,0,i29) + con(isnull(i28) eq
1,0,i28) + con(isnull(i27) eq 1,0,i27) + con(isnull(i26) eq 1,0,i26) + con(isnull(i25) eq
1,0,i25) + con(isnull(i24) eq 1,0,i24) + con(isnull(i23) eq 1,0,i23) + con(isnull(i22) eq
1,0,i22) + con(isnull(i21) eq 1,0,i21) + con(isnull(i20) eq 1,0,i20) + con(isnull(i19) eq
1,0,i19) + con(isnull(i18) eq 1,0,i18) + con(isnull(i17) eq 1,0,i17) + con(isnull(i16) eq
1,0,i16) + con(isnull(i15) eq 1,0,i15) + con(isnull(i14) eq 1,0,i14) + con(isnull(i13) eq
1,0,i13) + con(isnull(i12) eq 1,0,i12) + con(isnull(i11) eq 1,0,i11) + con(isnull(i10) eq
1,0,i10) + con(isnull(i9) eq 1,0,i9) + con(isnull(i8) eq 1,0,i8) + con(isnull(i7) eq 1,0,i7) +
con(isnull(i6) eq 1,0,i6) + con(isnull(i5) eq 1,0,i5) + con(isnull(i4) eq 1,0,i4) +
con(isnull(i3) eq 1,0,i3) + con(isnull(i2) eq 1,0,i2) + con(isnull(i1) eq 1,0,i1)
        &do &while %r% ge 1
                &sv killgrid i%r%
                kill i%r% all
                &sv killgrid h%r%
                kill h%r% all
                &sv killgrid g%r%
                kill g%r% all
                &sv r = %r% - 1
        &end
  &end
  &if %s% eq 33 &then
        &do
        &sv t = %t% + 1
        reset

m%t% = con(isnull(j33) eq 1,0,j33) + con(isnull(j32) eq 1,0,j32) + con(isnull(j31) eq
1,0,j31) + con(isnull(j30) eq 1,0,j30) + con(isnull(j29) eq 1,0,j29) + con(isnull(j28) eq
1,0,j28) + con(isnull(j27) eq 1,0,j27) + con(isnull(j26) eq 1,0,j26) + con(isnull(j25) eq
1,0,j25) + con(isnull(j24) eq 1,0,j24) + con(isnull(j23) eq 1,0,j23) + con(isnull(j22) eq
1,0,j22) + con(isnull(j21) eq 1,0,j21) + con(isnull(j20) eq 1,0,j20) + con(isnull(j19) eq
1,0,j19) + con(isnull(j18) eq 1,0,j18) + con(isnull(j17) eq 1,0,j17) + con(isnull(j16) eq
1,0,j16) + con(isnull(j15) eq 1,0,j15) + con(isnull(j14) eq 1,0,j14) + con(isnull(j13) eq
1,0,j13) + con(isnull(j12) eq 1,0,j12) + con(isnull(j11) eq 1,0,j11) + con(isnull(j10) eq
1,0,j10) + con(isnull(j9) eq 1,0,j9) + con(isnull(j8) eq 1,0,j8) + con(isnull(j7) eq 1,0,j7) +
con(isnull(j6) eq 1,0,j6) + con(isnull(j5) eq 1,0,j5) + con(isnull(j4) eq 1,0,j4) +
con(isnull(j3) eq 1,0,j3) + con(isnull(j2) eq 1,0,j2) + con(isnull(j1) eq 1,0,j1)

n%t% = con(isnull(k33) eq 1,0,k33) + con(isnull(k32) eq 1,0,k32) + con(isnull(k31) eq
1,0,k31) + con(isnull(k30) eq 1,0,k30) + con(isnull(k29) eq 1,0,k29) + con(isnull(k28) eq
1,0,k28) + con(isnull(k27) eq 1,0,k27) + con(isnull(k26) eq 1,0,k26) + con(isnull(k25) eq
```

```
1,0,k25) + con(isnull(k24) eq 1,0,k24) + con(isnull(k23) eq 1,0,k23) + con(isnull(k22) eq
1,0,k22) + con(isnull(k21) eq 1,0,k21) + con(isnull(k20) eq 1,0,k20) + con(isnull(k19) eq
1,0,k19) + con(isnull(k18) eq 1,0,k18) + con(isnull(k17) eq 1,0,k17) + con(isnull(k16) eq
1,0,k16) + con(isnull(k15) eq 1,0,k15) + con(isnull(k14) eq 1,0,k14) + con(isnull(k13) eq
1,0,k13) + con(isnull(k12) eq 1,0,k12) + con(isnull(k11) eq 1,0,k11) + con(isnull(k10) eq
1,0,k10) + con(isnull(k9) eq 1,0,k9) + con(isnull(k8) eq 1,0,k8) + con(isnull(k7) eq
1,0,k7) + con(isnull(k6) eq 1,0,k6) + con(isnull(k5) eq 1,0,k5) + con(isnull(k4) eq 1,0,k4)
+ con(isnull(k3) eq 1,0,k3) + con(isnull(k2) eq 1,0,k2) + con(isnull(k1) eq 1,0,k1)

o%t% = con(isnull(l33) eq 1,0,l33) + con(isnull(l32) eq 1,0,l32) + con(isnull(l31) eq
1,0,l31) + con(isnull(l30) eq 1,0,l30) + con(isnull(l29) eq 1,0,l29) + con(isnull(l28) eq
1,0,l28) + con(isnull(l27) eq 1,0,l27) + con(isnull(l26) eq 1,0,l26) + con(isnull(l25) eq
1,0,l25) + con(isnull(l24) eq 1,0,l24) + con(isnull(l23) eq 1,0,l23) + con(isnull(l22) eq
1,0,l22) + con(isnull(l21) eq 1,0,l21) + con(isnull(l20) eq 1,0,l20) + con(isnull(l19) eq
1,0,l19) + con(isnull(l18) eq 1,0,l18) + con(isnull(l17) eq 1,0,l17) + con(isnull(l16) eq
1,0,l16) + con(isnull(l15) eq 1,0,l15) + con(isnull(l14) eq 1,0,l14) + con(isnull(l13) eq
1,0,l13) + con(isnull(l12) eq 1,0,l12) + con(isnull(l11) eq 1,0,l11) + con(isnull(l10) eq
1,0,l10) + con(isnull(l9) eq 1,0,l9) + con(isnull(l8) eq 1,0,l8) + con(isnull(l7) eq 1,0,l7) +
con(isnull(l6) eq 1,0,l6) + con(isnull(l5) eq 1,0,l5) + con(isnull(l4) eq 1,0,l4) +
con(isnull(l3) eq 1,0,l3) + con(isnull(l2) eq 1,0,l2) + con(isnull(l1) eq 1,0,l1)
        &do &while %s% ge 1
                &sv killgrid l%s%
                kill l%s% all
                &sv killgrid k%s%
                kill k%s% all
                &sv killgrid j%s%
                kill j%s% all
                &sv s = %s% - 1
        &end
  &end

  &if %x% eq 1 &then &do
        setcell 30
        aw_%.num% = 0
        rank_%.num% = 0
        num_%.num% = 0

        reset

        &if %p% ge 1 &then &do
                aw_temp = con(isnull(a%p%) eq 1,0,a%p%) + con(isnull(aw_%.num%)
eq 1,0,aw_%.num%)
                btemp = con(isnull(b%p%) eq 1,0,b%p%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
                ctemp = con(isnull(c%p%) eq 1,0,c%p%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
```

```
		kill aw_%.num% all
		kill rank_%.num% all
		kill num_%.num% all
		rename aw_temp aw_%.num%
		rename btemp rank_%.num%
		rename ctemp num_%.num%
		/* kill a%p% all
		/* kill b%p% all
		/* kill c%p% all
		&sv p = %p% - 1
		&do &while %p% gt 0
			aw_temp =  con(isnull(aw_%.num%) eq 1,0,aw_%.num%) +
con(isnull(a%p%) eq 1,0,a%p%)
			btemp = con(isnull(rank_%.num%) eq 1,0,rank_%.num%) +
con(isnull(b%p%) eq 1,0,b%p%)
			ctemp = con(isnull(num_%.num%) eq 1,0,num_%.num%) +
con(isnull(c%p%) eq 1,0,c%p%)
			kill aw_%.num% all
			kill rank_%.num% all
			kill num_%.num% all
			rename aw_temp aw_%.num%
			rename btemp rank_%.num%
			rename ctemp num_%.num%
			/* kill a%p% all
			/* kill b%p% all
			/* kill c%p% all
			&sv p = %p% - 1
		&end
	&end

	&if %q% ge 1 &then &do
		aw_temp = con(isnull(d%q%) eq 1,0,d%q%) + con(isnull(aw_%.num%)
eq 1,0,aw_%.num%)
		btemp = con(isnull(e%q%) eq 1,0,e%q%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
		ctemp = con(isnull(f%q%) eq 1,0,f%q%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
		kill aw_%.num% all
		kill rank_%.num% all
		kill num_%.num% all
		rename aw_temp aw_%.num%
		rename btemp rank_%.num%
		rename ctemp num_%.num%
		/* kill d%q% all
		/* kill e%q% all
		/* kill f%q% all
```

```
			&sv q = %q% - 1
			&do &while %q% gt 0
				aw_temp = con(isnull(d%q%) eq 1,0,d%q%) +
con(isnull(aw_%.num%) eq 1,0,aw_%.num%)
				btemp = con(isnull(e%q%) eq 1,0,e%q%) +
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
				ctemp = con(isnull(f%q%) eq 1,0,f%q%) +
con(isnull(num_%.num%) eq 1,0,num_%.num%)
				kill aw_%.num% all
				kill rank_%.num% all
				kill num_%.num% all
				rename aw_temp aw_%.num%
				rename btemp rank_%.num%
				rename ctemp num_%.num%
				/* kill d%q% all
				/* kill e%q% all
				/* kill f%q% all
				&sv q = %q% - 1
			&end
		&end

		&if %r% ge 1 &then &do
			aw_temp = con(isnull(g%r%) eq 1,0,g%r%) + con(isnull(aw_%.num%) eq
1,0,aw_%.num%)
			btemp = con(isnull(h%r%) eq 1,0,h%r%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
			ctemp = con(isnull(i%r%) eq 1,0,i%r%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
			kill aw_%.num% all
			kill rank_%.num% all
			kill num_%.num% all
			rename aw_temp aw_%.num%
			rename btemp rank_%.num%
			rename ctemp num_%.num%
			/* kill g%r% all
			/* kill h%r% all
			/* kill i%r% all
			&sv r = %r% - 1
			&do &while %r% gt 0
				aw_temp = con(isnull(g%r%) eq 1,0,g%r%) +
con(isnull(aw_%.num%) eq 1,0,aw_%.num%)
				btemp = con(isnull(h%r%) eq 1,0,h%r%) +
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
				ctemp = con(isnull(i%r%) eq 1,0,i%r%) +
con(isnull(num_%.num%) eq 1,0,num_%.num%)
				kill aw_%.num% all
```

```
                    kill rank_%.num% all
                    kill num_%.num% all
                    rename aw_temp aw_%.num%
                    rename btemp rank_%.num%
                    rename ctemp num_%.num%
                    /* kill g%r% all
                    /* kill h%r% all
                    /* kill i%r% all
                    &sv r = %r% - 1
               &end
          &end

          &if %s% ge 1 &then &do
               aw_temp = con(isnull(j%s%) eq 1,0,j%s%) + con(isnull(aw_%.num%) eq
1,0,aw_%.num%)
               btemp = con(isnull(k%s%) eq 1,0,k%s%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
               ctemp = con(isnull(l%s%) eq 1,0,l%s%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
               kill aw_%.num% all
               kill rank_%.num% all
               kill num_%.num% all
               rename aw_temp aw_%.num%
               rename btemp rank_%.num%
               rename ctemp num_%.num%
               /* kill j%s% all
               /* kill k%s% all
               /* kill l%s% all
               &sv s = %s% - 1
               &do &while %s% gt 0
                    aw_temp = con(isnull(j%s%) eq 1,0,j%s%) +
con(isnull(aw_%.num%) eq 1,0,aw_%.num%)
                    btemp = con(isnull(k%s%) eq 1,0,k%s%) +
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
                    ctemp = con(isnull(l%s%) eq 1,0,l%s%) +
con(isnull(num_%.num%) eq 1,0,num_%.num%)
                    kill aw_%.num% all
                    kill rank_%.num% all
                    kill num_%.num% all
                    rename aw_temp aw_%.num%
                    rename btemp rank_%.num%
                    rename ctemp num_%.num%
                    /* kill j%s% all
                    /* kill k%s% all
                    /* kill l%s% all
                    &sv s = %s% - 1
```

```
                &end
        &end

        &if %t% ge 1 &then &do
                aw_temp = con(isnull(m%t%) eq 1,0,m%t%) + conisnull(aw_%.num%)
eq 1,0,aw_%.num%)
                btemp = con(isnull(n%t%) eq 1,0,n%t%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
                ctemp = con(isnull(o%t%) eq 1,0,o%t%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
                kill aw_%.num% all
                kill rank_%.num% all
                kill num_%.num% all
                rename aw_temp aw_%.num%
                rename btemp rank_%.num%
                rename ctemp num_%.num%
                /* kill m%t% all
                /* kill n%t% all
                /* kill o%t% all
                &sv t = %t% - 1
                &do &while %t% gt 0
                        aw_temp = con(isnull(m%t%) eq 1,0,m%t%) +
conisnull(aw_%.num%) eq 1,0,aw_%.num%)
                        btemp = con(isnull(n%t%) eq 1,0,n%t%) +
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
                        ctemp = con(isnull(o%t%) eq 1,0,o%t%) +
con(isnull(num_%.num%) eq 1,0,num_%.num%)
                        kill aw_%.num% all
                        kill rank_%.num% all
                        kill num_%.num% all
                        rename aw_temp aw_%.num%
                        rename btemp rank_%.num%
                        rename ctemp num_%.num%
                        /* kill m%t% all
                        /* kill n%t% all
                        /* kill o%t% all
                        &sv t = %t% - 1
                &end
        &end
  &end

  &sv killgrid ranktest
  kill ranktest all
  &sv killgrid areatest
  kill areatest all
  &sv killgrid numtest
```

```
  kill numtest all
  &sv killgrid dist
  kill dist all
  &sv killgrid area_al
  kill area_al all

  &if [mod %x% 20] eq 0 &then &do
        q
        &pause &seconds 5
        grid
  &end

  &sv x = %x% - 1

  &sv xminx = %minx% - 100000
  &sv xmaxx = %maxx% + 100000
  &sv xminy = %miny% - 100000
  &sv xmaxy = %maxy% + 100000

  /* setwindow %minx% %miny% %maxx% %maxy% mask
  reset

&end

&type loop exited

&if %x% eq 0 &then &do
  &type Begin Calculation
  /* rankave = rank / num
  /* aw_temp = rankave * aw_
  /* &sv killgrid aw_
  /* kill aw_ all
  /* &sv killgrid rank
  /* kill rank all
  /* &sv killgrid num
  /* kill num all
  /* &sv killgrid rankave
  /* kill rankave all
  &end

&else &goto redo

S:\GLUT_wetlands\wetland_model\layer1_7\statewide_product\aw_%.num% =
aw_%.num%
S:\GLUT_wetlands\wetland_model\layer1_7\statewide_product\rank_%.num% =
rank_%.num%
```

```
S:\GLUT_wetlands\wetland_model\layer1_7\statewide_product\num_%.num% =
num_%.num%

q
&stop

&routine cleanup

  &type cleanup kill
  q
  &pause &seconds 5
  &sys rd /s /q %killgrid%
  grid

&return

&routine swindow

  &sv iter = 0
  &sv buff = 12000

  &label wredo

  &sv minx = 0
  &sv maxx = 0
  &sv miny = 0
  &sv maxy = 0

  patch = con(%group% eq %x%,1)

  resample.%x% = sample(patch,patch)
  &sv fileunit = [open resample.%x% openstatus -read]
  &sv xy = [read %fileunit% readstatus]
  &sv xy = [read %fileunit% readstatus]
  &do &while %readstatus% = 0
        &do
        &sv xline = [trim [substr %xy% 3 15] -both ' ']
        &if %minx% eq 0 &then &sv minx = %xline%
                &else &if %xline% lt %minx% &then &sv minx = %xline%
        &if %maxx% eq 0 &then &sv maxx = %xline%
                &else &if %xline% gt %maxx% &then &sv maxx = %xline%
        &sv y = [trim [substr %xy% 19 15] -both ' ']
        &if %miny% eq 0 &then &sv miny = %y%
                &else &if %y% lt %miny% &then &sv miny = %y%
        &if %maxy% eq 0 &then &sv maxy = %y%
                &else &if %y% gt %maxy% &then &sv maxy = %y%
```

```
	&sv xy = [read %fileunit% readstatus]
	&end
&end

&if [close %fileunit%] eq 0 &then &type file closed
&sys del /f /q resample.%x%

&if %maxx% eq 0 &then &do

	&if %iter% eq 0 &then &do
		&sv group = group500
		&sv buff = 9000
	&end

	&if %iter% eq 1 &then &do
		&sv group = group250
		&sv buff = 7500
	&end

	&if %iter% eq 2 and %x% lt %z% &then &do
		setwindow %xminx% %xminy% %xmaxx% %xmaxy% mask
		&sv group = aw_rgrp
		&sv buff = 5000
	&end

	&else &if %iter% eq 2 &then &do
		setwindow mask mask
		&sv group = aw_rgrp
		&sv buff = 5000
	&end

	&if %iter% eq 3 &then &do
		setwindow mask mask
		&sv group = aw_rgrp
		&sv buff = 5000
	&end

	&sv killgrid patch
	kill patch all
	&sv iter = %iter% + 1
	&goto wredo
&end

&else &do
	&sv minx = %minx% - %buff%
```

```
        &sv maxx = %maxx% + %buff%
        &sv miny = %miny% - %buff%
        &sv maxy = %maxy% + %buff%

        &sv killgrid patch
        kill patch all

        setwindow %minx% %miny% %maxx% %maxy% mask
        &end
&return
```

LAYER 1.6: TERRESTRIAL DISPERSAL CORRIDORS BETWEEN WETLANDS – ADD AWSR AML

This AML takes the output from Layer 1.6: Terrestrial Dispersal Corridors between Wetlands – Connectivity AML and does the final processing steps to create the non-classified Layer 1.6

Note: The original number given to this Layer was 1.7. After removal on a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.7.

```
 Layer 1.7 Biodiversity Conservation average weighted species richness Model
 Created June 2nd,2006
 Created by:  Kevin Samples and Stephen M. Carpenedo
              Natural Resources Spatial Analysis Laboratory
              Odum School of Ecology, University of Georgia
              Athens, GA
 ---------------------------------------------------------------------------------
&args .wrkspc .start .end
&severity &error &ignore
&echo &on

w %.wrkspc%

/*&watch 1_7watch.txt &commands

grid

&sv x = %.end% - 1
&sv a = %.start%
&sv y = %.start%

setwindow h:\wet_temp\mask h:\wet_temp\mask

&do &while %y% gt %x%
```

```
  &if %y% eq %a% &then
  &do
          awsr_b = con(isnull(aw_%y%) eq 1, 0, aw_%y%)
          rank_b = con(isnull(rank_%y%) eq 1, 0, rank_%y%)
          num_b = con(isnull(num_%y%) eq 1, 0, num_%y%)
          &end
  &else
  &do
          awsr_tempb = con(isnull(aw_%y%) eq 1, 0, aw_%y%) + awsr_b
          rank_tempb = con(isnull(rank_%y%) eq 1, 0, rank_%y%) + rank_b
          num_tempb = con(isnull(num_%y%) eq 1, 0, num_%y%) + num_b
          kill awsr_b all
          kill num_b all
          kill rank_b all
          rename awsr_tempb awsr_b
          rename rank_tempb rank_b
          rename num_tempb num_b
          &end

  &sv y = %y% - 1
&end

layer1_7nc = (rank_b / num_b) * awsr_b

q
&stop
```

LAYYER 1.7: HYDROLOGIC CONNECTIVITY OF WETLANDS – HABITAT QUALITY PREP AML

```
----------------------------------------------------------------
 S:\GLUT_wetlands\wetland_model\amls\layer1_8hq_prep.aml
```

Note: The original number given to this Layer was 1.8. After removal on a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.8.

```
 Created: 4/11/2005
          Stephen M. Carpenedo
          Natural Resources Spatial Analysis Laboratory
          Institute of Ecology, University of Georgia
          Athens, GA, 30606
```

This AML is used to select all wetlands with a specified 8 Digit HUC and a buffer of 4500 meters. The 4500 meters is about the maximum size that Fragstats 3.3 can handle and reduces the "edge" effect when individual files are stitched back together to form a statewide raster.

```
  Input File:  .wrk is the workspace
S:\GLUT_wetlands\wetland_model\layer1_8\Basefiles
            .wet is the GLUT 2005 raster reclassed so wetlands = 2, all other data = 1
                  Located at:  S:\GLUT_wetlands\wetland_model\Library\glut05_frag
----------------------------------------------------------------------
&args .wrk .wet
&severity &error &fail
&echo &on
w %.wrk%
grid
setwindow S:\GLUT_wetlands\wetland_model\Library\mask
S:\GLUT_wetlands\wetland_model\Library\mask
huc8 = S:\GLUT_wetlands\wetland_model\Library\huc8
&describe huc8
&sv h = 55
/*  Note:  There is no HUC 10 so this program fails at that point.  To restart change h = 9
and rerun.
&do &while %h% gt 0
  huc = con(huc8 eq %h%, 1, 0)
  huc_rsmpl = resample(huc, 1500)
  &call swindow
  wet_%h% = con(%.wet% gt 0, %.wet%)
  kill huc all
  kill huc_rsmpl all
  &sv h = %h% - 1
  reset
&end
q
&stop
&routine swindow
  &sv minx = 0
  &sv maxx = 0
  &sv miny = 0
  &sv maxy = 0
  patch = con(huc_rsmpl gt 0,1)
  &label wredo
  resample.%h% = sample(patch,patch)
  &sv fileunit = [open resample.%h% openstatus -read]
  &sv xy = [read %fileunit% readstatus]
  &sv xy = [subst [read %fileunit% readstatus] '       ' ,]
  &do &while %readstatus% = 0
        &do
        &sv x = [extract 2 %xy%]
        &if %minx% eq 0 &then &sv minx = %x%
                &else &if %x% lt %minx% &then &sv minx = %x%
```

```
        &if %maxx% eq 0 &then &sv maxx = %x%
                &else &if %x% gt %maxx% &then &sv maxx = %x%
        &sv y = [extract 3 %xy%]
        &if %miny% eq 0 &then &sv miny = %y%
                &else &if %y% lt %miny% &then &sv miny = %y%
        &if %maxy% eq 0 &then &sv maxy = %y%
                &else &if %y% gt %maxy% &then &sv maxy = %y%
        &sv xy = [subst [read %fileunit% readstatus] '          ' ,]
        &end
  &end
  &if [close %fileunit%] eq 0 &then &type file closed
  &sys del /f /q resample.%h%

  &if %maxx% gt 0 &then &do
        &sv minx = %minx% - 4500
        &sv maxx = %maxx% + 4500
        &sv miny = %miny% - 4500
        &sv maxy = %maxy% + 4500
        setwindow %minx% %miny% %maxx% %maxy%
S:\GLUT_wetlands\wetland_model\Library\mask
  &end
  &else &do
        setwindow S:\GLUT_wetlands\wetland_model\Library\mask
S:\GLUT_wetlands\wetland_model\Library\mask
        kill patch all
        patch = con(huc gt 0,1)
        &goto wredo
  &end
  &sv killgrid patch
  kill patch all
&return
```

LAYER 1.7: HYDOLOGIC CONNECTIVITY OF WETLANDS – FRAGSTATS PREP PYTHON SCRIPT

S:\GLUT_wetlands\wetland_model\amls\layer1_8_hqFragstats.py

Note: The original number given to this Layer was 1.8. After removal on a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.8.

Created on: Mon Jun 18 2007
Stephen M. Carpenedo
Natural Resources Spatial Analysis Lab
Odum School of Ecology, University of Georgia
Athens, GA 30606

This python script takes the output from Fragstats 3.3 files (wet_id8, located in S:\GLUT_wetlands\wetland_model\layer1_8\base_files) and creates a .vat file with two additional fields, contig (float) and prox (float).

Some by hand processing is necessary before outputs from this script can be used in the next step S:\GLUT_wetlands\wetland_model\amls\layer1_8_hq_lookup.py.

```
print "starting"

# Import system modules
import sys, string, os, arcgisscripting
# Create the Geoprocessor object
gp = arcgisscripting.create()
# Check out any necessary licenses
gp.CheckOutExtension("spatial")
# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst
Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management
Tools.tbx")

x = 55

#  NOTE:  HUC 10 (x=10) does not exist and this script will crash at this point.  Change
x = 9 and restart python script to complete all files.

while x>1:

   frag_id =
"S:\\GLUT_wetlands\\wetland_model\\layer1_8\\base_files\\wet_"+str(x)+"id8"
   frag_feature =
"S:\\GLUT_wetlands\\wetland_model\\layer1_8\\base_files\\huc_"+str(x)

   print frag_id
   print frag_feature

   # Process: Make Feature Layer
   print "Feature Layer"
   gp.MakeTableView_management(frag_id, frag_feature ,"", "", "")

   try:
      # Process: Add Field...
      gp.AddField_management(frag_feature, "contig", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")
```

```
        print "Add Field Contig Successful"
    except:
        print gp.GetMessages()

    try:
        # Process: Add Field (2)...
        gp.AddField_management(frag_feature, "prox", "FLOAT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")
        print "Add Field Prox Successful"
    except:
        print gp.GetMessages()

    x = x - 1
```

LAYER 1.7: HYDOLOGIC CONNECTIVITY OF WETLANDS – HIGH QUALITY LOOKUP PYTHON SCRIPT

```
 -------------------------------------------------------------------------
 s:\glut_wetlands\wetland_model\amls\layer1_8_hq_lookup.py

Note:  The original number given to this Layer was 1.8.  After removal on a previous
layer it was renamed to 1.6.  All AMLs and associated files are still found under Layer
1.8.

 Created on:   07/09/2007
               Stephen M. Carpenedo
               Natural Resources Spatial Analysis Laboratory
               Odum School of Ecology, University of Georgia
               Athens, GA  30606

  This python script takes the rasters generated in running the batch file for the quality of
wetlands.  Initial prep of the files is necessary before this script.  *See details in Steps for
Layer 1_8.doc.  It reclassifies each raster using the lookup function for both proximity
and contiguity.

  Contiguity and Proximity are in two separate workspaces:
  S:\\GLUT_wetlands\\wetland_model\\layer1_8\\contig_huc
  S:\\GLUT_wetlands\\wetland_model\\layer1_8\\prox_huc

  Input Files are located at:
  S:\\GLUT_wetlands\\wetland_model\\layer1_8\\base_files
 -------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
```

```
gp = arcgisscripting.create()

# Check out any necessary licenses
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")

x = 55

#  Note there is NO HUC 10 and so the program crashes when this point is reached
Restart the program with x = 9.  There is also no HUC 1 so the program ends at x = 2

while x>2:

   frag_id = "S:\\GLUT_wetlands\\wetland_model\\layer1_8\\base_files\\wet_"+str(x)+"id8"
   output_contig = "S:\\GLUT_wetlands\\wetland_model\\layer1_8\\contig_huc\\contig_"+str(x)
   output_prox = "S:\\GLUT_wetlands\\wetland_model\\layer1_8\\prox_huc\\prox_"+str(x)

   print "Starting: " + str(x)

   # Process: Lookup...
   gp.Lookup_sa(frag_id, "contig", output_contig)
   print "contig"+str(x)+" complete"

   # Process: Lookup (2)...
   gp.Lookup_sa(frag_id, "prox", output_prox)
   print "Prox"+str(x)+" complete"

   x = x - 1
```

LAYER 1.7: HYDROLOGIC CONNECTIVITY OF WETLANDS – FINAL HIGH QUALITY PREP AML

S:\GLUT_wetlands\wetland_model\amls\l1_8_final_hq_prep.aml

Note: The original number given to this Layer was 1.8. After removal on a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.8.

Created: 07/10/2007
Stephen M. Carpenedo
Natural Resources Spatial Analysis Lab
Odum School of Ecology, University of Georgia
Athens, GA 30606
706-542-3489

This AML takes the output from S:\GLUT_wetlands\wetland_model\amls\layer1_8_hq_lookup.py and clips each contiguity and proximity file to their respective 8 Digit HUC and then creates an additive statewide raster for each Fragstats measure.

Final processing of this step is to reclassify both contig_state and prox_state using Jenks Optimization for nine classes. These are then added together and named "habqual_state".

INPUT FILES:
.wrk is the workspace S:\GLUT_wetlands\wetland_model\layer1_8\final_base_files
.huc is the 8 digit HUC raster. Located at: S:\GLUT_wetlands\wetland_model\Library\huc8
Mask file: S:\GLUT_wetlands\wetland_model\Library\Mask
Contiguity Files: These are named based on their respective 8 Digit HUCS (i.e. contig_55). Located at: S:\GLUT_wetlands\wetland_model\layer1_8\contig_huc
Proximity Files: These are named based on their respective 8 Digit HUCS (i.e prox_55). Located at: S:\GLUT_wetlands\wetland_model\layer1_8\prox_huc

OUTPUT FILES:
Statewide rasters of contiguity and proximity are located at and named contig_state & prox_state:
S:\GLUT_wetlands\wetland_model\layer1_8\final_base_files

```
&args .wrk .huc
&severity &error &ignore
&echo &on

w %.wrk%
grid
setwindow S:\GLUT_wetlands\wetland_model\Library\mask
  S:\GLUT_wetlands\wetland_model\Library\mask
&sv x = 54
&sv a = 2
```

```
&do &while %x% gt 1
  /*  The if loop is set up to eliminate the problem that
  S:\GLUT_wetlands\wetland_model\Library\huc8 does not have a value for 10.  It
  strictly skips this number and continues on with 9

  &if %x% eq 10 &then
        &do
        &sv x = %x% - 1
        &sv a = %a% + 1
  &end
  &else &do
        /*  Second loop that clips and adds successive 8 digit HUCs to the initial
  statewide file for contiguity and proximity created in the first loop

        setwindow S:\GLUT_wetlands\wetland_model\layer1_8\contig_huc\contig_%x%
  S:\GLUT_wetlands\wetland_model\layer1_8\contig_huc\contig_%x%
        &sv contig =
  S:\GLUT_wetlands\wetland_model\layer1_8\contig_huc\contig_%x%
        huc_cont_%x% = con(%.huc% eq %x%, %contig%)
        &sv prox = S:\GLUT_wetlands\wetland_model\layer1_8\prox_huc\prox_%x%
        huc_prox_%x% = con(%.huc% eq %x%, %prox%)
  &end
&sv x = %x% - 1
&sv a = %a% + 1
&end

setwindow S:\GLUT_wetlands\wetland_model\Library\mask
  S:\GLUT_wetlands\wetland_model\Library\mask

cont_merg1 = merge(huc_cont_2, huc_cont_3, huc_cont_4, huc_cont_5, huc_cont_6,
  huc_cont_7, huc_cont_8, huc_cont_9, huc_cont_11, huc_cont_12, huc_cont_13,
  huc_cont_14, huc_cont_15, huc_cont_16, huc_cont_16, huc_cont_17, huc_cont_18,
  huc_cont_19, huc_cont_20, huc_cont_21, huc_cont_22, huc_cont_23, huc_cont_24,
  huc_cont_25)

cont_merg2 = merge(huc_cont_26, huc_cont_27, huc_cont_28, huc_cont_29,
  huc_cont_30, huc_cont_31, huc_cont_32, huc_cont_33, huc_cont_34, huc_cont_35,
  huc_cont_36, huc_cont_37, huc_cont_38, huc_cont_39, huc_cont_40, huc_cont_41,
  huc_cont_42, huc_cont_43, huc_cont_44, huc_cont_45, huc_cont_46, huc_cont_47,
  huc_cont_48, huc_cont_49)

cont_merg3 = merge(huc_cont_50, huc_cont_51, huc_cont_52, huc_cont_53,
  huc_cont_54, huc_cont_55)

contig_state = merge(cont_merg1, cont_merg2, cont_merg3)
```

prox_merg1 = merge(huc_prox_2, huc_prox_3, huc_prox_4, huc_prox_5, huc_prox_6, huc_prox_7, huc_prox_8, huc_prox_9, huc_prox_11, huc_prox_12, huc_prox_13, huc_prox_14, huc_prox_15, huc_prox_16, huc_prox_16, huc_prox_17, huc_prox_18, huc_prox_19, huc_prox_20, huc_prox_21, huc_prox_22, huc_prox_23, huc_prox_24, huc_prox_25)

prox_merg2 = merge(huc_prox_26, huc_prox_27, huc_prox_28, huc_prox_29, huc_prox_30, huc_prox_31, huc_prox_32, huc_prox_33, huc_prox_34, huc_prox_35, huc_prox_36, huc_prox_37, huc_prox_38, huc_prox_39, huc_prox_40, huc_prox_41, huc_prox_42, huc_prox_43, huc_prox_44, huc_prox_45, huc_prox_46, huc_prox_47, huc_prox_48)

prox_merg3 = merge(huc_prox_49, huc_prox_50, huc_prox_51, huc_prox_52, huc_prox_53, huc_prox_54, huc_prox_55)

prox_state = merge(prox_merg1, prox_merg2, prox_merg3)

q
&stop

LAYER 1.7: HYDROLOGIC CONNECTIVITY OF WETLANDS – HIGH QUALITY HABITAT SPLIT AML

S:\GLUT_wetlands\wetland_model\amls\l1_8_hq_split_raster.aml

Note: The original number given to this Layer was 1.8. After removal on a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.8.

Created: 07/11/2007
Stephen M. Carpenedo
Natural Resources Spatial Analysis Lab
Odum School of Ecology, University of Georgia
Athens, GA 30606

This AML is used to split the additive reclassed habitat quality raster into parts that are exactly the same as the wetland raster that is divide using S:\GLUT_wetlands\wetland_model\amls\split_raster_by_num_attributes.py.

INPUT FILES:
.wrk is the workspace s:\GLUT_wetlands\wetland_model\layer1_8\final_base_files\habitat_quality
.wet_qual is the additive reclassed habitat quality raster. Located at S:\GLUT_wetlands\wetland_model\layer1_8\final_base_files\habitat_quality\habqual_state

OUTPUT FILES:
Output files are written to the workspace directory and named hab_qual_##. There will be 25 separate rasters
----
```
&args .wrk .wet_qual
&severity &error &fail
&echo &on
w %.wrk%
grid
setwindow S:\GLUT_wetlands\wetland_model\Library\mask
S:\GLUT_wetlands\wetland_model\Library\mask
&sv x = 25
&do &while %x% gt 0
  &sv wetland =
S:\GLUT_wetlands\wetland_model\layer1_8\final_base_files\wetlands\ex_wet05_%x%
  hab_qual_%x% = con(%wetland% ge 1, %.wet_qual%)
  &sv x = %x% - 1
  &end
q
&stop
```

LAYER 1.7: HYDROLOGIC CONNECTIVITY OF WETLANDS – CONNECTIVITY AML

Hydrologic Connectivity of Wetlands

S:\GLUT_wetlands\wetland_model\amls\1_8statewide.aml

Note: The original number given to this Layer was 1.8. After removal on a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.8.

Created June 2nd, 2006
Created by: Kevin Samples and Stephen M. Carpenedo
Natural Resources Spatial Analysis Laboratory
Odum School of Ecology, University of Georgia
Athens, GA

Calculates the connectivity of potential wetland restoration sites to 2005 Georgia Land use trends existing wetlands. A maximum distance of 1000 meters has been set to incorporate the range of emigration distances of most amphibians found in the State of Georgia.

INPUT FILES:

.mr should be the raster with the existing wetlands. These are divided into manageable units and are located at:
S:\GLUT_wetlands\wetland_model\layer1_8\final_base_files\wetlands\ex_wet05_##
.oq should be the habitat quality raster with the matching extent to .mr. These are located at:
S:\GLUT_wetlands\wetland_model\layer1_8\final_base_files\habitat_quality\hab_qual_##

OUTPUT FILES:
ew_%.num%##, rank_%.num%_##, num_%.num%_##

Final processing of the output is to put all of the output files into statewide rasters. This is accomplished using the AML
S:\GLUT_wetlands\wetland_model\amls\1_8final_step.aml

```
&args .wrkspc .mr .oq .num
&severity &error &routine cleanup
&echo &on

w %.wrkspc%

grid

ew_rgrp = regiongroup(%.mr%,#,EIGHT,WITHIN,#,NOLINK)
ew_zarea = zonalarea(ew_rgrp)
hq = con(isnull(%.oq%) eq 1, 0, %.oq%)


group1k = resample(ew_rgrp,1000)
group500 = resample(ew_rgrp,500)
group250 = resample(ew_rgrp,250)

q

&describe ew_rgrp

&sv z = %grd$zmax%
&sv x = %grd$zmax%
&sv p = 0
&sv q = 0
&sv r = 0
&sv s = 0
&sv t = 0

grid
setwindow mask mask
```

```
&sys del /f /q resample.*

&label redo

&do &while %x% gt 0

   &sv group = group1k
   &call swindow

   &sv p = %p% + 1

   /* This is for exwet_OQ2 which does the overall quality of existing wetlands based on
Fragstats ranktest gives us the summation of the overall quality, to this will be used in
conjugation with numtest to give us the habitat quality

   ranktest = con(ew_rgrp eq %x%, hq)

   /* This is for ex_wet_con.aml which does the connectivity buffer measure

   areatest = con(ew_rgrp eq %x%,ew_zarea)
   area_al = eucallocation(int(areatest),#,#,1000)

   numtest = con(ew_rgrp eq %x%,1)

   a%p% = (exp(-.002 * dist)) * area_al
   b%p% = eucallocation(int(ranktest),#,#,1000)
   c%p% = eucallocation(int(numtest),#,#,1000)

   &if %p% eq 33 &then
         &do
         &sv q = %q% + 1
         reset
         d%q% = con(isnull(a33) eq 1,0,a33) + con(isnull(a32) eq 1,0,a32) +
con(isnull(a31) eq 1,0,a31) + con(isnull(a30) eq 1,0,a30) + con(isnull(a29) eq 1,0,a29) +
con(isnull(a28) eq 1,0,a28) + con(isnull(a27) eq 1,0,a27) + con(isnull(a26) eq 1,0,a26) +
con(isnull(a25) eq 1,0,a25) + con(isnull(a24) eq 1,0,a24) + con(isnull(a23) eq 1,0,a23) +
con(isnull(a22) eq 1,0,a22) + con(isnull(a21) eq 1,0,a21) + con(isnull(a20) eq 1,0,a20) +
con(isnull(a19) eq 1,0,a19) + con(isnull(a18) eq 1,0,a18) + con(isnull(a17) eq 1,0,a17) +
con(isnull(a16) eq 1,0,a16) + con(isnull(a15) eq 1,0,a15) + con(isnull(a14) eq 1,0,a14) +
con(isnull(a13) eq 1,0,a13) + con(isnull(a12) eq 1,0,a12) + con(isnull(a11) eq 1,0,a11) +
con(isnull(a10) eq 1,0,a10) + con(isnull(a9) eq 1,0,a9) + con(isnull(a8) eq 1,0,a8) +
con(isnull(a7) eq 1,0,a7) + con(isnull(a6) eq 1,0,a6) + con(isnull(a5) eq 1,0,a5) +
con(isnull(a4) eq 1,0,a4) + con(isnull(a3) eq 1,0,a3) + con(isnull(a2) eq 1,0,a2) +
con(isnull(a1) eq 1,0,a1)
         e%q% = con(isnull(b33) eq 1,0,b33) + con(isnull(b32) eq 1,0,b32) +
con(isnull(b31) eq 1,0,b31) + con(isnull(b30) eq 1,0,b30) + con(isnull(b29) eq 1,0,b29) +
```

```
con(isnull(b28) eq 1,0,b28) + con(isnull(b27) eq 1,0,b27) + con(isnull(b26) eq 1,0,b26) +
con(isnull(b25) eq 1,0,b25) + con(isnull(b24) eq 1,0,b24) + con(isnull(b23) eq 1,0,b23) +
con(isnull(b22) eq 1,0,b22) + con(isnull(b21) eq 1,0,b21) + con(isnull(b20) eq 1,0,b20) +
con(isnull(b19) eq 1,0,b19) + con(isnull(b18) eq 1,0,b18) + con(isnull(b17) eq 1,0,b17) +
con(isnull(b16) eq 1,0,b16) + con(isnull(b15) eq 1,0,b15) + con(isnull(b14) eq 1,0,b14) +
con(isnull(b13) eq 1,0,b13) + con(isnull(b12) eq 1,0,b12) + con(isnull(b11) eq 1,0,b11) +
con(isnull(b10) eq 1,0,b10) + con(isnull(b9) eq 1,0,b9) + con(isnull(b8) eq 1,0,b8) +
con(isnull(b7) eq 1,0,b7) + con(isnull(b6) eq 1,0,b6) + con(isnull(b5) eq 1,0,b5) +
con(isnull(b4) eq 1,0,b4) + con(isnull(b3) eq 1,0,b3) + con(isnull(b2) eq 1,0,b2) +
con(isnull(b1) eq 1,0,b1)
        f%q% = con(isnull(c33) eq 1,0,c33) + con(isnull(c32) eq 1,0,c32) +
con(isnull(c31) eq 1,0,c31) + con(isnull(c30) eq 1,0,c30) + con(isnull(c29) eq 1,0,c29) +
con(isnull(c28) eq 1,0,c28) + con(isnull(c27) eq 1,0,c27) + con(isnull(c26) eq 1,0,c26) +
con(isnull(c25) eq 1,0,c25) + con(isnull(c24) eq 1,0,c24) + con(isnull(c23) eq 1,0,c23) +
con(isnull(c22) eq 1,0,c22) + con(isnull(c21) eq 1,0,c21) + con(isnull(c20) eq 1,0,c20) +
con(isnull(c19) eq 1,0,c19) + con(isnull(c18) eq 1,0,c18) + con(isnull(c17) eq 1,0,c17) +
con(isnull(c16) eq 1,0,c16) + con(isnull(c15) eq 1,0,c15) + con(isnull(c14) eq 1,0,c14) +
con(isnull(c13) eq 1,0,c13) + con(isnull(c12) eq 1,0,c12) + con(isnull(c11) eq 1,0,c11) +
con(isnull(c10) eq 1,0,c10) + con(isnull(c9) eq 1,0,c9) + con(isnull(c8) eq 1,0,c8) +
con(isnull(c7) eq 1,0,c7) + con(isnull(c6) eq 1,0,c6) + con(isnull(c5) eq 1,0,c5) +
con(isnull(c4) eq 1,0,c4) + con(isnull(c3) eq 1,0,c3) + con(isnull(c2) eq 1,0,c2) +
con(isnull(c1) eq 1,0,c1)
        &do &while %p% ge 1
                &sv killgrid c%p%
                kill c%p% all
                &sv killgrid b%p%
                kill b%p% all
                &sv killgrid a%p%
                kill a%p% all
                &sv p = %p% - 1
        &end
  &end

  &if %q% eq 33 &then
        &do
        &sv r = %r% + 1
        reset
        g%r% = con(isnull(d33) eq 1,0,d33) + con(isnull(d32) eq 1,0,d32) +
con(isnull(d31) eq 1,0,d31) + con(isnull(d30) eq 1,0,d30) + con(isnull(d29) eq 1,0,d29) +
con(isnull(d28) eq 1,0,d28) + con(isnull(d27) eq 1,0,d27) + con(isnull(d26) eq 1,0,d26) +
con(isnull(d25) eq 1,0,d25) + con(isnull(d24) eq 1,0,d24) + con(isnull(d23) eq 1,0,d23) +
con(isnull(d22) eq 1,0,d22) + con(isnull(d21) eq 1,0,d21) + con(isnull(d20) eq 1,0,d20) +
con(isnull(d19) eq 1,0,d19) + con(isnull(d18) eq 1,0,d18) + con(isnull(d17) eq 1,0,d17) +
con(isnull(d16) eq 1,0,d16) + con(isnull(d15) eq 1,0,d15) + con(isnull(d14) eq 1,0,d14) +
con(isnull(d13) eq 1,0,d13) + con(isnull(d12) eq 1,0,d12) + con(isnull(d11) eq 1,0,d11) +
con(isnull(d10) eq 1,0,d10) + con(isnull(d9) eq 1,0,d9) + con(isnull(d8) eq 1,0,d8) +
```

```
con(isnull(d7) eq 1,0,d7) + con(isnull(d6) eq 1,0,d6) + con(isnull(d5) eq 1,0,d5) +
con(isnull(d4) eq 1,0,d4) + con(isnull(d3) eq 1,0,d3) + con(isnull(d2) eq 1,0,d2) +
con(isnull(d1) eq 1,0,d1)
        h%r% = con(isnull(e33) eq 1,0,e33) + con(isnull(e32) eq 1,0,e32) +
con(isnull(e31) eq 1,0,e31) + con(isnull(e30) eq 1,0,e30) + con(isnull(e29) eq 1,0,e29) +
con(isnull(e28) eq 1,0,e28) + con(isnull(e27) eq 1,0,e27) + con(isnull(e26) eq 1,0,e26) +
con(isnull(e25) eq 1,0,e25) + con(isnull(e24) eq 1,0,e24) + con(isnull(e23) eq 1,0,e23) +
con(isnull(e22) eq 1,0,e22) + con(isnull(e21) eq 1,0,e21) + con(isnull(e20) eq 1,0,e20) +
con(isnull(e19) eq 1,0,e19) + con(isnull(e18) eq 1,0,e18) + con(isnull(e17) eq 1,0,e17) +
con(isnull(e16) eq 1,0,e16) + con(isnull(e15) eq 1,0,e15) + con(isnull(e14) eq 1,0,e14) +
con(isnull(e13) eq 1,0,e13) + con(isnull(e12) eq 1,0,e12) + con(isnull(e11) eq 1,0,e11) +
con(isnull(e10) eq 1,0,e10) + con(isnull(e9) eq 1,0,e9) + con(isnull(e8) eq 1,0,e8) +
con(isnull(e7) eq 1,0,e7) + con(isnull(e6) eq 1,0,e6) + con(isnull(e5) eq 1,0,e5) +
con(isnull(e4) eq 1,0,e4) + con(isnull(e3) eq 1,0,e3) + con(isnull(e2) eq 1,0,e2) +
con(isnull(e1) eq 1,0,e1)
        i%r% = con(isnull(f33) eq 1,0,f33) + con(isnull(f32) eq 1,0,f32) + con(isnull(f31)
eq 1,0,f31) + con(isnull(f30) eq 1,0,f30) + con(isnull(f29) eq 1,0,f29) + con(isnull(f28) eq
1,0,f28) + con(isnull(f27) eq 1,0,f27) + con(isnull(f26) eq 1,0,f26) + con(isnull(f25) eq
1,0,f25) + con(isnull(f24) eq 1,0,f24) + con(isnull(f23) eq 1,0,f23) + con(isnull(f22) eq
1,0,f22) + con(isnull(f21) eq 1,0,f21) + con(isnull(f20) eq 1,0,f20) + con(isnull(f19) eq
1,0,f19) + con(isnull(f18) eq 1,0,f18) + con(isnull(f17) eq 1,0,f17) + con(isnull(f16) eq
1,0,f16) + con(isnull(f15) eq 1,0,f15) + con(isnull(f14) eq 1,0,f14) + con(isnull(f13) eq
1,0,f13) + con(isnull(f12) eq 1,0,f12) + con(isnull(f11) eq 1,0,f11) + con(isnull(f10) eq
1,0,f10) + con(isnull(f9) eq 1,0,f9) + con(isnull(f8) eq 1,0,f8) + con(isnull(f7) eq 1,0,f7) +
con(isnull(f6) eq 1,0,f6) + con(isnull(f5) eq 1,0,f5) + con(isnull(f4) eq 1,0,f4) +
con(isnull(f3) eq 1,0,f3) + con(isnull(f2) eq 1,0,f2) + con(isnull(f1) eq 1,0,f1)
        &do &while %q% ge 1
                &sv killgrid f%q%
                kill f%q% all
                &sv killgrid e%q%
                kill e%q% all
                &sv killgrid d%q%
                kill d%q% all
                &sv q = %q% - 1
        &end
  &end
  &if %r% eq 33 &then
        &do
        &sv s = %s% + 1
        reset
        j%s% = con(isnull(g33) eq 1,0,g33) + con(isnull(g32) eq 1,0,g32) +
con(isnull(g31) eq 1,0,g31) + con(isnull(g30) eq 1,0,g30) + con(isnull(g29) eq 1,0,g29) +
con(isnull(g28) eq 1,0,g28) + con(isnull(g27) eq 1,0,g27) + con(isnull(g26) eq 1,0,g26) +
con(isnull(g25) eq 1,0,g25) + con(isnull(g24) eq 1,0,g24) + con(isnull(g23) eq 1,0,g23) +
con(isnull(g22) eq 1,0,g22) + con(isnull(g21) eq 1,0,g21) + con(isnull(g20) eq 1,0,g20) +
con(isnull(g19) eq 1,0,g19) + con(isnull(g18) eq 1,0,g18) + con(isnull(g17) eq 1,0,g17) +
```

```
con(isnull(g16) eq 1,0,g16) + con(isnull(g15) eq 1,0,g15) + con(isnull(g14) eq 1,0,g14) +
con(isnull(g13) eq 1,0,g13) + con(isnull(g12) eq 1,0,g12) + con(isnull(g11) eq 1,0,g11) +
con(isnull(g10) eq 1,0,g10) + con(isnull(g9) eq 1,0,g9) + con(isnull(g8) eq 1,0,g8) +
con(isnull(g7) eq 1,0,g7) + con(isnull(g6) eq 1,0,g6) + con(isnull(g5) eq 1,0,g5) +
con(isnull(g4) eq 1,0,g4) + con(isnull(g3) eq 1,0,g3) + con(isnull(g2) eq 1,0,g2) +
con(isnull(g1) eq 1,0,g1)
        j%s% = con(isnull(h33) eq 1,0,h33) + con(isnull(h32) eq 1,0,h32) +
con(isnull(h31) eq 1,0,h31) + con(isnull(h30) eq 1,0,h30) + con(isnull(h29) eq 1,0,h29) +
con(isnull(h28) eq 1,0,h28) + con(isnull(h27) eq 1,0,h27) + con(isnull(h26) eq 1,0,h26) +
con(isnull(h25) eq 1,0,h25) + con(isnull(h24) eq 1,0,h24) + con(isnull(h23) eq 1,0,h23) +
con(isnull(h22) eq 1,0,h22) + con(isnull(h21) eq 1,0,h21) + con(isnull(h20) eq 1,0,h20) +
con(isnull(h19) eq 1,0,h19) + con(isnull(h18) eq 1,0,h18) + con(isnull(h17) eq 1,0,h17) +
con(isnull(h16) eq 1,0,h16) + con(isnull(h15) eq 1,0,h15) + con(isnull(h14) eq 1,0,h14) +
con(isnull(h13) eq 1,0,h13) + con(isnull(h12) eq 1,0,h12) + con(isnull(h11) eq 1,0,h11) +
con(isnull(h10) eq 1,0,h10) + con(isnull(h9) eq 1,0,h9) + con(isnull(h8) eq 1,0,h8) +
con(isnull(h7) eq 1,0,h7) + con(isnull(h6) eq 1,0,h6) + con(isnull(h5) eq 1,0,h5) +
con(isnull(h4) eq 1,0,h4) + con(isnull(h3) eq 1,0,h3) + con(isnull(h2) eq 1,0,h2) +
con(isnull(h1) eq 1,0,h1)
        k%s% = con(isnull(i33) eq 1,0,i33) + con(isnull(i32) eq 1,0,i32) + con(isnull(i31)
eq 1,0,i31) + con(isnull(i30) eq 1,0,i30) + con(isnull(i29) eq 1,0,i29) + con(isnull(i28) eq
1,0,i28) + con(isnull(i27) eq 1,0,i27) + con(isnull(i26) eq 1,0,i26) + con(isnull(i25) eq
1,0,i25) + con(isnull(i24) eq 1,0,i24) + con(isnull(i23) eq 1,0,i23) + con(isnull(i22) eq
1,0,i22) + con(isnull(i21) eq 1,0,i21) + con(isnull(i20) eq 1,0,i20) + con(isnull(i19) eq
1,0,i19) + con(isnull(i18) eq 1,0,i18) + con(isnull(i17) eq 1,0,i17) + con(isnull(i16) eq
1,0,i16) + con(isnull(i15) eq 1,0,i15) + con(isnull(i14) eq 1,0,i14) + con(isnull(i13) eq
1,0,i13) + con(isnull(i12) eq 1,0,i12) + con(isnull(i11) eq 1,0,i11) + con(isnull(i10) eq
1,0,i10) + con(isnull(i9) eq 1,0,i9) + con(isnull(i8) eq 1,0,i8) + con(isnull(i7) eq 1,0,i7) +
con(isnull(i6) eq 1,0,i6) + con(isnull(i5) eq 1,0,i5) + con(isnull(i4) eq 1,0,i4) +
con(isnull(i3) eq 1,0,i3) + con(isnull(i2) eq 1,0,i2) + con(isnull(i1) eq 1,0,i1)
        &do &while %r% ge 1
                &sv killgrid i%r%
                kill i%r% all
                &sv killgrid h%r%
                kill h%r% all
                &sv killgrid g%r%
                kill g%r% all
                &sv r = %r% - 1
        &end
  &end
  &if %s% eq 33 &then
        &do
        &sv t = %t% + 1
        reset
        m%t% = con(isnull(j33) eq 1,0,j33) + con(isnull(j32) eq 1,0,j32) + con(isnull(j31)
eq 1,0,j31) + con(isnull(j30) eq 1,0,j30) + con(isnull(j29) eq 1,0,j29) + con(isnull(j28) eq
1,0,j28) + con(isnull(j27) eq 1,0,j27) + con(isnull(j26) eq 1,0,j26) + con(isnull(j25) eq
```

```
1,0,j25) + con(isnull(j24) eq 1,0,j24) + con(isnull(j23) eq 1,0,j23) + con(isnull(j22) eq
1,0,j22) + con(isnull(j21) eq 1,0,j21) + con(isnull(j20) eq 1,0,j20) + con(isnull(j19) eq
1,0,j19) + con(isnull(j18) eq 1,0,j18) + con(isnull(j17) eq 1,0,j17) + con(isnull(j16) eq
1,0,j16) + con(isnull(j15) eq 1,0,j15) + con(isnull(j14) eq 1,0,j14) + con(isnull(j13) eq
1,0,j13) + con(isnull(j12) eq 1,0,j12) + con(isnull(j11) eq 1,0,j11) + con(isnull(j10) eq
1,0,j10) + con(isnull(j9) eq 1,0,j9) + con(isnull(j8) eq 1,0,j8) + con(isnull(j7) eq 1,0,j7) +
con(isnull(j6) eq 1,0,j6) + con(isnull(j5) eq 1,0,j5) + con(isnull(j4) eq 1,0,j4) +
con(isnull(j3) eq 1,0,j3) + con(isnull(j2) eq 1,0,j2) + con(isnull(j1) eq 1,0,j1)
        n%t% = con(isnull(k33) eq 1,0,k33) + con(isnull(k32) eq 1,0,k32) +
con(isnull(k31) eq 1,0,k31) + con(isnull(k30) eq 1,0,k30) + con(isnull(k29) eq 1,0,k29) +
con(isnull(k28) eq 1,0,k28) + con(isnull(k27) eq 1,0,k27) + con(isnull(k26) eq 1,0,k26) +
con(isnull(k25) eq 1,0,k25) + con(isnull(k24) eq 1,0,k24) + con(isnull(k23) eq 1,0,k23) +
con(isnull(k22) eq 1,0,k22) + con(isnull(k21) eq 1,0,k21) + con(isnull(k20) eq 1,0,k20) +
con(isnull(k19) eq 1,0,k19) + con(isnull(k18) eq 1,0,k18) + con(isnull(k17) eq 1,0,k17) +
con(isnull(k16) eq 1,0,k16) + con(isnull(k15) eq 1,0,k15) + con(isnull(k14) eq 1,0,k14) +
con(isnull(k13) eq 1,0,k13) + con(isnull(k12) eq 1,0,k12) + con(isnull(k11) eq 1,0,k11) +
con(isnull(k10) eq 1,0,k10) + con(isnull(k9) eq 1,0,k9) + con(isnull(k8) eq 1,0,k8) +
con(isnull(k7) eq 1,0,k7) + con(isnull(k6) eq 1,0,k6) + con(isnull(k5) eq 1,0,k5) +
con(isnull(k4) eq 1,0,k4) + con(isnull(k3) eq 1,0,k3) + con(isnull(k2) eq 1,0,k2) +
con(isnull(k1) eq 1,0,k1)
        o%t% = con(isnull(l33) eq 1,0,l33) + con(isnull(l32) eq 1,0,l32) + con(isnull(l31)
eq 1,0,l31) + con(isnull(l30) eq 1,0,l30) + con(isnull(l29) eq 1,0,l29) + con(isnull(l28) eq
1,0,l28) + con(isnull(l27) eq 1,0,l27) + con(isnull(l26) eq 1,0,l26) + con(isnull(l25) eq
1,0,l25) + con(isnull(l24) eq 1,0,l24) + con(isnull(l23) eq 1,0,l23) + con(isnull(l22) eq
1,0,l22) + con(isnull(l21) eq 1,0,l21) + con(isnull(l20) eq 1,0,l20) + con(isnull(l19) eq
1,0,l19) + con(isnull(l18) eq 1,0,l18) + con(isnull(l17) eq 1,0,l17) + con(isnull(l16) eq
1,0,l16) + con(isnull(l15) eq 1,0,l15) + con(isnull(l14) eq 1,0,l14) + con(isnull(l13) eq
1,0,l13) + con(isnull(l12) eq 1,0,l12) + con(isnull(l11) eq 1,0,l11) + con(isnull(l10) eq
1,0,l10) + con(isnull(l9) eq 1,0,l9) + con(isnull(l8) eq 1,0,l8) + con(isnull(l7) eq 1,0,l7) +
con(isnull(l6) eq 1,0,l6) + con(isnull(l5) eq 1,0,l5) + con(isnull(l4) eq 1,0,l4) +
con(isnull(l3) eq 1,0,l3) + con(isnull(l2) eq 1,0,l2) + con(isnull(l1) eq 1,0,l1)
        &do &while %s% ge 1
                &sv killgrid l%s%
                kill l%s% all
                &sv killgrid k%s%
                kill k%s% all
                &sv killgrid j%s%
                kill j%s% all
                &sv s = %s% - 1
        &end
  &end

  &if %x% eq 1 &then &do
        setcell 30
        ew_%.num% = 0
        rank_%.num% = 0
```

```
num_%.num% = 0

reset

&if %p% ge 1 &then &do
        ew_temp = con(isnull(a%p%) eq 1,0,a%p%) + con(isnull(ew_%.num%)
eq 1,0,ew_%.num%)
        btemp = con(isnull(b%p%) eq 1,0,b%p%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
        ctemp = con(isnull(c%p%) eq 1,0,c%p%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
        kill ew_%.num% all
        kill rank_%.num% all
        kill num_%.num% all
        rename ew_temp ew_%.num%
        rename btemp rank_%.num%
        rename ctemp num_%.num%
        kill a%p% all
        kill b%p% all
        kill c%p% all
        &sv p = %p% - 1
        &do &while %p% gt 0
                ew_temp =  con(isnull(ew_%.num%) eq 1,0,ew_%.num%) +
con(isnull(a%p%) eq 1,0,a%p%)
                btemp = con(isnull(rank_%.num%) eq 1,0,rank_%.num%) +
con(isnull(b%p%) eq 1,0,b%p%)
                ctemp = con(isnull(num_%.num%) eq 1,0,num_%.num%) +
con(isnull(c%p%) eq 1,0,c%p%)
                kill ew_%.num% all
                kill rank_%.num% all
                kill num_%.num% all
                rename ew_temp ew_%.num%
                rename btemp rank_%.num%
                rename ctemp num_%.num%
                kill a%p% all
                kill b%p% all
                kill c%p% all
                &sv p = %p% - 1
        &end
&end

&if %q% ge 1 &then &do
        ew_temp = con(isnull(d%q%) eq 1,0,d%q%) + con(isnull(ew_%.num%)
eq 1,0,ew_%.num%)
        btemp = con(isnull(e%q%) eq 1,0,e%q%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
```

```
			ctemp = con(isnull(f%q%) eq 1,0,f%q%) + con(isnull(num_%.num%) eq 
1,0,num_%.num%)
			kill ew_%.num% all
			kill rank_%.num% all
			kill num_%.num% all
			rename ew_temp ew_%.num%
			rename btemp rank_%.num%
			rename ctemp num_%.num%
			kill d%q% all
			kill e%q% all
			kill f%q% all
			&sv q = %q% - 1
			&do &while %q% gt 0
				ew_temp = con(isnull(d%q%) eq 1,0,d%q%) + 
con(isnull(ew_%.num%) eq 1,0,ew_%.num%)
				btemp = con(isnull(e%q%) eq 1,0,e%q%) + 
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
				ctemp = con(isnull(f%q%) eq 1,0,f%q%) + 
con(isnull(num_%.num%) eq 1,0,num_%.num%)
				kill ew_%.num% all
				kill rank_%.num% all
				kill num_%.num% all
				rename ew_temp ew_%.num%
				rename btemp rank_%.num%
				rename ctemp num_%.num%
				kill d%q% all
				kill e%q% all
				kill f%q% all
				&sv q = %q% - 1
			&end
		&end

		&if %r% ge 1 &then &do
			ew_temp = con(isnull(g%r%) eq 1,0,g%r%) + con(isnull(ew_%.num%) eq 
1,0,ew_%.num%)
			btemp = con(isnull(h%r%) eq 1,0,h%r%) + con(isnull(rank_%.num%) eq 
1,0,rank_%.num%)
			ctemp = con(isnull(i%r%) eq 1,0,i%r%) + con(isnull(num_%.num%) eq 
1,0,num_%.num%)
			kill ew_%.num% all
			kill rank_%.num% all
			kill num_%.num% all
			rename ew_temp ew_%.num%
			rename btemp rank_%.num%
			rename ctemp num_%.num%
			kill g%r% all
```

```
			kill h%r% all
			kill i%r% all
			&sv r = %r% - 1
			&do &while %r% gt 0
				ew_temp = con(isnull(g%r%) eq 1,0,g%r%) +
con(isnull(ew_%.num%) eq 1,0,ew_%.num%)
				btemp = con(isnull(h%r%) eq 1,0,h%r%) +
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
				ctemp = con(isnull(i%r%) eq 1,0,i%r%) +
con(isnull(num_%.num%) eq 1,0,num_%.num%)
				kill ew_%.num% all
				kill rank_%.num% all
				kill num_%.num% all
				rename ew_temp ew_%.num%
				rename btemp rank_%.num%
				rename ctemp num_%.num%
				kill g%r% all
				kill h%r% all
				kill i%r% all
				&sv r = %r% - 1
			&end
		&end

		&if %s% ge 1 &then &do
			ew_temp = con(isnull(j%s%) eq 1,0,j%s%) + con(isnull(ew_%.num%) eq
1,0,ew_%.num%)
			btemp = con(isnull(k%s%) eq 1,0,k%s%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
			ctemp = con(isnull(l%s%) eq 1,0,l%s%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
			kill ew_%.num% all
			kill rank_%.num% all
			kill num_%.num% all
			rename ew_temp ew_%.num%
			rename btemp rank_%.num%
			rename ctemp num_%.num%
			kill j%s% all
			kill k%s% all
			kill l%s% all
			&sv s = %s% - 1
			&do &while %s% gt 0
				ew_temp = con(isnull(j%s%) eq 1,0,j%s%) +
con(isnull(ew_%.num%) eq 1,0,ew_%.num%)
				btemp = con(isnull(k%s%) eq 1,0,k%s%) +
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
```

```
                    ctemp = con(isnull(l%s%) eq 1,0,l%s%) +
con(isnull(num_%.num%) eq 1,0,num_%.num%)
                    kill ew_%.num% all
                    kill rank_%.num% all
                    kill num_%.num% all
                    rename ew_temp ew_%.num%
                    rename btemp rank_%.num%
                    rename ctemp num_%.num%
                    kill j%s% all
                    kill k%s% all
                    kill l%s% all
                    &sv s = %s% - 1
            &end
    &end

    &if %t% ge 1 &then &do
            ew_temp = con(isnull(m%t%) eq 1,0,m%t%) + conisnull(ew_%.num%)
eq 1,0,ew_%.num%)
            btemp = con(isnull(n%t%) eq 1,0,n%t%) + con(isnull(rank_%.num%) eq
1,0,rank_%.num%)
            ctemp = con(isnull(o%t%) eq 1,0,o%t%) + con(isnull(num_%.num%) eq
1,0,num_%.num%)
            kill ew_%.num% all
            kill rank_%.num% all
            kill num_%.num% all
            rename ew_temp ew_%.num%
            rename btemp rank_%.num%
            rename ctemp num_%.num%
            kill m%t% all
            kill n%t% all
            kill o%t% all
            &sv t = %t% - 1
            &do &while %t% gt 0
                    ew_temp = con(isnull(m%t%) eq 1,0,m%t%) +
conisnull(ew_%.num%) eq 1,0,ew_%.num%)
                    btemp = con(isnull(n%t%) eq 1,0,n%t%) +
con(isnull(rank_%.num%) eq 1,0,rank_%.num%)
                    ctemp = con(isnull(o%t%) eq 1,0,o%t%) +
con(isnull(num_%.num%) eq 1,0,num_%.num%)
                    kill ew_%.num% all
                    kill rank_%.num% all
                    kill num_%.num% all
                    rename ew_temp ew_%.num%
                    rename btemp rank_%.num%
                    rename ctemp num_%.num%
                    kill m%t% all
```

```
                kill n%t% all
                kill o%t% all
                &sv t = %t% - 1
            &end
        &end
    &end

    &sv killgrid ranktest
    kill ranktest all
    &sv killgrid areatest
    kill areatest all
    &sv killgrid numtest
    kill numtest all
    &sv killgrid area_al
    kill area_al all

    &if [mod %x% 20] eq 0 &then &do
        q
        &pause &seconds 5
        grid
    &end

    &sv x = %x% - 1

    &sv xminx = %minx% - 100000
    &sv xmaxx = %maxx% + 100000
    &sv xminy = %miny% - 100000
    &sv xmaxy = %maxy% + 100000

    /* setwindow %minx% %miny% %maxx% %maxy% mask
    reset

&end

&type loop exited

&if %x% eq 0 &then &do
    &type Begin Calculation
    /* rankave = rank_%.num% / num_%.num%
    /* ew_temp = rankave * ew_%.num%
    /* &sv killgrid ew_%.num%
    /* kill ew_%.num% all
    /* &sv killgrid rank_%.num%
    /* kill rank_%.num% all
    /* &sv killgrid num_%.num%
    /* kill num_%.num% all
```

```
  /* &sv killgrid rankave
  /* kill rankave all
  &end

&else &goto redo

S:\GLUT_wetlands\wetland_model\layer1_8\statewide_product\ew_%.num% =
ew_%.num%
S:\GLUT_wetlands\wetland_model\layer1_8\statewide_product\rank_%.num% =
rank_%.num%
S:\GLUT_wetlands\wetland_model\layer1_8\statewide_product\num_%.num% =
num_%.num%

q
&stop

&routine cleanup

  &type cleanup kill
  q
  &pause &seconds 5
  &sys rd /s /q %killgrid%
  grid

&return

&routine swindow

  &sv iter = 0
  &sv buff = 12000

  &label wredo

  &sv minx = 0
  &sv maxx = 0
  &sv miny = 0
  &sv maxy = 0

  patch = con(%group% eq %x%,1)

  resample.%x% = sample(patch,patch)
  &sv fileunit = [open resample.%x% openstatus -read]
  &sv xy = [read %fileunit% readstatus]
  &sv xy = [read %fileunit% readstatus]
  &do &while %readstatus% = 0
        &do
```

```
        &sv xline = [trim [substr %xy% 3 15] -both ' ']
        &if %minx% eq 0 &then &sv minx = %xline%
                &else &if %xline% lt %minx% &then &sv minx = %xline%
        &if %maxx% eq 0 &then &sv maxx = %xline%
                &else &if %xline% gt %maxx% &then &sv maxx = %xline%
        &sv y = [trim [substr %xy% 19 15] -both ' ']
        &if %miny% eq 0 &then &sv miny = %y%
                &else &if %y% lt %miny% &then &sv miny = %y%
        &if %maxy% eq 0 &then &sv maxy = %y%
                &else &if %y% gt %maxy% &then &sv maxy = %y%

        &sv xy = [read %fileunit% readstatus]
        &end
&end

&if [close %fileunit%] eq 0 &then &type file closed
&sys del /f /q resample.%x%

&if %maxx% eq 0 &then &do

        &if %iter% eq 0 &then &do
                &sv group = group500
                &sv buff = 9000
        &end

        &if %iter% eq 1 &then &do
                &sv group = group250
                &sv buff = 7500
        &end

        &if %iter% eq 2 and %x% lt %z% &then &do
                setwindow %xminx% %xminy% %xmaxx% %xmaxy% mask
                &sv group = ew_rgrp
                &sv buff = 5000
        &end

        &else &if %iter% eq 2 &then &do
                setwindow mask mask
                &sv group = ew_rgrp
                &sv buff = 5000
        &end

        &if %iter% eq 3 &then &do
                setwindow mask mask
                &sv group = ew_rgrp
                &sv buff = 5000
```

```
        &end

        &sv killgrid patch
        kill patch all
        &sv iter = %iter% + 1
        &goto wredo
  &end

  &else &do
        &sv minx = %minx% - %buff%
        &sv maxx = %maxx% + %buff%
        &sv miny = %miny% - %buff%
        &sv maxy = %maxy% + %buff%

        &sv killgrid patch
        kill patch all

        setwindow %minx% %miny% %maxx% %maxy% mask
        &end
&reend
```

LAYER 1.7: HYDROLOGIC CONNECTIVITY OF WETLANDS – CREATE NON-CLASSIFIED LAYER AML

```
-------------------------------------------------------------------------------------------------------
 S:\GLUT_wetlands\wetland_model\amls \1_8final_step.aml

Note:  The original number given to this Layer was 1.8.  After removal on a previous
  layer it was renamed to 1.6.  All AMLs and associated files are still found under Layer
  1.8.

 Created by:  Stephen M. Carpenedo
        Natural Resource Spatial Analysis Laboratory
        Odum School of Ecology, University of Georgia
        Athens, GA

  This scrip takes the product of 1_8statewide.aml and 1_7.aml and combines them to be
  run in the connectivity measurement identified in the wetlands report.  The connectivity
  identifies where potential wetland restoration would increase the connectivity of
  existing wetlands.
-------------------------------------------------------------------------------------------------------

&args .wrk
&severity &error &fail
&echo &on

w %.wrk%
```

```
grid

setwindow S:\GLUT_wetlands\wetland_model\Library\mask
  S:\GLUT_wetlands\wetland_model\Library\mask

max_num_a = con(isnull(num_1) eq 1, 0, num_1) + con(isnull(num_2) eq 1, 0, num_2) +
  con(isnull(num_3) eq 1, 0, num_3) + con(isnull(num_4) eq 1, 0, num_4) +
  con(isnull(num_5) eq 1, 0, num_5) + con(isnull(num_6) eq 1, 0, num_6) +
  con(isnull(num_7) eq 1, 0, num_7) + con(isnull(num_8) eq 1, 0, num_8) +
  con(isnull(num_9) eq 1, 0, num_9)

max_num_b = con(isnull(num_10) eq 1, 0, num_10) + con(isnull(num_11) eq 1, 0,
  num_11) + con(isnull(num_12) eq 1, 0, num_12) + con(isnull(num_13) eq 1, 0,
  num_13) + con(isnull(num_14) eq 1, 0, num_14) + con(isnull(num_15) eq 1, 0,
  num_15) + con(isnull(num_16) eq 1, 0, num_16) + con(isnull(num_17) eq 1, 0,
  num_17) + con(isnull(num_18) eq 1, 0, num_18)

max_num_c = con(isnull(num_19) eq 1, 0, num_19) + con(isnull(num_20) eq 1, 0,
  num_20) + con(isnull(num_21) eq 1, 0, num_21) + con(isnull(num_22) eq 1, 0,
  num_22) + con(isnull(num_23) eq 1, 0, num_23) + con(isnull(num_24) eq 1, 0,
  num_24) + con(isnull(num_25) eq 1, 0, num_25)

max_num = con(isnull(max_num_a) eq 1, 0, max_num_a) + con(isnull(max_num_b) eq
  1, 0, max_num_b) + con(isnull(max_num_c) eq 1, 0, max_num_c)


rank_a = con(isnull(rank_1) eq 1, 0, rank_1) + con(isnull(rank_2) eq 1, 0, rank_2) +
  con(isnull(rank_3) eq 1, 0, rank_3) + con(isnull(rank_4) eq 1, 0, rank_4) +
  con(isnull(rank_5) eq 1, 0, rank_5) + con(isnull(rank_6) eq 1, 0, rank_6) +
  con(isnull(rank_7) eq 1, 0, rank_7) + con(isnull(rank_8) eq 1, 0, rank_8) +
  con(isnull(rank_9) eq 1, 0, rank_9)

rank_b = con(isnull(rank_10) eq 1, 0, rank_10) + con(isnull(rank_11) eq 1, 0, rank_11) +
  con(isnull(rank_12) eq 1, 0, rank_12) + con(isnull(rank_13) eq 1, 0, rank_13) +
  con(isnull(rank_14) eq 1, 0, rank_14) + con(isnull(rank_15) eq 1, 0, rank_15) +
  con(isnull(rank_16) eq 1, 0, rank_16) + con(isnull(rank_17) eq 1, 0, rank_17) +
  con(isnull(rank_18) eq 1, 0, rank_18)

rank_c = con(isnull(rank_19) eq 1, 0, rank_19) + con(isnull(rank_20) eq 1, 0, rank_20) +
  con(isnull(rank_21) eq 1, 0, rank_21) + con(isnull(rank_22) eq 1, 0, rank_22) +
  con(isnull(rank_23) eq 1, 0, rank_23) + con(isnull(rank_24) eq 1, 0, rank_24) +
  con(isnull(rank_25) eq 1, 0, rank_25)

OQ = con(isnull(rank_a) eq 1, 0, rank_a) + con(isnull(rank_b) eq 1, 0, rank_b) +
  con(isnull(rank_c) eq 1, 0, rank_c)
```

```
q

&describe max_num

&sv gmax = %grd$zmax%

grid

setwindow S:\GLUT_wetlands\wetland_model\Library\mask
  S:\GLUT_wetlands\wetland_model\Library\mask

quality = (float(max_num) / %gmax%) + (float(OQ) / (float(max_num) * 18))

aw_a = con(isnull(aw_1) eq 1, 0, aw_1) + con(isnull(aw_2) eq 1, 0, aw_2) +
  con(isnull(aw_3) eq 1, 0, aw_3) + con(isnull(aw_4) eq 1, 0, aw_4) + con(isnull(aw_5)
  eq 1, 0, aw_5) + con(isnull(aw_6) eq 1, 0, aw_6) + con(isnull(aw_7) eq 1, 0, aw_7) +
  con(isnull(aw_8) eq 1, 0, aw_8) + con(isnull(aw_9) eq 1, 0, aw_9)

aw_b = con(isnull(aw_10) eq 1, 0, aw_10) + con(isnull(aw_11) eq 1, 0, aw_11) +
  con(isnull(aw_12) eq 1, 0, aw_12) + con(isnull(aw_13) eq 1, 0, aw_13) +
  con(isnull(aw_14) eq 1, 0, aw_14) + con(isnull(aw_15) eq 1, 0, aw_15) +
  con(isnull(aw_16) eq 1, 0, aw_16) + con(isnull(aw_17) eq 1, 0, aw_17) +
  con(isnull(aw_18) eq 1, 0, aw_18)

aw_c = con(isnull(aw_19) eq 1, 0, aw_19) + con(isnull(aw_20) eq 1, 0, aw_20) +
  con(isnull(aw_21) eq 1, 0, aw_21) + con(isnull(aw_22) eq 1, 0, aw_22) +
  con(isnull(aw_23) eq 1, 0, aw_23) + con(isnull(aw_24) eq 1, 0, aw_24) +
  con(isnull(aw_25) eq 1, 0, aw_25)

sum_ex = con(isnull(aw_a) eq 1, 0, aw_a) + con(isnull(aw_b) eq 1, 0, aw_b) +
  con(isnull(aw_c) eq 1, 0, aw_c)


/* NC stands for not yet classified by natural breaks.

S:\GLUT_wetlands\wetland_model\layer1_7\final_nc\layer1_7nc = con(isnull(quality)
  eq 1, 0, quality) * con(isnull(sum_ex) eq 1, 0, sum_ex)

S:\GLUT_wetlands\wetland_model\Final_layers\not_classified\layer1_7nc =
  S:\GLUT_wetlands\wetland_model\layer1_7\final_nc\layer1_7nc

q
&stop
```

LAYER 1.8: NATURAL UPLAND HABITAT SURROUNDING WETLANDS – INITIAL PROCESSING AML

```
-------------------------------------------------------------------------
 S:\GLUT_wetlands\wetland_model\amls\layer1_9.aml

  Created:  6/30/2007
          Stephen M. Carpenedo
          Natural Resources Spatial Analysis Lab
          Odem School Of Ecology, University of Georgia
          Athens, GA  30606

Note:  The original number given to this Layer was 1.9.  After removal of a previous
layer it was renamed to 1.6.  All AMLs and associated files are still found under Layer
1.9.

  This aml is used to calculate the number of pixels that are considered as natural
  upland vegetation within 500 meters of a potential wetland restoration area.  Further
  processing is necessary to receive the percentage which is done by running the output
  through S:\GLUT_wetlands\wetland_model\amls\layer1_9_final_steps.aml

  Input Files:
   .wrkspc = S:\GLUT_wetlands\wetland_model\layer1_9\base_files
   .input = S:\GLUT_wetlands\wetland_model\Library\natural_veg

  Output Files:
   nat_up_veg = This is the natural vegetation with all wetland areas removed
   upveg_rawdata = This is the number of upland vegetation pixel within 500 meters
                  of a potential wetland restoration area.  This is the .input for
                 layer1_9_final_steps.aml

   Note:  This has been update from when last run.  Original if problems exist is located at
          G:\narsal\steve\Wetlands_project\course_model\AML\naatveg2.aml
----------------------------------------------------------------------------

&args .wrkspc .input
&severity &error &routine cleanup
&echo &on

w %.wrkspc%

&watch natveg_test.txt &commands

/*  This section takes the natural vegetation raster and converts all data to 1 and zero.
This has already been done and unless GA WRD updates the natural vegetation this
section does not need to be rerun.  File is currently called nat_up_veg located at
```

S:\GLUT_wetlands\wetland_model\layer1_9\base_files. If not updating the nat_up_veg file block out (/*) the following to and including q.

```
&describe %.input%

&sv col = %grd$ncols%

grid

setcell 30
setwindow S:\GLUT_wetlands\wetland_model\Library\mask
S:\GLUT_wetlands\wetland_model\Library\mask

unique = $$colmap + (%col% * $$rowmap) + 1

nv_unique = con(%.input% eq 1, unique)

buildvat nv_unique
createremap nv_unique nv_table RECNO # # INFO # #

nv_rcls = reclass(nv_unique, nv_table, DATA, #, #)

nat_up_veg = con(S:\GLUT_wetlands\wetland_model\Library\glut05_frag eq 2, 0,
nv_rcls)

kill unique all
kill nv_rcls all
kill nv_unique all

q

&describe nat_up_veg

&sv z = %grd$zmax%
&sv x = %grd$zmax%
&sv p = 0
&sv q = 0
&sv r = 0
&sv s = 0
&sv t = 0
&sv u = 0
&sv v = 0

grid
```

```
setwindow S:\GLUT_wetlands\wetland_model\Library\mask
S:\GLUT_wetlands\wetland_model\Library\mask
&sys del /f /q resample.*

&label redo

&do &while %x% gt 0

        &call swindow

        &sv p = %p% + 1
        areatest = con(nat_up_veg eq %x%, 1)
        a%p% = eucallocation(int(areatest),#,#,500)

        &if %p% eq 33 &then
                &do
                &sv q = %q% + 1
                reset
                b%q% = con(isnull(a33) eq 1,0,a33) + con(isnull(a32) eq 1,0,a32) +
con(isnull(a31) eq 1,0,a31) + con(isnull(a30) eq 1,0,a30) + con(isnull(a29) eq 1,0,a29) +
con(isnull(a28) eq 1,0,a28) + con(isnull(a27) eq 1,0,a27) + con(isnull(a26) eq 1,0,a26) +
con(isnull(a25) eq 1,0,a25) + con(isnull(a24) eq 1,0,a24) + con(isnull(a23) eq 1,0,a23) +
con(isnull(a22) eq 1,0,a22) + con(isnull(a21) eq 1,0,a21) + con(isnull(a20) eq 1,0,a20) +
con(isnull(a19) eq 1,0,a19) + con(isnull(a18) eq 1,0,a18) + con(isnull(a17) eq 1,0,a17) +
con(isnull(a16) eq 1,0,a16) + con(isnull(a15) eq 1,0,a15) + con(isnull(a14) eq 1,0,a14) +
con(isnull(a13) eq 1,0,a13) + con(isnull(a12) eq 1,0,a12) + con(isnull(a11) eq 1,0,a11) +
con(isnull(a10) eq 1,0,a10) + con(isnull(a9) eq 1,0,a9) + con(isnull(a8) eq 1,0,a8) +
con(isnull(a7) eq 1,0,a7) + con(isnull(a6) eq 1,0,a6) + con(isnull(a5) eq 1,0,a5) +
con(isnull(a4) eq 1,0,a4) + con(isnull(a3) eq 1,0,a3) + con(isnull(a2) eq 1,0,a2) +
con(isnull(a1) eq 1,0,a1)
                &do &while %p% ge 1
                        &sv killgrid a%p%
                        kill a%p% all
                        &sv p = %p% - 1
                &end
        &end

        &if %q% eq 33 &then
                &do
                &sv r = %r% + 1
                reset
                c%r% = con(isnull(b33) eq 1,0,b33) + con(isnull(b32) eq 1,0,b32) +
con(isnull(b31) eq 1,0,b31) + con(isnull(b30) eq 1,0,b30) + con(isnull(b29) eq 1,0,b29) +
con(isnull(b28) eq 1,0,b28) + con(isnull(b27) eq 1,0,b27) + con(isnull(b26) eq 1,0,b26) +
con(isnull(b25) eq 1,0,b25) + con(isnull(b24) eq 1,0,b24) + con(isnull(b23) eq 1,0,b23) +
con(isnull(b22) eq 1,0,b22) + con(isnull(b21) eq 1,0,b21) + con(isnull(b20) eq 1,0,b20) +
```

```
con(isnull(b19) eq 1,0,b19) + con(isnull(b18) eq 1,0,b18) + con(isnull(b17) eq 1,0,b17) +
con(isnull(b16) eq 1,0,b16) + con(isnull(b15) eq 1,0,b15) + con(isnull(b14) eq 1,0,b14) +
con(isnull(b13) eq 1,0,b13) + con(isnull(b12) eq 1,0,b12) + con(isnull(b11) eq 1,0,b11) +
con(isnull(b10) eq 1,0,b10) + con(isnull(b9) eq 1,0,b9) + con(isnull(b8) eq 1,0,b8) +
con(isnull(b7) eq 1,0,b7) + con(isnull(b6) eq 1,0,b6) + con(isnull(b5) eq 1,0,b5) +
con(isnull(b4) eq 1,0,b4) + con(isnull(b3) eq 1,0,b3) + con(isnull(b2) eq 1,0,b2) +
con(isnull(b1) eq 1,0,b1)
                &do &while %q% ge 1
                        &sv killgrid b%q%
                        kill b%q% all
                        &sv q = %q% - 1
                &end
        &end
        &if %r% eq 33 &then
                &do
                &sv s = %s% + 1
                reset
                d%s% = con(isnull(c33) eq 1,0,c33) + con(isnull(c32) eq 1,0,c32) +
con(isnull(c31) eq 1,0,c31) + con(isnull(c30) eq 1,0,c30) + con(isnull(c29) eq 1,0,c29) +
con(isnull(c28) eq 1,0,c28) + con(isnull(c27) eq 1,0,c27) + con(isnull(c26) eq 1,0,c26) +
con(isnull(c25) eq 1,0,c25) + con(isnull(c24) eq 1,0,c24) + con(isnull(c23) eq 1,0,c23) +
con(isnull(c22) eq 1,0,c22) + con(isnull(c21) eq 1,0,c21) + con(isnull(c20) eq 1,0,c20) +
con(isnull(c19) eq 1,0,c19) + con(isnull(c18) eq 1,0,c18) + con(isnull(c17) eq 1,0,c17) +
con(isnull(c16) eq 1,0,c16) + con(isnull(c15) eq 1,0,c15) + con(isnull(c14) eq 1,0,c14) +
con(isnull(c13) eq 1,0,c13) + con(isnull(c12) eq 1,0,c12) + con(isnull(c11) eq 1,0,c11) +
con(isnull(c10) eq 1,0,c10) + con(isnull(c9) eq 1,0,c9) + con(isnull(c8) eq 1,0,c8) +
con(isnull(c7) eq 1,0,c7) + con(isnull(c6) eq 1,0,c6) + con(isnull(c5) eq 1,0,c5) +
con(isnull(c4) eq 1,0,c4) + con(isnull(c3) eq 1,0,c3) + con(isnull(c2) eq 1,0,c2) +
con(isnull(c1) eq 1,0,c1)
                &do &while %r% ge 1
                        &sv killgrid c%r%
                        kill c%r% all
                        &sv r = %r% - 1
                &end
        &end
        &if %s% eq 33 &then
                &do
                &sv t = %t% + 1
                reset
                e%t% = con(isnull(d33) eq 1,0,d33) + con(isnull(d32) eq 1,0,d32) +
con(isnull(d31) eq 1,0,d31) + con(isnull(d30) eq 1,0,d30) + con(isnull(d29) eq 1,0,d29) +
con(isnull(d28) eq 1,0,d28) + con(isnull(d27) eq 1,0,d27) + con(isnull(d26) eq 1,0,d26) +
con(isnull(d25) eq 1,0,d25) + con(isnull(d24) eq 1,0,d24) + con(isnull(d23) eq 1,0,d23) +
con(isnull(d22) eq 1,0,d22) + con(isnull(d21) eq 1,0,d21) + con(isnull(d20) eq 1,0,d20) +
con(isnull(d19) eq 1,0,d19) + con(isnull(d18) eq 1,0,d18) + con(isnull(d17) eq 1,0,d17) +
con(isnull(d16) eq 1,0,d16) + con(isnull(d15) eq 1,0,d15) + con(isnull(d14) eq 1,0,d14) +
```

```
con(isnull(d13) eq 1,0,d13) + con(isnull(d12) eq 1,0,d12) + con(isnull(d11) eq 1,0,d11) +
con(isnull(d10) eq 1,0,d10) + con(isnull(d9) eq 1,0,d9) + con(isnull(d8) eq 1,0,d8) +
con(isnull(d7) eq 1,0,d7) + con(isnull(d6) eq 1,0,d6) + con(isnull(d5) eq 1,0,d5) +
con(isnull(d4) eq 1,0,d4) + con(isnull(d3) eq 1,0,d3) + con(isnull(d2) eq 1,0,d2) +
con(isnull(d1) eq 1,0,d1)
                &do &while %s% ge 1
                        &sv killgrid d%s%
                        kill d%s% all
                        &sv s = %s% - 1
                &end

        &if %t% eq 33 &then
                &do
                &sv u = %u% + 1
                reset
                f%u% = con(isnull(e33) eq 1,0,e33) + con(isnull(e32) eq 1,0,e32) +
con(isnull(e31) eq 1,0,e31) + con(isnull(e30) eq 1,0,e30) + con(isnull(e29) eq 1,0,e29) +
con(isnull(e28) eq 1,0,e28) + con(isnull(e27) eq 1,0,e27) + con(isnull(e26) eq 1,0,e26) +
con(isnull(e25) eq 1,0,e25) + con(isnull(e24) eq 1,0,e24) + con(isnull(e23) eq 1,0,e23) +
con(isnull(e22) eq 1,0,e22) + con(isnull(e21) eq 1,0,e21) + con(isnull(e20) eq 1,0,e20) +
con(isnull(e19) eq 1,0,e19) + con(isnull(e18) eq 1,0,e18) + con(isnull(e17) eq 1,0,e17) +
con(isnull(e16) eq 1,0,e16) + con(isnull(e15) eq 1,0,e15) + con(isnull(e14) eq 1,0,e14) +
con(isnull(e13) eq 1,0,e13) + con(isnull(e12) eq 1,0,e12) + con(isnull(e11) eq 1,0,e11) +
con(isnull(e10) eq 1,0,e10) + con(isnull(e9) eq 1,0,e9) + con(isnull(e8) eq 1,0,e8) +
con(isnull(e7) eq 1,0,e7) + con(isnull(e6) eq 1,0,e6) + con(isnull(e5) eq 1,0,e5) +
con(isnull(e4) eq 1,0,e4) + con(isnull(e3) eq 1,0,e3) + con(isnull(e2) eq 1,0,e2) +
con(isnull(e1) eq 1,0,e1)
                &do &while %t% ge 1
                        &sv killgrid e%t%
                        kill e%t% all
                        &sv t = %t% - 1
                &end
        &end

        &if %u% eq 33 &then
                &do
                &sv v = %v% + 1
                reset
                g%v% = con(isnull(f33) eq 1,0,f33) + con(isnull(f32) eq 1,0,f32) +
con(isnull(f31) eq 1,0,f31) + con(isnull(f30) eq 1,0,f30) + con(isnull(f29) eq 1,0,f29) +
con(isnull(f28) eq 1,0,f28) + con(isnull(f27) eq 1,0,f27) + con(isnull(f26) eq 1,0,f26) +
con(isnull(f25) eq 1,0,f25) + con(isnull(f24) eq 1,0,f24) + con(isnull(f23) eq 1,0,f23) +
con(isnull(f22) eq 1,0,f22) + con(isnull(f21) eq 1,0,f21) + con(isnull(f20) eq 1,0,f20) +
con(isnull(f19) eq 1,0,f19) + con(isnull(f18) eq 1,0,f18) + con(isnull(f17) eq 1,0,f17) +
con(isnull(f16) eq 1,0,f16) + con(isnull(f15) eq 1,0,f15) + con(isnull(f14) eq 1,0,f14) +
con(isnull(f13) eq 1,0,f13) + con(isnull(f12) eq 1,0,f12) + con(isnull(f11) eq 1,0,f11) +
```

```
con(isnull(f10) eq 1,0,f10) + con(isnull(f9) eq 1,0,f9) + con(isnull(f8) eq 1,0,f8) +
con(isnull(f7) eq 1,0,f7) + con(isnull(f6) eq 1,0,f6) + con(isnull(f5) eq 1,0,f5) +
con(isnull(f4) eq 1,0,f4) + con(isnull(f3) eq 1,0,f3) + con(isnull(f2) eq 1,0,f2) +
con(isnull(f1) eq 1,0,f1)
		&do &while %u% ge 1
			&sv killgrid f%u%
			kill f%u% all
			&sv u = %u% - 1
		&end
	&end

	&if %x% eq 1 &then &do
		setcell 30
		upveg_rawdata = 0
		rank = 0
		num = 0

		reset

		&if %p% ge 1 &then &do
			natveg_temp = con(isnull(a%p%) eq 1,0,a%p%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
			rename natveg_temp upveg_rawdata
			kill a%p% all
			&sv p = %p% - 1
			&do &while %p% gt 0
				natveg_temp =  con(isnull(upveg_rawdata) eq
1,0,upveg_rawdata) + con(isnull(a%p%) eq 1,0,a%p%)
				kill upveg_rawdata all
				rename natveg_temp upveg_rawdata
				kill a%p% all
				&sv p = %p% - 1
			&end
		&end

		&if %q% ge 1 &then &do
			natveg_temp = con(isnull(b%q%) eq 1,0,b%q%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
			kill upveg_rawdata all
			rename natveg_temp upveg_rawdata
			kill b%q% all
			&sv q = %q% - 1
			&do &while %q% gt 0
				natveg_temp = con(isnull(b%q%) eq 1,0,b%q%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
				kill upveg_rawdata all
```

```
                rename natveg_temp upveg_rawdata
                kill b%q% all
                &sv q = %q% - 1
            &end
        &end

        &if %r% ge 1 &then &do
            natveg_temp = con(isnull(c%r%) eq 1,0,c%r%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
            kill upveg_rawdata all
            rename natveg_temp upveg_rawdata
            kill c%r% all
            &sv r = %r% - 1
            &do &while %r% gt 0
                natveg_temp = con(isnull(c%r%) eq 1,0,c%r%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
                kill upveg_rawdata all
                rename natveg_temp upveg_rawdata
                kill c%r% all
                &sv r = %r% - 1
            &end
        &end

        &if %s% ge 1 &then &do
            natveg_temp = con(isnull(d%s%) eq 1,0,d%s%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
            kill upveg_rawdata all
            rename natveg_temp upveg_rawdata
            kill d%s% all
            &sv s = %s% - 1
            &do &while %s% gt 0
                natveg_temp = con(isnull(d%s%) eq 1,0,d%s%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
                kill upveg_rawdata all
                rename natveg_temp upveg_rawdata
                kill d%s% all
                &sv s = %s% - 1
            &end
        &end

        &if %t% ge 1 &then &do
            natveg_temp = con(isnull(e%t%) eq 1,0,e%t%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
            kill upveg_rawdata all
            rename natveg_temp upveg_rawdata
            kill e%t% all
```

```
                &sv t = %t% - 1
                &do &while %t% gt 0
                        natveg_temp = con(isnull(e%t%) eq 1,0,e%t%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
                        kill upveg_rawdata all
                        rename natveg_temp upveg_rawdata
                        kill e%t% all
                        &sv t = %t% - 1
                &end
        &end

        &if %u% ge 1 &then &do
                natveg_temp = con(isnull(f%u%) eq 1,0,f%u%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
                kill upveg_rawdata all
                rename natveg_temp upveg_rawdata
                kill f%u% all
                &sv u = %u% - 1
                &do &while %u% gt 0
                        natveg_temp = con(isnull(f%u%) eq 1,0,f%u%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
                        kill upveg_rawdata all
                        rename natveg_temp upveg_rawdata
                        kill f%u% all
                        &sv u = %u% - 1
                &end
        &end

        &if %v% ge 1 &then &do
                natveg_temp = con(isnull(g%v%) eq 1,0,g%v%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
                kill upveg_rawdata all
                rename natveg_temp upveg_rawdata
                kill g%v% all
                &sv v = %v% - 1
                &do &while %v% gt 0
                        natveg_temp = con(isnull(g%v%) eq 1,0,g%v%) +
con(isnull(upveg_rawdata) eq 1,0,upveg_rawdata)
                        kill upveg_rawdata all
                        rename natveg_temp upveg_rawdata
                        kill g%v% all
                        &sv v = %v% - 1
                &end
        &end
    &end
 &end
```

```
  &sv killgrid areatest
  kill areatest all

  &if [mod %x% 20] eq 0 &then &do
        q
        &pause &seconds 5
        grid
  &end

  &sv x = %x% - 1

  &sv minx = %minx% - 10000
  &sv maxx = %maxx% + 10000
  &sv miny = %miny% - 10000
  &sv maxy = %maxy% + 10000

  setwindow %minx% %miny% %maxx% %maxy%
S:\GLUT_wetlands\wetland_model\Library\mask

  &end

&type loop exited

if %x% eq 0 &then &do
  &type Begin Calculation
  &end

&else &goto redo

q
&stop

&routine cleanup

  &type cleanup kill
  q
  &pause &seconds 5
  &sys rd /s /q %killgrid%
  grid

&return

&routine swindow

  &sv iter = 0
```

```
&sv buff = 600

&label wredo

&sv minx = 0
&sv maxx = 0
&sv miny = 0
&sv maxy = 0


    patch = con(nat_up_veg eq %x%,1)

    resample.%x% = sample(patch,patch)
    &sv fileunit = [open resample.%x% openstatus -read]
    &sv xy = [read %fileunit% readstatus]
    &sv xy = [read %fileunit% readstatus]
    &do &while %readstatus% = 0
        &do
        &sv xline = [trim [substr %xy% 3 15] -both ' ']
        &if %minx% eq 0 &then &sv minx = %xline%
            &else &if %xline% lt %minx% &then &sv minx = %xline%
        &if %maxx% eq 0 &then &sv maxx = %xline%
            &else &if %xline% gt %maxx% &then &sv maxx = %xline%
        &sv y = [trim [substr %xy% 19 15] -both ' ']
        &if %miny% eq 0 &then &sv miny = %y%
            &else &if %y% lt %miny% &then &sv miny = %y%
        &if %maxy% eq 0 &then &sv maxy = %y%
            &else &if %y% gt %maxy% &then &sv maxy = %y%

        &sv xy = [read %fileunit% readstatus]
        &end
    &end

    &if [close %fileunit%] eq 0 &then &type file closed
    &sys del /f /q resample.%x%

    &if %maxx% eq 0 &then &do

        &if %iter% eq 0 &then &do
            setwindow S:\GLUT_wetlands\wetland_model\Library\mask
S:\GLUT_wetlands\wetland_model\Library\mask
            &sv group = nat_up_veg
            &sv buff = 600
            &sv killgrid patch
            kill patch all
            &sv iter = %iter% + 1
```

```
                    &goto wredo

            &end

            &if %iter% ge 1 &then &do
                    &sv killgrid patch
                    kill patch all
                    &sv x = %x% - 1
                    &goto redo
            &end

    &end

    &else &do
            &sv minx = %minx% - %buff%
            &sv maxx = %maxx% + %buff%
            &sv miny = %miny% - %buff%
            &sv maxy = %maxy% + %buff%

            &sv killgrid patch
            kill patch all

            setwindow %minx% %miny% %maxx% %maxy%
S:\GLUT_wetlands\wetland_model\Library\mask
    &end
&return
```

LAYER 1.8: NATURAL UPLAND HABITAT SURROUNDING WETLANDS – FINAL PROCESSING AML

S:\GLUT_wetlands\wetland_model\amls\layer1_9_final_steps.aml

Note: The original number given to this Layer was 1.9. After removal of a previous layer it was renamed to 1.6. All AMLs and associated files are still found under Layer 1.9.

Created by: 6/28/2007
Stephen M. Carpenedo
Natural Resources Spatial Analysis Lab
Odem School of Ecology, University of Georgia
Athens, GA 30606
(706)542-3489

This .aml is used to take data generated in s:\GLUT_wetlands\wetland_model\amls\layer1_9.aml and calculate the percent of natural upland vegetation within 500 meters of a potential wetland restoration area. It also takes the percentage and masks out all areas considered not restorable from Layer 1.1 and areas of natural upland vegetation that do not have hydric soils identified in Layer 1.2.

Further processing is needed on the output of this AML, including running the masking additive layer AML and reclassifying using Jenks Optimization in ArcMAP.

Input Files:
.wrkspc = S:\GLUT_wetlands\wetland_model\layer1_9\base_files
.input is the raw data that is the final product of S:\GLUT_wetlands\wetland_model\amls\layer1_9.aml which calculated the number of pixels within 500 meters of a PWRA that are considered as natural upland vegetation. Located at:
S:\GLUT_wetlands\wetland_model\layer1_9\base_files\upveg_rawdata
hydsoils = the STATSGO hydric soils classified as either 9 or 0. Located at:
S:\GLUT_wetlands\wetland_model\Library\statsgo_soils
upland_veg = the natural vegetation with all of the areas that are considered wetlands in GLUT 2005 removed to give only natural upland patches. It is located at
S:\GLUT_wetlands\wetland_model\layer1_9\base_files\nat_up_veg
restor = Layer 1.1 which is the areas that are considered as restorable or not restorable based on land cover classification
S:\GLUT_wetlands\wetland_model\Final_layers\layer1_1

```
&args .wrkspc .input
&severity &error &ignore
&echo &on

w %.wrkspc%

grid

setwindow S:\GLUT_wetlands\wetland_model\Library\mask
  S:\GLUT_wetlands\wetland_model\Library\mask

upveg_temp = focalsum(%.input%, CIRCLE, 500, data)

/*  Calculated the percent of natural upland vegetation within 500 meters
upveg_perc = ((float(upveg_temp) * 900) / 250000) * 100

kill upveg_temp all

/* creates mask that removes all natural upland vegetation that does not have hydric soils
  identified in Layer 1.2

&sv hydsoils = S:\GLUT_wetlands\wetland_model\Library\statsgo_soils
```

&sv upland_veg = S:\GLUT_wetlands\wetland_model\layer1_9\base_files\nat_up_veg

up_veg_mask = con(%hydsoils% eq 9, 0, %upland_veg%)

/* removes all natural upland vegetation and not restorable areas

&sv restor = S:\GLUT_wetlands\wetland_model\Final_layers\layer1_1

mask_temp1 = con(%restor% eq 1, 0, upveg_perc)
S:\GLUT_wetlands\wetland_model\layer1_9\not_classified\layer1_9nc =
con(up_veg_mask eq 1, 0, mask_temp1)

kill mask_temp1 all

q
stop

LAYER 1.9: MAINTENANCE OF HIGH WATER QUALITY STREAMS AML

S:\GLUT_wetlands\wetland_model\amls\layer1_10.aml

Created 4/5/2007
Stephen M. Carpenedo and Kevin Samples
Natural Resources Spatial Analysis Laboratory
Odum School of Ecology, University of Georgia
Athens, GA 30606

This AML is divided into two separate parts. Part One calculated the potential runoff entering an open water source from the landscape. This is done using flow accumulation models that are unweighted and weighted by the Natural Resource Conservation Service's Runoff Curve Number Method. Part Two calculates the distance of a source pixel to open water.

Further processing is necessary to complete Layer 1.10, including, reclassifying the output of the Potential Runoff and Distance to impairment indices. The reclassified files are then multiplied to receive the final unclassified data layer.

INPUT FILES: .wrk is the workspace
S:\GLUT_wetlands\wetland_model\layer1_10\base_files
glut_2005: the 2005 Georgia land Use Trends Database located at:
S:\GLUT_wetlands\wetland_model\Library\glut_2005
for this a copy is located in the workspace folder.
hydgrp: the hydrologic soils group map created using STATSGO Soils located at
S:\GLUT_wetlands\wetland_model\layer1_10\base_files\hydgrp
.huc is the raster image containing the 8 digit HUCs located at

S:\GLUT_wetlands\wetland_model\Library\huc8
.out is the for the distance to impairment index it is located at
S:\GLUT_wetlands\wetland_model\layer1_10\base_files\DII
ISOPLUVIAL MAPS: Map calculating the potential 2 year/24 hour storm event
is located at S:\GLUT_wetlands\wetland_model\Library\iso_map
FLOW CALCULATION: All flowlength and open water sources are generated using
GANHP High Priority Streams coverage, variables used are identified in the
report
S:\GLUT_wetlands\wetland_model\Library\hpstreams
MASK: located s:\dems\mask

WORKSPACE: Workspace for this aml is
S:\GLUT_wetlands\wetland_model\layer1_10\base_files
and all files generated are in the base_files folder.

```
&args .wrk .huc .out
&severity &error &fail
&echo &on

w %.wrk%

grid

setwindow f:\l1_10\mask f:\l1_10\mask

/*  SET 1:  POTENTIAL RUNOFF INDEX
/*        Does not reclassify data, this is done by hand!

/*    RUNOFF POTENTIAL INDEX IS CALCULATED IN LAYER 1.4 AND NOT
  RECALCULATED FOR THIS LAYER USING WS THE RPI (NON-CLASSIFIED)
  IS MASKED SO ONLY WATERSHEDS WITH A HIGH PRIORITY STREAMS
  ARE USED.

/* SET 2: Distance to Impairment Index
/*        Does  not reclassify data, this is done by hand

impnd = setnull(%.huc% eq 0, %.huc%)
impgrp = regiongroup(impnd,#,eight)
impsnp = snappour(impgrp, f:\l1_4\flowacc, 60)
ws = watershed(f:\l1_4\flow_dir,impsnp)

&describe ws

&sv h = %grd$zmax%
&sv z = %grd$zmax%
```

```
flowlen = f:\l1_4\flowlen

&do &while %h% gt 0
  ws_%h% = con(ws eq %h%, 1)
  ws_rsmpl = resample(ws_%h%, 1000)
  &call swindow
  ws_temp  = ws_%h%
  kill ws_%h%
  rename ws_temp ws_%h%
  dem_%h% = con(ws_%h% gt 0, f:\l1_4\ned_u17)
  implen = con(ws_%h% gt 0 && impnd gt 0, flowlen)
  cost = costallocation(int(implen),con(dem_%h% lt 0,0,dem_%h%), #, #, #, #)

  &if %z% eq %h% &then
        &do
        %.out% = con(ws_%h% gt 0, abs(int(flowlen) - cost),0)
        &end
  &else
        &do

        reset
        &sv out = %.out%
        temp = con(ws_%h% gt 0, abs(int(flowlen) - cost),0)
        temp2 = con(isnull(temp) eq 1, 0, temp)
        output = con(isnull(%.out%) eq 1, 0, %.out%)
        disttemp = temp2 + output
        kill temp all
        kill temp2 all
        kill output all
        kill %.out% all
        rename disttemp cost_ncls
        &end

  kill dem_%h% all
  kill ws_%h% all
  kill implen all
  kill cost all
  kill ws_rsmpl all

  &sv h = %h% - 1

  reset

&end
q
```

```
&stop

/*  This section sets the window to a smaller size to increase data processing speed

&routine swindow
  &sv minx = 0
  &sv maxx = 0
  &sv miny = 0
  &sv maxy = 0

  patch = con(ws_rsmpl gt 0,1)

  &label wredo

  resample.%h% = sample(patch,patch)
  &sv fileunit = [open resample.%h% openstatus -read]
  &sv xy = [read %fileunit% readstatus]
  &sv xy = [subst [read %fileunit% readstatus] '        ' ,]
  &do &while %readstatus% = 0
        &do
        &sv x = [extract 2 %xy%]
        &if %minx% eq 0 &then &sv minx = %x%
                &else &if %x% lt %minx% &then &sv minx = %x%
        &if %maxx% eq 0 &then &sv maxx = %x%
                &else &if %x% gt %maxx% &then &sv maxx = %x%
                &sv y = [extract 3 %xy%]
        &if %miny% eq 0 &then &sv miny = %y%
                &else &if %y% lt %miny% &then &sv miny = %y%
        &if %maxy% eq 0 &then &sv maxy = %y%
                &else &if %y% gt %maxy% &then &sv maxy = %y%
                &sv xy = [subst [read %fileunit% readstatus] '          ' ,]
        &end
  &end

  &if [close %fileunit%] eq 0 &then &type file closed
  &sys del /f /q resample.%h%

  &if %maxx% gt 0 &then &do
        &sv minx = %minx% - 4500
        &sv maxx = %maxx% + 4500
        &sv miny = %miny% - 4500
        &sv maxy = %maxy% + 4500
        setwindow %minx% %miny% %maxx% %maxy% f:\l1_10\mask
  &end

  &else &do
```

```
        setwindow f:\l1_10\mask f:\l1_10\mask
        kill patch all
        patch = con(ws_%h% gt 0,1)
        &goto wredo
  &end

  &sv killgrid patch
  kill patch all

&return
```

APPENDIX D

OCTOBER 18TH, 2006 SURVEY USED TO EVALUATE THE IMPORTANCE OF INDIVIDUAL LAYERS IN COMPONENT ONE AND WETLAND FUNCTIONS AND VALUES WHEN SELECTING COMPENSATORY WETLAND MITIGATION SITES

**Note: In the thesis body and survey form layer numbers do not match due to the removal of layer 1.6 Biodiversity conservation - Weighted Density after results of the survey showed that all respondents deemed it to misrepresent locations for potential wetland restoration sites.*

Classification and Weighting Score Card

Name of Organization: __________________

Primary purpose when dealing with wetland mitigation? ___________________________
____
____

Part 1

Please choose one of the following classification schemes that may best highlight the information you and your organization deem important regarding each particular layer of component 1. Please also offer a brief explanation of what you and your organization deemed most important when choosing a classification for each layer.

Layer 1.2 Hydric soils
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____

Layer 1.3 Jurisdictional designation
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____

Layer 1.4 Water quality and quantity index
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____

Layer 1.5 Connectivity to existing conservation areas
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____

Layer 1.6 Biodiversity conservation - Weighted density
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____

Layer 1.7 Terrestrial dispersal corridors between wetlands
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____
____

Layer 1.8 Hydrologic connectivity of wetlands
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____

Layer 1.9 Natural upland vegetation surrounding wetlands
___ Natural Breaks
___ Equal Area
___ Equal Interval
___ Standard Deviation
____
____

Part 2

Based on importance of the information represented by each layer in component one of the potential wetland restoration model to you and your organization please rank each layer by their importance, Low, Medium or High.

___ Layer 1.2 Hydric soils
___ Layer 1.3 Jurisdictional designation
___ Layer 1.4 Water quality and quantity index
___ Layer 1.5 Connectivity to existing conservation areas
___ Layer 1.6 Biodiversity conservation - Weighted density
___ Layer 1.7 Terrestrial dispersal corridors between wetlands
___ Layer 1.8 Hydrologic connectivity of wetlands
___ Layer 1.9 Natural upland vegetation surrounding wetlands
___ Layer 1.10 Maintenance of high water quality streams

Part 3

Based on importance of individual wetland function and values in terms of wetland mitigation to you and your organization please rank each identified wetland function and value on their importance, Low, Medium or High.

___ Water quality / water quantity
___ Flow regulation / flood control
___ Wildlife habitat
___ Ecological services
___ Biodiversity conservation
___ Recreation
___ Education
___ Connectivity
___ Ease of restoration
___ Scenic value