A SPATIAL MODEL RANKING THE POTENTIAL FOR MITIGATION SITES BASED ON ECOSYSTEM FUNCTIONS: AN ANALYSIS OF COASTAL GEORGIA IN 2008 AND 2030

by

HEATHER LOUISE ASHBY

(Under the Direction of Elizabeth Kramer)

ABSTRACT

Wetland mitigation can be accomplished through the enhancement, protection, creation or restoration of wetlands. In coastal regions, mitigated sites are at risk of being lost or degraded due to the land use changes that occur in response to sea-level rise, loss of shoreline stability, and human alterations. To improve the success of mitigated coastal wetlands, it is imperative that the future risks to these sites be known. To accomplish this, a future land use map is created for the year 2030 for coastal Georgia which is used in a risk assessment to identify 1) the wetlands that are most at risk of being lost or degraded in the year 2030, 2) where sites with the greatest potential for benefiting wetland functions occur in the landscape for the years 2008 and 2030, and 3) where the potential will increase the most during this time frame.

INDEX WORDS: Wetlands, Wetland Mitigation, Coastal Wetlands, GIS, Spatial Analysis Modeling, SLAMM, SLEUTH, AMBUR, Future Land Use, Marshes, Sea Level Rise, Shoreline Stability

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DEDICATION

This work is dedicated to my wonderful husband, who was by my side and encouraging me throughout the entire thesis process.

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CHAPTER 1

INTRODUCTION

Over 117 million acres, or approximately 50%, of wetlands have been lost in the contiguous United States since colonial times (Connolly et al. 2005). Acts such as dredging, filling and the conversion of wetlands to agriculture have led to this loss in wetland acreage. Even more important than the loss of acreage is the loss of functions that wetlands provide to society. These functions include maintaining water quality, regulating hydrologic flows, storing water, reducing erosion, providing habitat to various terrestrial and aquatic species, providing areas of recreation (Costanza et al. 1987), and stabilizing shorelines from storm and erosion damage (Gedan et al. 2011).

To prevent the further loss of wetland acreage and function due to dredging and filling, the practice of compensatory wetland mitigation was created under Section 404 of the Clean Water Act (Pruitt and Somerville 2006). In this act, the preferred method of restoration, establishment, preservation or enhancement of wetlands is mitigation banking because it promotes the aggregation of wetland sites, which in turn reduces monitoring costs and improves the likelihood that the mitigated sites will successfully perform wetland functions (Federal Register 2008; Sakyi 2010). Future risks can compromise the success of these mitigated wetland sites. Current techniques used to select compensatory wetland mitigation sites do not consider how future land use changes, due to natural and anthropogenic means, can alter the potential of a mitigation site to perform wetland functions (Kramer 2011; Kramer and Carpenedo 2009). Coastal regions are especially susceptible to land use changes and the alteration of wetlands due to rising sea-levels, increased storm surges and human development (Adam 2002; Brock and Nielson 2009; Cahoon and Guntenspergen 2010; Connolly et al. 2005; Erwin 2009; Freeman et al. 2007; Hopkinson et al. 2008; Scavia 2002; Tiner 1999). By knowing where future land use changes occur for the coast of Georgia, the future potential for mitigation sites can be determined.

For the coastal region of Georgia, human development has increased by 502,539 ha between the years 1974 and 2008 and the area of forested wetlands, saltwater wetlands and freshwater wetlands has decreased by 74,869 ha, 90,398 ha and 1,272,059 ha, respectively. Besides the direct loss of wetlands through development, the functions that wetlands provide are also degraded through the increase in pollution which is associated with increased runoff of these impervious surfaces. Specific to coastal areas, the amount of impervious surface in a watershed is correlated with the level of fecal coliform found in water bodies so that watersheds with higher percentages of impervious surface tend to have higher levels of fecal coliform(Kelsey et al. 2004; Mallin et al. 2001; Mallin et al. 2009; Mallin et al. 2000). Fecal coliform, which is assimilated by shellfish in estuaries and accumulated in beach areas, is hazardous to human health (Burkhardt III and Calci 2000) so it is important for wetlands to be able to improve the quality of the water before it reaches shellfish nurseries and beaches. In the future, the population of coastal Georgia is predicted to increase by 50%, which will cause a further loss and degradation to existing wetlands. If the future location of urban development in the landscape were known, mitigated wetland sites could be placed between developed areas and shellfish nurseries and beaches to prevent an increase of fecal coliform over time.

Natural processes, such as sea-level rise, storm surges, and the accretion of sediments are also predicted to alter the spatial location and the condition of wetlands in coastal areas, which will affect the stability of the shoreline. Climate change scenarios predict that there will be a sea-level rise of 2.98 mm/yr and that the number and intensity of storm surges will increase (National Oceanic and Atmospheric Administration 2011). If the rise in sea-level is greater than the accumulation of sediments, then wetlands can respond by either moving farther inland or becoming inundated. Either of these responses can cause a loss in shoreline stability because the loss of wetland between the ocean and the upland lessens the ability of wetlands to reduce the effects of storms and erosion (Gedan et al. 2011). The salinity of water displaced on the upland during a storm surge and the winds associated with hurricanes can degrade the quality of wetlands, and in some cases cause the wetlands to be lost(Michener and Blood 1997), which will also lessen the ability of wetlands to stabilize the coast. When shoreline stability decreases, the low-lying coastal areas become more vulnerable to future storm events, which can lead to an increase in property damage and human deaths (IPCC 2007; McGranahan et al. 2007). In coastal regions, mitigation sites need to be used to increase shoreline stabilization in addition to the other functions mentioned previously, and the only way to determine where the mitigation sites need to be placed in the landscape to improve this wetland function is to be able to predict what areas are at the most risk of changing due to the risks of sea-level rise, storm surge and the increase of human development.

Previous methodologies (The Potential Wetland Restoration Site Index and the Wetland Site Index), which rank the potential for wetland mitigation based on the functions performed by forested wetlands, have been created by the staff of the Natural Resources and Spatial Analysis Laboratory (NARSAL). These methodologies do not include functions that are specific to coastal wetlands, such as their ability to improve water quality to shellfish areas and beaches and improve shoreline stability, nor do they evaluate the effect that future risks will have on the potential for mitigation at specific locations in the landscape. To account for these things, several steps are taken to create a methodology that specifically looks at the potential of wetland mitigation to improve coastal wetland functions and how a future change in land use will affect the potential for mitigation at a given location. The first step in the methodology is to create a future land use map for the year 2030 which estimates the changes that will occur in the landscape of the coast of Georgia due to the influences of sea-level rise, storm surges and human alterations. This future land use map is used to create a Risk Mask, which is used to identify where risks to wetlands occur, where wetlands are created by migration inland as well as where land use changes due to human development. Next, the two previous methodologies that were created by NARSAL are adapted to include the coastal wetland functions of reducing fecal coliform to shellfish nurseries and beaches and improving shoreline stability. Also adapted from the previous methodologies is the initial stream file used to determine the location of water bodies in the landscape. This file is adapted to include newly ditched areas because they act as conduits for pollution to move from the upland to wetlands and water bodies and can elevate the movement of nutrients and pollution across the landscape. The two adapted methodologies are performed for the years 2008 and 2030 to determine the change in wetland potential that occurs due to the predicted change in land use. Next, the results, and the results of a shoreline stability analysis, are included in a risk assessment that is used to highlight where the potential for wetland mitigation improves the most within the specified time frame. The final results of the risk analysis are seven maps that can be used by resource managers in selecting the location for wetland mitigation sites along the coast that have the highest potential of benefiting wetland functions while also having the lowest risk of becoming degraded or lost due to the changes in land use that are projected to occur as a result of the risks associated with wetlands in coastal regions.

This thesis is divided into six chapters, which include: 1) Introduction, 2) Literature Review and Problem Statement, 3) Methodologies, 4) Analysis of Results and Techniques, 5) the Discussion of results, and 6) the Conclusion. The second chapter includes a brief background on the history of wetlands and the causes of degradation to coastal regions, previous methodologies and research that my thesis is based on, and a problem statement. Chapter three presents the methodology used in the creation of the coastal risk assessment and the final outputs as well as the methodologies used in the analysis of results. The methodologies used to analyze the results of the risk assessment include an analysis of the parameters used to create the future land use map and a description of how to perform a sensitivity analysis. A sensitivity analysis determines which wetland function has the most influence on the final results of the indices used in the risk assessment because those functions will be the most likely to be improved through wetland mitigation. Chapter four presents the results from chapter three. Specifically, this chapter determines the change in land use predicted by the future land use map, the areas of risk along the coast as shown by the Risk Mask, the acreage of sites on the coast that will have a high, medium or low potential of performing wetland services as determined by the four indices used in the risk assessment, and the results of the sensitivity analysis. Chapter five discusses the results and how they can be interpreted by natural resource managers in the selection of wetland mitigation sites, and chapter six reiterates the main results of the risk assessment and discusses how the model can be improved.

CHAPTER 2

LITERATURE REVIEW AND PROBLEM STATEMENT

BACKGROUND INFORMATION

Wetlands in the United States

The sentiments that the American public and the United States government have had towards wetlands and marshes have evolved since colonial times. In the nineteenth century and early twentieth century, wetlands within the United States were considered unhealthy and unproductive. Federal and local regulations were created to encourage the public to drain wetlands and convert them to agriculture and silviculture lands, which were considered more productive land uses (Camp and Daugherty 2002; Mitsch and Gosselink 2007; Pruitt and Somerville 2006). In 1849 a statute was granted to the State of Louisiana that allowed swamps that were considered 'unfit for cultivation' to be filled and altered (Camp and Daugherty 2002). This statute was the basis for the Swamp Land Act of 1850, which gave landowners possession of wetlands under the condition that they were drained and filled for agriculture (Connolly et al. 2005). Under the act, 64 million acres of swamp were 'reclaimed' as agricultural lands (Pruitt and Somerville 2006). To help maintain the drained agricultural areas, the Watershed Protection and Flood Prevention Act of 1954 allowed the United States Department of Agriculture Soil Conservation Service to channelize streams to reduce flooding into their floodplains. In 1955, 103 million acres of wetlands were converted to drainage systems (Connolly et al. 2005) and by 1971 the Soil Conservation Service channelized 6,000 miles of streams (Vileisis 1997).

Wetlands in the United States were also altered or destroyed due to dredging and filling in navigable waters to maintain maritime navigation under the Rivers and Harbors Act (RHA) of 1899. Under Section 10 of the RHA, wetlands were not protected, but in Section 13 (The Refuse Act) the Unites States Army Corp of Engineers (USACE) was given charge of regulating any tributaries where pollution flows or is washed into jurisdictional 'navigable waters" (Pruitt and Somerville 2006). Section 10 and Section 13 were contradictory in their definitions of the jurisdictional extent of the USACE. Besides acts of dredging and filling, wetlands were also drained to reduce mosquito populations in an effort to stop the spread of diseases, such as malaria (Kitron and Spielman 1989).

The attitude of the United States towards wetlands began to change when people began to realize that wetlands provide important functions to humans and the environment. Those functions include maintaining or improving the quality of water, protecting shorelines against erosion, providing recreational areas and habitat for a variety of terrestrial and aquatic species as well as prohibiting or reducing damage from floods or storms (Connolly et al. 2005). In 1918, wetlands that were associated with migratory birds were protected by the Migratory Bird Act. The Fish and Wildlife Coordination Act was passed by Congress in 1967, and it required that in order to get authorization or license to divert, modify or impound any water body, that the United States Fish and Wildlife Services (USFWS) and the responsible state agency must be consulted first to determine the practices that should be adopted to prevent loss of or damage to wildlife resources (Pruitt and Somerville 2006). The Coastal Zone Management Act (CZMA) was enacted in 1972 by Congress to address the worsening condition of wetlands on the coast due to overdevelopment. This national policy was enacted to protect, restore and enhance coastal wetland resources, which include "wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, fish and wildlife and their habitat," (Pruitt and Somerville 2006) as well as to encourage coastal management plans to be developed at the state level.

The Federal Water Pollution Control Act (FWPCA) of 1972 had the goal of improving the nation's waters chemically, physically and biologically. It did not explicitly state that wetlands should be regulated, instead using the vague term 'navigable waters of the United States' to leave room for future interpretation. The extent of jurisdiction was first decided by the USACE to follow the guidelines set forth by RHA Section 10. Their decision was challenged by the National Resource Defense Council (NRDC) in the *NRDC vs. Callaway* case and it was ruled that the USACE had to extend their jurisdiction in the FWPCA Section 404 to include wetlands and tributaries (Lewis 2000; Pruitt and Somerville 2006). Thus it became the USACE's responsibility to consider preserving the environmental values when issuing RHA permits (Connolly et al. 2005). At the same time as the *NRDC vs. Callaway* case, Congress was discussing the scope of Section 404 of the FWPCA, and in 1977 the FWPCA was amended as the Clean Water Act (CWA). The new section 404 regulated dredge and fill practices in navigable and non-navigable waters. Guidelines for the CWA 404(b) were determined by the U.S. Environmental Protection Agency (USEPA) and USACE. The guidelines address the need to seek practicable alternatives to discharge of dredge and fill material. These alternatives include avoiding discharge into any aquatic site and minimizing the adverse effects of material into water by changing discharge practices or locations. The 1980's amendment of the CWA Section 404 emphasized the minimization of adverse impacts to navigable water, wetlands and tributaries and compensation for any habitats that are destroyed. The guidelines given in the amended 1980's version of the CWA Section 404(b) led to the idea of compensatory mitigation (Pruitt and Somerville 2006).

Compensatory mitigation is a tool used by the federal government to meet the goal of "no net loss" (Federal Register 2008). "No net loss" was enacted in 1988 and promotes cooperation between agencies (Pruitt and Somerville 2006) by making it a national goal to maintain wetland acreage and functions (Federal Register 2008) describe four methods in which compensatory mitigation can be performed in their final ruling of "Compensatory Mitigation for Losses of Aquatic Resources". Those four methods are:

1. <u>Restoration:</u> restore a previously existing aquatic site or wetland
2. <u>Enhancement:</u> improve existing aquatic site or wetland function
3. <u>Establishment:</u> create a new aquatic site or wetland
4. <u>Preservation:</u> maintain existing aquatic site or wetland

There are three different ways of performing the aforementioned methods. Those are: permitee-responsible compensatory mitigation, mitigation banking, and in-lieu fee mitigation. Permitee-responsible compensatory mitigation occurs at the same location or adjacent to the site that is impacted and the permittee is responsible to ensure that mitigation standards are met and the mitigation site is successful (Pruitt and Somerville 2006). On-site mitigation has been shown to be an ineffective tool in the long term goal of "no net loss" of wetlands and their functions because of situations such as fragmentation, isolation, reduction of water quality, and lack of monitoring mitigation projects (Sakyi 2010). Mitigation banks and in-lieu fee mitigation are conducted by someone besides the permit holder and they are done off-site of the impact site while in-lieu fee is usually performed by local governments, state governments, or non-profit organizations. Mitigation banks are usually run by public and non-profit organizations (Federal Register 2008) and are the preferred method of compensatory mitigation because they are thought to be the most successful at providing "no net loss," allowing aggregate mitigation in a watershed, and decreasing enforcement and monitoring costs (Marble and Riva 2002; Sakyi 2010).

Wetland Degradation

Even with policies protecting and restoring wetlands, 117 million acres or approximately 50% of wetlands have been lost in the contiguous United States since colonial times (Connolly et al. 2005). Degradation of wetlands can be caused by both human and natural means. Humans compact the soil, increase the amount of nutrients moving in the system and cause an increase in the amount of water entering wetlands and streams. The increased water flow moves loose sediments into streams. Alien plant species and nutrients tend to get trapped in wetlands due to the flat topography that slows water movement. Owing to this process, "most wetlands are mildly to severely degraded" (Zedler 2006) and there are very few pristine wetlands. Coastal wetlands are vulnerable to eutrophication because they receive non-point source runoff from an entire upstream watershed. Increased levels of nitrogen in the watershed that reach salt marshes can alter the spatial location of plant species by favoring tall plants (*spartina alterniflora*) over shorter plants (Pennings and Sharitz 2006). Nitrogen eutrophication is one of the most common threats to salt marshes (Scavia et al. 2002). Runoff from developed areas on the coast can alter plant communities, which affects the functions of wetlands.

Actual manipulations that degrade wetlands occur through filling with dredge materials, withdrawing water, diverting water, draining wetlands, channelization, and contamination by non-point source runoff and point source pollution. Ditches, dikes and canals fall under the category of hydrologic manipulation that can degrade coastal wetlands. Ditches and canals can divert water out of wetlands and cause them to be dry for longer periods of time, which can degrade wetlands because they may no longer have a hydroperiod long enough to cause anoxic soil conditions (Tiner 1999). Ditches in salt marshes act as conduits between the upland and the estuaries and can rapidly transfer nitrogen to estuaries, which can enhance the growth of phytoplankton and can affect the consumption of oxygen in estuaries. Thus ditches can be considered as degrading to the water quality of estuaries (Golder and Koch 2008). Dikes created on the coast can prevent the natural migration of wetlands and inhibit the wetlands from functioning as dispersers of extreme wave action (Erwin 2009).

Coastal wetlands are subject to not only the stresses previously mentioned. They are also influenced by sea-level rise, storm surges, subsidence, erosion and accretion. For wetlands to maintain their functionality and spatial location during a rise in sea-level they need to maintain their elevation in relation to the sea. Wetlands do this through the accumulation of organic matter or sediment deposition (Cahoon and Guntenspergen 2010). Marsh soil elevation is affected by many factors, including the rate in sea-level rise, altered river flows, storms, atmospheric carbon dioxide, disturbances, nutrient inputs, and subsidence. Sea-level rise, river flows and storm surges directly affect the sedimentation and erosion of the coasts, the duration and depth of flooding and salinity (Cahoon and Guntenspergen 2010). Sedimentation and erosion influences the amount of nutrients in the system that can be decomposed and converted into biomass that accumulates and increases soil elevation. Subsidence lowers the soil elevation, increases flood depth and duration, and decreases plant growth. Atmospheric carbon dioxide affects plant growth, which in turn affects biomass accumulation and soil elevation (Cahoon and Guntenspergen 2010). The ability of salt marshes to accumulate organic material may be compromised by nitrate eutrophication. In situations where nutrient addition is used in restoration, the additional plant growth can trap more inorganic material, but it can take decades for the degraded wetland to reach reference wetland conditions (Turner 2004). A coastal wetland a dynamic system and determining how a change in any of the physical or biotic factors will affect marsh accretion is difficult because there are many feedback loops. To better understand the wetland feedback loops associated with coastal wetland systems, a diagram of the physical and biotic drivers was developed by Cahoon et al (2009) and can be seen in Figure 2.1.

The coast of the state of Georgia has been predicted to be highly vulnerable to a loss of coastal wetlands due to low tidal range and a predicted rise in sea level (Hoozemans et al. 1999). Coupled with the additional stress of increases in human population (Adam 2002; Brock and Nielson 2009; Freeman et al. 2007; Gedan et al. 2009; Hoozemans et al. 1999; Hopkinson et al. 2008; Michener and Blood 1997; Morris et al. 2002; Scavia et al. 2002) the loss of wetlands can be greater than predicted by sea level rise scenarios alone.

Despite uncertainties of the magnitude of sea level rise that will occur over the next hundred years, the literature provides a rise of water level within the range of 26 cm to 59 cm (Michener and Blood 1997; Ramhstorf 2007; Scavia et al. 2002; Solomon et al. 2007). Hoozemans et al. (1999) suggests five responses of coastal wetlands to the rise in sea level. These are:

1. no change because the coastal elevation keeps pace with the rise in sea level
2. the retreat of the coastline and inland migration of non-forested wetlands
3. retreat of coastline with no inward migration of wetlands
4. retreat of coastline and an increase of flooded area landward
5. total loss of coastal wetlands

The first two responses of wetlands to a rise in sea-level are the most desirable for wetland mitigation because the functions that wetlands perform would remain. It is important to keep the functions of coastal wetlands, even if this means a loss of coastline, because wetlands help to prevent erosion and protect the inland region from the effects of storm surges. Barrier Islands also provide a means of protection for the inland from storm surges, but in the process the boundaries of the islands will continually change through the erosion and accretion of their shorelines (Jackson 2010). Titus (2005) suggests that if there was no human interference, barrier islands can respond to a rise in sea-level by either break up and drowning in place or moving landward and staying intact. From the Georgia Land Use Trends for the years 1974 and 2008, it seems as though this is happening for parts of the Georgia coast below Savannah. Storm surges can destroy coastal wetlands due to flooding and increased salinity in the freshwater wetlands, which leaves the upland region unprotected from further natural risks (Scavia et al. 2002; Tobey et al. 2010). The coastline response in this situation would be the retreat of coastline with either little migration of wetlands upland or an increase in flooding, or a total loss of coastal wetlands (Hoozemans et al. 1999). To try and prevent this, two forms of action can be taken: either attempt to maintain sediment supply in coastal wetlands so that the wetlands can remain above sea level, or create space upland for wetland migration to occur (Scavia et al. 2002; Turner 2004).

PREVIOUS METHODOLOGIES AND PROGRAMS

Potential Wetland Mitigation Sites

Carpenedo (2008) developed a watershed planning tool to identify where wetland mitigation sites would have the greatest influence on wetland functions and values in the state of Georgia. The product of his work was a landscape map that prioritized potential wetland restoration sites based on their ability to improve wetland ecosystem functions. The main functions that were chosen included restorability of wetlands, wetland jurisdiction, water quality and quantity, flood control and regulation, recreation, wildlife habitat, scenic value, connectivity to existing conservation areas, education, and hydrologic connectivity.

The final map, the Potential Wetland Restoration Site (PWRS) Index, is a compilation of nine layers that accounts for specific wetland functions. The first two layers were put together to create a masking layer to determine the restorability based on wetland history and hydric soils and was used to scale layers four through nine. Layer three identifies where wetlands can be located based on USACE jurisdictional guidelines. Layers four through nine are described in Table 2.1. In layer four, water quality and quantity, two indices were developed that have been used in various applications related to potential wetland mitigation analysis.

The Potential Runoff Index (PRI) calculates the "potential proportion of saturated variable source runoff entering water bodies after a two year 24 hour storm event" (Carpenedo 2008). Land use categories from Georgia Land Use Trends (GLUT), hydrologic soil groups (HSG), antecedent runoff conditions and hydrologic conditions were used in the calculation. The runoff from specific land use pixels were calculated using the Natural Resources Conservation Service (NRCS) runoff equation where the curve number was determined using the known characteristics of land cover and hydric soils. The PRI value was calculated by subtracting a flow accumulation that is weighted by the runoff equation and an un-weighted runoff and then dividing it by the un-weighted runoff.

The Distance to Impairment Index (DII) is a measurement of the potential of a created/restored wetland site to improve nonpoint source pollution based on a land cover pixel's location in the landscape. The DII was calculated by doing cost allocation and flow length models in ArcINFO (ESRI 2007). The cost allocation used a Digital Elevation Model (DEM) to determine the path that water would flow after saturation occurs. The flow length model uses a flow accumulation model created in ArcGIS from the DEM to calculate the distance of a land cover pixel from a water body. The DII is the absolute value of the flow length model minus the cost allocation model (Carpenedo 2008).

After the layers are masked with the masking layer, they are added together and re-scaled from one to nine, with one having the least potential for wetland restoration to improve wetland functionality and nine corresponding to the areas with the highest potential for wetland restoration to improve wetland ecosystem functions (Carpenedo 2008).

From the analysis of the final map of the PWRS Index, Carpenedo (2008) found that the coastal plain had the highest percent (9.8%) of its area with a high potential for restoration and that the Southeast Coastal Plain ecoregion has 152,426 ha identified as high potential for restoration as well. A sensitivity analysis performed for the Southeast Coastal Plain regions shows that the results of the PWRS Index are the most sensitive to water quality and quantity and the conservation of biodiversity in high priority streams (Carpenedo 2008).

Existing Wetland Condition

The Natural Resources and Spatial Analysis Lab (NARSAL) at the University of Georgia extended the methodology created by Carpenedo (2008) to spatially model the condition of existing wetlands (Kramer, *pers. Comm.)*. There were nine layers in the analysis and those are described in Table 2.2. All nine layers are masked to only look at wetland areas, added together and then reclassified to get the Wetland Site Index (WSI), which ranks the potential of wetland areas to perform wetland ecosystem functions. Those areas that are given a value of one are considered to have the lowest potential of performing wetland functions, and those with a value of nine have the highest potential of performing wetland functions (Kramer, *pers. Comm.*).

Risks to Coastal Wetlands

To predict where land use will change along the coast of Georgia due the influence coastal stresses such as sea-level rise, storm surges, population growth and barrier island migration, a future land use map needs to be created that accounts for all of these stresses. To aide in this endeavor a number of modeling tools exist that are able to predict changes that occur in coastal land uses due to the stressors described previously. These programs also require initial data which can be easily accessed or created. The models that are of interest in this study include the urban growth model Slope, Land cover, Elevation, Urban areas, Transportation and Hill-slope (SLEUTH), a coastline sea level rise model called Sea Level Affecting Marshes Model (SLAMM) and a coastal shoreline stability model Analyzing Moving Boundaries Using R (AMBUR).

The SLEUTH model can be used to predict where future urban areas will occur along the coast of Georgia based upon current land use change patterns. SLEUTH is a cellular automated model which computationally experiments with spatial locations over time. The output is a spatial map of the probability of any pixel to urbanize over time. The SLUETH model output is created for and can be coupled with other models to help natural resource managers make informed decisions (Clarke 2008).

The spatial change in wetland location due to sea-level rise and storm surge is a complicated problem that involves many variables. The software SLAMM 6.0.1 considers six primary processes that will affect wetlands during sea-level rise and storm surges. These processes are 1) inundation, 2) erosion, 3) over wash of barrier islands, 4) saturation, 5) accretion, and 6) salinity. The processes listed were chosen by the creators of SLAMM to model the movement of marshes because research has shown them to be the most influential parameters that link sea-level rise and storm surges with the changes that happen to wetlands. To determine landscape changes. A decision tree is used which incorporates geometric and qualitative relationships to represent changes among coastal wetland types. SLAMM has been used for studies in California, Florida, Georgia, South Carolina and Washington and has provided high-resolution maps depicting marsh migration due to tidal influences (Craft 2007; Galbraith et al. 2002; Warren Pinnacle 2010).

The AMBUR model was created by Jackson (2010) and currently still under development. This model analyzes barrier islands that have very curved or complex shorelines and can be used to project the movement of barrier islands. AMBUR does this by calculating the erosion and accretion rates at each transect of an island for the entire island shoreline. The output of this program is an outline of the island shoreline that can be extrapolated to a given year (Jackson 2010).

The outputs of these models are used to develop a final layer which represents where coastal marshes and wetlands will be in the year 2030. The layer identifies where it might be best to place current investments for future wetland mitigation successes.

PROBLEM STATEMENT

The coastal area of Georgia needs to be analyzed for potential mitigation sites separately from the previous state analyses for three reasons. First, the wetlands along the coast (salt water wetlands and fresh water wetlands) provide ecosystem functions that were not evaluated in the previous state prioritization analyses (Carpenedo 2008; Kramer *pers Comm.*). Those ecosystem functions include the reduction of fecal coliform to shellfish nurseries and to beaches and the stabilization of shorelines from the effect of storms and erosion (Tiner 1999). Second, coastal wetlands are dynamic and constantly changing systems due to the influence of sea-level rise, storm surges, erosion, accretion, and human disturbances. For management to make informed decisions about where to restore/establish new wetlands or enhance/preserve existing wetlands in coastal regions, they need to have a better understanding of where wetland functions will change due to coastal risks. Third, the coastal region of Georgia was identified by Carpenedo (2008) to be the region with the largest percent of highly prioritized mitigation sites for restoration/establishment. Performing additional analysis in a region that already has a high potential for wetland mitigation will increase the likelihood of identifying sites for mitigation that will be able to perform the ecosystem functions of interest. To solve the problem of identifying potential mitigation sites for the restoration/establishment of new wetlands and the enhancement/preservation of existing wetlands, a risk assessment for the coast of Georgia was developed using the following information:

1. A future land use map for the year 2030 that accounts for the influence of sea-level rise, storm surges, erosion, accretion and population growth
2. The layers from the previous two research papers on mitigation (Carpenedo, 2008; Kramer, *pers. Comm.*) that are identified by Carpenedo (2008) as having the most influence on mitigation potential for improving the following wetland functions: water quality and quantity and the maintenance of high priority streams through the conservation of biodiversity. Specifically, I will be investigating:
    a. Potential creation/restoration of wetlands (Table 2.1)
        i. Layer 4: water quality and quantity
        ii. Layer 9: maintenance of high biodiversity streams
    b. Potential enhancement/preservation of existing wetlands (Table 2.2)
        i. Layer 1: deviation from reference

ii. Layer 2: conservation of biodiversity in high priority streams

3. New methodologies that are created to spatially show where the highest potential for mitigation occurs that will improve fecal coliform levels in potential shellfish nursery and beach areas as well as improve shoreline stability.
4. Compare the results for the years 2008 and 2030 to create a prioritized index that shows how a change in land use can affect the potential of a wetland mitigation site to improve the wetland functions of improving water quality, maintaining high priority streams, reducing fecal coliform to shellfish nurseries and beaches.
5. Use the results from step four and the methodology used to improve shoreline stability from step three to create two indices that identify where the greatest increases in the potential for wetland mitigation occur between the years 2008 and 2030.

Table 2.1: Description of layers four through nine developed for the Potential Wetland Restoration Site Index (Carpenedo 2008)

Layer	Title	The Functions that Restoration Would Improve
4	Water Quality and Quantity Index	Water quality and quantity
5	Connectivity to Existing Conservation Areas	Connectivity, size and wetland ecosystem functions
6	Terrestrial Dispersal Corridor between Wetlands	Metapopulation of facultative wetland species, such as amphibians
7	Hydrologic Connectivity of Wetlands	Biodiversity, recreation, education
8	Natural Upland Habitat	Habitat for wildlife
9	Maintenance of High Water Quality Streams	Conservation of biodiversity and improved areas for recreation

Table 2.2: Description of layers one through nine for the Wetland Site Index (Kramer, *pers Comm.*)

Layer	Title	Function that Affects Wetlands
1	Deviation from Reference	Water quality and quantity entering wetlands
2	Connectivity to Existing Conservation Areas	Connectivity and size of wetlands
3	Terrestrial Dispersal Corridor between Wetlands	Ability to support facultative wetland species
4	Hydrologic Connectivity of Wetlands	Biodiversity, recreation and education
5	Natural Upland Habitat Surrounding Wetlands	Habitat for wildlife
6	Maintenance of High Priority Streams	Non-point source impairment to high priority streams
7	Percent of Impervious Surface within a Basin	Non-point source pollution and flooding
8	Percent of Impaired Streams and Rivers per 12 Digit HUC	Stream health
9	Percent Wetland Change	Changes in wetland functions

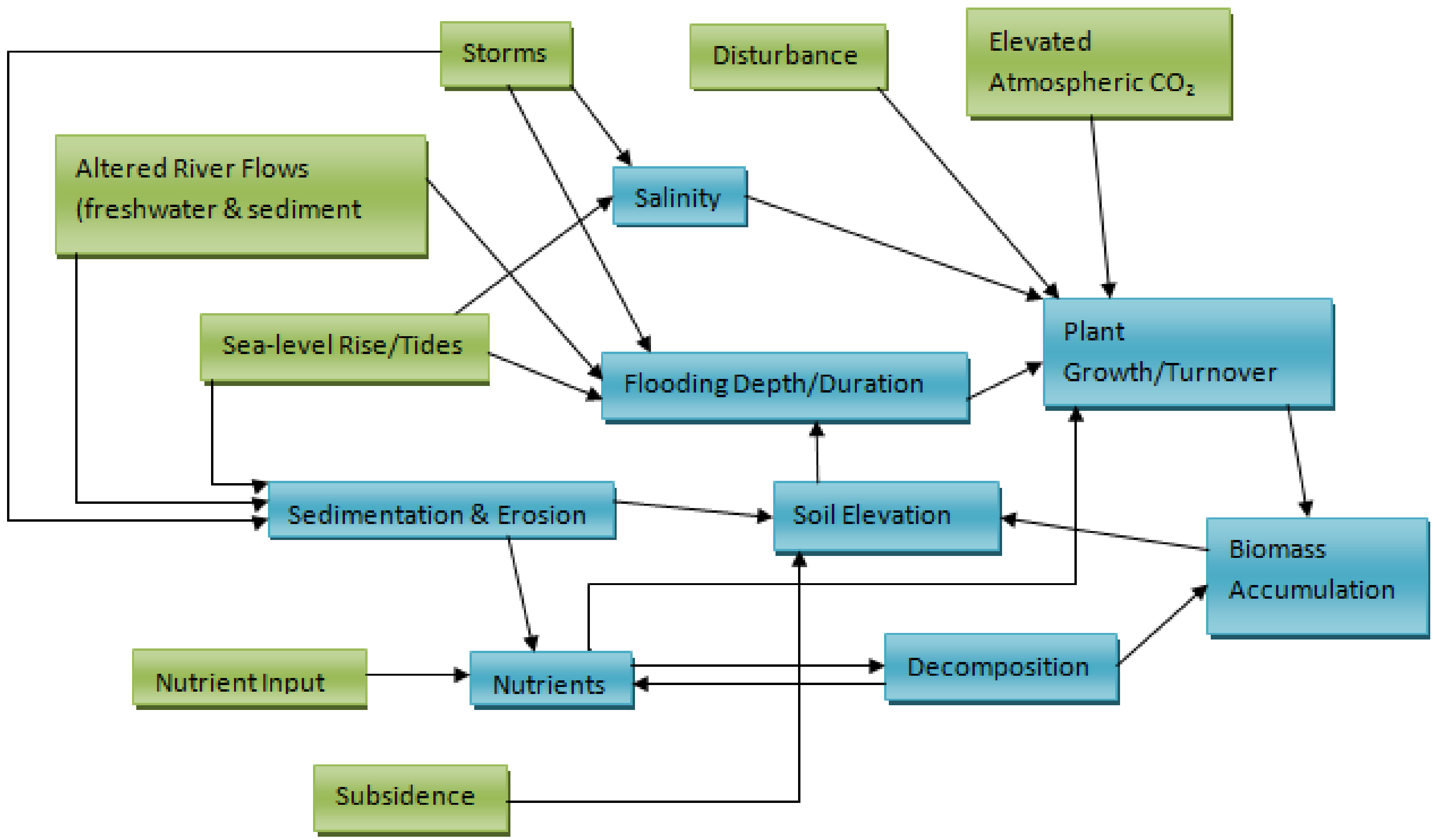


Figure 2.1: Diagram of the physical and biotic drivers and feedback loops associated with marsh elevation in coastal wetlands. Green boxes indicate system drivers and blue boxes are the system dynamics that the drivers influence (diagram adapted from Cahoon et al. 2009).

CHAPTER 3

METHODOLOGY

In this chapter a watershed-based planning tool is created for the coast of Georgia in order to identify areas where coastal risks are projected to change the potential for successful wetland mitigation over a period of approximately two decades. The final products of this risk assessment planning tool are two Geographical Information System (GIS) based maps which prioritize the changes that occur in the potential of wetland mitigation to either 1) restore/establish new wetlands or 2) enhance/protect existing wetlands. The change in the potential for wetland mitigation represents a landscape level assessment of the location where the potential for wetland mitigation methods to improve coastal wetland functions are going to change the most over time.

The coastal risk assessment uses four indices and a Risk Mask to create the final products. The indices used include the Potential Wetland Restoration Site Index (PWRS), the Wetland Site Index (WSI), the Change in Potential Wetland Restoration Site (CPWRS) index and the Change in Wetland Sites Index (CWSI). Resource managers can use all of the indices and the Risk mask to aide in the selection of wetland mitigation sites in coastal regions, as described previously and in the following list.

- PWRS Index
    - Selects upland areas along the coast that have a high potential of performing wetland functions. These general areas can be improved through the

compensatory wetland mitigation methods of restoration or establishment of wetlands.

- CPWRS Index
    - This index shows non-wetland locations that will increase in their potential to perform wetland functions over time. The general areas where the potential for restoration or establishment of wetlands increases over time are locations with the least risk for mitigation failure to occur due to coastal risks. The locations with a low potential for the establishment or restoration of wetlands over time are regions that have a high threat of being unsuitable for the compensatory mitigation practices of restoration or establishment of wetland sites due to projected coastal risks.
- WSI
    - The Wetland Site Index ranks the ability of existing wetlands to perform wetland functions. The areas which are identified as having a low potential are locations where the mitigation practice of enhancement can be used to improve wetland conditions. The high potential areas will need to be maintained through the compensatory wetland mitigation method of preservation .
- CWSI
    - Ranks the change in potential in the condition of existing wetlands over a specified time period. Wetland areas that have a high potential of their condition improving need to be preserved while those areas that are degraded over time can be enhanced by wetland mitigation.

- Risk Mask
    - Predicts specific locations where land use changes occur over time. Locations where wetlands are created have a high potential for the wetland mitigation methods of establishment and restoration due to their potential to successfully support wetlands while the areas where wetlands are lost have a low potential for wetland mitigation because of their associated risk of failure.

The coastal wetland functions that are used in the indices of the risk assessment are water quality and quantity (WQQI), conservation of biodiversity (BIO), deviation of existing wetlands from reference conditions (Dev Ref), reduction of fecal coliform (Reduced FC), and shoreline stability (SS). Three of the five functions (WQQI, BIO, and Dev Ref) are used in the Potential Wetland Restoration Site (PWRS) Index (Kramer and Carpenedo 2009) and the Wetland Site Index (WSI) (Kramer, p*ers Comm.)* and are incorporated into the risk analysis because they are identified as being the most influential wetland functions for southeast coastal Georgia (Carpenedo 2008). The other two functions, Reduced FC and Shoreline Stability, are chosen because resource managers are interested in reducing the amount of fecal coliform to beaches and shellfish nursery areas (Christy and Glasoe 2004; GA DNR: Coastal Resources Division 2011; Solo-Gabriele et al. 2011) in order to reduce the harm that the bacteria can cause to the humans, as well as creating a stable shoreline to protect inland resources (Bush et al. 1999; Hoozemans et al. 1999).

The first map in the risk assessment is created using the Change in Potential Wetland Restoration Site (CPWRS) Index. This output shows where changes in the potential of a restored/established wetland mitigation site to improve wetland functions may occur over time by incorporating existing functions previously discussed as shown in Figure 3.1. Specifically, the

CPWRS Index creates the first risk analysis map in four steps, or components. The first component involves three models that are combined to estimate the spatial location of land use in the year 2030. The final output of the first component is the future land use map for the year 2030. The second component is the coastal PWRS Index, which is composed of three layers that are based on the WQQI, BIO and Reduced FC wetland functions. Each layer prioritizes the potential of established/restored wetlands to improve their respective functions. The three layers are then added together to create the PWRS Index. The procedures in component two are performed twice: the first time using the current land use map from 2008 and the second time using the future land use map for the year 2030. Component three of the risk analysis is the creation of the Risk Mask. The Risk Mask compares the land cover from the 2008 land use file and the 2030 projected land use file to identify areas where changes in land use occurs. The Risk Mask can be used by resource managers in order to identify areas where wetlands have a high probability of being lost or created so that managers can avoid selecting wetland mitigation sites that are at a high risk of being lost due to coastal risks and concentrate their efforts in selecting mitigation sites in areas where wetland sites will be created in the future or where the land use is projected not to change. The CPWRS incorporates the three layers from the 2030 PWRS and 2008 PWRS as well as a layer that is based on the function of shoreline stability. The four layers in the CPWRS Index are weighted using the Risk Mask in order to lower the potential for mitigation in the locations where wetlands are lost or land use changes between 2008 and 2030. The masked layers are then added together and the final output is the CPWRS Index, which is the first part of the risk assessment.

The second map in the risk analysis is created using the Change in Wetland Site Index (CWSI). This index is created in a similar manner as the CPWRS Index in that it is composed of four components and two of those components are the creation of the future land use map for 2030 and the creation of the Risk Mask. The main difference between the second map and the first is that they are looking at different types of wetland mitigation for different types of land cover. For the CPWRS Index, the land use of interest are the areas that are not already classified as being wetlands or open water and these areas are prioritized to identify the best areas for wetland establishment/restoration. In the CWSI, all existing wetlands are used in the analysis in order to determine their potential in performing wetland functions. Those areas that are prioritized as having a high potential for performing wetland functions can be preserved, while wetland areas with a low potential can be enhanced.

The general steps taken to create the CWSI include using the future land use map for 2030 that was created in component one and the current land use map to create the Wetland Site Index (WSI) for 2008 and 2030 (Figure 3.1). The WSI is potential composed of three layers that rank the potential ability of wetlands to protect water quality by reducing runoff, to conserve biodiversity in high priority streams, and the relative amount fecal coliform that can enter wetland areas. Component five of the risk assessment includes the processes used for creating and adding the three layers together to create the WSI for 2008 and the WSI for 2030. Component six is the creation of the Change in Wetland Site Index (CWSI). The CWSI is composed of four layers, with the first three layers being the difference between the layers of the WSI for 2008 and 2030. The fourth layer is a shoreline stability layer which prioritizes the ability of existing wetlands to perform the function of improving shoreline stability by reducing erosion and maintaining their elevation. The final map for the CWSI is created by weighting the four layers by the Risk Mask and then adding them together. The final map shows the locations where the ability of existing wetlands to perform coastal wetland functions will change the most between the years 2008 and 2030.

Also important to note is that all layers in components two, four, five, and six receive the same post-processing treatment. Each layer and the final indices are reclassified on a scale from one to nine, with nine corresponding to those locations in the landscape which have the highest potential for improving/performing their respective coastal wetland functions. Reclassification is done in ArcMap (ESRI 2007) using either the classification approach known as Jenks Optimization (Dent 1999) or Quantiles. Jenks Optimization, also known as Natural Breaks, reclassifies data by first building a histogram of all the values within a layer and then separating them based on where natural breaks occur. Using this reclassification method minimizes the variance within a cluster of values while maximizing the variance between clusters. The Quantiles classification method is generally used in this chapter when the data in a histogram are fairly linear and there is little clustering of data.

When reading through the methodologies used to create the layers and indices in the preceding sections of this chapter, it is important to refer back to the diagram in Figure 3.1 and the list describing what the indices are and how they are to be used. There are a lot of different components occurring in the risk assessment and these two items are provided as a guide to help in the interpretation of the methodologies and the final maps within this chapter.

COMPONENT ONE: PROJECTED LAND USE MAP FOR THE YEAR 2030

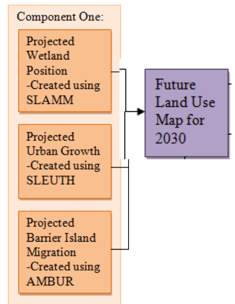


Figure 3.1.1: Diagram for the first component of the risk assessment, the creation of the future land use map for the year 2030

Coastal wetlands are constantly changing in nature and spatial location due to the stresses of a rising sea-level, storm surges and alterations from human development. The first component in this chapter creates a future land use map which evaluates how land use categories and the barrier islands change in response to these stresses in order to aide resource managers in the process of selecting locations for successful wetland mitigation sites. For the purpose of this paper, a successful mitigation site is one that performs the desired wetland function as remains functioning in the landscape approximately twenty years in the future.

The future land use map is composed of three different prediction maps; each made using a different computer software program. The three programs are: the Sea-Level Affecting Marshes Model (SLAMM 6.0.1), the Slope, Land cover, Exclusions, Urban Areas, Transportation and Hill-slope (SLEUTH) model, and the Analyzing Moving Boundaries using R (AMBUR) model. These three programs are chosen based on their capacity to spatially depict predictions, their availability to the public, and because they are models that resource managers are already familiar with or can become familiar with easily. The final map for component one is the projected land use map of coastal Georgia for the year 2030. This map is used in parallel with the 2008 Georgia Land Use Trends (GLUT) map in components two through six of this chapter in order to show where changes in the potential for wetland mitigation occurs in the landscape.

Sea-Level Rise and Storm Surges

Part one of component one is a landscape analysis to determine how wetlands will change due to sea-level rise and storm surges. Inputs for SLAMM 6.0.1 include the National Elevation Dataset (NED), National Wetland Inventory (NWI), slope, dike and impervious files for coastal Georgia. The NED file is downloaded from the USGS Seamless Viewer (http://seamless.usgs.gov/website/seamless/viewer.htm) in three tiles that are combined into one large elevation file. NWI files and slope files are downloaded from the Georgia GIS Clearinghouse (http://data.georgiaspatial.org/index.asp?body=search) for the entire state of Georgia and then clipped to the coastal region of interest. The coastal region of interest is delineated by selecting the 12 Digit Hydrologic Unit Codes (HUCs) which include either all tidally influenced waters or the region where streams/rivers transition between fresh and saltwater. To make the NWI file compatible with the SLAMM program, the wetland classification system is crosswalked to the SLAMM wetland classification system (Clough, Fuller and Park 2010).The impervious file, which was created by the NARSAL lab, depicts the percentage of impervious surface in a 30 meter resolution pixel and is also clipped to the coastal extent. The dike file is created in ArcMap by reclassifying the NWI file to only include those areas that are listed as having dikes. Next, all of the files are converted into a raster file, if required, with a 30 meter resolution, clipped to the same extent, and converted into ASCII files.

In order to distinguish the differences in mean tide level, great diurnal range, and salt elevation along the coast of Georgia, sub-sites are created and added to the Site Parameters feature in SLAMM (Table 3.1). Five sub-sites are established based on the Georgia Sounds that had both gauge stations and datum information from the National Oceanic and Atmospheric Administration (NOAA). Those sub-sites and their values derived from the NOAA website are:

1. Tybee and Wassaw Sounds
    a. Corrected Elevation of the sea-level (Mean Tide Level (MTL) –North American Vertical Datum of 1988 (NAVD88)) is -0.116 meters
    b. Difference between the Mean Higher High Water (MHHW) and the Mean Lower Low Water (MLLW) is the Great Diurnal Tidal range(GT), which is 2.287 meters
    c. Elevation of salt transition zone is 1.054 meters above Mean Tide Level (MTL)
2. Ossabaw, St. Catherines and Sapelo Sounds
    a. Corrected Elevation (MTL – NAVD88) is -0.226 meters
    b. Difference between MHHW and MLLW (GT) is 2.423 meters
    c. Elevation of salt transition zone is 1.121 meters above MTL
3. Doboy and Altamaha Sounds
    a. Corrected Elevation (MTL – NAVD88) is -0.247 meters
    b. Difference between MHHW and MLLW (GT) is 2.264 meters
    c. Elevation of salt transition zone is 0.947 meters above MTL
4. St. Simons and St. Andrews Sounds
    a. Corrected Elevation (MTL – NAVD88) is -0.21 meters
    b. Difference between MHHW and MLLW (GT) is 2.186 meters
    c. Elevation of salt transition zone is 1.006 meters above MTL
5. Cumberland Sound
    a. Corrected Elevation (MTL – NAVD88) is -0.775 meters
    b. Difference between MHHW and MLLW (GT) is 1.971 meters

c. Elevation of salt transition zone is 0.902 meters above MTL

Due to limited data on erosion and accretion rates within the specified sub-sites, the global values of erosion and accretion for specific wetland types are the same for all sub-sites and the values are based on those used in a study done on Wassaw Sound which used SLAMM 5.0 (Table 3.2) (Ehman 2008). Specific erosion parameters that are used include a horizonatal loss of two meters per year in marsh areas, one meter per year for swamp areas, and six meters per year for tidal flat areas. There are also vertical accretions of sediments and organic matter defined as being 1.9 mm per year in regularly flooded marshes, 4.3mm per year in irregularly flooded marshes, 4.8 mm per year in tidal fresh marshes and 0.5 mm per year for beach areas. For this analysis of coastal Georgia, it is predicted that a hurricane will produce storm surges which will overwash barrier islands every 25 years. This frequency of overwash may be high for the state of Georgia considering only four hurricanes have reached the land of the Georgia coast since the beginning of the 20th Century (GEMA 2011), but with the projected increase in hurricanes and tropical storms due to climate change (Hoozemans et al. 1999; Hopkinson et al. 2008), the frequency of overwash may actually be underestimated.

The SLAMM program provides an elevation Pre-Processor to help alleviate errors in the final wetland position projections which can occur due to low quality elevation data (Clough et al. 2010). The NED file used to determine elevation for coastal Georgia is considered to be of low quality owing to the flatness of the coastal topography, so the Pre-Processor tool is used in the analysis.

The SLAMM program is executed using the IPCC A1B maximum scenario, which projects a rise of 694 mm in sea level between the years 2000 and 2100 (Clough et al. 2010). The A1B scenario is based on a future where there initially is a very rapid economic growth and the world's population peaks around 2050. The scenario also projects that more efficient technologies will be introduced to the public and that there will be a balance of energy resources such as wind, water, coal, and oil (Solomon et al. 2007). In the execution of SLAMM, the developed lands are not protected since it is difficult to predict how effective the protection of developed lands will be over a long time period. The sea-level rise scenarios are assessed for the years 2008 and 2030. The reason for predicting the spatial change of wetlands in 2008 is because the NWI file used in the execution of SLAMM is more than two decades old and the differences between the projected 2008 and the actual 2008 land use files needs to be evaluated to make sure there are not any large discrepancies in the spatial position or classification of wetland areas. The evaluation of discrepancies is performed in Chapter 4 and the methods used to calculate the discrepancies are presented at the end of this chapter. Results from the year 2030 are used in further mitigation analyses to provide a time scale that is easier for management to plan for and to limit error in land use conversions that can be inherent in programs that predict long term change.

The land cover classes for SLAMM are not the same as those used by GLUT, so the projected land use file needs to be crosswalked from SLAMM categories to GLUT categories, and this is done with the first section of the Project AML (Appendix C) using ArcINFO (ESRI 2007). Since the conversion from SLAMM land cover categories to GLUT categories has not been done before, a reclassification table is created (Table 3.3) based on the comparisons of the 2008 SLAMM and GLUT files as well as the comparison of the definitions of land cover classes for the National Wetland Inventory and GLUT. SLAMM categories are defined as: Developed Dry Land (1), Undeveloped Dry Land (2), Swamp (3), Cypress Swamp (4), Inland Fresh Marsh (5), Tidal Fresh Marsh (6), Scrub Shrub (7), Regularly Flooded Marsh (8), Mangrove (9), Estuarine Beach (10), Tidal Flat (11), Ocean Beach (12), Inland Open Water (15), Riverine Tidal (16), Estuarine Water (17), Tidal Creek (18), Open Ocean (19), Irregularly Flooded Marsh (20), Inland Shore (22) and Tidal Swamp (23). The GLUT categories used in the reclassification are defined as: Beach/Dune/Mud (7), Open Water (11), Developed Land (22), Undeveloped Land (41), Forested Wetlands (91), Saltwater wetlands (92), and Freshwater Wetlands (93). The final maps for the 2008 and 2030 projected change in wetlands using the before mentioned GLUT classification can be seen in Figure 3.2.

Identifying the changes in the spatial location of wetlands from 2008 to 2030 due to future risks will help in predicting changes to the condition of existing wetlands, determining the future potential of the landscape to support mitigated wetlands, and identifying areas in the landscape that need to be protected in order to allow marsh migration inland. Changes in wetlands can be divided into five categories:

1. <u>Not Classified as Wetlands:</u> This includes all areas that are not wetlands in the current land use map as well as the future land use map.
2. <u>Wetlands Lost:</u> Those wetland areas that are converted to open water, urban or agricultural areas are considered areas that are at high risk of permanently losing wetland functions.
3. <u>Wetlands Gained:</u> Those wetland areas that are converted to wetlands from a different land use.
4. <u>Converted Wetlands:</u> Wetlands that are converted to a different wetland classification (i.e. fresh marsh to salt marsh) are considered regions that are at less of a risk of losing important wetland functions such as flood regulation, water quality and hydrologic connectivity.

5. <u>No Change:</u> The wetland areas that do not change wetland classification or spatial location with time. These wetlands are considered to have the least risk of losing wetland functions.

The changes that can occur to wetlands over time are determined using the 2008 and 2030 projected land use maps created with SLAMM as well as the Wetlands Migration AML (Appendix C). The projected change in wetlands can be seen in Figure 3.3.

Population Growth

Coastal regions have been shown to expect great increases in population in the near future (Brock and Nielson 2009; Gedan et al. 2009; Morris et al. 2002) and the coast of Georgia is no exception, with a projected increase of population of 50% between 2005 and 2030 (Leone 2006). As part of a water resource assessment for the Georgia Regional Water Planning Process, the Georgia EPD worked with the University of Georgia to develop spatially explicit urban growth scenarios for the state of Georgia using the Slope, Land cover, Exclusions, Urban areas, Transportation and Hill-slope (SLEUTH) model. The data from the assessment also includes the projected agricultural growth of irrigated row crop land cover pixels. Before the projected growth map can be utilized in creating a future land use map, it is first manipulated to convert areas identified as new urban growth (pixel value of 25) into one of the GLUT's four urban land use classifications: open space (pixel value of 21), low intensity (pixel value of 22), medium intensity (pixel value of 23), and high intensity of development (pixel value 24). The reason for this modification is that the methodologies in components two through six make a distinction between the different development intensities and their influence on water quality, so the new urban growth areas need to be assigned an intensity of urbanization within the parameters of the four urban land use classes identified by GLUT.

To predict the development intensity of the new urban areas, section two of the Project AML in ArcINFO is used. This AML first evaluates the majority of the initial urban land use within a 510 meter radius using the FocalMajority tool (ESRI, 2007). A value of 510 meters represents 17 pixels in ArcMap and this distance was decided upon after trying various distances and seeing their distribution of development intensity. The values obtained from the output of the FocalMajority assessment are then assigned to the projected urban land use areas. This approach assumes that areas with a majority of specific development intensity will add areas of the same intensity in the future, and is more than likely an underestimation of the development intensity that will occur in 2030 because it does not take into account the increase in development intensity that can occur between 2008 and 2030 in urban areas that already exist. To demonstrate how urban growth is projected to change between 2008 and 2030 before and after the manipulations discussed in this section, a portion of the city of Savannah is extracted and reclassified to highlight only urban areas. These maps can be seen in Figure 3.4.

Erosion and Accretion of Barrier Islands

The National Oceanic and Atmospheric Administration (NOAA) website defines barrier islands to be “accumulations of sand that are separated from the mainland by open water” (National Oceanic and Atmospheric Administration 2011). Barrier islands are also described as being valuable to society because they provide recreational areas, habitats for coastal species, and protect the mainland from storms. These valuable services are threatened by the change in location and/or shape of barrier islands due to wave processes, tidal forces and the rise in sea-level. In response to sea-level rise, barrier islands can either migrate landward or drown (Gornitz 1991). For the coast of Georgia, Tybee island is showing characteristics of drowning. The SLAMM model output did not predict that this island area would diminish with the parameters that were used (Figure 3.5), so another analysis is needed to account for the changes in barrier islands.

Analyzing Moving of Boundaries Using R (AMBUR) is a program that can determine the rates of barrier island migration for both the ocean and the inland facing portion of a barrier island and then project those rates to produce a map of the new barrier island position. The only inputs into the program are the historic shorelines of an island. AMBUR assumes that the shorelines for the island are created using Light Detection and Ranging (LiDAR), aerial photos and elevation maps of an island (Jackson 2010) but LiDAR information for the entire coast of Georgia does not exist yet and the elevation maps of coastal Georgia are at low spatial resolutions. Since the shoreline files could not be made using any of the assumed methods, I decided to use the GLUT maps from 1974, 1985, 1992, 1998, 2001, 2005 and 2008 in the analysis to determine barrier island shoreline positions. The shoreline file for Jekyll Island in 1974 that is created using the land use maps are compared with the Jekyll Island 1974 shoreline file (Figure 3.6) that was created by Jackson (2010) to evaluate if there are significant differences between the methods used.

The input files necessary for AMBUR are created using the Shorelines AML in ArcINFO as well as the Baselines python script (Appendix C). The inputs for the Shorelines AML are the land use maps for the years previously specified and a mask that delineates all the barrier islands of interest. The Shorelines AML then creates shoreline polygons for all the given years by masking out all the islands of the coast, removing small water bodies (less than 18000 m^2) and converting the land use raster files to polygon files. Then the python script is used to create the shorelines, outer baseline and inner baseline polyline files for all of the barrier islands. The outer baseline is a five meter buffer around the outer most shorelines and the inner baseline is a five meter buffer from the inner most shorelines, as suggested by Jackson (2010). Small land masses are then removed from the baselines to focus on the barrier islands and to get a smooth inner and outer shoreline. Each island is then analyzed separately in AMBUR by first selecting the shoreline, inner baseline and outer baseline for each island in turn in ArcMap and entering those files in the AMBUR program. The shoreline files are then extrapolated to the year 2030 and the outputs of the process are the projected shorelines for each of the islands for the year 2030. The projected shorelines for the individual barrier islands are merged together and converted into a polygon file so that they can be used to represent the risk of barrier island movement in the final future land use map.

Future Land Use Map

The final step of component one is to combine the three parts to create a future land use map. To merge the three parts, the third section of the Project AML is used and it is based on a hierarchical structure that determines which risks are more likely to happen (Figure 3.7). What this means is that if a wetland area is projected to move into an area where there is also projected to be urban growth, then the risk due to urban growth is given preference and the land use pixel is converted to the urban growth value. The output of component one is a land use map of the future position of land uses along the coast of Georgia. This map is used for the subsequent components in this chapter (Figure 3.8).

COMPONENT TWO: POTENTIAL WETLAND RESTORATION SITE INDEX FOR THE YEARS 2008 AND 2030

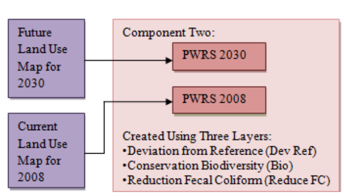


Figure 3.1.2: Diagram of the second component of the risk assessment, the creation of the PWRS Index for the year 2008 and 2030

The Potential Wetland Restoration Site Index for the coast of Georgia is created to determine the location where the mitigation methods of establishment and restoration of non-wetland sites will have the greatest positive effect on the wetland functions of water quality and quantity (WQQI), conservation of biodiversity in high priority streams (BIO), and reducing fecal coliform (Reduced FC) to shellfish nurseries and beaches. The WQQI and BIO layers are calculated in the same way as was done by Carpenedo (2008) with the only difference being that the initial National Hydrography Dataset (NHD) is altered to include currently ditched areas in the coast of Georgia. The Reduced FC layer is created specifically for the coastal analysis of the PWRS Index. The diagram in Figure 3.9 shows how the WQQI, BIO, and Reduced FC are added together, weighted using the Restorability Mask, and reclassified to create the PWRS Index.

Restorability Mask

The restorability mask is based on two procedures. The first procedure separates those land use pixels that are restorable from ones that are not restorable based on a hierarchical structure. The output is a layer identifying highly restorable (value of 9), non-restorable (value of 1) and secondary restoration sites (value of 6). The second procedure determines the potential for restorability based on hydric soils and presence of wetland vegetation, because these are two of the three qualifications necessary to delineate a wetland (Batzer and Sharitz 2006). Those areas that meet hydric soil requirements are given a value of 9, and those that have upland vegetation but do not have hydric soils are given a value of 8 while all other soils are given a value of 6. These two layers are then combined to create a masking layer. The masking layer is used in the remaining layers in component two in order to separate non-restorable land use pixels from restorable ones by weighting them during the final processing of the three layers (Carpenedo 2008).

The final processing steps in component one are the same for every layer and they are similar to the final processing steps done by Carpenedo (2008). After each layer is calculated and the final output determined, the final output is weighted using the restorability mask. The mask consists of the values 1, 6, 8, and 9 and the meaning of these values is described in Table 3.4. When the mask is used in weighting, this means that the spatial location in the final output that corresponds which corresponds with a specific value in the restorability mask is weighted by the mask value. When the mask equals 1, the minimum value of the output table is assigned to the corresponding location in the mask. Where the mask equals 6, the final output is multiplied by 0.66, and where the mask equals 8, the output is multiplied by 0.89. Where the mask equals 9, the output file retains its original value (Table3.5). After the layers are scaled according to the mask, the wetland and water landcover types are removed from the layers. Then the layers are reclassified using either Quantiles or Jenks Optimization, as defined at the end of the chapter introduction. The layers are reclassified from one to nine, with one corresponding with the lowest potential for wetland restoration/establishment to improve wetland functions and nine corresponding with the highest potential for wetland restoration/establishment to improve wetland functions. Calculations for each layer are performed twice, once using the 2008 GLUT and again using the projected land use map for 2030.

Jurisdiction

The jurisdictional layer is not included in the final analysis of the Potential Wetland Restoration Site Index, but it is a useful map that determines where the qualities of wetland jurisdiction are met. Jurisdiction is evaluated based on the Savannah Georgia's USACE jurisdictional definition for regulating navigable waters. According to the definition, the agency is responsible for regulating those areas within the 100 year flood plain or that are within 100 feet of a navigable stream (Carpenedo 2008). In the jurisdictional layer, those land use pixels that meet the jurisdictional guidelines are given a value of 9. To account for errors due to the resolution of the NHD data, land use pixels within a 30 meter (or one pixel) buffer around the value 9 pixels are given a value of 8. For the remaining land areas, those that are identified as being non-restorable in the Restorability Mask are given a value of 1 and all other land areas are given a value of 6 (Carpenedo 2008). The final jurisdictional map can be seen in Figure 3.10.

Water Quality and Quantity (Layer 2.1)

Layer one of component two identifies areas where the restoration/establishment of wetlands will improve water quality (Zedler 2006) as well as improve flood control and regulation (Cedfeldt et al. 2000). The water quality and quantity index (WQQI) is composed of two separate indices: the potential runoff index (PRI) and the Distance to Impairment Index (DII), as described in the Literature Review. The PRI and DII are calculated in the same manner as described in Carpenedo (2008) and shown in the with only one difference. That difference is that one of the input files for the DII is altered to reflect hydrological conditions specific to coastal conditions.

The DII evaluates the hydrologic distance of a land use pixel to a water body to help identify the spatial locations where a restored/established wetland site will provide the most improvement in water quality (Johnston et al. 1990; McAllister et al. 2000). The reasoning behind this is that the position of a wetland in the landscape (White and Fennessy 2005) determines if it is able to receive and remove the nonpoint source pollution before it reaches a stream. The original analysis used streams identified by the National Hydrography Dataset (NHD), but this data does not contain newly ditched areas in the coast. It is important to include these ditched areas in the analysis because ditches can act as conduits for nonpoint source pollution to move from the upland to a water body (Koch and Gobler 2008) by increasing runoff and peak flow and reducing the landscape's natural ability to absorb contaminants. Extensive ditching has also been correlated with higher bacteria levels within a basin, which will reduce water quality (Christy and Glasoe 2004). To adjust the NHD file to include recently ditched areas, a new ditch file is created by comparing the NHD file, aerial photographs from 1999, 2005, 2007 and 2009, and elevation data for the entire coastal region of Georgia. To locate ditched areas a systematic approach is adopted that looks over the entire coast by analyzing a 500 m x 500 m patch of land at a time using the most recent aerial photograph which show bare ground. The areas that looked as though they were ditched are then delineated (Figure 3.11). The final ditch shape file is then added to the original NHD dataset (Figure 3.12). This new NHD file is then used in the calculation of the DII for the WQQI in this layer and in all subsequent layers (Carpenedo 2008). The final WQQI for 2008 and 2030 are shown in Figure 3.13.

Conservation of Biodiversity in High Priority Streams (Layer 2.2)

High priority streams are water bodies that support aquatic species that are in need of conservation, and are identified by the Georgia Natural Heritage Program for the "Comprehensive Wildlife Conservation Strategy of Georgia" (GADNR, 2005). This layer evaluates the spatial locations where wetland restoration/establishment will reduce the contribution of nonpoint source pollution to high priority streams by placing wetlands or riparian buffers in areas where saturated variable runoff accumulates. The BIO layer is created in the same manner as described by Carpenedo (2008), which is similar to the way that the WQQI layer is calculated except that streams of high priority are used in the calculation of the DII instead of the NHD file. This new DII is then called the Distance to High Priority Streams Index (DHPSI).

The WQQI in this layer is calculated using the PRI from the WQQI layer (Layer 2.1) as shown in equation 1.

$$WQQI = PRI_{rcls} * DHPSI_{rcls} \qquad \text{(eq 1)}$$

Where:

PRI_{rcls} = the reclassified potential runoff index created in the WQQI layer of the PWRS

$DHPSI_{rcls}$ = the reclassified distance to high priority streams

The WQQI for this layer is reclassified using Jenks, and the final BIO layer (Figure 3.14) represents the potential wetland restoration sites that can minimize impairments to high priority streams and rivers and increase the likelihood that the species that are in need of conservation continue to persist.

Coastal Fecal Coliform Index (Layer 2.3)

Pollution of estuaries and beaches due to high levels of fecal coliform is a growing problem in coastal regions. It has been shown by several studies (Kelsey et al. 2004; Lockaby and Schoonover 2006; Mallin et al. 2001; Mallin et al. 2000) that the level of fecal coliform in water bodies is highly correlated with the amount of impervious surface in a watershed. Since the human population is increasing in coastal areas (Christy and Glasoe 2004; Scavia et al. 2002) the level of fecal coli form may rise as well. An increase in population will also raise the demand for coastal resources (Scavia et al. 2002) such as shellfish and beaches, so it is even more important to protect these areas from fecal coliform contamination. Resource managers need to be able to identify areas where restoration can improve the coastal wildlife habitat and recreational areas that are most affected by elevated levels of fecal coliform by placing restored/established wetlands in locations where they can reduce nonpoint source pollution from urban areas and target restoration efforts in watersheds with a high percentage of impervious surface.

To evaluate where the restoration/establishment of wetland sites will improve shellfish nursery and recreation areas, two separate analyses are performed using the Habitat and Beach AML in ArcInfo. The first analysis determines where restored/established wetlands will reduce the amount of fecal coliform entering streams by evaluated where the highest potential sources of nonpoint source runoff occurs and their distance to the stream. This analysis is performed in Layer 2.1 with the Water Quality and Quantity Index. The second analysis evaluates the percentage of impervious surface within a 12 Digit HUC by first selecting the developed landcover classes from the 2008 and 2030 land use files. There are four different levels of development which relate to the amount of the land use pixel that is actually covered by impervious surfaces. These levels of development intensity include open space (0-19% impervious surface cover), low intensity (20-49% impervious surface cover), medium intensity (50-79% impervious surface cover), and high intensity urban areas (80-100% impervious surface cover). To calculate the area, the impervious surface pixel area (900 m^2) is multiplied by the average percent of pixel coverage for each development landcover type. The average percentage of impervious surface is used because in order to use equations 2 and 3, a finite value is needed and using the average of the impervious surface range for each of the four development landcover types helps to reduce the overestimation or underestimation of urban area. The average percentage of impervious surface for open space is 10%, low intensity is 34.5%, medium intensity is 64.5%, and high intensity is 90%. After the area is determined for each of the urban landcover pixels in the coast, the percentage of impervious area within a watershed is calculated using equation 2.

$$PercImpv_i = \left(\sum Area_{imp} \right) / Area_i \qquad \text{(eq 2)}$$

Where:

$Area_{imp}$ = Impervious area within HUC i

$Area_{HUC}$ = Area of the watershed i

The percent of impervious surface per watershed is then reclassified from 1-9 using Jenks Optimization (Dent, 1999) so that the higher the percentage of impervious surface in a watershed correlates with a higher potential need for wetland restoration. The Coastal Fecal Coliform Index (CFCI) for a 12 Digit HUC is then created using the WQQI from Layer 2.1 and the Percent of Impervious Surface as shown in equation 3.

$$CFCI = WQQI_{nc} * PercImpv_{rcl} \qquad \text{(eq. 3)}$$

Where:

$WQQI_{nc}$ = the non-classified water quality and quantity index from Layer 2.1

$PercImpv_{rcl}$ = the reclassified percent of impervious surface within a 12 Digit HUC

The CFCI determines the spatial position in the landscape where the highest potential of variable source runoff will enter water bodies and is weighted by the percentage of impervious surface within a watershed. The values of the unclassified CFCI range from 1 to 729. The unclassified CFCI is weighted using the Restorability mask and is then reclassified using Quantiles (1-9) so that the value of 9 corresponds with the highest potential for wetland restoration. The final output (Figure 3.15) shows the spatial location where wetland mitigation sites can reduce the levels of fecal coliform to streams, estuaries and beaches.

PWRS Index

The Potential Wetland Restoration Site (PWRS) index is an additive model that highlights areas in the landscape that have the greatest potential of improving wetland ecosystem function through the restoration/establishment of wetlands. The PWRS is created for both 2008 and 2030 by summing the final outputs of the WQQI, BIO, and Reduced FC layers. The highest possible value is 27 and the lowest is 3. The PWRS is then reclassified using Jenks Optimization (Dent, 1999) from one to nine, with nine corresponding with the highest potential to improve ecosystem functions through wetland restoration/establishment, and one corresponding to the least potential for improvement (Figure 3.16). The sites with the maximum values (value 7, 8 or 9) have the highest potential to positively influence wetland functions.

COMPONENT THREE: RISK MASK

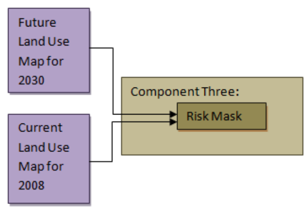


Figure 3.1.3: Diagram of the third component of the risk assessment, the creation of the Risk Mask

"How far in the future does you responsibility extend?" Titus (2000) asked this question in the beginning of his article about the responsibility of the government to protect wetlands and beaches from being destroyed by sea-level rise. Currently compensatory wetland mitigation practices identify sites that are appropriate for mitigation purposes based on current and past conditions of the landscape (Kramer and Carpenedo 2009; Kramer, *pers Comm.)*. Coastal wetlands are dynamic systems that are constantly changing, so the identification of potential wetland mitigation sites needs to reflect their transitory nature. To do this, resource managers need a tool that will allow them to assess the future risks that can occur to potential mitigation site locations and to identify where the changes in land use that occur over time may create new potential mitigation sites. The first step in creating this tool is a Risk Mask, which is presented in this component.

The Risk Mask, which is created using the Risk Mask AML (Appendix C), identifies the changes that occur to wetlands and other landcover types by comparing the land use map for

2008 and the future land use map for 2030, which was created in Component One. The land use changes can be divided into four categories (Figure 3.17):

1. Wetlands Lost (value of 1)
2. Land Use Changes (value of 6)
3. Land Use Stays the Same (value of 8)
4. Wetlands Gained (value of 9)

Lost wetlands are those regions that are identified as wetlands in 2008 but have been converted to another land use in 2030 due to sea-level rise, storm surges, barrier island migration or anthropogenic influences. The land use changes category identifies those regions of the coast where the land use change transitions from one land cover type to another. This category does not discriminate between changes of one wetland type to another or the change from forested landcover to urban landcover. The category, "Land Use Stays the Same", identifies locations where there are no land cover class changes between 2008 and 2030. The fourth category identifies the wetland areas that are created between 2008 and 2030 as a result of the land use change caused by sea-level rise and storm surges. The different values associated with the categories (value of 1, 6, 8 or 9) represent the potential loss of wetland function for a land cover pixel in such a way that the pixel which corresponds with a value of 9 has the least risk of wetland mitigation failure due to coastal stresses.

The layers in the two final parts of the Risk Analysis (Change in Potential Wetland Restoration Site Index and the Change in Wetland Site Index) use the Risk Mask to weight their output. This weighting is done in the same manner as the Restorability Mask is used to weight the level of restorability of Potential Wetland Restoration Sites in Component Two. A land cover pixel in the unclassified layers of the CPWRS Index or CWSI that is in the same location as a mask pixel with the value nine will retain its original value. Where the layer corresponds with the masking value of 8, it will retain 89% of its value, and the location where the layer corresponds with the masking value of 6 it will retain 66% of its original value. In the locations where the layer corresponds with a Risk mask value of 1, it is assigned the lowest value of the layer. By masking the layers in the risk assessment, areas of high risk of losing the potential to improve wetland functions through compensatory mitigation are assigned a low potential for wetland mitigation over time and resource managers can use this information to avoid placing mitigation sites in high risk areas.

COMPONENT FOUR: THE EFFECT OF COASTAL RISKS ON THE POTENTIAL OF NON-WETLAND SITES TO PERFORM WETLAND FUNCTION FROM 2008 TO 2030

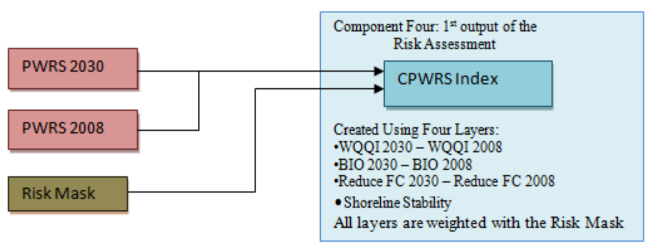


Figure 3.1.4: Diagram of the fourth component of the risk assessment, the creation of the CPWRS Index

Wetland mitigation in coastal regions can be used to help improve wetland ecosystem functions in the future as well as the present time. By reserving those areas that could change into wetlands through migration, we are allowing the wetlands to have room to naturally adjust to a rise in sea-level (Burkett and Kusler 2000). What is currently happening in coastal areas is that developed areas are originally placed away from the shoreline to help protect existing wetlands and beaches (Titus 2005). As the sea-level rises, bulkheads are placed between the developed areas and the wetlands to protect them from ocean waters. This bulkhead acts as a barrier to marsh migration, and the wetlands and beaches become inundated as the sea-level rises (Titus 2000; Titus 2005). To keep coastal wetlands and the functions that they provide, it is important to identify areas where marsh migration will happen. Once the areas of marsh migration are identified, those areas can either be preserved from development, or wetland mitigation sites can be placed in those areas to help facilitate marsh migration. Improving or reserving these potential wetland migration areas will help to stablize shorelines from the influence of storm surges and reduce erosion by increasing the amount of wetlands between the shoreline and the upland.

In component four, the Change in Potential Wetland Restoration Sites (CPWRS) Index identifies where changes to the potential of restoration/establishment of wetlands occur between 2008 and 2030 and highlights those non-wetland areas that need to be preserved for future mitigation efforts. The CPWRS is divided into four layers and the first three layers are the difference between the potentials evaluated for the WQQI, BIO, and Reduced FC layers for the years 2008 and 2030. The fourth layer prioritizes the ability of non-wetland areas to improve the function of shoreline stability over time. These four layers are each weighted by the Risk Mask and then added together to create the CPWRS Index as shown in Figure 3.18.

Difference in Potential for the Layers in the PRWS Index from 2008 to 2030 (Layer 4.1, 4.2, and 4.3)

The difference in the potential of a non-wetland site to perform wetland functions between 2008 and 2030 is evaluated to determine the locations in the coast that either increase or decrease in their potential for performing the wetland functions of improving water quality and quantity, increasing conservation of biodiversity in high priority streams, and reducing the level of fecal coliform in water bodies, estuaries, and beaches. By identifying the locations where the potential for performing one of the three wetland functions varies, resource managers can then select the position in the landscape where restored/established wetland sites will increase the longevity of mitigated sites by placing them in positions that are at a low risk of being lost or changed over time.

The change in potential is calculated in the same way for all three layers in the PWRS Index. For a given layer, the 2008 file is subtracted from the 2030 file and the result is a map that ranges from -9 to +9. The highest value (+9) represents the locations where the potential to improve the respective wetland functions increases the most between the time period of 2008 and 2030. Conversely, the lowest value (-9) represents the locations where the potential to improve respective wetland functions decreases the most between the time period 2008 and 2030. The resulting map does not take into consideration where risks to wetland mitigation occur in the landscape, so to account for this the Difference Layers are weighted by the Risk Mask. The final process for Layers 4.1, 4.2, and 4.3 is reclassifying the layers from 1-9 using Jenks Optimization, where the value 9 corresponds with the highest positive change in potential, and the value 1 corresponds with the largest negative change in potential. The final outputs are the CWQQI (Layer 4.1), CBIO (Layer 4.2), and CReduced FC (Layer 4.3), which can been seen in Figures 3.19, 3.20 and 3.21, respectively.

Shoreline Stability (Layer 4.4)

Storm surge is the abnormal rise of water that is created by a storm event, such as hurricanes, and is usually much higher than local tides (National Hurricane Center 2011). Storm surges can flood coastal areas, erode beaches, and also damage barrier islands (Caldwell 2008). Coastal wetlands help to protect inland regions from the effects of storm surges by dissipating the energy of the storm surge water and binding soils with plant root systems (Michaud 2001). The role that coastal wetlands play in reducing damage to inlands from storm surges depends on the intensity of the storm and the size of the coastal wetland (Zinn 2005). Research has shown that for every square mile of wetland that a storm surge passes over that the elevation of the storm surge on adjacent inland areas is reduced by approximately one foot (Army Corps of Engineers 1963).

To account for the new wetland regions that are created in the future land use map in component one, a methodology is used that identifies the new wetland areas and ranks their ability to reduce the effects of storm surge and coastal erosion based on their size and proximity to existing wetlands and storm surge areas. When ranking the new areas by size, the ability of the new wetland regions to improve biodiversity also increases with the increase in wetland size. This phenomenon is explained by the theory of island biography (Simberloff et al. 1999), which predicts that larger wetland sites are more likely to contain a variety of habitats and species due to the increase in dispersal to the wetland site and the decrease in species extirpation (Zedler 2006).

The first step in creating Layer 4.4 is to rank the size of the new wetlands, which is done using the Shoreline Stability AML in ArcINFO. Specifically, the new wetland regions from the future land use map are grouped into patches using the RegionGroup tool (ESRI 2007). Next the areas of these patches are calculated using the ZonalArea tool. The result, the Indexed Wetland Size (IWS), is an unbounded inverse index that can vary from 900 to ∞, where 900 corresponds to a new wetland region that is one pixel in size, which is the smallest possible area based on the resolution of the map. The IWS is then reclassified from 1-9 using Jenks where a value of nine corresponds with those wetland areas that have the largest patch size. The new wetland patches with the largest area are those that would provide the most surface area to reduce the effects of storm surge and erosion along the coast which usually occur during hurricane events.

The second step in the evaluation of the CFCI is to rank the potential for a new wetland area to reduce the effects of hurricane events based on a land use pixel's proximity to existing wetlands and the shoreline, because for every 2.7 miles of wetlands that a storm surge passes over, the elevation of the storm surge is reduced by approximately one foot (Zinn 2005). The land use pixels of interest in this analysis are the land use classes in the 2008 GLUT file that are not classified as being a wetland or water area. The shoreline for this analysis is defined as the water body in the 2008 GLUT that has the largest area. The distance of a land use pixel to the closest shoreline and existing wetland pixel are both calculated using the Shoreline Stability AML (Appendix C), which uses the Euclidian Distance tool (ESRI 2007). Both the distance to an existing wetland and the distance to the shoreline are then masked to remove those areas that are wetland or water in the 2008 GLUT or the future land use map for 2030. Then the two distance layers are reclassified from 1-9 using Quantiles, where a value of nine corresponds with the lowest value of either the distance to an existing wetland or the distance to the shoreline. The Land Use Distance Index (LUDI) is then calculated using the reclassified distances as shown in equation 4.

$$LUDI = D_{EWrcl} * D_{Srcl} \qquad \text{(eq 4)}$$

Where:

D_{EWrcl} = the reclassified distance of a land use class pixel to the closest wetland

$D_{S\ rcl}$ = the reclassified distance of a land use class pixel to the closest water body

The LUDI ranges from 1 to 81, with 1 implying that the land use pixel's spatial location will provide the most benefit to shoreline stability. The LUDI is reclassified from 1-9 using Jenks so that a value of nine corresponds to the lowest LUDI value, or the shortest linear distance to both existing wetlands and the shoreline.

Layer 4.4, the shoreline stability layer, is then created by multiplying the reclassified IWS and LUDI. This new layer ranges from 1 to 81 and identifies those new wetland areas that have the highest potential of improving shoreline stability between the years 2008 and 2030. The Risk Mask is then used to weight the shoreline stability layer in order to adjust the potential for restoration/establishment based on a land use pixel's associated risk category. The shoreline stability layer (Layer 4.4) is then reclassified from 1-9 using Jenks so that a value of 9 corresponds to a new wetland area that has the highest potential of improving shoreline stability and thus is an area of interest in wetland mitigation (Figure 3.22).

The Change in Potential for Wetland Restoration Sites from 2008 to 2030

One of the two final outputs of the coastal risk assessment is the Change in Potential Wetland Restoration Sites. The CPWRS is an additive model that highlights areas where the potential for restored/established wetland sites increase in their ability to perform wetland functions between the years 2008 and 2030. Several processing steps are necessary to create the CPWRS.

The first step is to add the final CWQQI, CBIO, CReduced FC, and Shoreline Stability layers (Layers 4.1-4.4) as shown in equation 5.

$$\text{CPWRS} = \text{CWQQI} + \text{CBIO} + \text{CReduced FC} + \text{SS} \qquad \text{(eq. 5)}$$

Where:

CWQQI = the change in potential between the 2008 and 2030 WQQI (Layer 4.1)

CBIO = the change in potential between the 2008 and 2030 BIO (Layer 4.2)

CReduced FC = the change in potential between the 2008 and 2030 Reduced FC (Layer 4.3)

SS = the shoreline stability layer (Layer 4.4)

The maximum possible value of the unclassified CPWRS is 36, which is representative of an area with the greatest probability of having an increase in potential for wetland mitigation in the future based on shoreline stability and the change in potential for water quality, conservation of biodiversity, and the ability to improve fecal coliform levels.

The second step is masking the CPWRS so that only areas that are non-wetland land cover classes remain, and then this is reclassified from 1-9 using Jenks, where the value 9 corresponds to the highest value in the unclassified CPWRS. The final output (Figure 3.23) can be used by management when selecting areas for potential creation/restoration of wetlands by providing them with a means of accounting for future changes in the landscape and the effects that they will have on wetland functions.

COMPONENT FIVE: WETLAND SITE INDEX FOR THE YEARS 2008 AND 2030

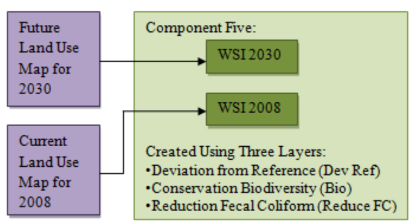


Figure 3.1.5: Diagram of the fifth component of the risk assessment, the creation of the WSI for the years 2008 and 2030

All of the layers in component five, except the Coastal Fecal Coliform Index (Layer 5.3), were developed by the Natural Resources and Spatial Analysis Laboratory (NARSAL) at the University of Georgia, in Athens. Since these layers are not adapted for the coastal Wetland Site Index, other than adding the ditched areas to the NHD file as discussed in the WQQI layer in component two, a brief summary of each layer and its final output is given to help readers understand what the layers are and how they are created. A flow diagram is provided in Figure 3.24, which shows how the three layers (Dev Ref, BIO, and Reduced FC) are combined to create the Wetland Site Index.

Deviation in Potential Runoff (Layer 5.1)

Layer one of component five is designed to prioritize the potential condition of wetlands based on the amount of non-point source pollution that enters a wetland. Human altered landscapes, such as urban and agricultural areas, have been shown to have increased runoff that is linked with higher levels of non-point source pollution (Berka et al. 2001; Gergel et al. 2002; Herlihy et al. 2010; Mattikalli and Richards 1996; Meador and Goldstein 2003; Wang 2001). Restoring or establishing wetlands in areas where there is a high accumulation of runoff will aide in the removal non-point source pollution (Mitsch 1992; Mitsch and Day 2006; van der Valk and Jolly 1992).

To evaluate the opportunity that wetlands have to improve water quality, a reference PRI is compared to the PRI calculated in the WQQI layer of Component Two. The reference layer represents a scenario where there are no human disturbances. To create the reference layer, all non-wetland land cover classes from the 2008 GLUT file or the 2030 future land use map are reclassified as forest and all existing wetlands are left as wetlands. The difference between the reference and actual PRI are calculated to determine the deviation of a wetland from its reference condition. The resulting index has a value between zero and one, where a value of zero represents no difference between the reference and actual PRI and a value of one represents the greatest deviation. The change in PRI is masked so that only wetlands remain and a focal mean with a 500 meter radius is used to acknowledge the influence of surrounding wetlands in improving water quality to other wetland pixels.

The output of the focal mean calculation is again clipped to the spatial extent of the wetlands and is then reclassified from 1-9 using Jenks. The final output (Figure 3.25) is the potential deviation of a wetland from its reference condition with 9 corresponding to the least deviation and 1 corresponding with the greatest deviation of current wetland water quality from the reference water quality (Kramer, *pers. Comm.*). For mitigation purposes, those wetland areas that are identified as having the greatest deviation from reference condition (value 1, 2, or 3) would also be the areas that would benefit the most from the mitigation method of wetland enhancement.

Conservation of Biodiversity in High Priority Streams (Layer 5.2)

The conservation of biodiversity in high priority streams layer ranks the condition of wetlands based on their ability to minimize non-point source pollution to high priority streams. This layer is evaluated using the same steps and is based on the same reasoning as described in the Conservation of Biodiversity layer (Layer 2.2) in Component Two of this chapter. The only difference is that in the final processing, the reclassification values are reversed. The PRI and DHPSI that are used in the creation of the water quality and quantity index for high priority streams are reclassified from 1-9 using Jenks so that a value of 9 corresponds with the highest PRI/DHPSI value. The reclassified PRI and DHPSI are then multiplied together to get the WQQI, which is then reclassified using Jenks so that a wetland with the highest unclassified WQQI will correspond with the value 9. This means that the higher the WQQI value, the lower amount of variable source runoff and are the greater the distance from high priority streams. The WQQI is then masked to remove wetlands and reclassified from 1-9 with Jenks (Dent 1999) so that wetlands that have a rank of nine (Figure 3.26) have the highest potential of improving water quality and biodiversity to high priority streams (Kramer, *pers Comm.*).

Coastal Fecal Coliform Index (Layer 5.3)

The third layer of the Wetland Site Index evaluates where existing wetlands would be least affected by elevated levels of fecal coliform. Wetland areas, such as estuaries, provide habitat, food and shelter for nearly two-thirds of the commercially important shellfish (Hemesath and Nunez 2002). These shellfish are highly susceptible to accumulating fecal coliform because when they filter water to remove nutrients, they are inadvertently consuming fecal coliform, which is slow to leave their systems (Burkhardt III and Calci 2000). Humans that consume shellfish with high levels of fecal coliform, especially the *E. coli* bacterium, can become sick (Hemesath and Nunez 2002) and have symptoms such as abdominal pain and diahria (Tarr 1995). Efforts are being made by regulatory agencies such as the Department of Natural Resources (DNR) to monitor the levels of fecal coliform in estuaries to ensure that shellfish from areas with elevated fecal coliform levels are not consumed by the public. Resource managers need to target the wetland areas that show the highest potential for elevated fecal coliform levels for mitigation purposes in order to improve the quality of shellfish for human consumption.

Layer 5.3 is calculated in the same way as the Reduced FC layer (Layer 2.3) in Component Two, except for the final processing. There are three indices used to calculate the reduced fecal coliform layer: the Potential Restoration Index, Distance to Impairment Index and the percent of impervious surface per 12 Digit HUC. The first step in the final process for Layer 5.3 is to reclassify the PRI and the DII from 1-9 using Quantiles so that a value of 9 corresponds to the highest PRI and DII values. Then the reclassified PRI and DII are multiplied together to get the WQQI. The WQQI ranges from 1 to 81 where the highest value (81) corresponds to the spatial location that is the farthest from a water body and has the lowest nonpoint pollution. The WQQI is reclassified from 1-9 using Jenks, so that the highest value of the WQQI corresponds with the value nine.

Next, the percent impervious surface per 12 Digit HUC is reclassified in a similar manner, except that nine corresponds to the lowest value of the percent of impervious surface.

The reclassified percent impervious and the reclassified WQQI are multiplied together to create the Coastal Fecal Coliform Index (CFCI) and this is reclassified from 1-9 using Jenks Optimization, where a value of nine corresponds with the highest CFCI value. The final CFCI (Figure 3.27) ranks the condition of existing wetlands so that wetlands that potentially have low levels of fecal coliform are considered to be the least impaired.

Wetland Site Index

The Wetland Site Index (WSI) is created in the same manner as the PWRS index in Component Two; by summing the final output of layers 4.1 (Dev Ref), 4.2 (BIO) and 4.3 (Reduced FC). The highest possible value in the unclassified WSI is 27 and the lowest value is 3. The WSI is reclassified using Jenks Optimization (Dent 1999) from one to nine, with nine corresponding with the wetland pixels that have the highest potential of performing ecosystem functions and one corresponding to wetlands with the least potential of performing ecosystem functions (Figure 3.28). Those wetlands ranked as having a low potential for performing ecosystem functions are areas where the mitigation practice of enhancement may improve their functionality and those with a high potential are areas that should be preserved (Federal Register Federal Register 2008).

COMPONENT SIX: THE EFFECT OF COASTAL RISKS ON THE POTENTIAL OF EXISTING WETLAND SITES TO PERFORM WETLAND FUNCTIONS FROM 2008 TO 2030

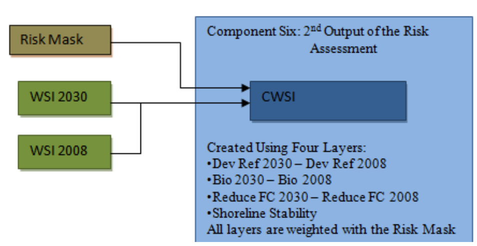


Figure 3.1.1: Diagram of the sixth component of the risk assessment, the creation of the CWSI.

Hoozemans et al. (1999) suggests that there are five scenarios of shoreline change that can occur due to sea-level rise and storm surges, as described in the Literature Review. To describe the stability of a coastal shoreline, these five scenarios can be condensed into three groups as described as follows.

1. The first group represents a stable shoreline where the elevation of wetlands are maintained with the elevation of the sea. In this scenario, the proportion of wetlands to beach and water areas along the coast remains the same between the years 2008 and 2030.
2. The second group represents a less stable shoreline where the proportion of wetlands to water and beach area changes in such a way that either
    a. the area of wetlands stays the same between 2008 and 2030 and the beach and water area increase as wetlands migrate inland or
    b. the area of wetlands decreases because of limited wetland migration and the beach and water areas still increase between 2008 and 2030.
3. The third group represents the most unstable shoreline position, which is a complete loss of wetlands and the regions where wetlands usd to be are converted into either beach or water landcover types.

In the context of a mitigation standpoint, it is important to know those areas where there is a projected retreat in coastline and wetland areas are destroyed so that wetland mitigation is not performed in these sites.

In component five the Change in the Wetland Site Index highlights the areas where the potential for enhancing/preserving wetlands varies from 2008 to 2030. The CWSI is divided into four layers and the first three layers are the difference between the potentials evaluated for the

Dev from Ref, BIO, and Reduced FC layers in Component Five for the years 2008 and 2030. The fourth layer prioritizes the ability of existing wetland areas to perform the function of shoreline stability between the years 2008 and 2030. These four layers are each weighted by the Risk Mask and then added together to create the CWSI Index as shown in Figure 3.29.

Difference in Potential for the Layers in the PRWS Index from 2008 to 2030 (Layer 4.1, 4.2, and 4.3)

The difference in the potential condition of an existing wetland site between the years 2008 and 2030 is evaluated to determine the locations in the coast where wetland conditions are projected to either improve or become more degraded. The change in wetland condition is evaluated using the three layers created in component five (Dev Ref, BIO, Reduced FC) and the change in shoreline stability that can occur due to a rise in sea-level and storm surges from 2008 to 2030. By identifying the locations where the condition of wetlands vary over time, resource managers can then select the position in the landscape where the preservation/enhancement of existing wetlands will provide the most benefit to wetland functions within a watershed. To increase the likelihood of successfully preserving/enhancing wetland sites it is also important to select wetlands that are at a low risk of being lost due to coastal stresses.

The change in the potential condition of wetlands is calculated in the same way for all three layers in the Wetland Site Index. For a given layer, the 2008 file is subtracted from the 2030 file and the result is a map that ranges from -9 to +9. The highest value (+9) represents the locations where the potential to improve the wetland conditions increases the most between the time period of 2008 and 2030. Conversely, the lowest value (-9) represents the locations where the most degradation to a wetlands ability to perform a specific function occurs within the given time period. The resulting map does not take into consideration where risks to wetland mitigation occur in the landscape, so to account for this the Difference Layers are weighted by the Risk Mask. The final process for Layers 6.1, 6.2, and 6.3 is reclassifying the layers from 1-9 using Jenks Optimization, where the value 9 corresponds with the largest improvement in wetland condition from 2008 to 2030, and the value 1 corresponds with the largest decrease in wetland condition. The final outputs are the CDev Ref(Layer 6.1), CBIO (Layer 6.2), and CReduced FC (Layer 6.3), which can been seen in Figures 3.30, 3.31 and 3.32, respectively.

Loss of Shoreline Stability due to the Loss of Wetlands (Layer 6.4)

As discussed in Layer 4.4 (Shoreline Stability) of Component Four, the size and the spatial location of wetlands can reduce the negative effects that storm surges have on the upland and help to maintain shoreline stability by reducing erosion. Just as increasing the size and of wetlands in close proximity to existing wetlands on the shoreline can improve shoreline stability, reducing the size of the existing wetland will reduce shoreline stability by leaving the upland more exposed to storm surges. Another way to determine shoreline stability is described in the introduction of this component. By being able to look at the proportion of wetlands to beach and water areas in 2008 and 2030, the general trend of shoreline stability can be determined. Knowing where wetlands are lost and the general areas where the shoreline is less stable to the influence of sea-level rise and storm surges can aid resource managers in avoiding these sites for preservation/enhancement mitigation projects.

Layer 6.4 is determined in two parts. The first part ranks the size of the wetland areas lost in the same manner that is done in Layer 5.1, except that the area of interest are those wetland areas that are destroyed between 2008 and 2030. The final processing of the IWS is different because in the reclassification, a value of 9 corresponds to the destroyed wetland areas that are smallest since they would have less of a risk in changing the potential of shoreline stability (Army Corps of Engineers 1963) and wildlife biodiversity , as described in Component Four (Zedler 2006).

The second part of this layer ranks the change of the proportion of wetlands destroyed per 12 Digit HUC in order to provide management with a means of considering restoration at the watershed scale, since this is emphasized in compensatory mitigation projects (Federal Register 2008). The first step in this analysis is to calculate the percent of wetlands, beaches and water within a 12 Digit HUC for the years 2008 and 2030. This is done using the ZonalSum tool (ESRI 2007). Then the percent areas for those three land cover classifications are calculated for each HUC and the values are used in equation 6 to rank the wetlands within a12 Digit HUC on their ability to provide a stable shoreline over time. The calculation used to determine the proportion of wetland to beach and water area over time is shown in equation 6.

$$\text{Change in Proportion}_i = \frac{Wet_{30i}}{(B_{30i} + W_{30i})} - \frac{Wet_{08i}}{(B_{08i} + W_{08i})} \qquad \text{(eq 6)}$$

Where:

B_{30i} = the percentage of beach in HUC *i* for the year 2030

B_{08i} = the percentage of beach in HUC *i* for the year 2008

W_{30i} = the percentage of water in HUC *i* for the year 2030

W_{08i} = the percentage of water in HUC *i* for the year 2008

Wet_{30i} = the percentage of wetland in HUC *i* for the year 2030

Wet_{08i} = the percentage of wetland in HUC *i* for the year 2008

In the final steps, the Change in Proportion layer is masked so that only areas that are wetlands in 2008 and 2030 remain and then it is weighted by the Risk Mask. The masked and weighted Change in Proportion layer is then reclassified from 1-9 using Jenks so that the value of

9 is assigned to those wetland areas with the smallest deviation their proportion of wetlands to beach and water areas.

The shoreline stability layer is calculated by multiplying the reclassified Change in Proportion (CP) by the reclassified IWS. The highest values represent the smallest wetland areas with the smallest change in the proportion of wetlands to beach and water. Then Layer 5.2 is reclassified from 1-9 using Jenks, where a value of 9 corresponds with that wetland which exhibits the highest potential ability of performing the shoreline stability function (Figure 3.33).

The Change in the Wetland Site Index from 2008 to 2030

The second of the two final outputs for the risk assessment of coastal wetlands is the Change in Wetland Site Index (CWSI). The CWSI is an additive model that identifies existing wetlands that have the highest potential of performing the wetland functions of water quality and quantity, conservation of biodiversity, reducing fecal coliform, and stabilizing the shoreline. The Change in Wetland Site Index is calculated using equation 7, which is similar to the equation used to calculate the CPWRS Index.

$$CWSI = CDevRef + CBIO + CReduced\ FC + SS \qquad \text{(eq. 7)}$$

Where:

CDevRef = the change in the deviation of a wetland site to improve water quality when compared to a reference for the years 2008 to 2030(Layer 6.1)

CBIO = the change in the ability of a wetland to conserve biodiversity between the years 2008 and 2030 (Layer 6.2)

CReduced FC = the change in level of fecal coliform in wetlands between the 2008 and 2030 (Layer 6.3)

SS = the shoreline stability layer (Layer 6.4)

The final CWSI represents those areas with the highest potential for wetland functionality based on shoreline stability and the change in potential for water quality, conservation of biodiversity in high priority streams, and fecal coliform levels. The final step in the processing of the CWSI is the reclassification from 1-9 using Jenks, where the value 9 corresponds to the highest value in the unclassified CWSI. The final output (Figure 3.34) can be used by resource management when selecting areas for potential enhancement/preservation of wetlands by providing them with a means of accounting for future changes in the landscape and the effects that those changes will have on wetland functions.

METHODS USED TO CALCULATE RESULTS

SLAMM per12 digit HUC for 2008

The SLAMM program predicts the spatial change of wetland location due to stressors such as sea-level rise and storm surges. The inputs into this program include an elevation file, wetland (NWI) file, a dike file, an impervious surface file and a slope file. The NWI file that is used has inaccuracies because it was created in the 1970s and the elevation file used is not accurate due to the difficulties involved in measuring differences in elevation of a rather flat topography within the spatial resolution used by the NED. These inaccuracies can affect the ability of the SLAMM to predict the change in wetland location. To evaluate if there are great inaccuracies due to the initial files and the initial parameters entered into SLAMM for the sub-sites, the projected change in wetland location for the year 2008 is created using the SLAMM. The percentage of beach, water, impervious surface, forested wetlands, freshwater wetlands, saltwater wetlands and all other land uses not already accounted for are calculated within a 12 Digit HUC for both the projected 2008 land use map and the 2008 GLUT. Then the percentage that is calculated for the 2008 GLUT is subtracted from the projected 2008 land use map percentage of area for each land use. The larger the percentage, the more that the projected land use map for 2008 deviates from the 2008 GLUT map used in all of the indices. The end product of the analysis is a range of percentage deviations for all the identified landcover types for the entire coast.

Barrier Island Shoreline Technique

Due to the barrier island migration being determined based on land use and not on elevation data, aerial photos or LiDAR, it is necessary to make sure that the two techniques are comparable. To do this, the shoreline of Jekyll Island for 1974 that was created using the 1974 GLUT file is compared to the 1974 shoreline of Jekyll Island that was made using LIDAR and elevation data by Chester Jackson, the creator of AMBUR (Jackson 2010). This was accomplished by buffering Jackson's 1974 shoreline by 60, 120, 180 and 240 m. These buffer values were chosen to account for the 60 meter resolution of the 1974 land use raster file, which would inherently change the shoreline position. The percent length of the 1974 shoreline created using GLUT that was within a specified buffer distance was calculated as shown in equation 8.

$$PL_i = \frac{\mathrm{L_{Bi}}}{\mathrm{L_{LU}}} \qquad \text{(eq 8)}$$

Where:

PL_i = the Percentage of Length contained within buffer i

L_{Bi} = the length (m) of the 1974 GLUT shoreline within a buffer i

L_{LU} = the length (m) of the 1974 GLUT shoreline

The final output of this analysis will be the percentage of the 1974 GLUT shoreline within a specified distance of the 1974 Jekyll shoreline created using LiDAR.

Sensitivity Analysis

The PWRS, CPWRS, WSI, and CWSI are additive indices, which mean that each layer in the indices is given the same weight and has an equal impact on the final index. This may not necessarily be true. There are errors and uncertainties inherent in each layer due to inaccuracies of the initial data, assumptions that are made and the methods that are used to create the layers. These errors and uncertainties can create inaccurate identification of areas that have a high priority for mitigation. For the indices presented in this paper to be useful in informing natural resource management decisions about wetland mitigation, the influence that each layer has on the final index needs to be determined (Rae et al. 2007). By performing a sensitivity analysis on the layers, the direct and relative importance of each layer on the final indices can be determined (Turner et al. 2001).

A sensitivity analysis determines the direct and the indexed effect that a layer has on the final index. There are five steps that need to be taken in order to perform the sensitivity analysis, and they are:

1. Creating the standard output for of high priority sites for all of the layers. The standard output will be the same for each layer within an index. The process for doing this is described later.
2. Calculating the weighted output for each layer. This is done by multiplying the area of high priority values for one of the layers in an index by 5 and then summing this with the un-weighted areas of high priority pixels for all the other layers. This step is performed for each of the layers.
3. The difference between the weighted and the standard output for each layer is used to create the third component: The change in high priority areas.

4. The direct effect of a layer on the final index is determined by dividing the change in high priority area from step three by the standard area calculated in step one. The direct effect on the final Index represents the effect that a layer without considering the effect of the other layers.
5. The indexed effect is calculated by dividing each layer's weighted output by the lowest weighted output for all of the layers. This means that one layer will always have an indexed effect of one. The indexed effect represents the effect that a layer has on the final index in relation to the other layers, so the layer with an indexed effect of one is considered to have the least effect on the final Index.

The sensitivity analysis is performed twice for each index: once using the mean patch size of pixels and again using the total area of high priority pixels. The mean patch size of high priority (value 7, 8 or 9) pixels is determined by first reclassifying each layer so that any value below a seven is reassigned to a value of zero, and then reclassifying the values 7, 8 and 9 to one. The pixels are then grouped into patches using the RegionGroup command in ArcINFO and the mean area of the patches for each layer is calculated using the ZonalMean tool. The individual layer's mean patch values are used to calculate the weighted output. For now, the standard output of the mean patch area of high priority pixels is created by summing the mean patch size for each layer.

For the second sensitivity analysis, the total area of high priority (value 7, 8 or 9) pixels is calculated by reclassifying each layer in the same manner as was done for the mean patch size analysis, except for instead of assigning the high priority pixels a value of one, they are assigned a value of 900, which represents the area within one pixel. The total area for each layer is then calculated using the ZonalSum command in ArcINFO. These value are used later to calculate the weighted output of each layer. To get the standard output for the total area of high priority pixels analysis, the final area for each layer is summed. The rest of the sensitivity analysis for the mean patch size and the total area is calculated as described in the previous list.

A sensitivity model is a useful tool to evaluate whether a model performs as anticipated, or desired. The layers used in this thesis are all related to improving the water quality to specific areas or for a specific habitat purpose, so it is expected that they should all have a similar influence on the PWRS and the WSI. The sensitivity model is also used to determine if the influence of the layers on the PWRS and the WSI changed from 2008 to 2030. For the final maps of the risk assessment, the CPWRS and the CWSI, the sensitivity analysis is used to see which of the four layers has the most influence and to observe if the ranking of the layer’s influence is the same as it was for the PWRS and WSI sensitivity analyses.

Table 3.1: Parameters used for the sub-sites in the SLAMM model of coastal Georgia. Values are derived from data on the NOAA website for the coast of Georgia. NWI is the National Wetland Inventory, DEM is the Digital Elevation Model, MTL is the mean tide level, NAVD88 is the North American Vertical Datum of 1988, and GT is the Great Diurnal Tide Range.

Parameter	Global	Sub-Site 1	Sub-Site 2	Sub-Site 3	Sub-Site 4	Sub-Site 5
Description of Site	GA Coast	Tybee/ Wassaw	Ossabaw/ St. Catherines/ Sapelo	Doboy/ Altamaha	St. Simons/ St. Andrews	Cumberland
NWI Date	1977	1977	1977	1977	1977	1977
DEM Date	2002	2002	2002	2002	2002	2002
Historic Trend (mm/yr)	2.98	2.98	2.98	2.98	2.98	2.98
MTL – NAVD88 (m)	-0.116	-0.116	-0.226	-0.247	-0.21	-0.775
GT (m)	2.25	2.287	2.423	2.264	2.186	1.971
Salt Elev. (m above MTL)	1.69	1.054	1.121	0.947	1.006	0.902

Table 3.2: The erosion and accretion parameters used in the SLAMM analysis which are based on values from Ehman (2008).

Parameter	Global and Sub-Site Value
Marsh Elevation (horz. m/yr)	2
Swamp Erosion (horz. m/yr)	1
Tidal Flat Erosion (horz. m/yr)	4
Regularly Flooded Marsh Accretion (mm/yr)	1.9
Irregularly Flooded Marsh Accretion (mm/yr)	4.3
Tidal Fresh Marsh Accretion (mm/yr)	4.8
Beach Sedimentation Rate (mm/yr)	0.5

Table 3.3: The value crosswalk for SLAMM land use to GLUT land use classification

SLAMM value	GLUT value	Land Cover Classes
1	22	Developed Land
2	41	Undeveloped Upland
3, 4, 7, 9, 23	91	Forested Wetlands
5, 6	93	Freshwater Wetlands
8, 20, 22	92	Saltwater Wetlands
10, 11, 12	7	Beach/Dune/Mud
15, 16, 17, 18, 19	11	Open Water

Table 3.4: Description of the masking values used in the Restorability Mask

Value	Description
1	Land use pixel is not restorable due to it already being a wetland or a body of water
6	Can potentially be restored, but was not historically a wetland in 1974
8	Land use pixel was a wetland in 1974, and now has natural upland vegetation
9	Land use pixel that was a wetland in 1974 and currently meets the hydric soil requirements

Table 3.5: Scaling factors used to account for restorability in the mitigation layers

If Mask Value Equals	Then the Corresponding Land Use in the Specified Layer is:
1	the minimum value of the specified layer
6	66% of the specified layer's original value
8	89% of the specified layer's original value
9	100% of the specified layer's original value

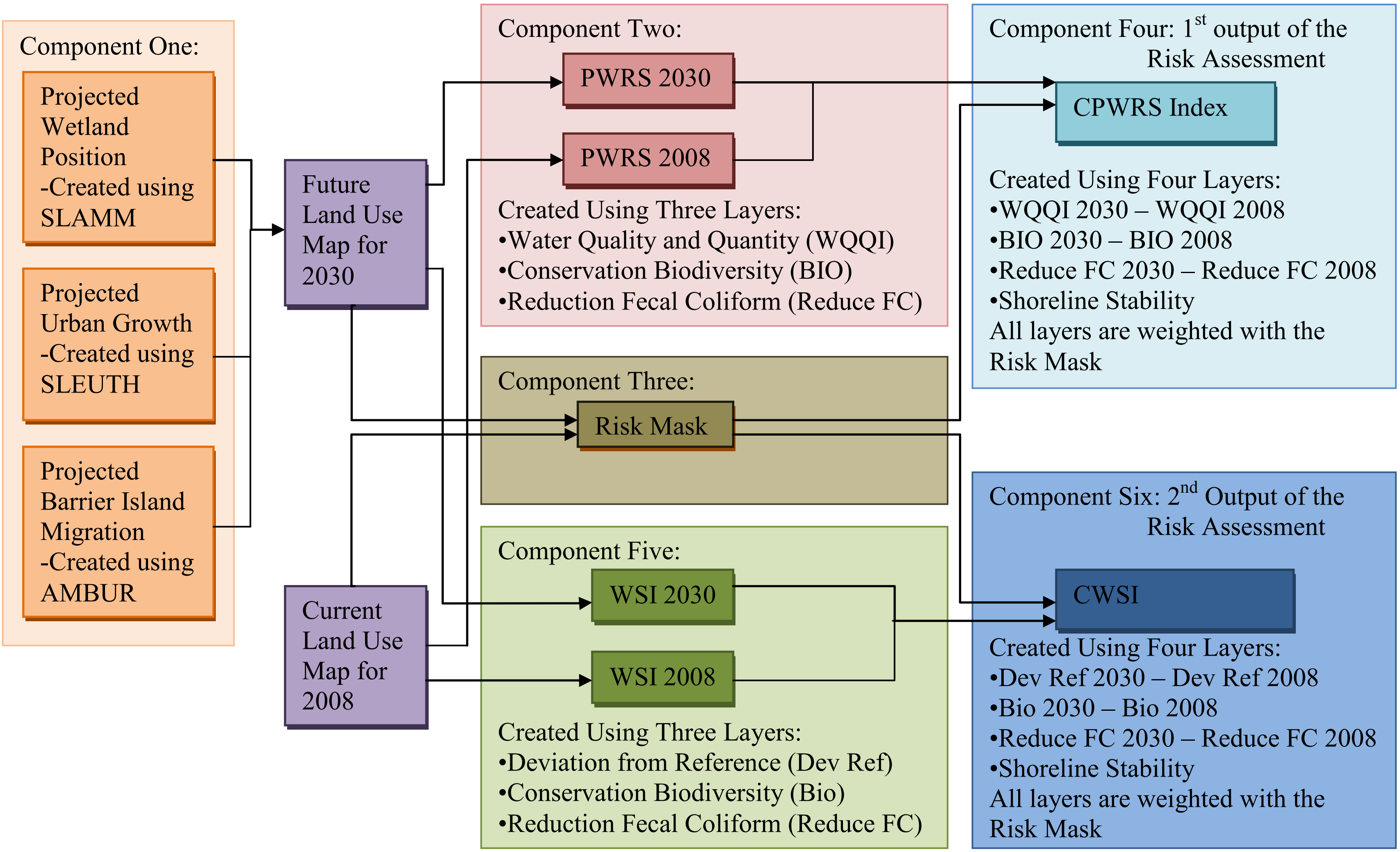


Figure 3.1: Diagram showing the six components, three software programs, and the fourteen layers used to create the Change in the Potential Wetland Restoration Site (CPWRS) Index and the Change in the Wetland Sites Index (CWSI), which are the final two outputs of the coastal Risk Assessment.

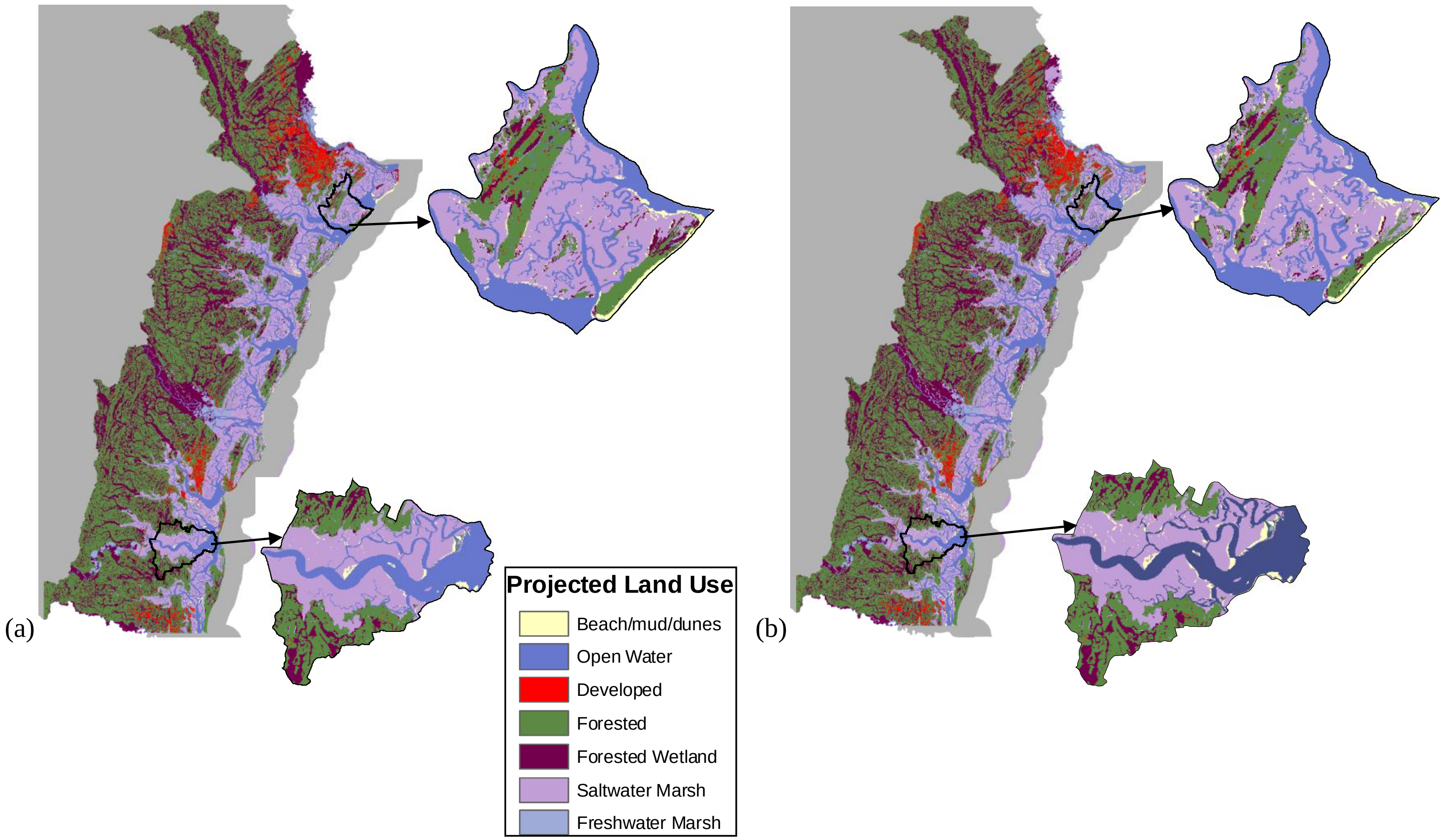


Figure 3.2: The estimated spatial location of wetlands for (a) 2008 and (b) 2030 determined using the Sea-Level Affecting Marsh Migration Model (SLAMM) in Component One with representative 12 Digit Hydrologic Unit Codes shown for the northern and southern portions of the coast of Georgia.

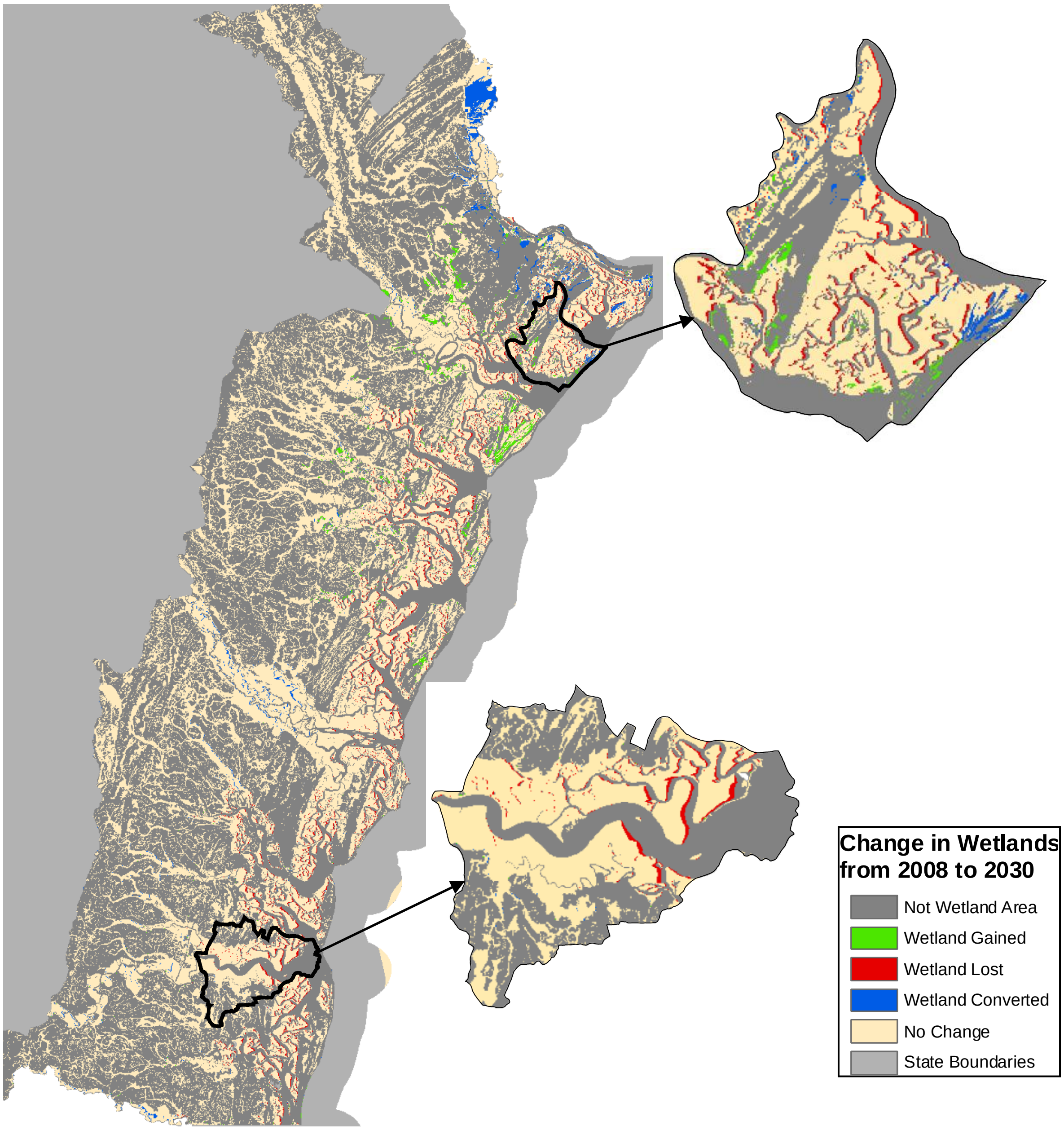


Figure 3.3: Spatial map depicting where changes occur for wetlands when comparing the projected 2008 and 2030 land use files created with the Sea-Level Affecting Marsh Migration Model (SLAMM) in Component One. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern portion of the Georgia coast.

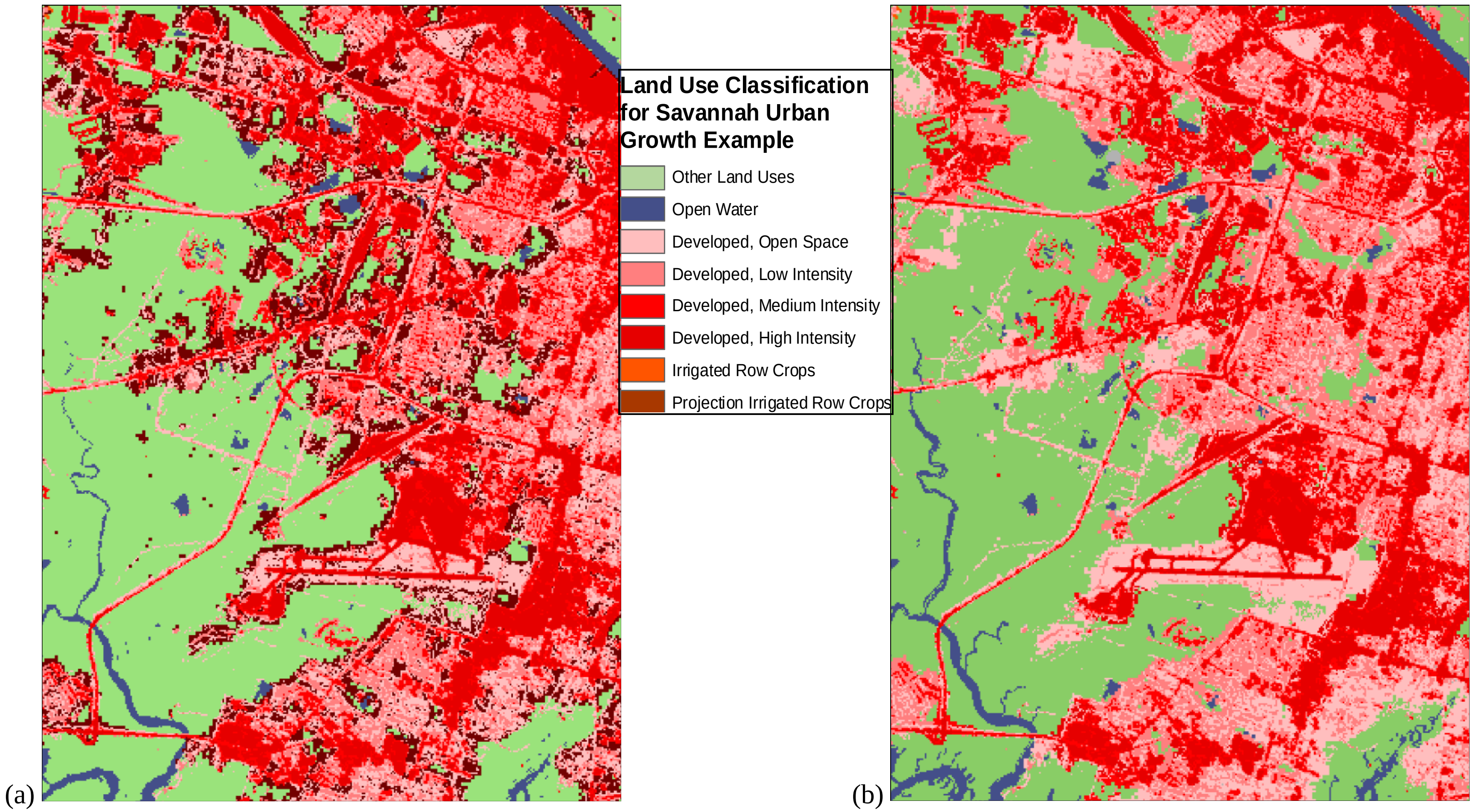


Figure 3.4: Extraction of the western portion of the city of Savannah, Georgia to show (a) where urban growth is predicted to occur and (b) the values assigned to the occur in the landscape when the new urban locations are reclassified to one of the four development classes used by the Georgia Land Use Trends classification system.

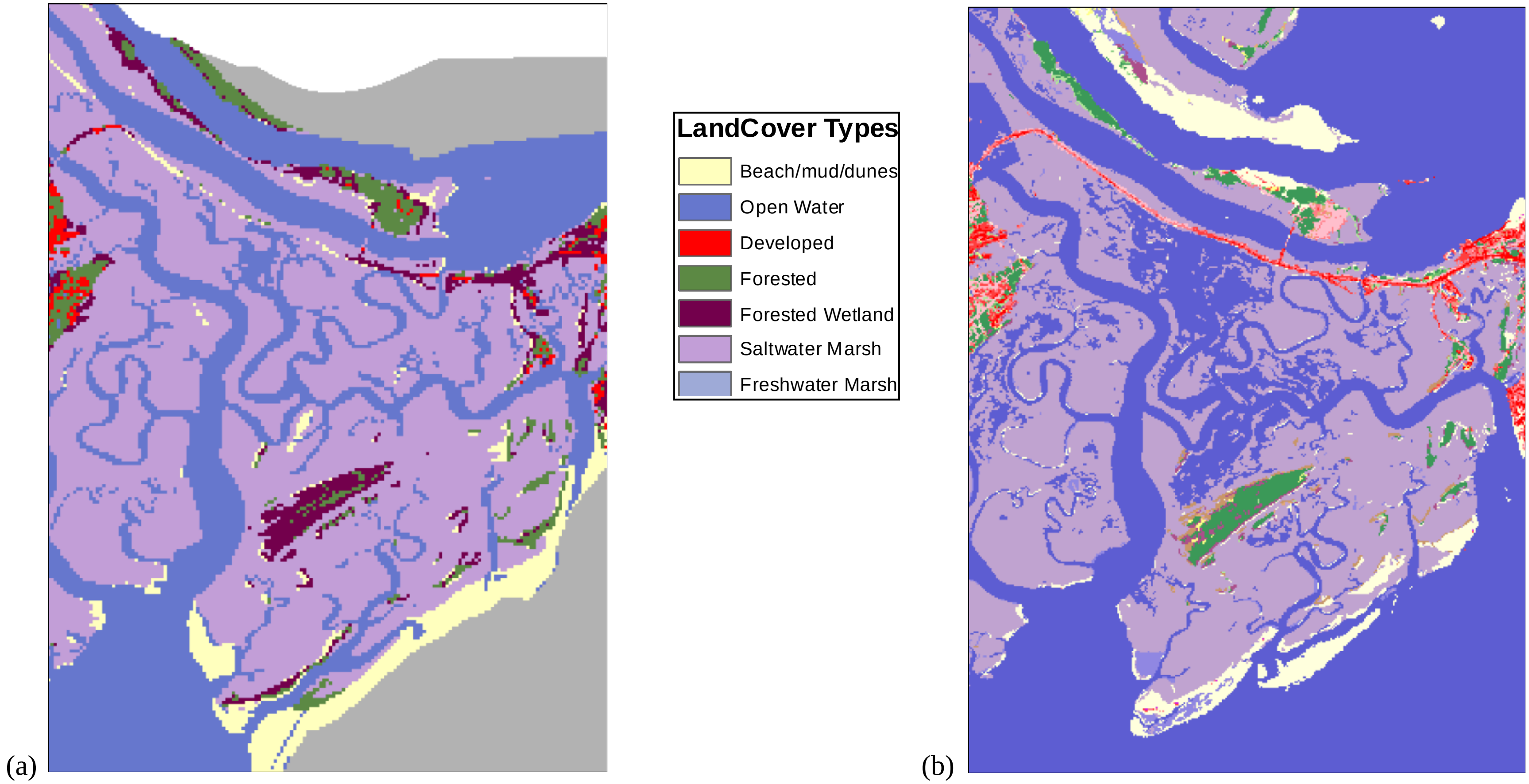


Figure 3.5: The SLAMM land use map (a) and the GLUT map (b) for Tybee Island in 2008. The SLAMM land use map does not predict the inundation of salt water marshes that is shown to occur in the GLUT map when using the parameters given in Tables 3.1 and 3.2.

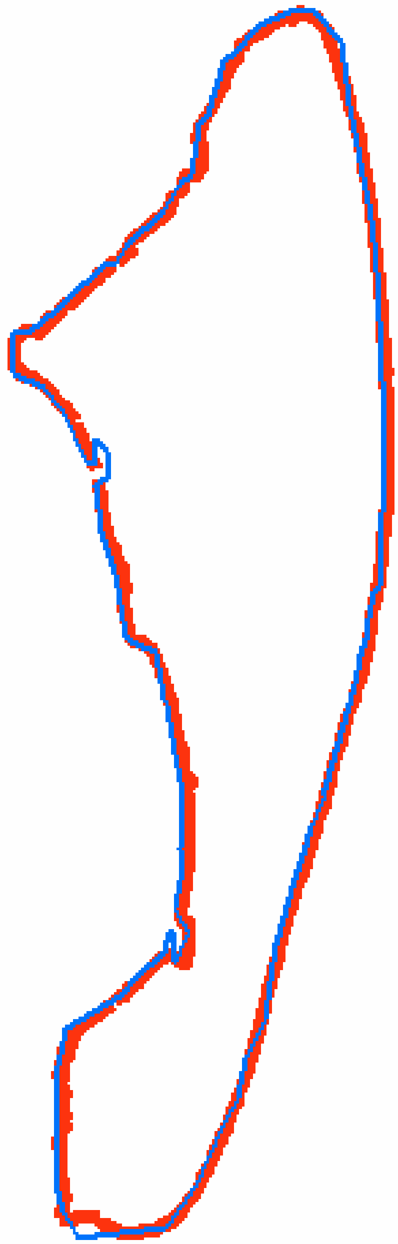


Figure 3.6: Map showing the 1974 shorelines using LiDAR (*in red*) (Jackson 2010) and using Georgia Land Use Trends (GLUT) (*in blue)*. For the spatial scale of the GLUT map (1:24,000), the two shorelines are very similar in spatial location.

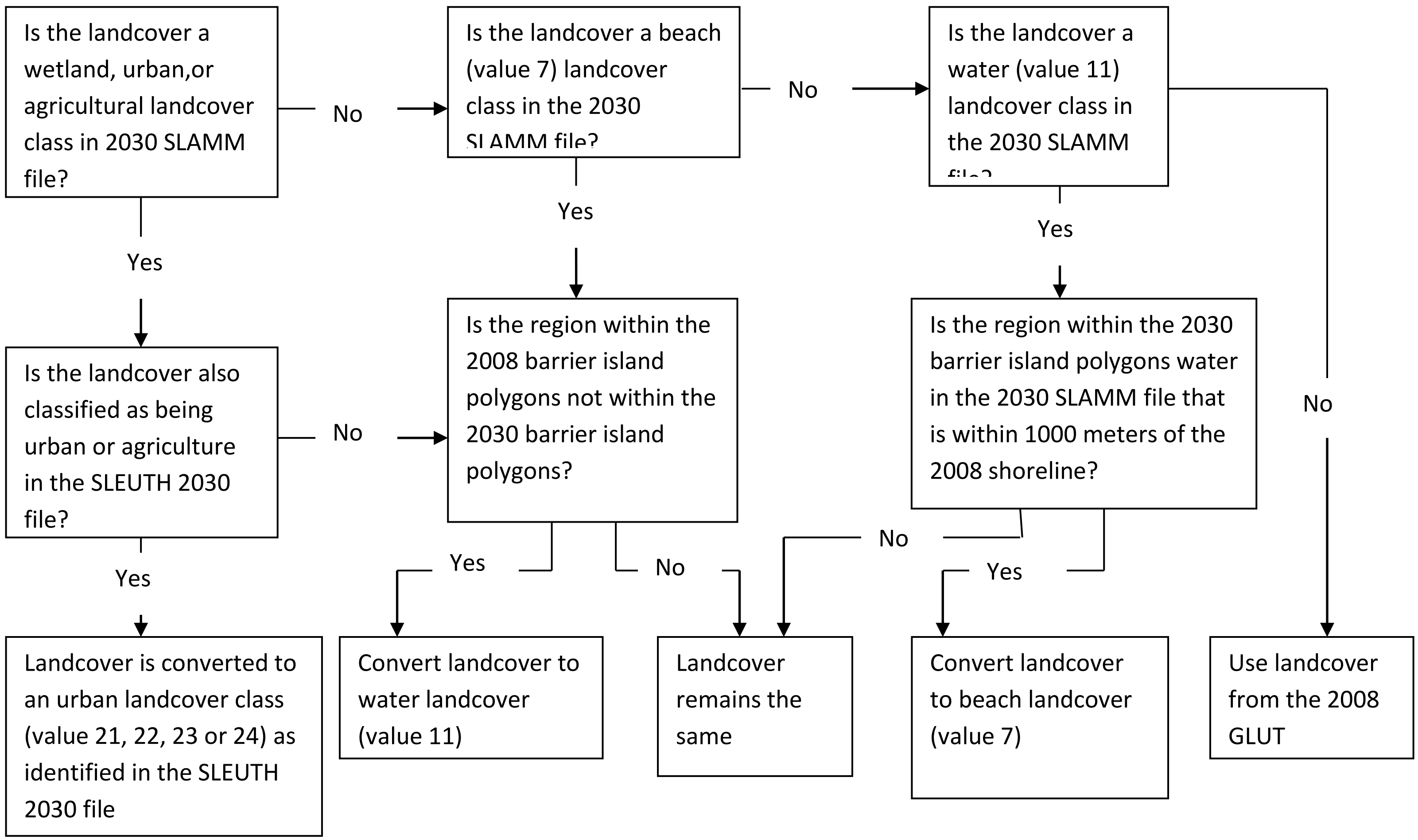


Figure 3.7: Diagram depicting the decisions made when combining the files from the Sea-Level Rise Affecting Marshes Model (SLAMM), the Slope, Land cover, Exclusions, Urban areas, Transportation and Hill-slope (SLEUTH) model and the Analyzing Moving Boundaries Using R (AMBUR) model to create the future land use map for the year 2030

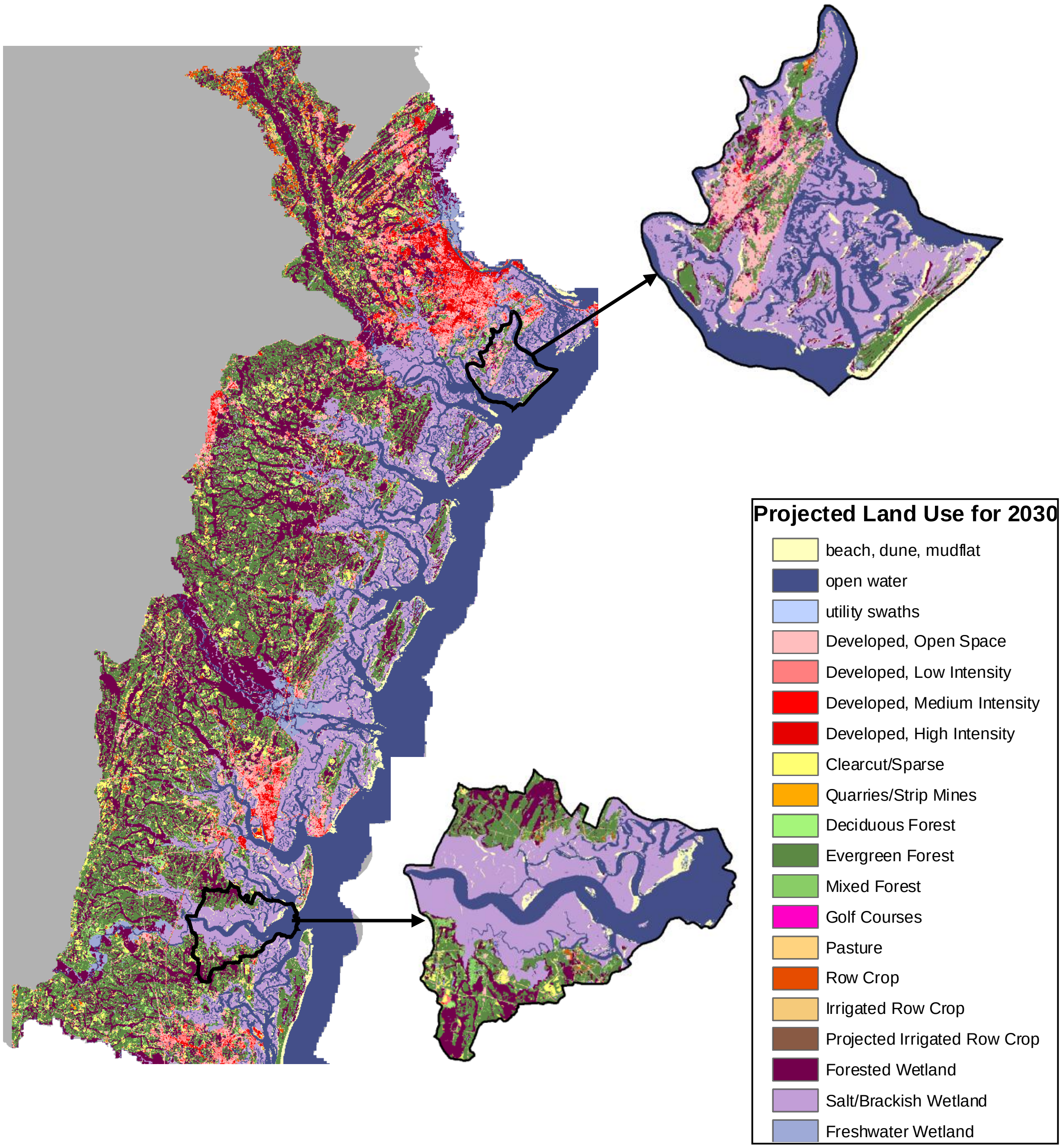


Figure 3.8: The future land use map for the year 2030 created in Component One. The map shows where land use is projected to be located when influenced by sea-level rise, storm surge, barrier island migration, and population growth. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern portion of the Georgia coast.

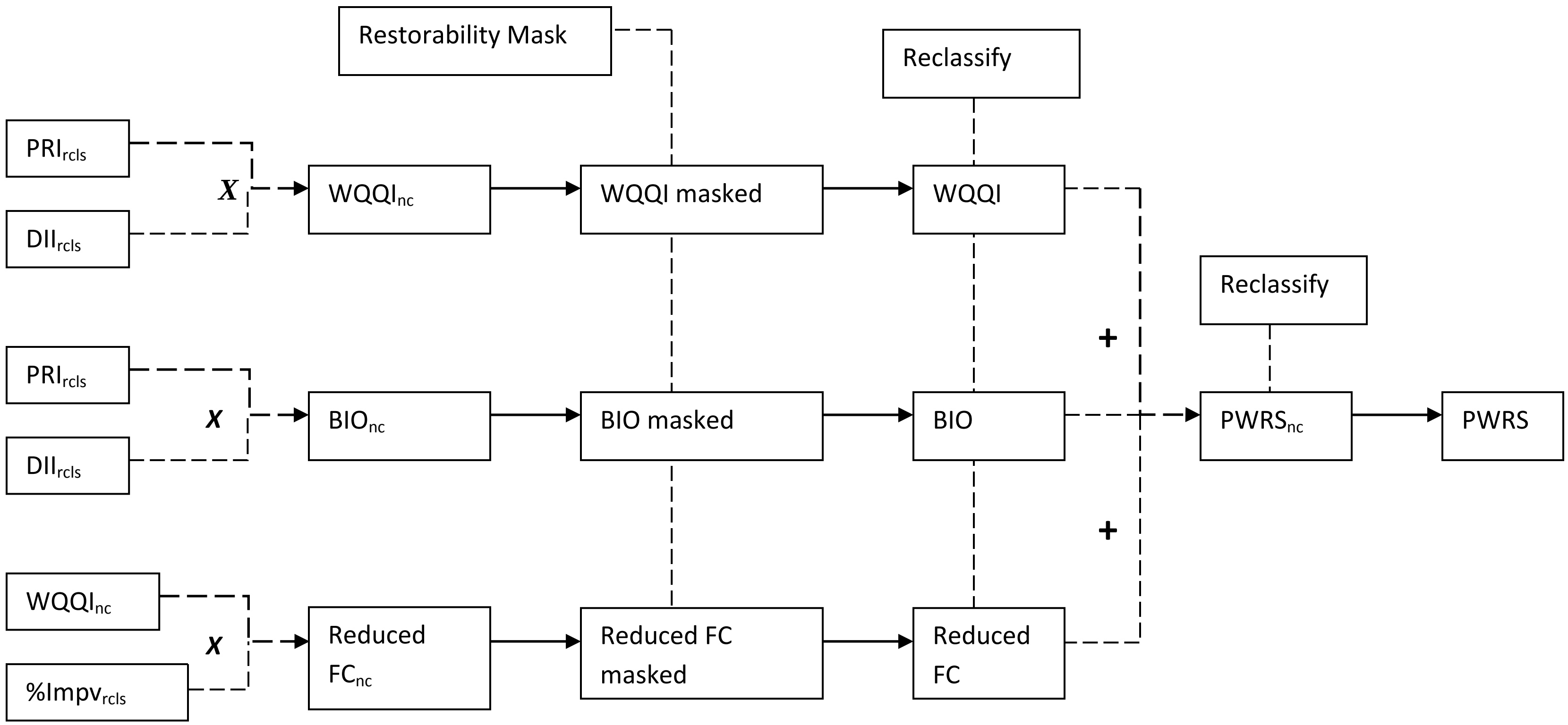


Figure 3.9: Flowchart describing how the Potential Wetland Restoration Site Index is created by combining the three layers in Component Two. Dashed lines represent process in the model and solid lines represent the progression of each layer. The term *nc* refers to a layer that has not been reclassified using either Quantiles or Jenks Optimization.

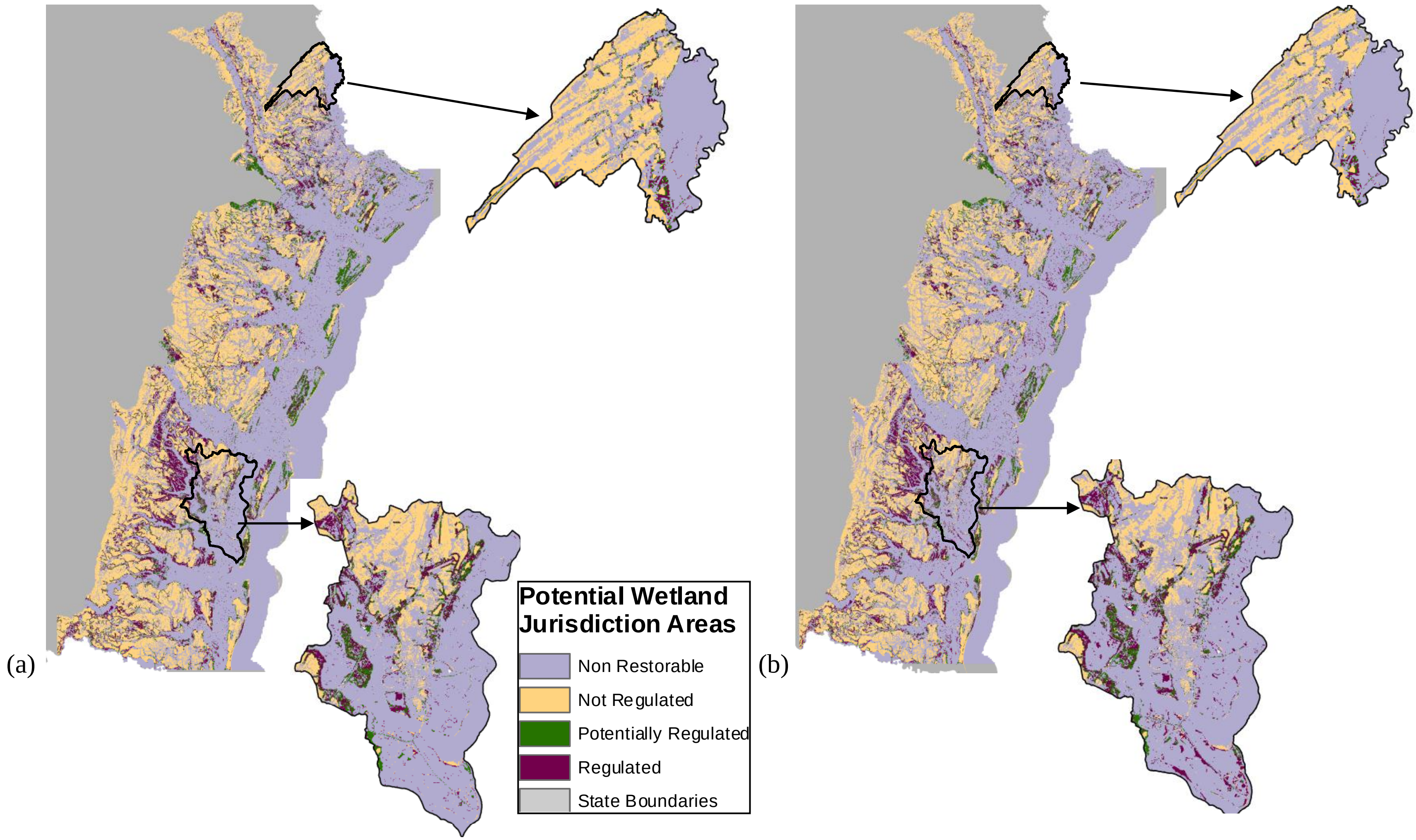


Figure 3.10: Potential jurisdictional map for the years (a) 2008 and (b) 2030 created in Component Two. Representative 12 Digit Hydrologic Unit Codes are shown for the north and south regions of the coast of Georgia.

Figure 3.11: Example of a ditched area (dark lines branching from the stream to the upland) that is delineated in the Distance to Impairment Index (DII) in the water quality and quantity layer of Component Two. The delineated ditch areas are added to the National Hydrography Dataset used in the DII in order to account for the increase in the surface flow of water and nonpoint source pollution from the upland to the streams.

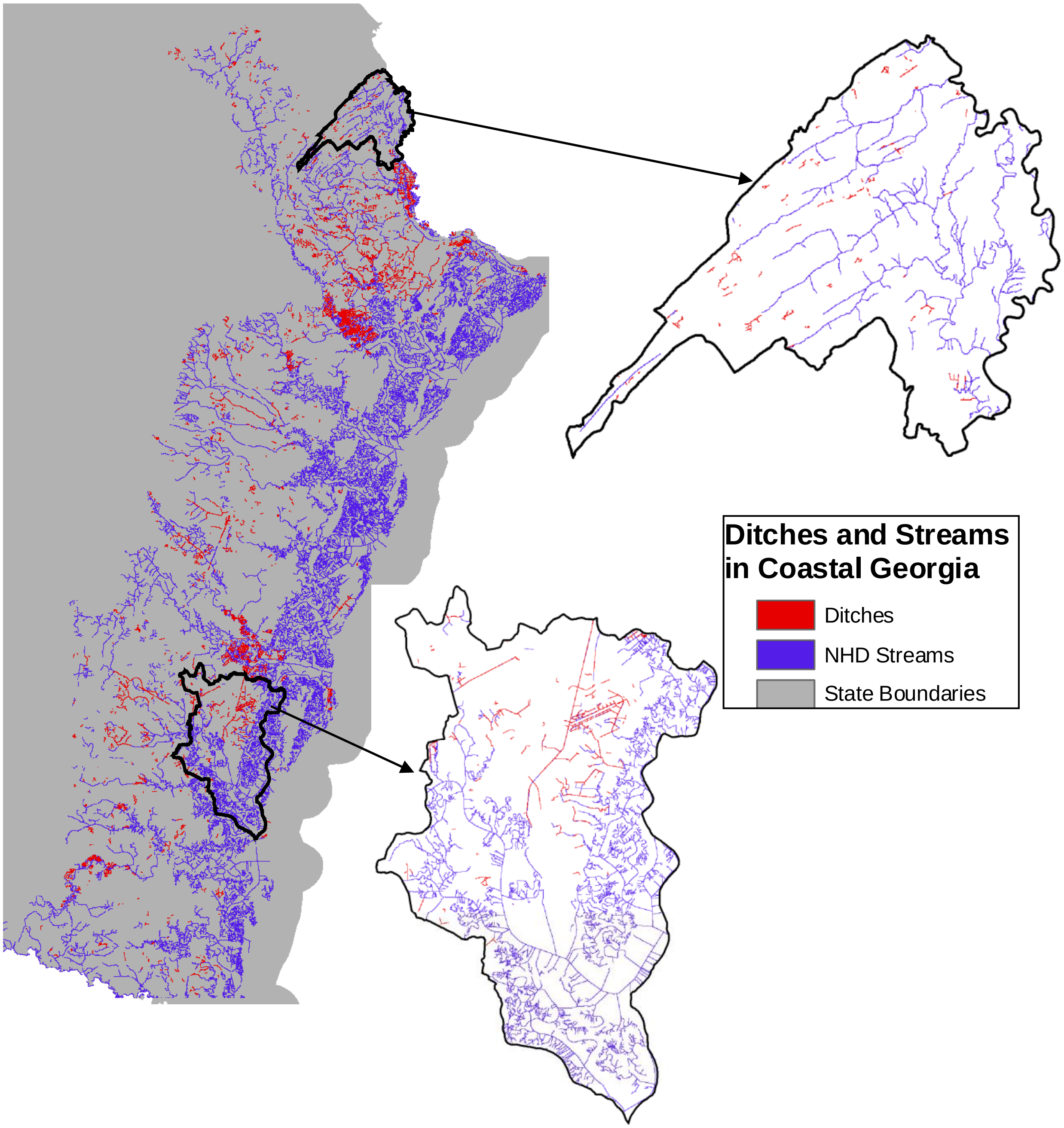


Figure 3.12: A map showing the stream areas identified by the National Hydrography Dataset and the ditches delineated using the methods described in the water quality and quantity layer of component one. The combined ditched and stream file is used in every layer of the coastal risk assessment. Representative 12 Digit Hydrologic Unit Codes for the northern and southern regions of the coast of Georgia are shown.

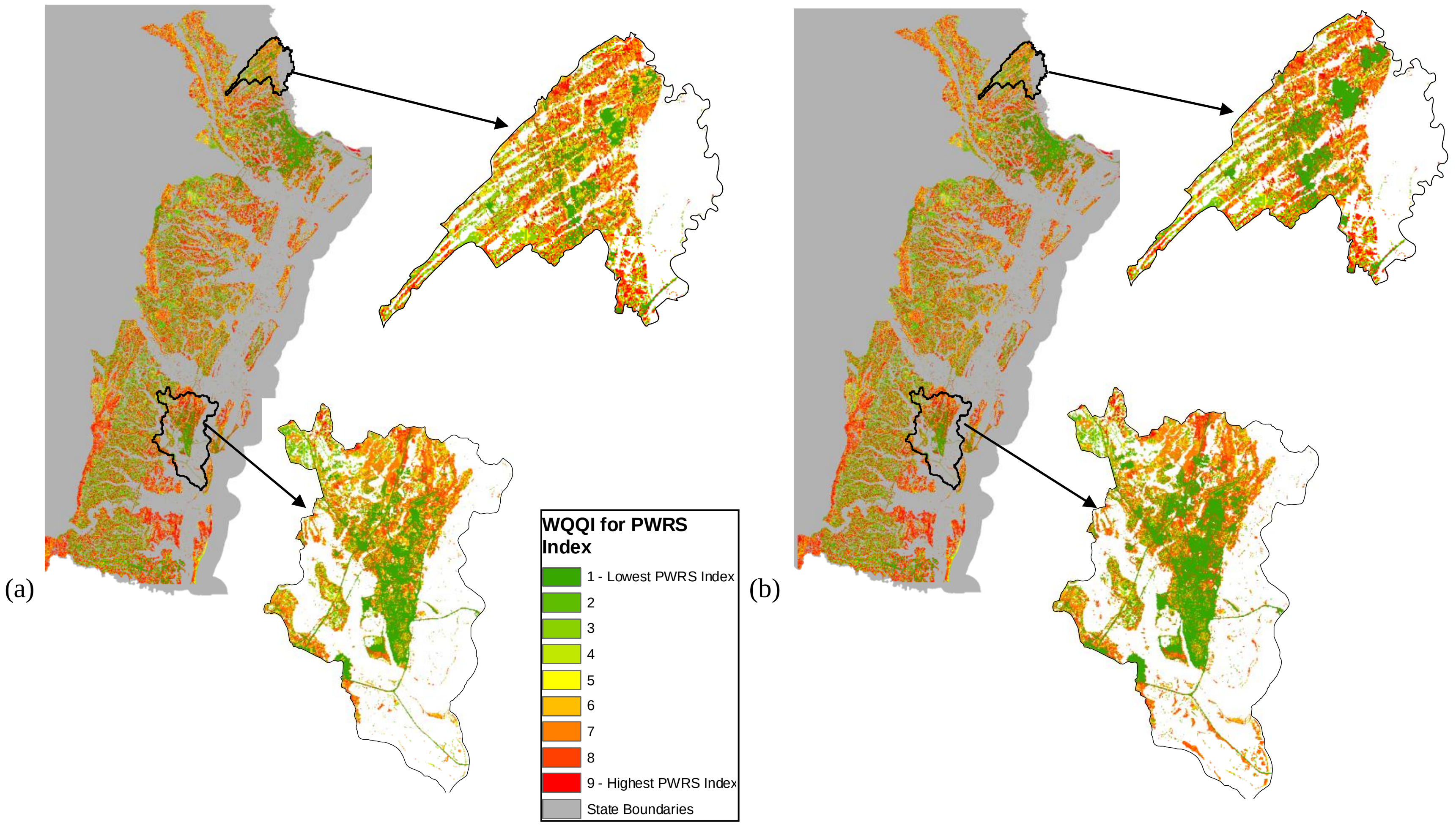


Figure 3.13: Water Quality and Quantity Index (Layer 2.1) for the year 2008(a) and 2030(b) used in the PWRS Index with representative 12 Digit Hydrologic Unit Codes in the northern and southern regions of coastal Georgia. A high potential area is a location which can potentially improve Water Quality and Quantity if it is restored/established into a wetland.

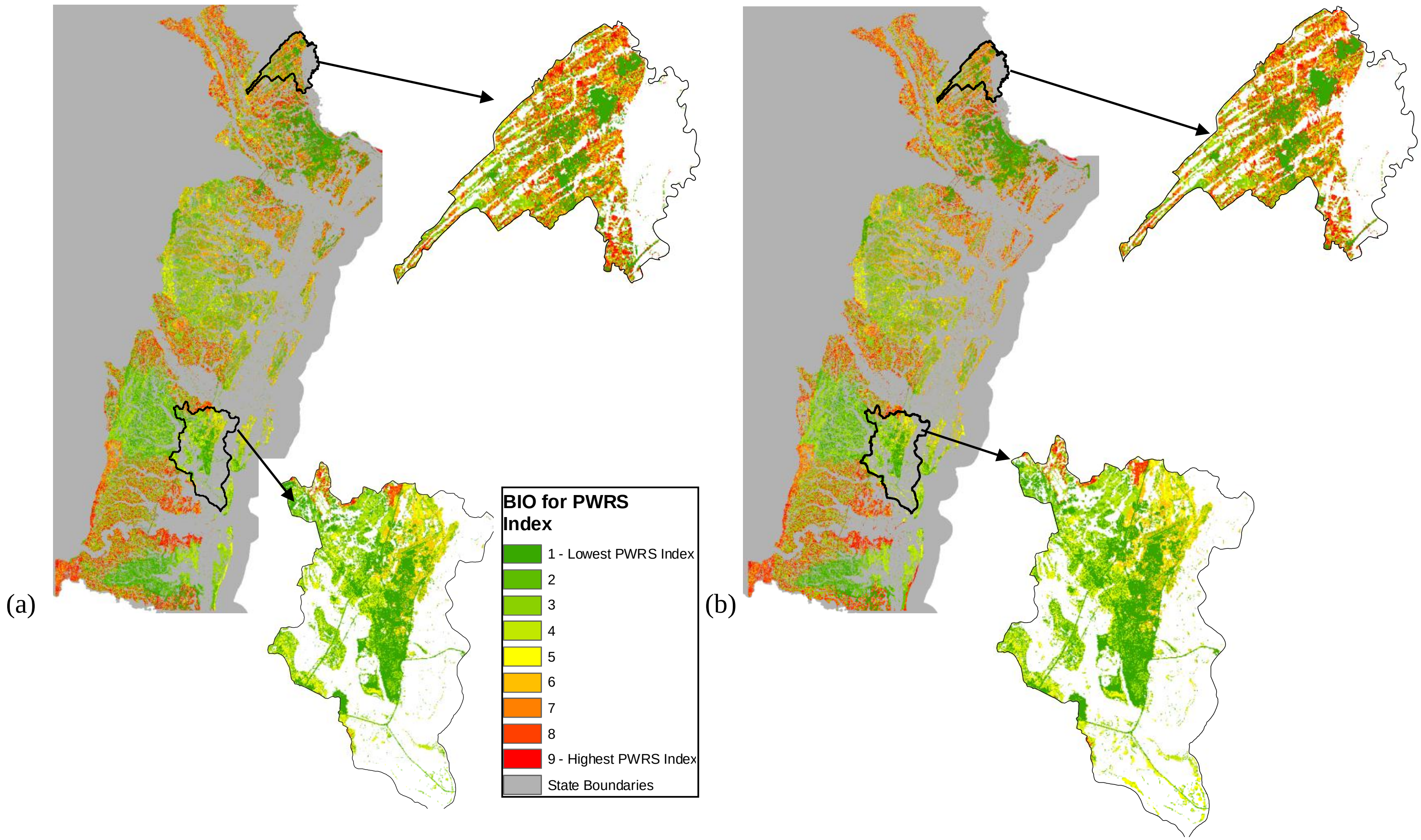


Figure 3.14: Conservation of Biodiversity in High Priority Streams (Layer 2.2) for the year 2008(a) and 2030(b) used in the PWRS Index with representative 12 Digit Hydrologic Unit Codes for the northern and southern regions of coastal Georgia. A high potential area is a location which can potentially improve the Conservation of Biodiversity if it is restored/established into a wetland.

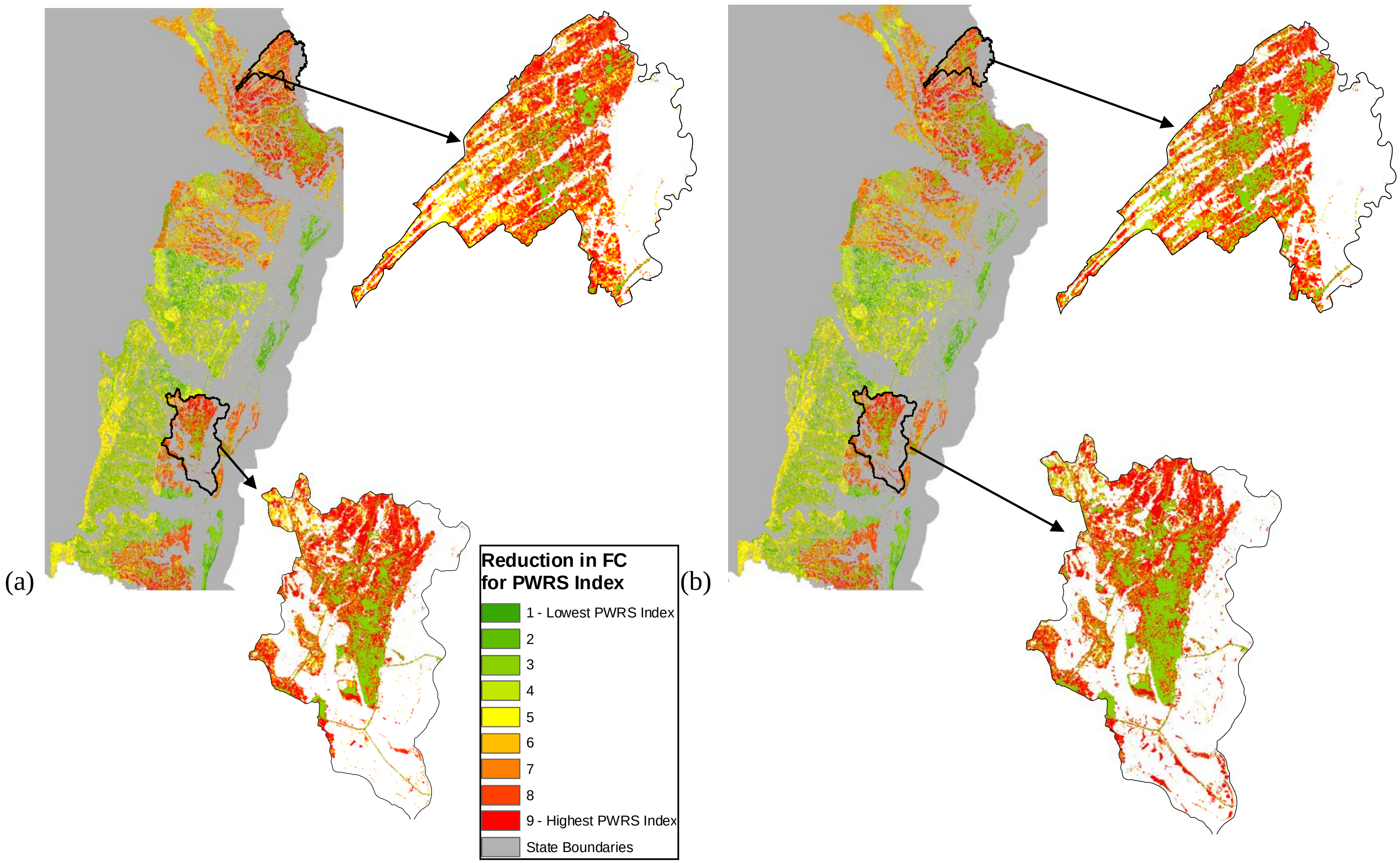


Figure 3.15: Reduction of fecal coliform (Layer 2.3) for the year 2008(a) and 2030(b) used in the PWRS Index with representative 12 Digit Hydrologic Unit Codes for the northern and southern regions of coastal Georgia. A high potential area is a location which has the greatest probability of reducing fecal coliform if it is restored/established into a wetland.

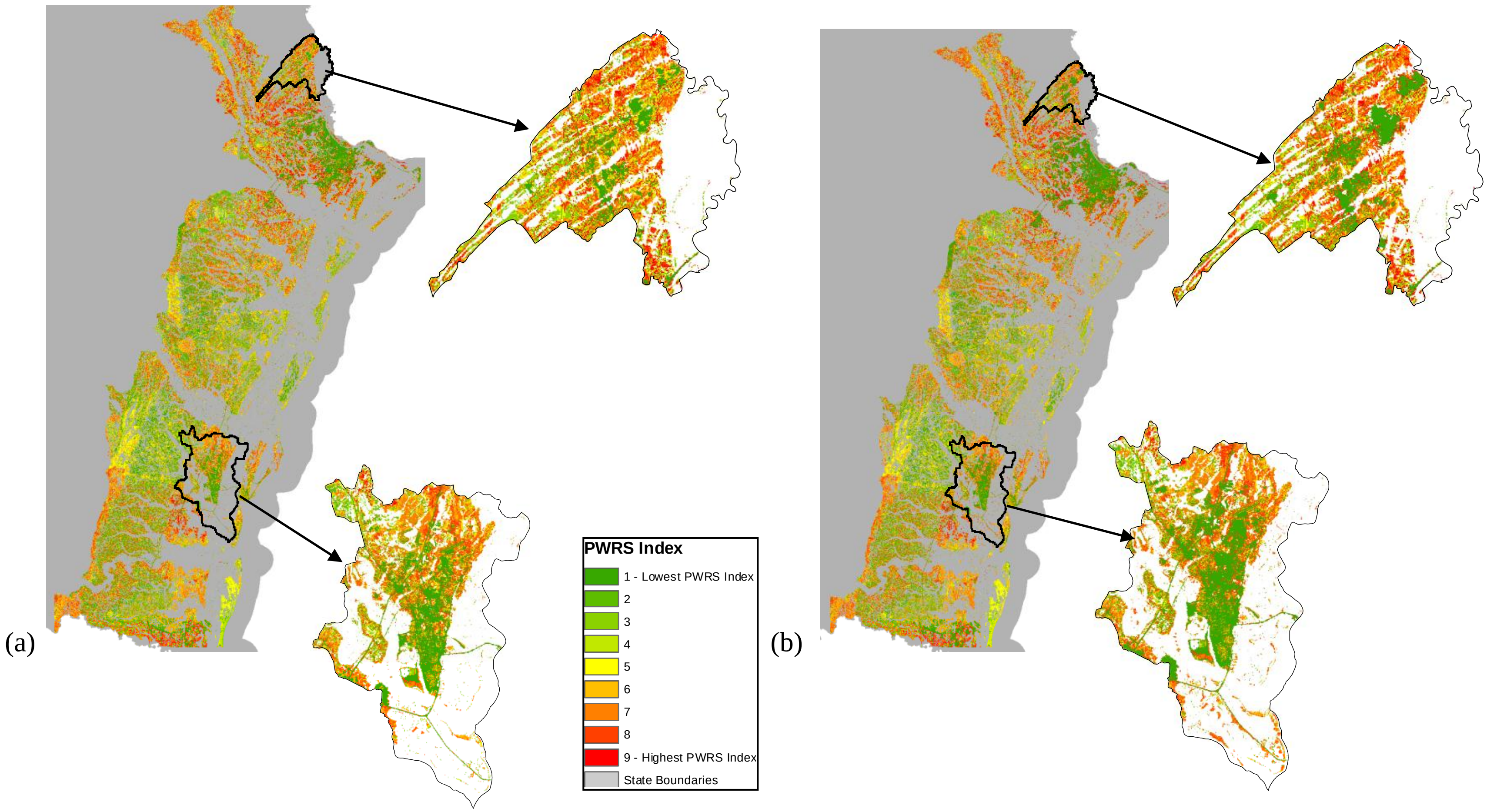


Figure 3.16: Potential Wetland Restoration Site Index for 2008(a) and 2030(b). A high index value represents those areas that have a high potential of improving the wetland functions of water quality and quantity, conservation of biodiversity and reducing fecal coliform to water bodies, estuaries and streams. The high index value areas are also potential sites for the restoration/establishment of wetland sites. Representative 12 Digit HUCs are shown for north and south coastal Georgia.

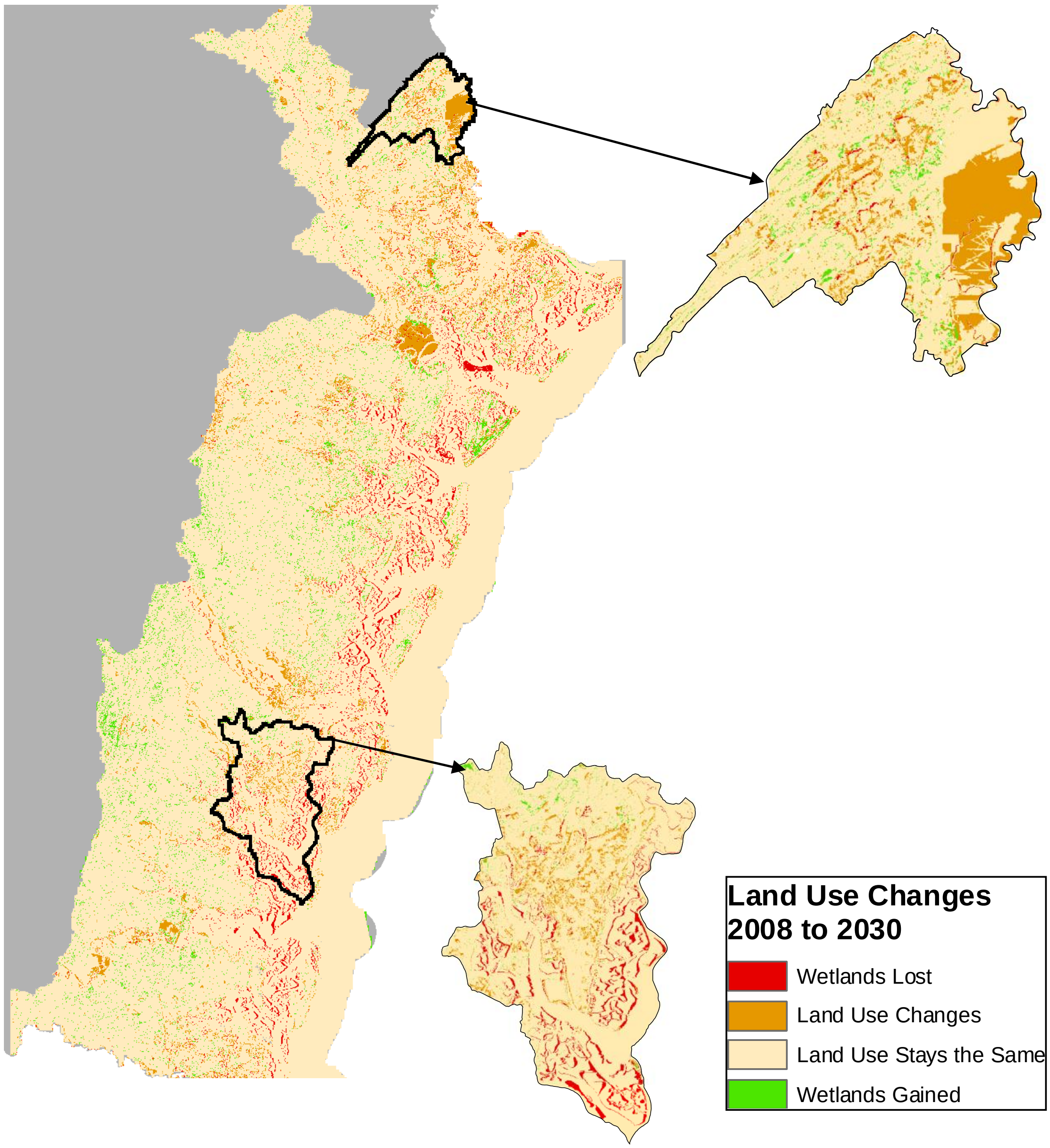


Figure 3.17: Risk Mask of the Georgia coast identifying how land use changed between 2008 and 2030. The land use is projected to change in the year 2030 due to the influence of sea-level rise, storm surge, population growth and barrier island migration. Representative 12 Digit Hydrologic Unit Codes for the northern and southern regions of coastal Georgia are shown.

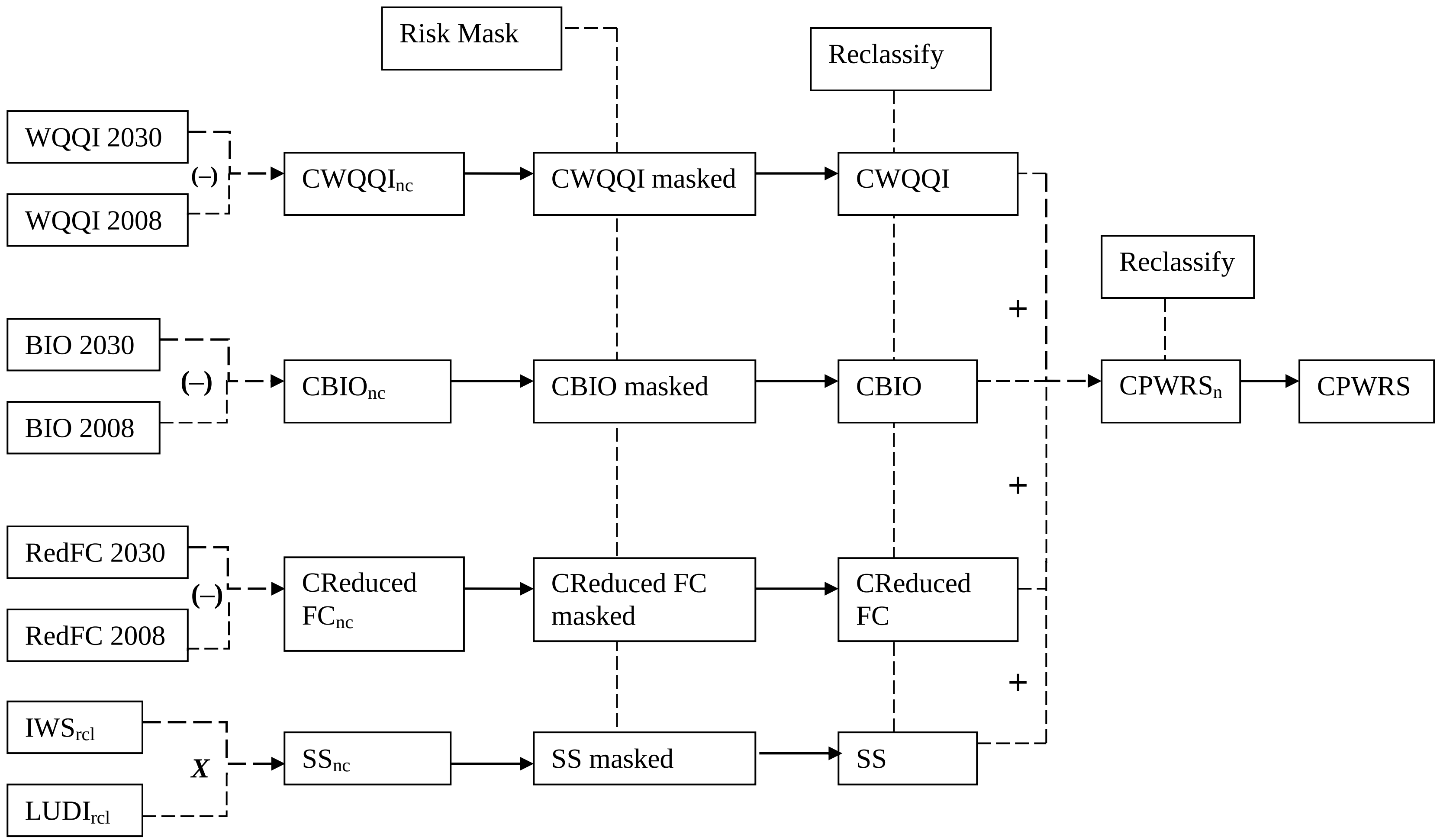


Figure 3.18: Flowchart describing how the Change in Potential Wetland Restoration Site Index is created by combining the four layers in Component Four. Dashed lines represent process in the model and solid lines represent the progression of each layer. The term *nc* refers to a layer that has not been reclassified using either Quantiles or Jenks Optimization.

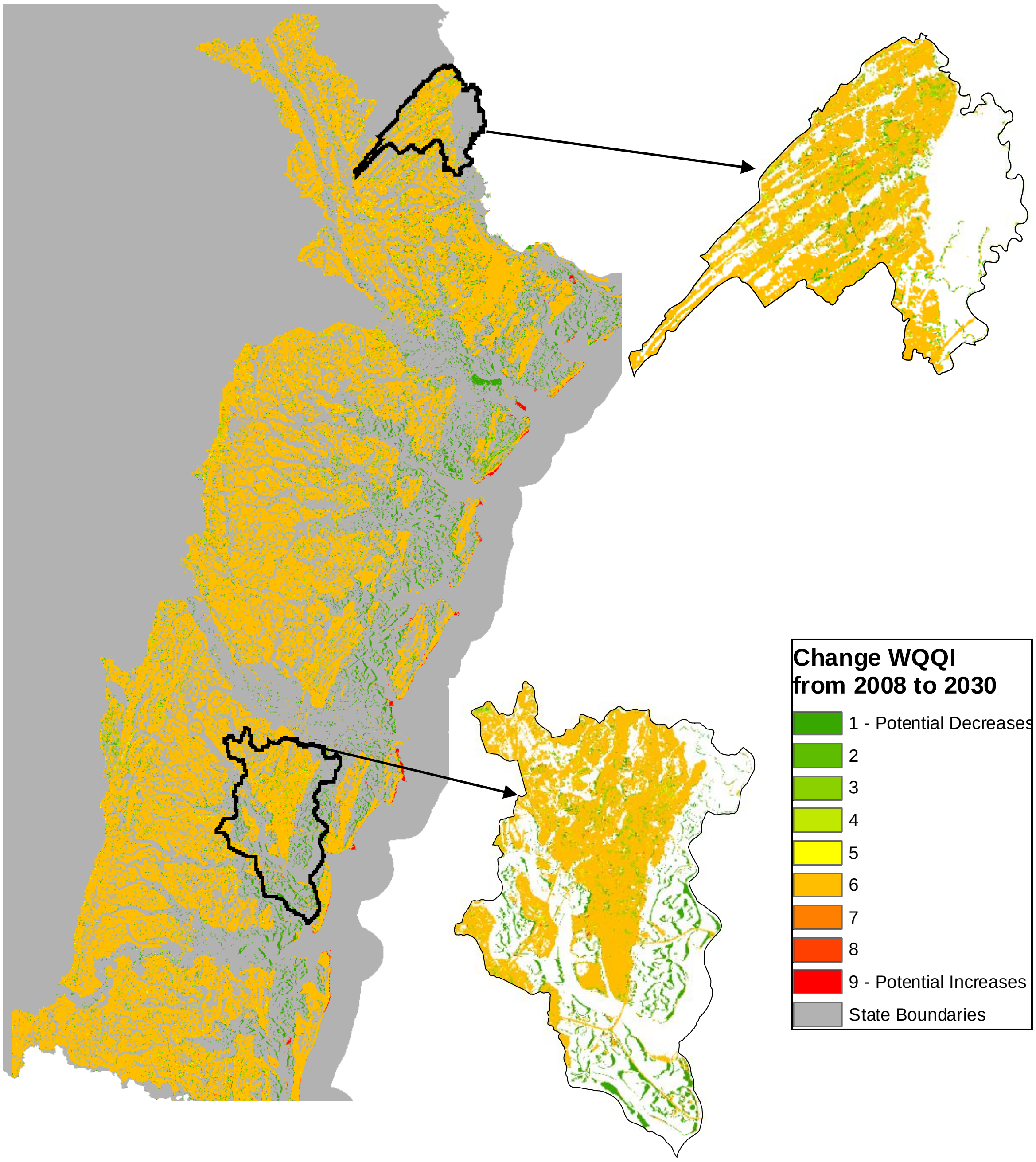


Figure 3.19: Change in Water Quality and Quantity Index (Layer 4.1) from 2008 to 2030 used in the CPWRS Index with representative 12 Digit Hydrologic Unit Codes in the northern and southern regions of coastal Georgia. A high potential area is one where the potential of a non-wetland site to provide the function of water quality and quantity improves from the year 2008 to 2030.

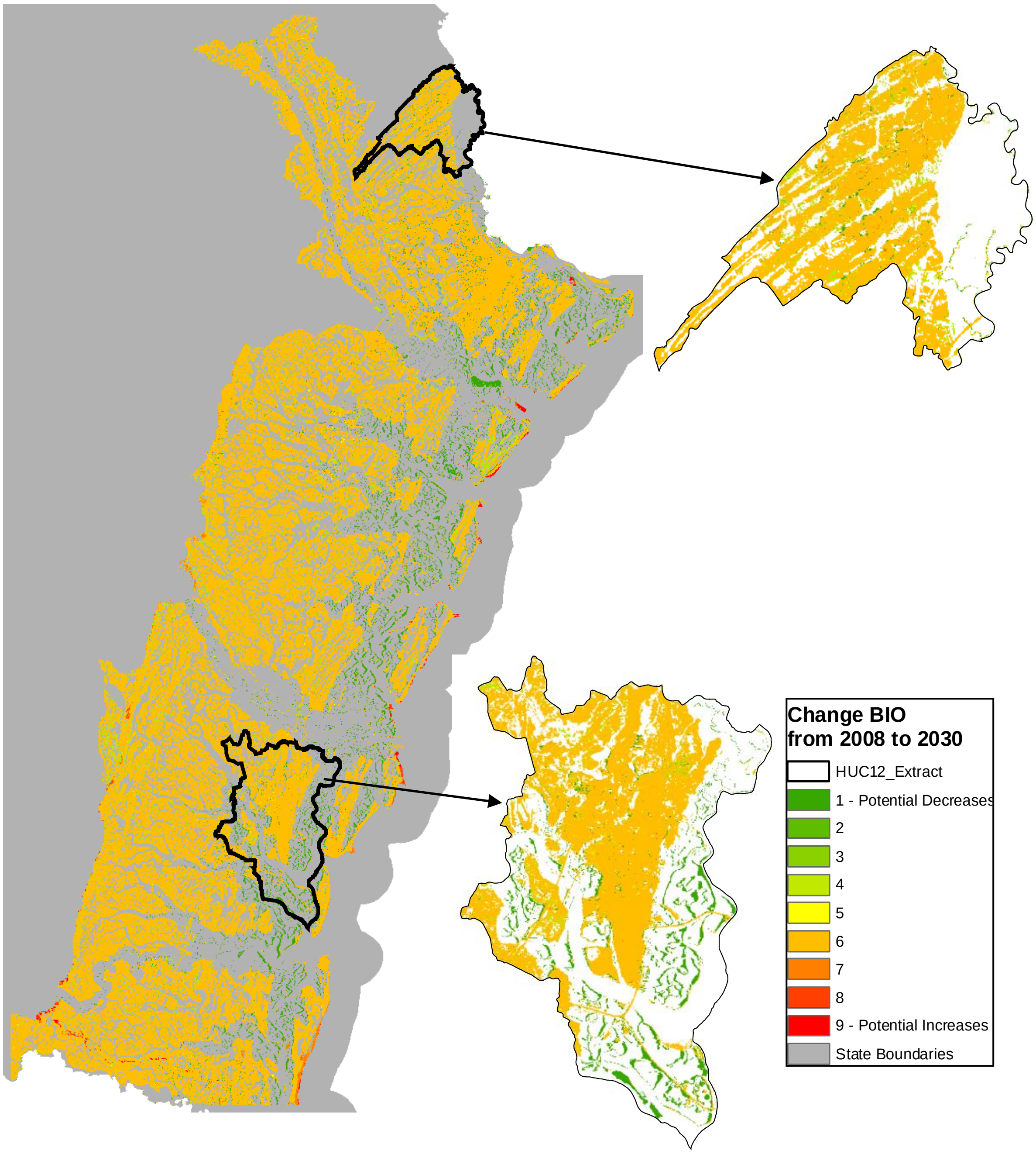


Figure 3.20: Change in Conservation of Biodiversity (Layer 4.2) from the year 2008 to 2030 used in the CPWRS Index. In high potential areas, the function of conservation of biodiversity is improved within the specified time frame. Representative 12 Digit Hydrologic Unit Codes for the northern and southern regions of coastal Georgia are shown.

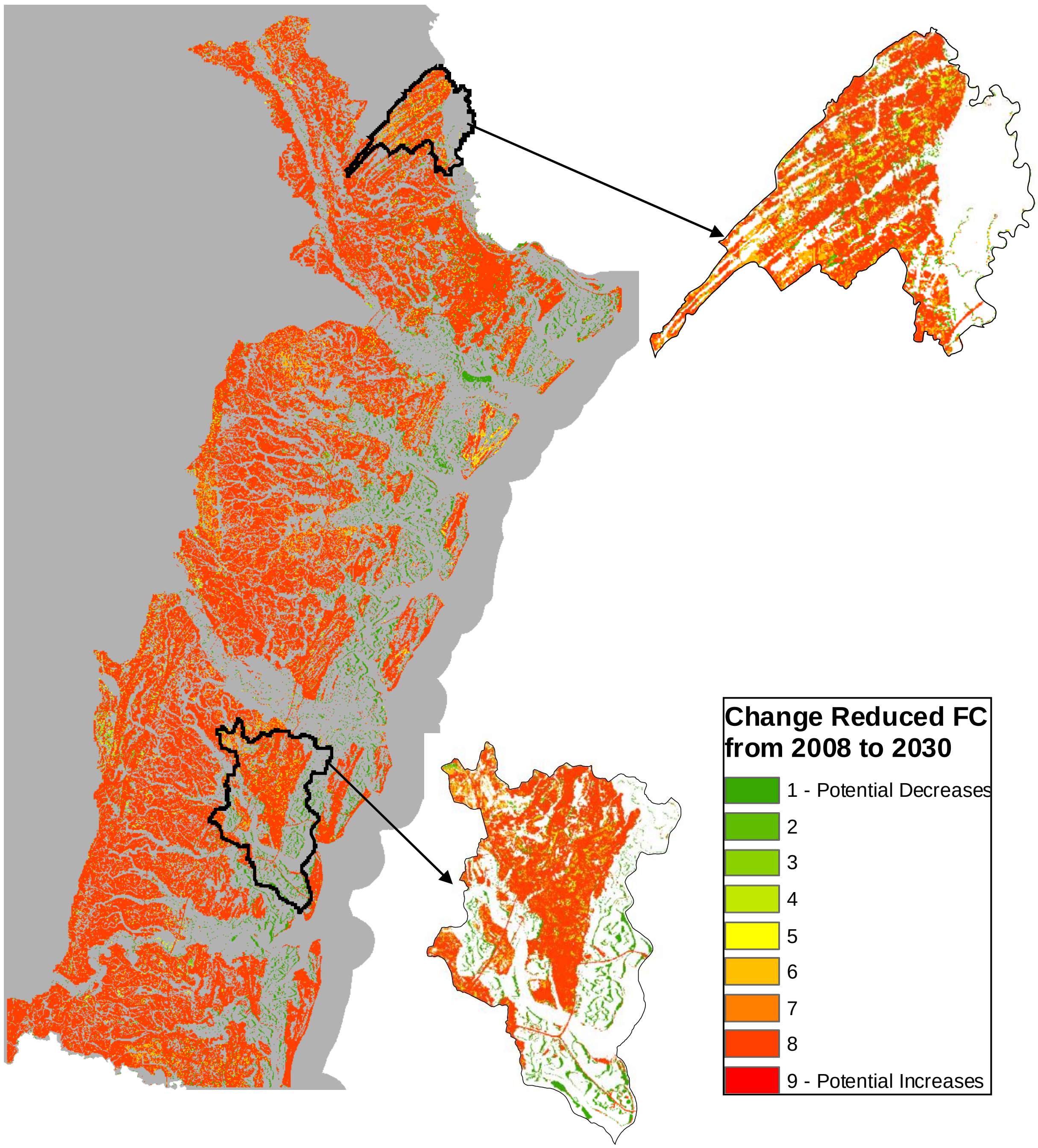


Figure 3.21: Change in the Reduction of Fecal Coliform (Layer 4.3) from the year 2008 to 2030 used in the CPWRS Index. In high potential areas, the function of reducing fecal coliform to estuaries, beaches and water bodies improves the most within the specified time frame. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern portion of coastal Georgia.

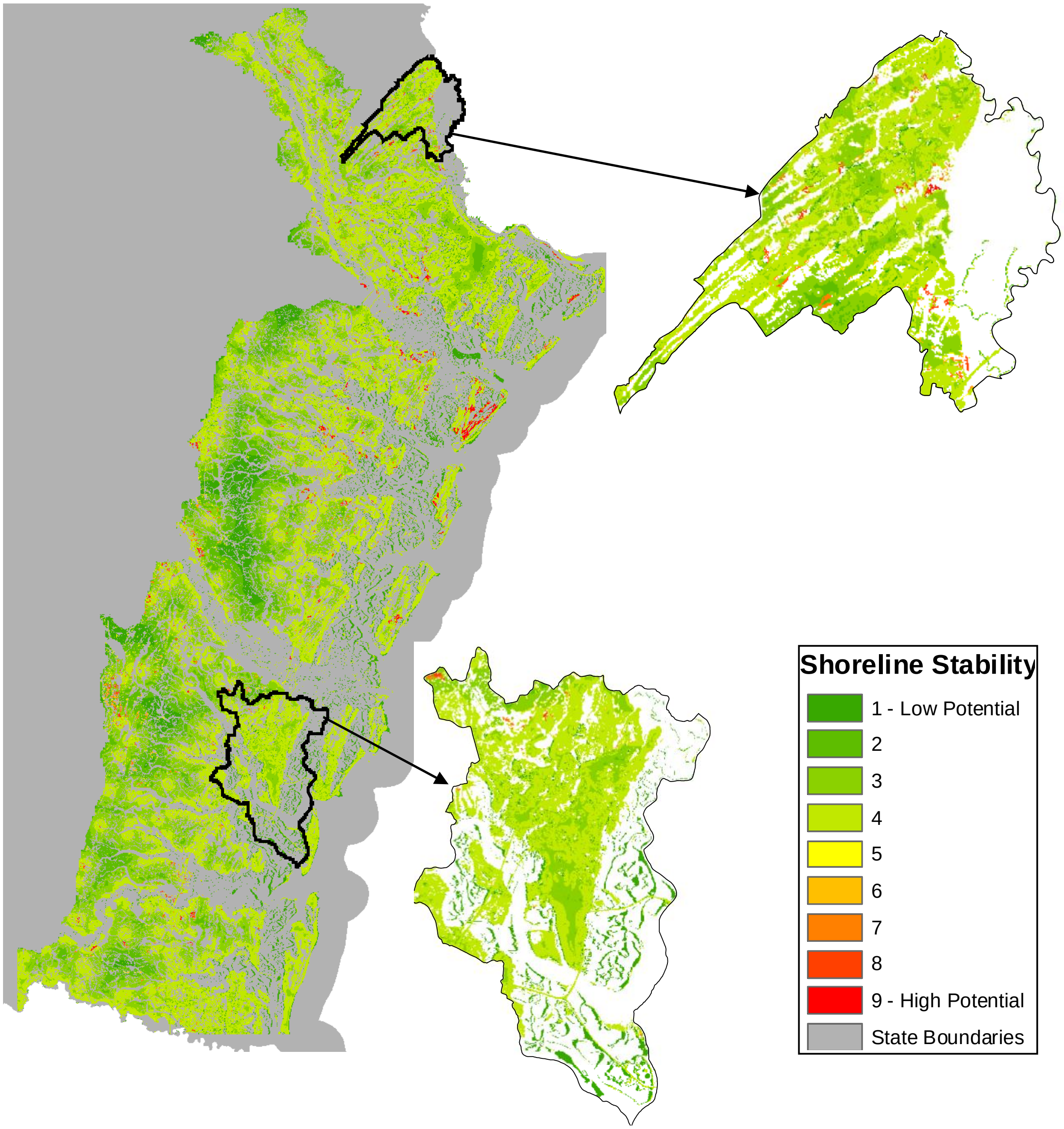


Figure 3.22: Shoreline Stability Layer (Layer 4.4) for the CPWRS Index where a high potential value corresponds with an increase in shoreline stability between 2008 and 2030 and a low potential corresponds with a decrease in shoreline stability between the two time periods. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern regions of coastal Georgia.

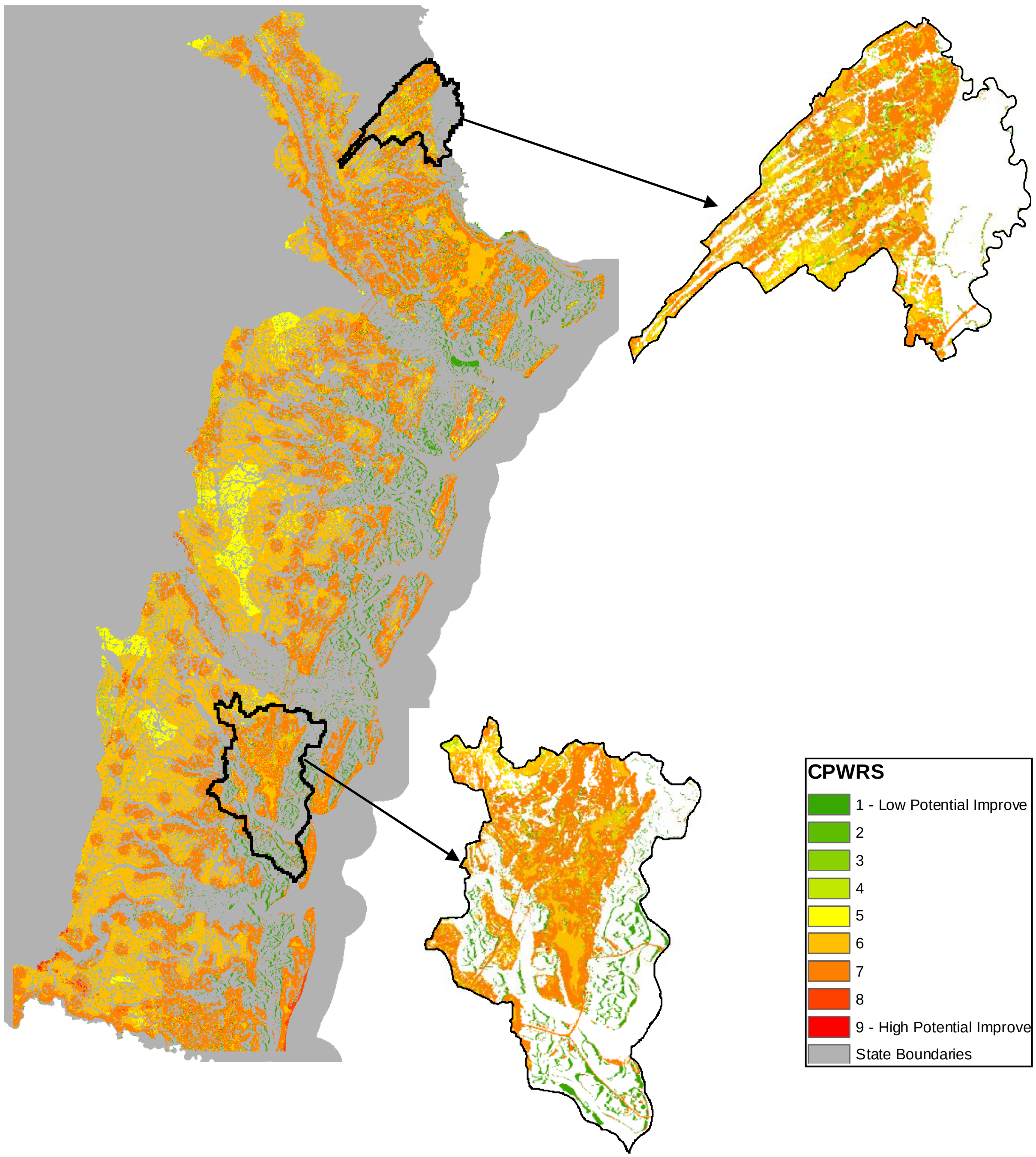


Figure 3.23: The Change in the Potential Wetland Restoration Site Index from 2008 to 2030. A high potential value corresponds with an increase in the ability of a restored/established wetland site to perform wetland functions (Layers 4.1 to 4.4) between the two time periods. Representative 12 Digit Hydrologic Unit Codes are shown for both the northern and southern regions of coastal Georgia.

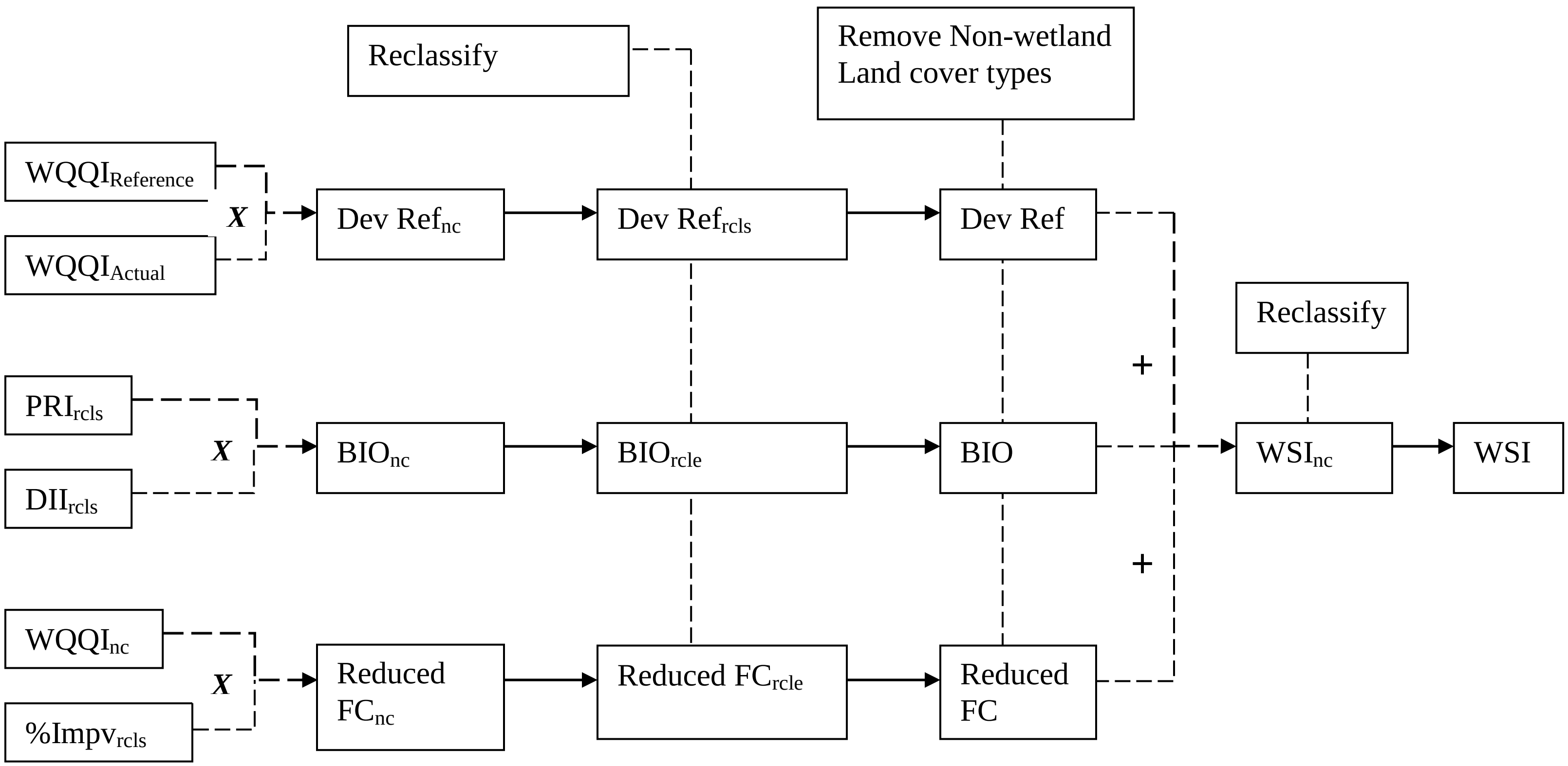


Figure 3.24: Flowchart depicting how the Wetland Site Index is created by combining the three layers in Component Five. Dashed lines represent processes in the model and solid lines represent the progression of each layer. The term *nc* refers to a layer that has not been reclassified using either Quantiles or Jenks Optimization.

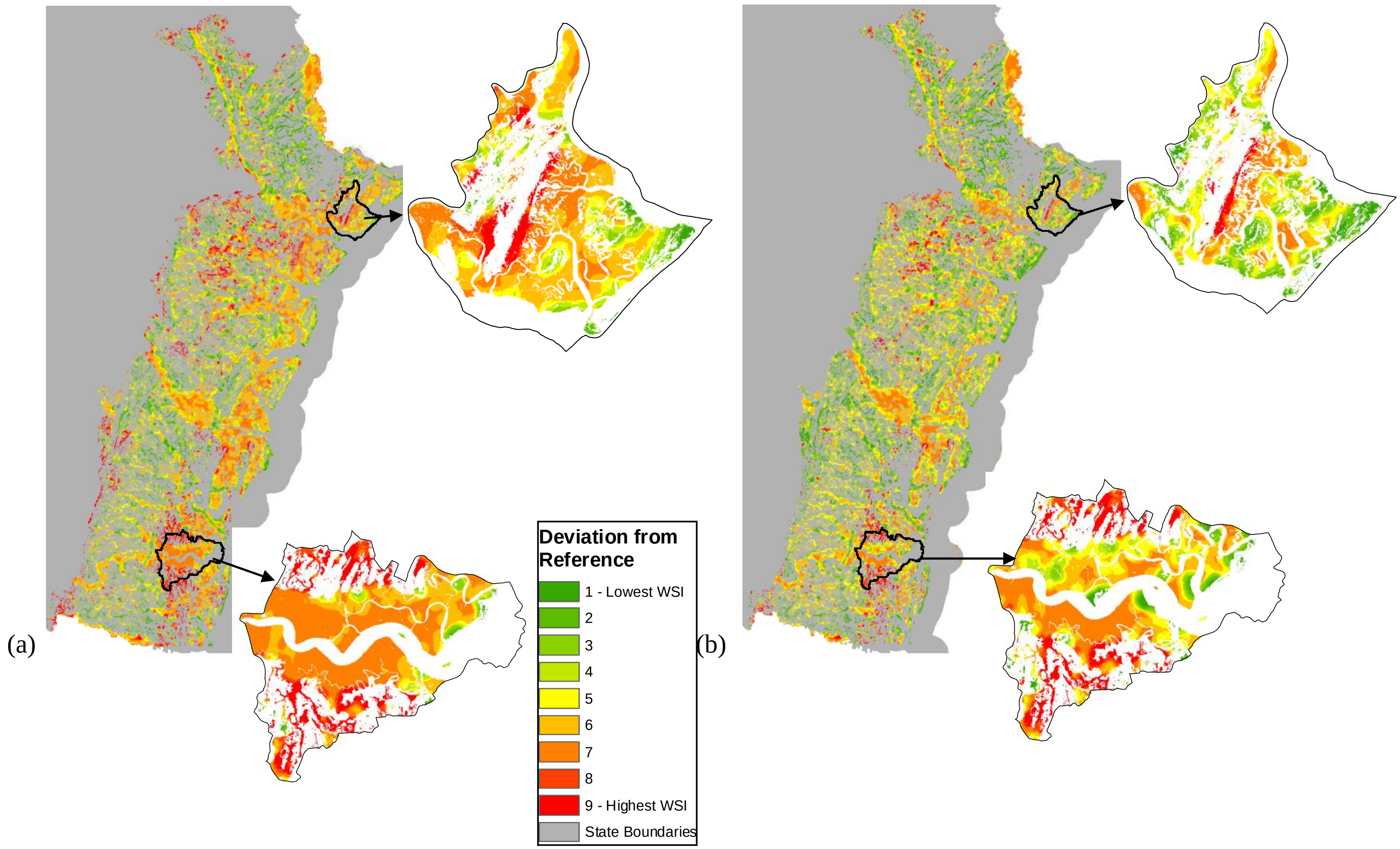


Figure 3.25: Deviation of wetlands from Reference Conditions (Layer 5.1) for the year 2008(a) and 2030(b) used in the Wetland Site Index with representative 12 Digit Hydrologic Unit Codes in the northern and southern regions of coastal Georgia. A high potential area is a location with low deviation from reference condition.

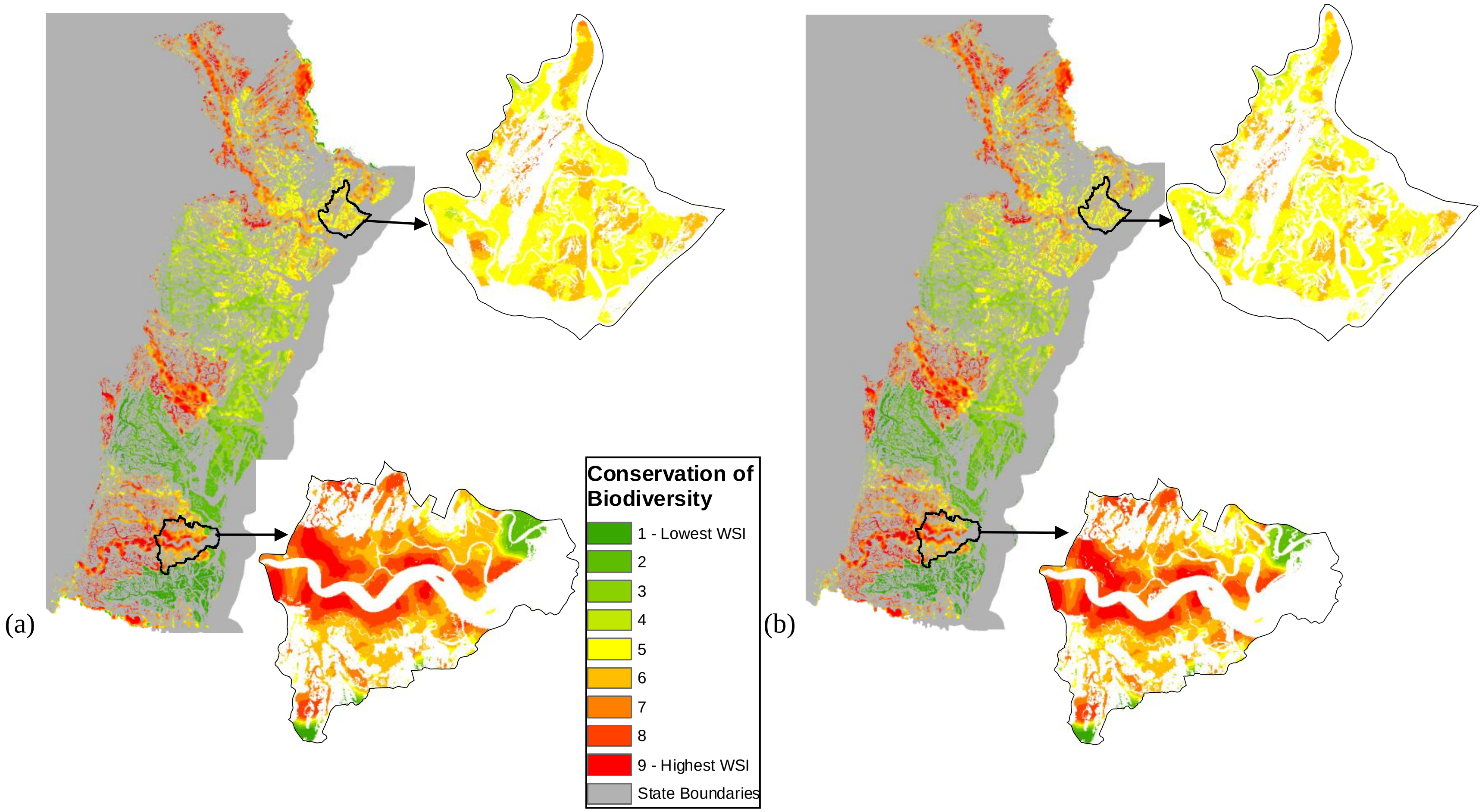


Figure 3.26: Conservation of Biodiversity in High Priority Streams (Layer 5.2) for the years 2008(a) and 2030(b). A high value corresponds with a wetland that has the greatest potential in conserving biodiversity in high priority streams. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern regions of coastal Georgia.

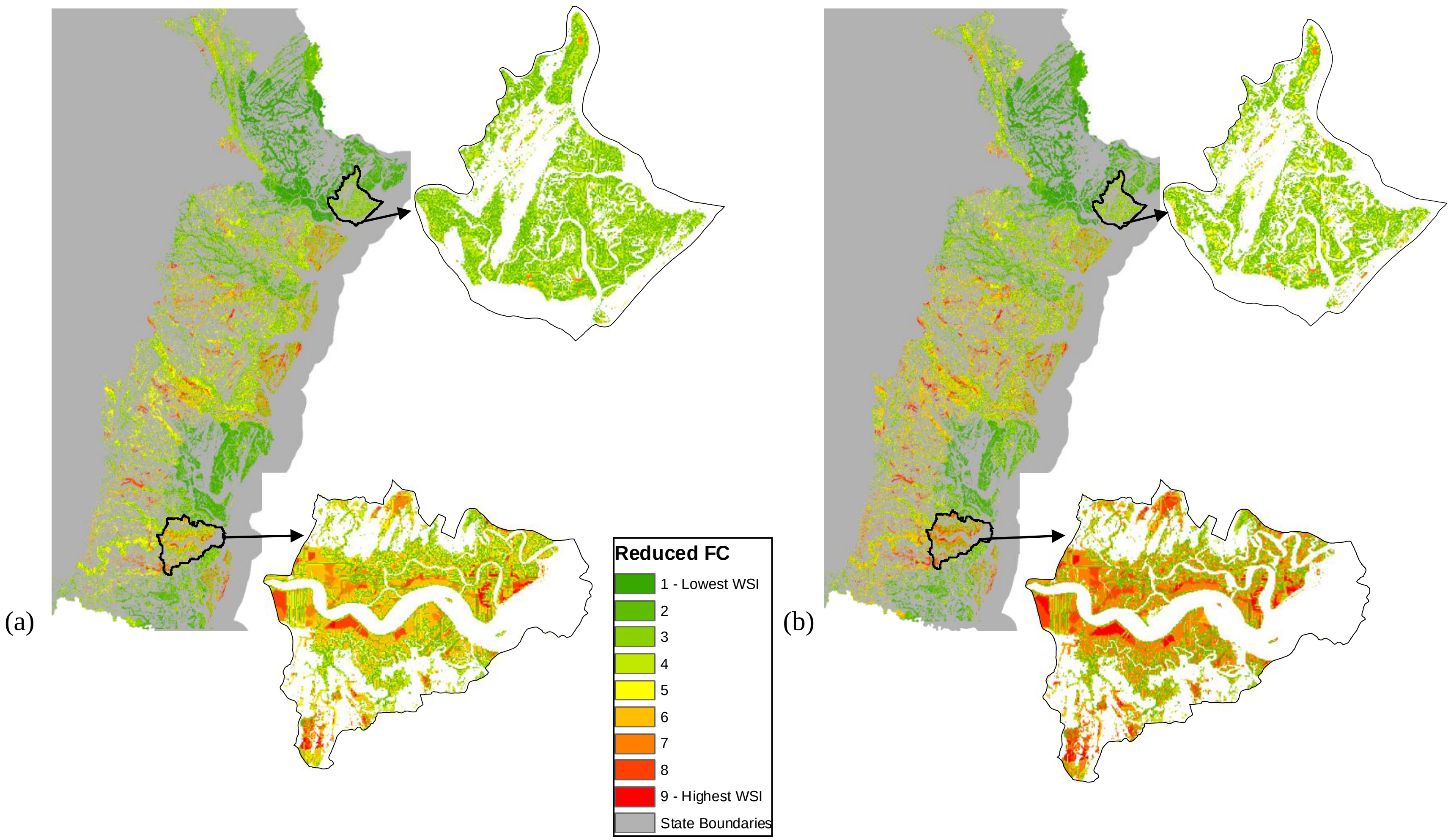


Figure 3.27: Coastal Fecal Coliform Index (Layer 5.3) in Component Five for the years 2008(a) and 2030(b). Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern regions of coastal Georgia, and the highest ranked values correspond to wetlands that potentially have the lowest levels of fecal coliform.

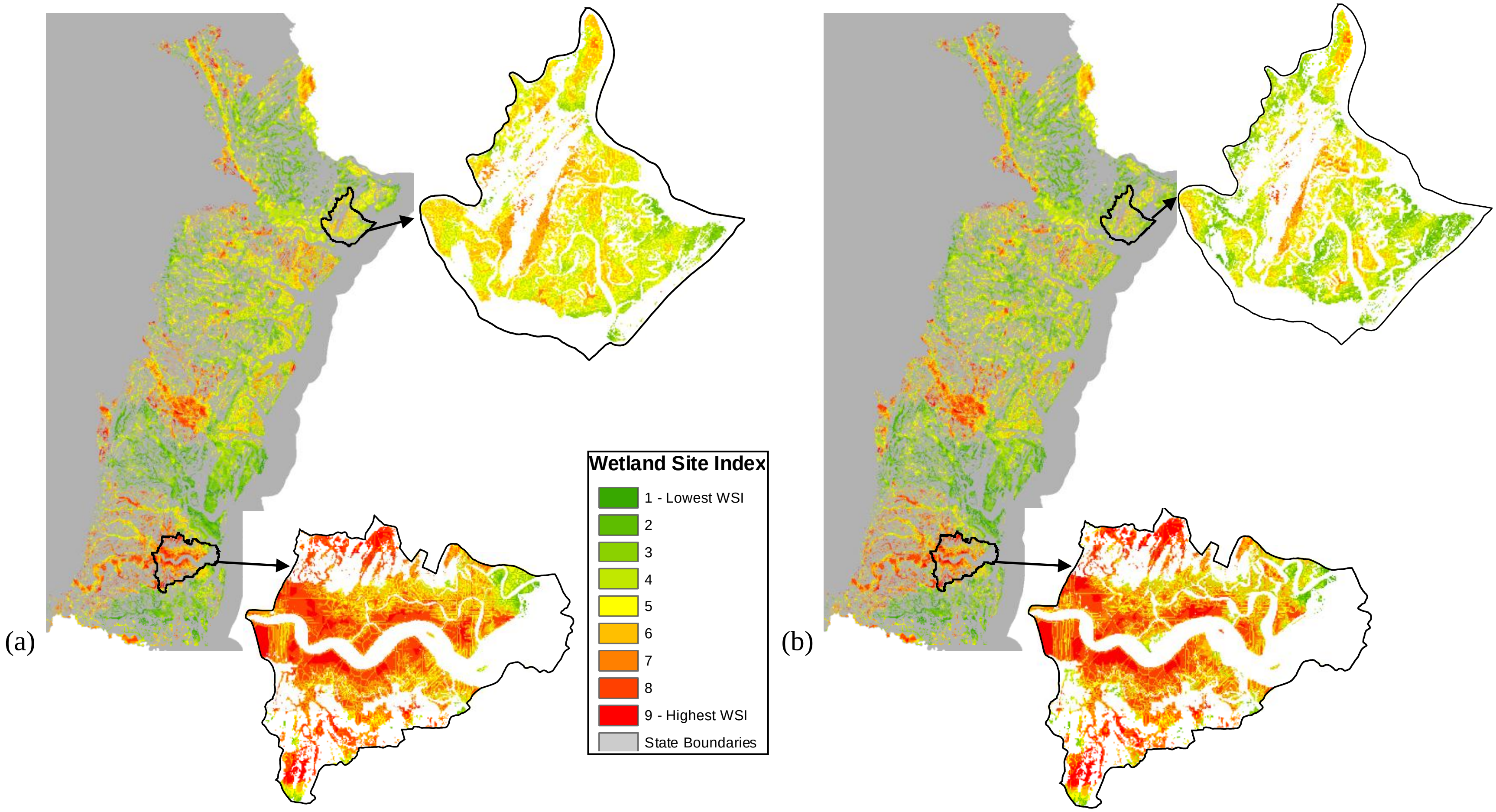


Figure 3.28: Wetland Site Index for 2008(a) and 2030(b). A high index value represents those wetland areas that have a high potential of performing wetland functions. Layers used to create the WSI include deviation from reference (Layer 5.1), conservation of biodiversity (Layer 5.2) and reducing fecal coliform (Layer 5.3). The high index value areas are also potential sites for the restoration/establishment of wetland sites. Representative 12 Digit HUCs are shown for northern and southern coastal Georgia.

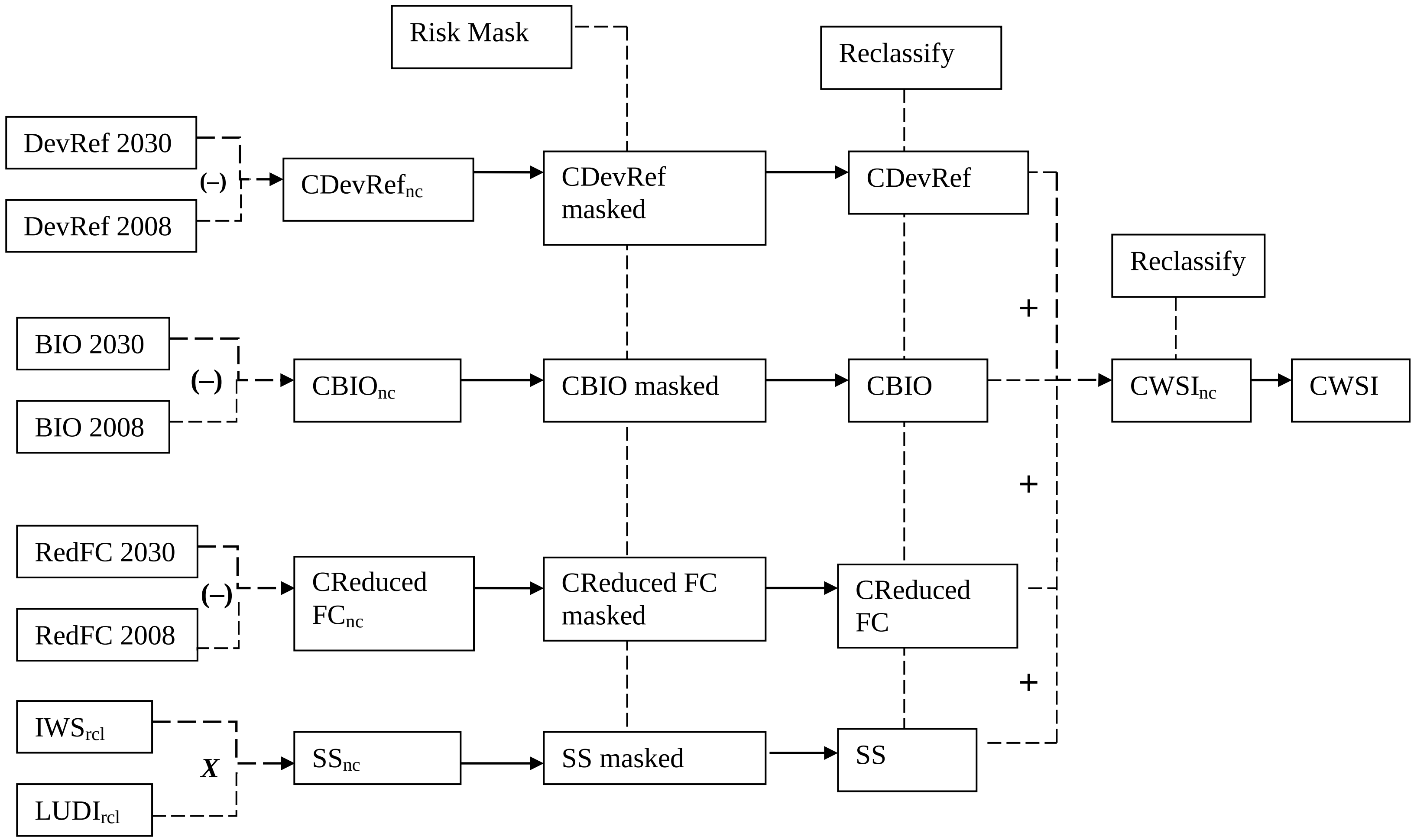


Figure 3.29: Flow chart depicting how the Change in the Wetland Site Index is created by combining the four layers in Component Six. Dashed lines represent process in the model and solid lines represent the progression of each layer. The term *nc* refers to a layer that has not been reclassified using either Quantiles or Jenks Optimization.

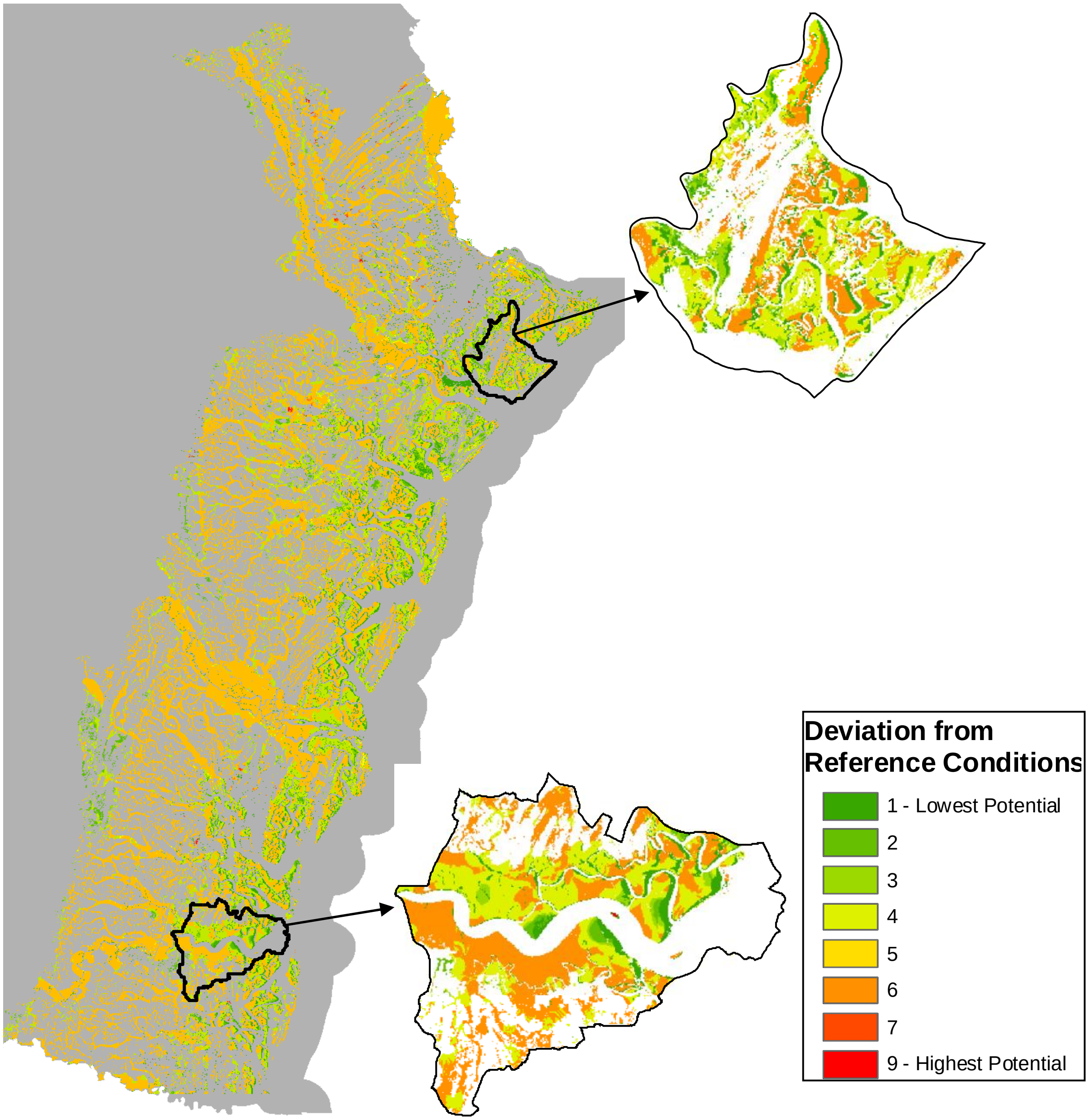


Figure 3.30: Change in the Deviation of a wetland from Reference Condition (Layer 6.1) from 2008 to 2030. Areas with a high potential value are considered to have positively changed the in their ability to improve water quality over time. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern regions of coastal Georgia.

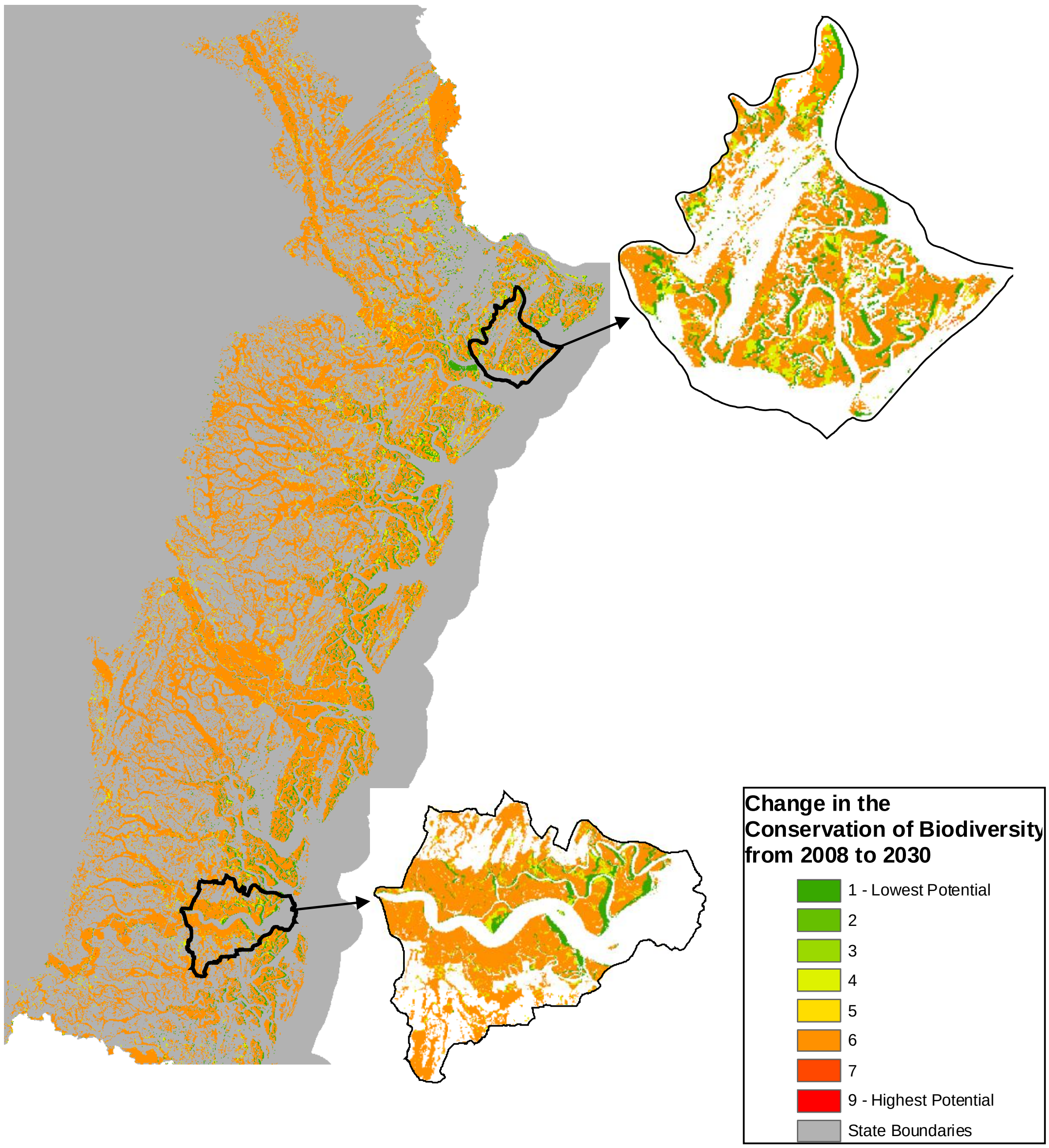


Figure 3.31: Change in Conservation of Biodiversity (Layer 6.2) from 2008 to 2030. Areas identified as having a high potential (value 7, 8, or 9) are considered to have increased in their potential to perform the function of the conservation of biodiversity within the time frame. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern regions of the Georgia coast.

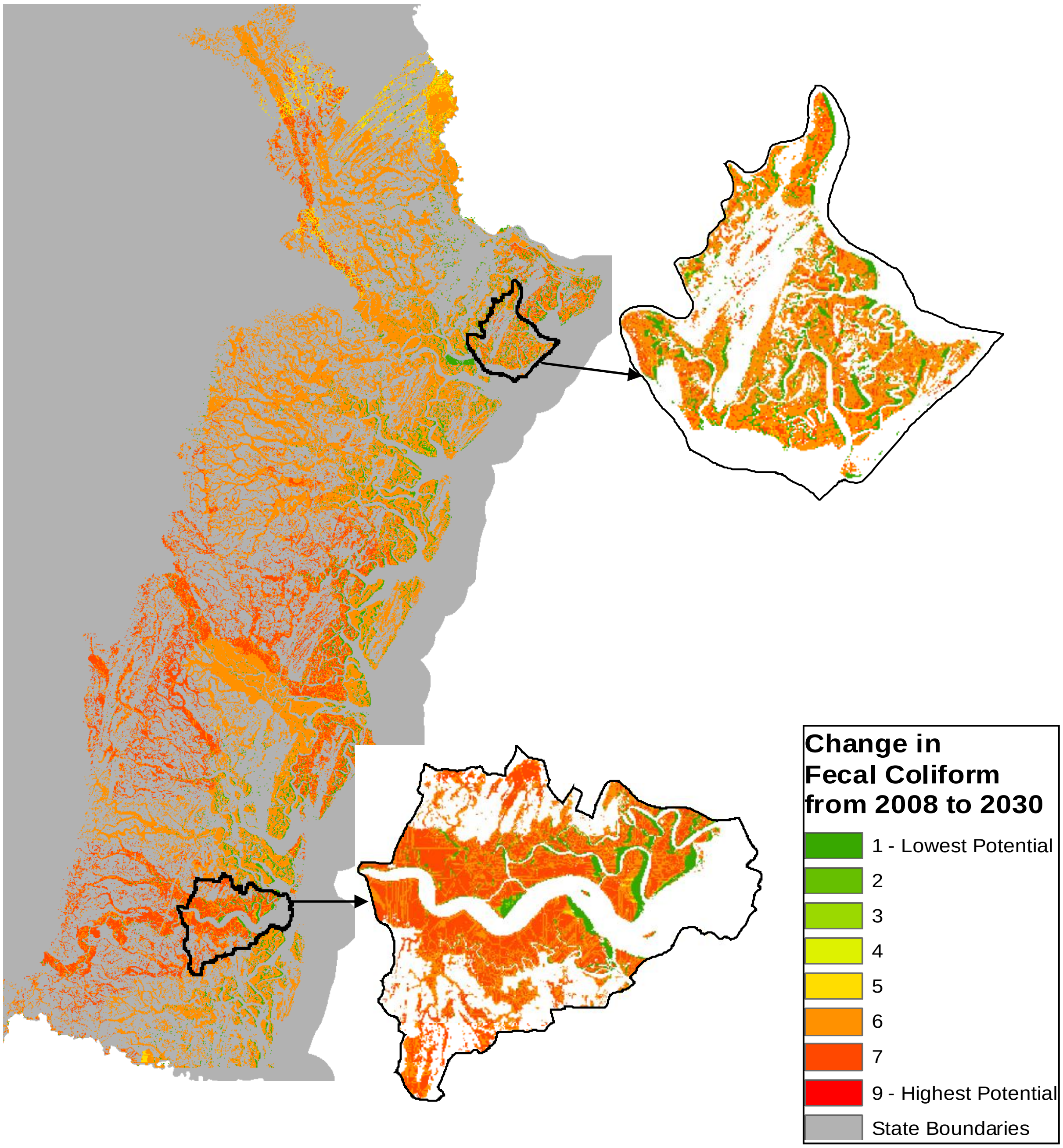


Figure 3.32: Change in the function of Reduced of Fecal Coliform (Layer 6.3) from 2008 to 2030. Areas identified as having a high potential (value 7, 8, or 9) are considered to be less influenced by fecal coliform levels in 2030 than in 2008. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern region of the Georgia coast.

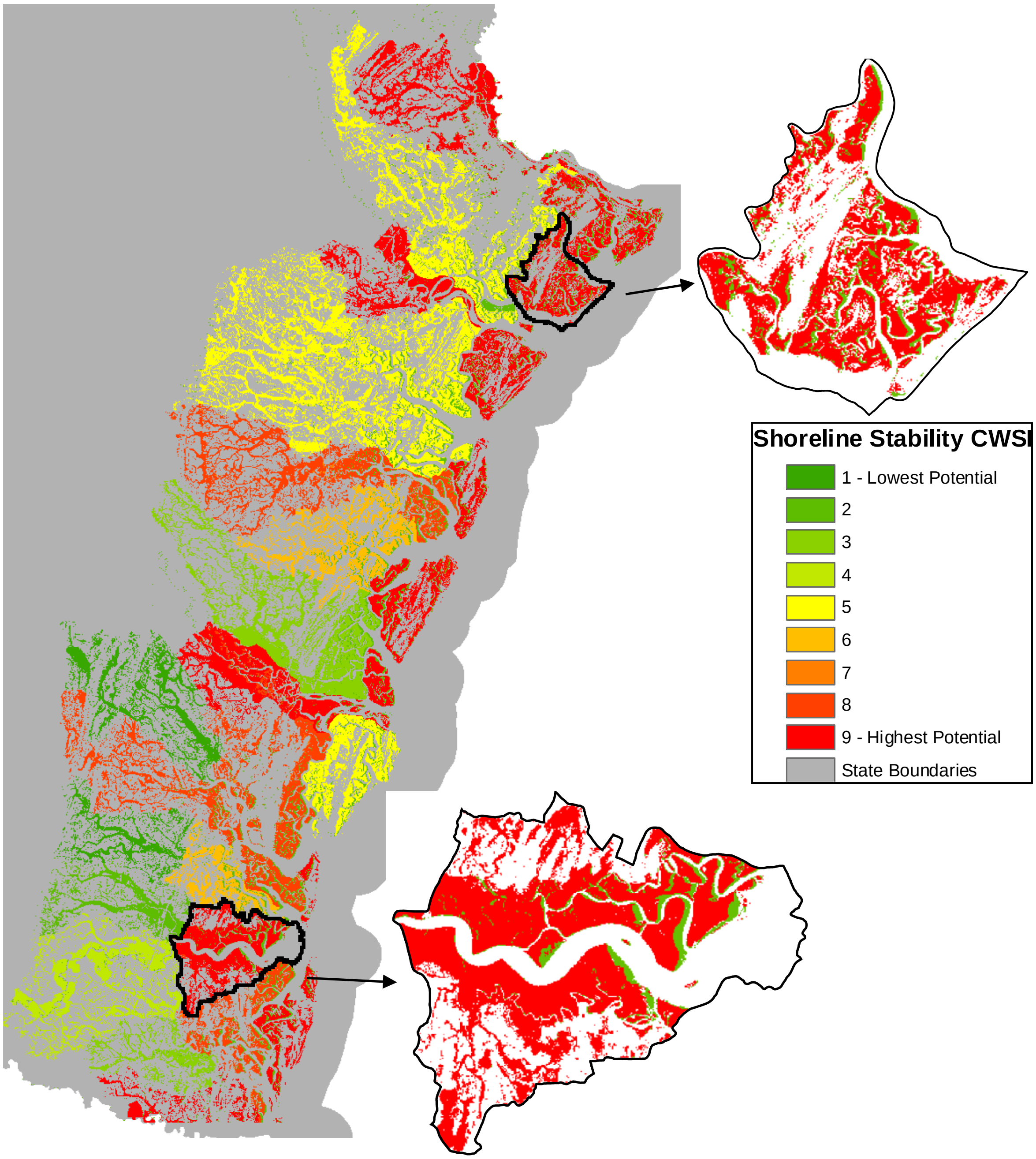


Figure 3.33: Loss of Shoreline Stability due to the loss of wetlands (Layer 6.4) from 2008 to 2030. Wetland areas with a high value of potential (value 7, 8, or 9) are considered to have the least risk of losing shoreline stability within the given time frame. Representative 12 Digit Hydrologic Units are shown for the northern and southern region of the Georgia coast.

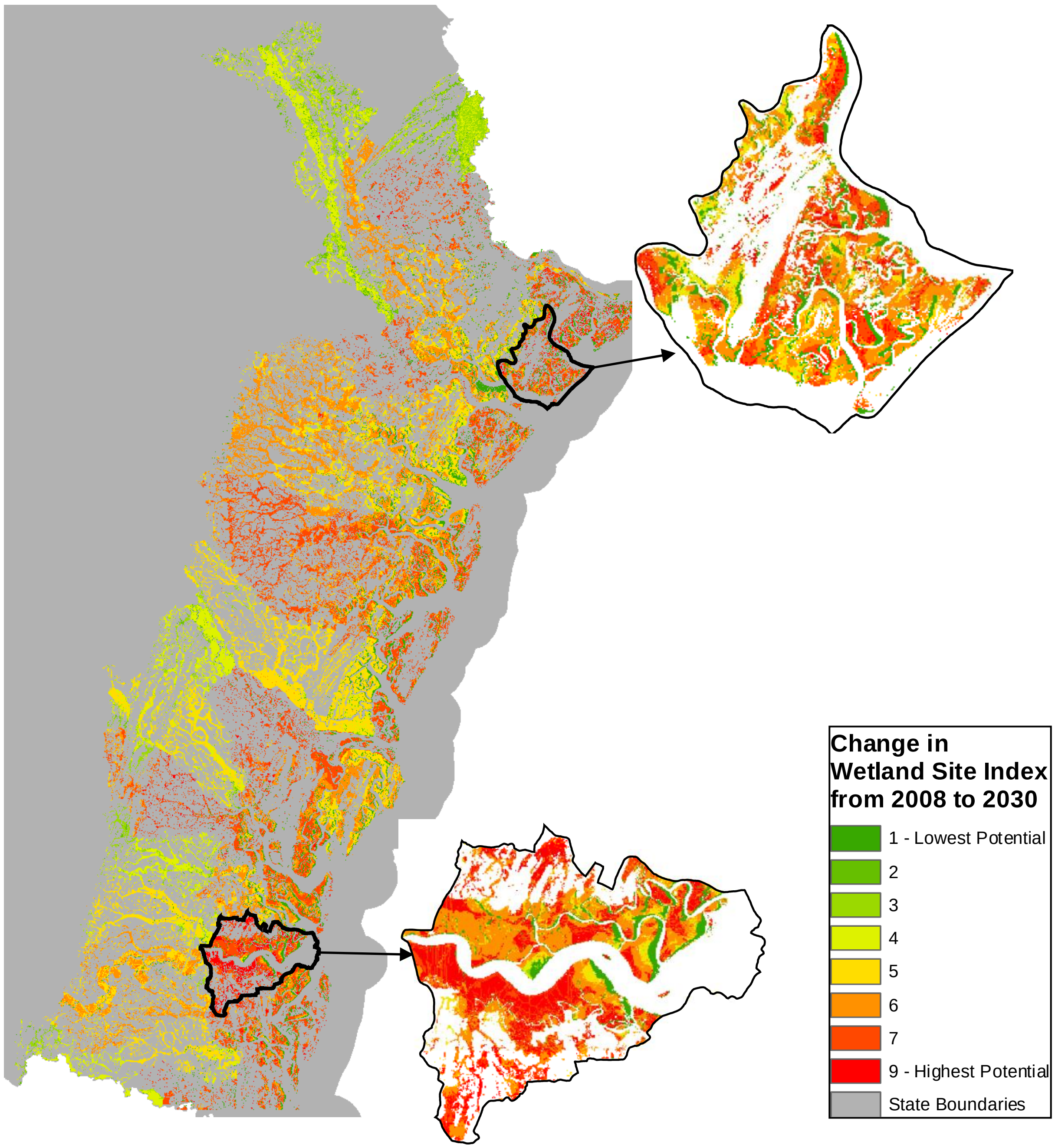


Figure 3.34: The Change in Wetland Site Index from 2008 to 2030. A wetland area that has a high potential (value 7, 8, or 9) is considered to have the least risk of degradation of the wetland functions of water quality and quantity, conservation of biodiversity, fecal coliform and shoreline stability. Representative 12 Digit Hydrologic Unit Codes are shown for the northern and southern regions of the Georgia coast.

CHAPTER 4

RESULTS

There are 9,433,679 ha of land in the coast of Georgia. The Risk Mask, which is one of the main outputs of the risk assessment, predicts that between the years 2008 and 2030 there will be a gain in wetland area of 255,510 ha (3%) and a loss of 262,368 ha (3%) of wetland area within the Chatham, McIntosh, Glynn, and Camden counties and the portions of the Effingham, Bryan, Liberty, Long, Wayne, Brantley and Charlton counties of Georgia that coincide with the 12 Digit Hydrologic Unit Codes that have tidal influences (Table 4.1, Figure 4.1) While there is little difference in the percentage of wetlands created versus those that are lost, there is a change in their spatial location which affects the potential of mitigation sites to perform wetland functions. For natural resource managers to better understand how the spatial change in land use affects the potential for wetland mitigation, the results of the future land use map for the year 2030, the Risk Mask, and the results of the indices created in Chapter Three need to be well understood. The rest of this chapter is devoted to evaluating the results of the risk assessment and Chapter Five is devoted to interpreting how the results can be used in the selection of wetland mitigation sites.

PREDICTED LAND USE CHANGE BETWEEN 2008 AND 2030

Change in Wetland Area Predicted Using SLAMM

The Sea-Level Rise Affecting Marshes Model is used to predict the changes in spatial location of wetlands between the years 2008 and 2030. Using the output for these two years, the change in area for forested wetlands, saltwater wetlands, freshwater wetlands and beach/mud/dune areas is determined. In addition to this, the conversion of the different wetland areas either from or to a different land use type is calculated to show where the greatest threats to these wetlands occur and the regions that they are most likely to migrate.

From the SLAMM output for 2008, the composition of the landscape is 54% forested wetlands (1,923,948 ha), 40% saltwater wetlands (14,153,901 ha), 4% freshwater wetlands (134,618 ha) and 2% beach/mud/dune areas (66,049 ha) (Table 4.2, Figure 4.2; Figure 4.3). The projected land use composition in 2030 is 43% forested wetland (1,896,973 ha), 31% saltwater wetlands (1,393,009 ha), 3% freshwater wetlands (134,617 ha) and 23% beach/mud/dune areas. When comparing the two years, the beach/mud/dune varies the most while the freshwater wetland areas have the smallest variation (Figure 4.4). Also, the forested wetlands are predicted to have the greatest loss in area while the beach/mud/dune areas are predicted to have the largest gain. Specifically, there is a predicted loss of 26,975 ha of forested wetlands, 22481 ha of saltwater wetland and 3.6 ha of freshwater wetlands and a predicted gain of 934,002 ha of beach/mud/dune areas between 2008 and 2030. Freshwater wetlands in the coast of Georgia are predicted to have the least change, or are the least influenced by sea-level rise and storm surges, because there is only a loss of 3.6 ha within the time frame of the study.

For forested wetlands, the greatest loss of area occurs through the conversion to saltwater wetlands (72,284 ha) and the greatest gain comes from the conversion of uplands (forest, agriculture, etc) to forested wetlands (43,226 ha) (Table 4.3). The majority of the loss of saltwater wetlands occurs through the conversion to beach/mud/dune areas (59,148 ha) and the second greatest loss is from the conversion to open water (38,340 ha). The conversion of developed land to saltwater wetlands constitutes the largest gain in wetland acreage (2,236 ha) which is still much less than the projected gain experienced by forested wetlands when they are created in upland areas. There is no gain of freshwater wetlands between 2008 and 2030; instead there is only a small loss of 3.6 ha predicted in areas where the freshwater wetlands are converted into saltwater wetlands.

Change in Developed Area Predicted Using SLEUTH

The Slope, Land cover, Exclusions, Urban Areas, Transportation and Hill-slope (SLEUTH) model is used in component one of Chapter Three to predict the growth of developed areas in the coast of Georgia. While this projected developed areas file was originally created by the NARSAL for the EPD, it is adapted for this study by assigning a landcover development intensity value to the predicted growth regions. After performing this adaptation, it is found that there is an increase in developed areas of 140,170 ha between 2008 and 2030 (Table 4.4). Looking specifically at the landcover development intensity classes (open space, low intensity, medium intensity and high intensity), there is very little change in the proportion of each development intensity between the years 2008 and 2030 when compared with the total area of developed pixels in the coast of Georgia (Figures 4.5 and 4.6). There is a difference of +1% open space, +1% low intensity, -2% medium intensity and no difference in the percentage of high intensity in the specified time frame. The actual amount of acreage that is predicted to change between 2008 and 2030 is 74,982 ha for open space, 45,157 ha for low intensity, 3,506 ha for medium intensity, and 16,526 ha for high intensity land cover areas. The lower development intensities (open space and low intensity) have the greatest increase in acreage when compared to the medium and high intensity development areas.

Total Predicted Land Use Change between 2008 and 2030

The final future land use map for 2030 is created by combining the predicted landscape changes that are created from the SLAMM, SLEUTH, and AMBUR models. The predicted land use change between 2008 and 2030 is evaluated using the 2008 Georgia Land Use Trends (GLUT) file and the future land use map for 2030, which are also the files that are used in determining the potential for wetland mitigation in the four indices presented in Chapter Three. The land use categories of interest for both files are the 1) beach/mud/dunes, 2) open water, 3) urban, 4) forested wetlands, 5) saltwater wetlands, 6) freshwater wetlands and 7) upland (agriculture, forested, golf courses, mines, sparse/barren, and utility swaths).

The total amount of area for each land use category of interest for 2008 is: 108369 ha for beach/mud/dunes, 1,833,904 ha for open water, 695,332 ha for urban development, 1,953,218 ha for forested wetlands, 1,322,304 ha for saltwater wetlands, 168,770 ha for freshwater wetlands and 3,336,777 ha for the upland (Table 4.5). For the projected land use areas in 2030 upland (2,891,442 ha), forested wetlands (2,021,138 ha), open water (1,997,186 ha) and saltwater wetlands (1,267,890 ha) all have over one million hectares while the urban (914,433 ha), beach/mud/dunes (187,818 ha) and freshwater wetlands (138,766 ha) landcover types are under one million hectares.

There is an increase in area between 2008 and 2030 for the beach/mud/dunes (+79,449 ha), open water (+163,283 ha), urban (+219,101 ha), and forested wetlands (+67,920 ha) landcover types. Saltwater wetlands decrease by 54,414 ha for the entire coast of Georiga and freshwater wetlands are projected to have 30,004 less hectares in 2030 than 2008. The land cover type with the largest loss of area is upland land use category. This category lost 445,335 ha of land between 2008 and 2030.

The change in acreage is broken down further to investigate the specific losses and gains that are projected to occur to forested wetlands, saltwater wetlands and freshwater wetlands over the 22 year time span (Tables 4.6, 4.7 and 4.8). For forested wetlands, the greatest loss occurs due to a conversion from forested wetlands to saltwater wetlands (-89,744 ha; -50%) and the second greatest loss from the conversion to freshwater wetlands (-49,865 ha; -28%) (Figure 4.7). Between 2008 and 2030, forested wetlands gain a total of 246,651 ha, with 89% coming from the conversion of upland (220,091 ha), 7% from freshwater wetlands (16,419 ha), and 4% from saltwater wetlands (10,142 ha) (Figure 4.8).

There is a larger gain in area for saltwater wetlands from 2008 to 2030 than there are for forested wetlands (Table 4.7). Specifically, saltwater wetlands gain of their area 54% from forested wetlands (89,744 ha), 33 % from freshwater wetlands (55,415 ha) and 13% from upland areas (22,067 ha) (Figure 10). The greatest loss in saltwater wetland area for the 2008 to 2030 time period occurs when the saltwater wetlands are converted to open water (-146,993 ha; 66%) and to beach/mud/dune (-61,068 ha; 28%)

The greatest predicted loss of area for freshwater wetlands (-55,415 ha; -62%) from 2008 to 2030 comes from the conversion of freshwater wetlands to saltwater wetlands (Table 4.8; Figure 4.11). Forested wetlands cause the loss of 18% (- 16,419 ha) of freshwater wetlands while a loss of 14% is associated with the conversion of freshwater wetlands to open water (-12,458 ha). The majority of the landscape (49,865 ha; 84%) that is converted to freshwater wetlands is originally forested wetlands in 2008.

MITIGATION POTENTIAL FOR THE PWRS, WSI, CPWRS AND CWSI INDICES

The Potential Wetland Restoration Site Index, Wetland Site Index, Change in Potential Wetland Restoration Site Index and Change in Wetland Site Index are indices that rank the potential for the wetland mitigation methods of restoration, establishment, preservation or enhancement in the coastal landscape. For the purpose of determining the potential for the placement of mitigation sites, the areas that are ranked from 1-9 in Chapter Three are reclassified into three different groups: low potential (value 1, 2, or 3), medium potential (value 4, 5, or 6), and high potential (value 7, 8, or 9). The locations in the landscape that correspond with a low potential value are the least suitable for wetland mitigation. The locations that correspond with a high potential are the most suitable for wetland mitigation because they have a higher potential to improve the performance of wetland functions in the landscape.

Potential Wetland Restoration Site Index

The Potential Wetland Restoration Site Index ranks the non-wetland, restorable sites for their ability to improve wetland functions through the act of wetland restoration or establishment. For the PWRS Index, the areas of the coast that are identified as having a high, medium or a low potential for improving the function of wetlands through mitigation changes between the years 2008 and 2030 (Table 4.9). In 2008, there are 1354288 ha (33%) of high potential areas, 1,291,298 ha (31%) of medium potential areas and 1,473,235 ha (36%) of low potential areas. In 2030, it is predicted that the high potential areas will increase by 85,021 ha while the medium and low potential decrease by 191,311 ha and 50,929 ha, respectively. The final areas of potential in 2030 are: 1,429,209 ha (36%) of high potential, 1,099,987 ha (28%) of medium potential and 1,422,306 ha (36%) of low potential. With the increase of areas with high potential within a 22 year time period, the possible locations for mitigation sites increases and these newly identified high potential wetland sites can be areas that are targeted for future wetland mitigation sites.

Wetland Site Index

The Wetland Site Index prioritizes the condition of existing wetlands to perform the designated wetland functions discussed in Chapter Three. The results of the WSI are very different than the PWRS Index. For the WSI in 2008, the majority of the landscape (1,856,934 ha; 54%) is identified as having a medium potential (Table 4.10). Low potential sites compose the next highest percent of the landscape, with 31% and 1,076,522 ha. The lowest percentage (15%) is associated with the high potential areas in 2008. The percentage of potential sites does not vary much between 2008 and 2030, but the area of potential wetland restoration sites does increase for all three potential mitigation categories (low, medium, high). In 2030, the medium potential has the most area and the highest percentage (2,668,614 ha; 60%), low potential sites have the second highest percentage (28%) and the high potential areas has an area of 524,948 ha (12%). While there is an increase in area for each potential mitigation category, the percent area decreases for the high potential and low potential wetland restoration sites between the years 2008 and 2030. This shows that although the acreage increases for the high, medium and low potential sites from 2008 to 2030, this does not necessarily mean that there is an increase in the percent area for each of the levels of potential wetland mitigation.

Change in Potential Wetland Restoration Site Index

The Change in Potential Wetland Restoration Site Index ranks the potential of land pixels that are identified as being non-wetland for either 2008 or 2030 to improve in their ability in performing wetland functions over time. The area of those pixels identified as having a high potential to improve wetland functions over time is 1,905,894 ha, or 44% (Table 4.11). The medium potential for wetland restoration/establishment is the highest area (2,068,387 ha) and percentage (47%) for the coast of Georgia between 2008 and 2030. The low potential ranking for wetland mitigation has the lowest percentage (9%) and actual area (406,282 ha). Over time there is little potential for mitigation lost due to a low potential ranking, while there are over 40% of areas that are identified to have a high potential for improving wetland functions over time.

Change in Wetland Site Index

The Change in Wetland Site Index prioritizes the potential of a wetland condition to improve between the years 2008 and 2030. The results of the percent area for the CWSI are similar to those in the CPWRS because the medium potential areas have the highest total area and percentage, while the low potential for wetland mitigation areas have the lowest total and percent area. Specifically, the high potential sites have an area of 1,085,645 ha (32%), medium potential sites have an area of 1,888,855 ha (55%) and low potential wetlands have an area of 459,918 ha (13%). The distribution of the percent of area for high, medium and low potential sites show that over time there is a small percentage of wetlands that lessen in their potential for wetland mitigation over time, and there is a large percentage of wetlands along the coast of Georgia that do not change potential between the years 2008 and 2030.

Overall Change in Mitigation Potential for the PWRS, WSI, CPWRS and CWSI Indices

The area and percentage of the high, medium and low potential sites is different for all of the indices in the risk assessment. The WSI for 2030 has the largest area (2,668,614 ha) and percentage (60%) of medium priority sites of all the indices (Figures 4.13 and 4.14). The 2008 WSI has the largest area (597,730 ha) of high potential sites, and the CPWRS has the largest percentage (44%) of high potential sites. For the coastal areas identified as low potential wetland mitigation sites, the 2008 PWRS has the largest total area (1,473,235 ha) and the 2008 and 2030 PWRS have the largest percentage of low potential areas.

The index with the lowest amount of high potential wetland areas is the WSI 2030 (524,948 ha) and the WSI 2008 is a close second (507,730 ha). These two indices also have the lowest percentage of high potential wetland areas, with the WSI 2030 having 12% and the WSI 2008 having 15%. The indices with the lowest area and percentage of medium potential wetland sites are the PWRS 2030 and the PWRS 2008, with 1,099,987 ha (31%) and 1,291,298 ha (28%), respectively. Even though the PWRS 2008 has a lower total area, it has a higher percentage of the coast identified as medium potential for wetland mitigation. The CPWRS and CWSI Indices have the lowest area and percentage of coastal land area for the low potential of wetland mitigation sites. The values of the CPWRS and CWSI are 406281.60 ha (0.09) and 459,918 ha (0.13), respectively. In this instance, the index with the lower total area also has the lower percent area that is identified as low potential compensatory wetland mitigation sites.

Looking at Figure 4.13 and 4.14, a coupling of the indices can be seen. The equations of these trend lines can be seen in Table 4.13. The coupling occurs for the total area and percentage of area for the 2008 and 2030 PWRS, the 2008 and 2030 WSI as well as the CPWRS and CWSI.

RESULTS OF THE ANALYSIS OF TECHNIQUES AND METHODOLOGIES CREATED AND USED IN CHAPTER THREE

The results calculated in the *Predicted Land Use Change between 2008 and 2030* section of this chapter, as well as the *Mitigation Potential for the PWRS, WSI, CPWRS and CWSI* section, are only as accurate as the methods and techniques used to create the final maps used in the analyses. Errors can be introduced based on low quality files, the way files are created and the assumptions used in the methodologies that created the PWRS, WSI, CPWRS and CWSI indices. The methods described in the *Methods Used to Calculate Results* section at the end of Chapter Three are used to determine any discrepancies between the outcome of the indices and the files used to create the future land use map of 2030.

SLAMM per 12 Digit HUC for 2008

The SLAMM program predicts the spatial change of wetland location due to stressors such as sea-level rise and storm surges. The ability of the SLAMM program to predict the movement of wetlands depends on the accuracy of the initial files and parameters used. By comparing a 2008 land use file created in SLAMM with the 2008 GLUT file, the ability of the SLAMM model to predict the position of wetlands in 2008 is determined.

From the analysis, there is never more than a 10 % difference in the percentage of land use between the actual and the projected land use for 2008. The highest percentage of difference (9.7%) occurred for salt water wetlands in a region that is identified as being freshwater wetland in the 2008 GLUT and saltwater wetland in NWI dataset (Figure 4.15). Looking back at the NWI file, a large area of land that is classified as being a fresh water wetland in the 2008 GLUT is classified as a salt water wetland in the NWI, which may be the source of the large percent difference in the area of saltwater wetlands for that 12 Digit HUC. The area below the city of Savannah Georgia also showed a great difference in salt marsh area because this area is being inundated and the barrier island is breaking apart. The barrier island portion of the future land use map creation accounted for change in this barrier island so that it did not have a large affect on the final output of the risk assessment indices. The least difference between the projected and actual land use map occurred for impervious surfaces (0.02 – 3.7 %). This is most likely due to the fact that the impervious surface file that is used in SLAMM 6. 0.1 is derived from the same file that is used to delineate the urban areas in the 2008 GLUT. Other discrepancies in land use percentages can be seen in Table 4.14.

Barrier Island Shoreline Creation Technique

The Analyzing Moving Boundaries Using R (AMBUR) is designed to use barrier island shorelines that are created using LIDAR, elevation and/or aerial photos. These files are not available for the entire coast of Georgia at the time of this study, so the land use files for seven different years are used to create the shoreline files of barrier islands. To check if the two techniques of creating shorelines are compatible in their ability to predict shoreline position, the shoreline file for Jekyll Island in 1974 is compared to the Jekyll Island file created by Jackson (2010) using the methodology described in the *Barrier Island Shoreline Technique* of the *Methods Used to Calculate Results* section of Chapter Three.

The results of the technique used to create barrier shorelines analysis are the percentages of the 1974 shoreline created using land use files that are within a specified buffer distance from the LIDAR, elevation and aerial photograph created 1974 Jekyll shoreline. From the analysis, 88% of the land use shoreline is within 60 meters (Table 4.15) of the Jekyll shoreline that was created by Jackson (2010). Approximately 9% of the land use shoreline is within 60 to 120 meters of the LIDAR shoreline, and 3% is within 120 to 180 meters. The buffer of 180 to 240 meters contains less than 1% of the Jekyll Island shoreline created using the 1974 GLUT file.

Sensitivity Analysis of the Indices

The sensitivity of the Potential Wetland Restoration Site (PWRS) Index and the Wetland Site Index (WSI) for the years 2008 and 2030 are calculated for two reasons. First, the sensitivity analysis is used to determine if the rank of the influence of the layers that compose the index changes from the year 2008 to 2030. Second, the sensitivity analysis is used to evaluate the magnitude that the layer directly affects the PWRS or WSI indices and what the indexed effect would be in order to determine if there is a difference in the influence that each layer has on the final index. A sensitivity analysis is also performed for the Change in Potential Wetland Restoration Sites (CPWRS) Index and the Change in Wetland Site Index (CWSI) to determine if a one layer has more of a direct or indexed effect, or influence, than another layer on the final index output. The sensitivity analysis is calculated as described in the *Sensitivity Analysis* portion of the *Methods Used to Calculate Results* section of Chapter Three. The final results for each index is the direct and indexed effect that each layer has on an index as well as a graph depicting the magnitude of the direct effect for each layer in reference to the layer with the lowest direct effect value.

- *Sensitivity Analysis of the Potential Wetland Restoration Site Index for the years 2008 and 2030*

The sensitivity analysis for the Potential Wetland Restoration Site Index determines which of the three layers that compose the index (WQQI, BIO and Reduced FC) have the most influence on the final area and position of high priority mitigation areas in the PWRS index for the years 2008 and 2030. The first sensitivity analysis performed is for the mean patch area of high priority (value 7, 8, or 9) pixels in the PWRS for the year 2008. This analysis determines the effect that the mean patch area has on the final index and reduces the importance of layers whose high priority pixels are fragmented. The results show that the WQQI (Layer 2.1) has the highest direct and indexed effect, with a value of 1.73 and 1.64, respectively (Table 4.16). The direct effect of the WQQI has a magnitude of 2.58 times more influence on the final PWRS mean patch areas of high priority than does the Reduced FC layer, which has the lowest value of direct effect (0.67). Looking at the total area of high priority pixels within the coast of Georgia for the PWRS analysis, the layer that has the most direct and indirect effect on the index is again the WQQI (Layer 2.1). In this instance, the WQQI has a direct effect of 1.77 and an indexed effect of 1.33 (Table 4.17). The WQQI has a magnitude of 1.65 times the effect on the PWRS than the BIO layer (Figure 4.16), which has the lowest direct effect of 1.07. For the year 2008, the ranking did not stay the same when looking at different landscape scales, but the WQQI layer (Layer 2.1) always had the greatest direct effect.

For the year 2030, the layer with the greatest mean patch size of high priority pixels is the WQQI layer. This layer has a direct effect of 1.76 and an indexed effect of 1.72 (Table 4.18).

The layer with the least influence on the PWRS Index for the year 2030, when considering mean patch size, is the Reduced FC layer (Layer 2.3). The value of the direct effect of the Reduced FC layer is 0.61, which means that the WQQI layer has 2.89 times more influence on the final PWRS. The layer with the greatest total area of high priority pixels is also the WQQI (Layer 2.1), which has a direct effect of 1.78 and an indexed effect of 1.33 (Table 4.19). The WQQI is a magnitude of 1.63 times more influential than the layer with the lowest direct effect, the Reduced FC layer (direct effect = 1.09) (Figure 4.17).

Between the two years, there is very little change on the influence that each layer has on the final PWRS Index. The WQQI (Layer 2.1) is the most influential layer for the PWRS because it is ranked as having the highest direct effect for both landscape scales (patch and total area) and for the years 2008 and 2030. The WQQI had the highest magnitude of influence (2.89) for the 2030 PWRS when looking at mean patch size of high potential restoration sites. Overall, the BIO layer had the second highest influence on the Potential Wetland Restoration Site Index.

Carpenedo (2008) identified the wetland functions that are of the most interest to resource managers, with the most important wetland function being the improvement of water quality and quantity and second most important being the conservation of biodiversity in high priority streams. The ranking of the influence of the PWRS reflects the order of layers deemed most important by resource managers for the 2008 mean patch analysis and for both the mean patch and total area analysis for the year 2030. This is not true for the total area sensitivity analysis in 2008 because the second most influential layer identified is the reduction of fecal coliform instead of the conservation of biodiversity.

- *Sensitivity Analysis of the Wetland Site Index for the Years 2008 and 2030*

The sensitivity analysis for the Wetland Site Index calculates the direct and indexed effects that the layers from component five, Chapter Three (Dev Ref, BIO, Reduced FC) have on the WSI. The layer with the highest direct effect on the 2008 WSI, when considering mean patch size, is the Dev Ref layer (Table 4.20). This layer (Layer 5.1) has a direct effect of 1.40 and an indexed effect of 1.05. The BIO (Layer 5.2) and the Reduce FC (Layer 5.3) layers have the same direct (1.30) and indexed effects (1.00). The Dev Ref (Layer 5.1) has a magnitude of 1.08 times the influence on the WSI than both the BIO and Reduce FC layers (Figure 4.18). The rank of the layers on the influence to the WSI changes when looking at the total area of high priority pixels. At this landscape scale, the BIO layer has the highest direct and indexed effects (2.07 and 2.65, respectively) and the Reduced FC (Layer 5.3) has the lowest direct and indexed effects (0.16 and 1.00, respectively) (Table 4.21). The direct effect of the BIO layer increases by a magnitude of 12.94 times in comparison to the direct effect of the Reduced FC layer (Figure 4.19).

The direct and indexed effects, based on the mean patch area of high potential mitigation sites, have a reversed ranking when comparing the years 2008 and 2030 (Table 4.22). In 2030, the most influential layer is the Reduced FC layer (Layer 5.3), which has a direct effect of 1.79. The least influential layer is the WQQI (Layer 5.1), which has a direct effect of 1.07. The Reduced FC layer has 1.67 times the influence on the WSI than the WQQI layer. The direct and the indexed effects are also different for the years 2008 and 2030 when basing the calculations on the total area with a high potential for wetland restoration. The layer with the greatest direct and indexed effect on the WSI is the BIO layer, which has a direct effect of 2.43 and an indexed effect of 2.98 (Table 4.23). This layer also has an increase in its influence on the WSI of 12.79 times that of the Reduced FC (Layer 5.3) (Figure 4.19).

For both 2008 and 2030, the ranking order of the influence of each layer on the WSI changes based on the landscape scale. For the mean patch area with high potential for restoration, the Dev Ref (Layer 5.1) has the highest direct effect while the BIO and Reduced FC layers are tied with the second greatest influence on the WSI. When considering the total area of sites with a high potential for restorations, the rank of potential influence changes so that the BIO layer has the most influence and the Dev Ref (Layer 5.1) has the next highest influence. The direct and indexed effects for the mean patch area of the layers on the WSI are the same for the years 2008 and 2030. When considering the total area of high potential wetlands for 2008 and 2030, the influence of the Dev Ref layer is much less in 2030 than in 2008 and the influence of BIO decreases slightly from the year 2008 to 2030 (Figure 4.19).

- *Sensitivity Analysis of the Change in Potential Wetland Restoration Site Index*

The sensitivity analysis for the Change in Potential Wetland Restoration Sites Index calculates the direct and indexed effect that each layer has on the final index. The final output of the analysis are two tables, where the first ranks the influence of each layer based on the mean patch size of high priority areas, and the second ranks the influence of each layer based on the total area of high priority wetland areas. The layers with the most influence represent the functions that have the highest likelihood of improving in providing wetland functions between 2008 and 2030.

For the mean patch size of high potential areas that will most likely improve in wetland functions by 2030, the Reduced FC (Layer 4.3) has the highest direct effect (1.44), and the Shoreline Stability layer (Layer 4.4) has the lowest direct effect (0.29) (Table 4.24). The influence of the layer with the greatest effect on the CPWRS, the Reduced FC layer, has 1.13

times more influence on the index than the next ranked layer, WQQI (Layer 4.1), and is 4.97 times more influential than the Shoreline Stability layer (Layer 5.4) (Figure 4.20).

The rankings of the layers are very different when considering the total area of pixels with a high potential for wetland mitigation (Table 4.25). The layer with the highest direct and indexed effect is still the Reduced FC layer (Layer 5.3), but the layer with the second direct and indexed effects is the Shoreline Stability layer (Layer 5.4). The Reduced FC layer has a direct effect of 3.86 and an indexed effect of 4.70, while the Shoreline Stability layer has a direct effect of .07 and an indexed effect of 1.03. Even though the ranking for the WQQI, BIO and Shoreline Stability layers changed when looking at a different landscape scale, the actual direct effects for these ranges only range from 0.03 to 0.07, so their influence on the CPWRS Index is similar (Figure 4.21). The magnitude of the influence of the Reduced FC layer increases 128.67 times in comparison with the WQQI layer, 96.5 times in comparison with the BIO layer, and 55.14 % in comparison with the Shoreline Stability layer.

- *Sensitivity Analysis of the Change in Wetland Site Index*

The sensitivity analysis for the Change in Wetland Site Index calculates the direct and indexed effects that the layers from component six, Chapter Three (Dev Ref, BIO, Reduced FC and Shoreline Stability) have on the CWSI. When looking at the mean patch size of high potential areas for wetland mitigation, the ranking and values of the direct effect of the layers on the CWSI from largest to smallest are given as follows: 1) Reduced FC (Layer 6.3) with a value of 2.79, 2) BIO (Layer 6.2) with a value of 0.62, 3) Shoreline Stability (Layer 6.4) with a value of 0.54, and 4) Dev Ref (Layer 6.1) with a value of 0.05 (Table 4.26). The Reduced FC layer has a magnitude of 55.8 times the influence on the CWSI than the Dev Ref layer (Figure 4.22).

In the analysis of the total area of high value potential pixels, the order of importance of the direct effect changed. The Reduced FC shoreline stability layer (Layer 6.4) has the greatest direct effect (2.42), the Reduced FC layer is next with 1.43 and the BIO layer and the Dev Ref layer have the least affect on the CWSI, with values of 0.12 and 0.03, respectively (Table 4.27). The shoreline stability layer also has 80.6 times the influence on the final results of the CWSI than the Dev Ref (Layer 6.1) (Figure 4.23).

Table 4.1: Acreage and percent area of wetlands lost, wetlands gained and land use changes as predicted by the Risk Mask from Chapter Three, component three when comparing the landcover for the years 2008 and 2030.

Change in Land Use from 2008 to 2030	Area (ha)	Percentage Area
Wetlands Lost	262358.10	0.03
Wetlands Gained	255510.00	0.03
Land Use Changes	402497.98	0.04
Land Use Stays the Same	8502312.45	0.90
Total Area	9422678.53	1.00

Table 4.2 Change in wetland and beach area from 2008 and 2030 as predicted using the Sea Level Affecting Marshes Model (SLAMM) from Chapter Three, component one.

Land Use Classification	Area in 2008 (ha)	Area in 2030 (ha)	Net Change in Area (ha)
Forested Wetland	1923948.0	1896973.2	-26974.8
Saltwater Wetland	1415390.5	1393009.2	-22381.3
Freshwater Wetland	134618.4	134614.8	-3.6
Beach/mud/dunes	66049.2	1000051.2	934002.0

Table 4.3: The division of area lost, gained or converted for forested wetlands, saltwater wetlands, and freshwater wetlands from 2008 to 2030. The files used to calculate these changes are the projected 2008 and 2030 wetland migration maps created using the Sea-Level Affecting Marshes Model (SLAMM) in Chapter Three, component one.

Type of Land Use Change	Land Use Converted From	Land Use Converted To	Area (ha)
Wetlands Lost:	Forested Wetlands	beach/mud/dunes	7.2
	Forested Wetlands	water	3.6
	Saltwater Wetlands	beach/mud/dunes	59148
	Saltwater Wetlands	water	38340
	Freshwater Wetlands	beach/mud/dunes	0
	Freshwater Wetlands	water	0
Total Wetland Area Lost			97498.8
Wetlands Gained:	upland	Forested Wetlands	43225.2
	developed land	Forested Wetlands	2095.2
	upland	Saltwater Wetlands	583.2
	developed land	Saltwater Wetlands	2235.6
	upland	Freshwater Wetlands	0
	developed land	Freshwater Wetlands	0
Total Wetland Area Gained			48139.2
Wetlands Converted:	Forested Wetlands	Saltwater Wetlands	72284.4
	Forested Wetlands	Freshwater Wetlands	0
	Saltwater Wetlands	Forested Wetlands	0
	Saltwater Wetlands	Freshwater Wetlands	0
	Freshwater Wetlands	Forested Wetlands	0
	Freshwater Wetlands	Saltwater Wetlands	3.6
Total Wetland Area Converted			72288

Table 4.4: Increase of developed area from 2008 to 2030 predicted using the SLEUTH model in Chapter Three, component one. Also shown is the percent composition of the four development intensity land cover classes for each year.

Development Type	Area 2008 (ha)	% Area 2008	Area 2030 (ha)	% Area 2030	Increase in Area (ha)
Open Space	396270.9	51.2	471252.6	51.5	74981.7
Low Intensity	211599.0	27.3	256755.6	28.1	45156.6
Medium Intensity	89776.8	11.6	93282.3	10.2	3505.5
High Intensity	76617.0	9.9	93142.8	10.2	16525.8

Table 4.5: Overall change in land use area derived from the comparison of areas for the years 2008 and 2030. The 2008 land use file is the 2008 GLUT and the 2030 land use file if the future land use map created in component one of Chapter Three.* - 'upland' includes agriculture, forested, golf courses, mines, sparse/barren and utility swath land use types.

Land Use Classification	Area 2008 (ha)	Area 2030 (ha)	Change in Area between 2008 and 2030 (ha)
Beach/mud/dunes	108369.0	187818.3	79449.3
Open Water	1833903.9	1997186.4	163282.6
Urban	695331.9	914433.3	219101.4
Forested Wetlands	1953217.8	2021138.0	67920.3
Saltwater Wetlands	1322304.3	1267890.2	-54414.0
Freshwater Wetlands	168769.8	138765.6	-30004.2
Upland*	3336777.0	2891441.7	-445335.3
Total Land Use	9418673.6	9418673.6	0.0

Table 4.6: Total area of forested wetlands that are created through the conversion of a landcover type to forested wetlands as well as the loss of forested wetlands through the conversion of the forested wetlands to another landcover type from 2008 to 2030. * - ‘upland’ includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

Type Land Use Change	Land Use Category	Change Area (ha)
Forested Wetlands Lost by Conversion to:	beach/mud/dune	-1404.0
	open water	-10222.2
	developed	-27433.8
	saltwater wetlands	-89744.4
	freshwater wetlands	-49865.4
	upland*	-61.2
Total Forested Wetlands Lost:		-178731.0
Forested Wetlands Gained by Conversion from:	freshwater wetlands	16418.7
	saltwater wetlands	10142.1
	upland*	220090.5
Total Forested Wetlands Gained:		246651.3
Net Change Forested Wetlands from 2008 to 2030:		67920.3

Table 4.7: Total area of saltwater wetlands that are created through the conversion of forested wetlands, freshwater wetlands, and upland* to saltwater wetlands as well as the total saltwater wetlands lost through their conversion to beach/mud/dunes, open water, development, forested wetlands, freshwater wetlands, and upland* from 2008 to 2030. * - 'upland' includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

Type Land Use Change	Land Use Category	Change Area (ha)
Saltwater Wetlands Lost by Conversion to:	beach/mud/dune	-61067.7
	open water	-146992.5
	developed	-3019.5
	forested wetlands	-10142.1
	freshwater wetlands	-367.2
	upland*	-51.3
Total Saltwater Wetlands Lost:		-221640.3
Saltwater Wetlands Gained by Conversion from:	forested wetlands	89744.4
	freshwater wetlands	55414.8
	upland*	22067.1
Total Saltwater Wetlands Gained:		167226.3
Net Change Saltwater Wetlands from 2008 to 2030:		-54414.0

Table 4.8: Total area of freshwater wetlands that are created through their conversion from forested wetlands, saltwater wetlands, and upland* as well as the total freshwater wetlands lost through their conversion to beach/mud/dunes, open water, development, forested wetlands, freshwater wetlands, and upland* from 2008 to 2030. * - 'upland' includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

Type of Land Use Change	Land Use Category	Change Area (ha)
<u>Freshwater Wetlands Lost by Conversion to:</u>	beach/mud/dune	-2565.9
	open water	-12457.8
	developed	-2732.4
	forested wetlands	-16418.7
	saltwater wetlands	-55414.8
	upland*	-7.2
Total Freshwater Wetlands Lost:		-89596.8
<u>Freshwater Wetlands Gained by Conversion from:</u>	forested wetlands	49865.4
	saltwater wetlands	367.2
	upland*	9360.0
Total Freshwater Wetlands Gained:		59592.6
Net Change Saltwater Wetlands from 2008 to 2030:		-30004.2

Table 4.9: The area (hectares) and percentage of land use pixels with high (value 7, 8 or 9), medium (4, 5, or 6) or low (1, 2, or 3) potential for compensatory wetland mitigation for the Potential Wetland Restoration Site (PWRS) Index for the years 2008 and 2030.

Potential for Mitigation	Area in 2008 (ha)	Percent Area 2008	Area in 2030 (ha)	Percent Area 2030	Difference 2008 to 2030 (ha)
High Potential	1354287.62	0.33	1439308.80	0.36	85021.18
Medium Potential	1291298.43	0.31	1099987.20	0.28	-191311.23
Low Potential	1473235.20	0.36	1422306.05	0.36	-50929.15

Table 4.10: The area (hectares) and percentage of land use pixels with high (value 7, 8 or 9), medium (4, 5, or 6) or low (1, 2, or 3) potential for compensatory wetland mitigation for the Wetland Site Index (WSI) for the years 2008 and 2030.

Potential for Mitigation	Area in 2008 (ha)	Percent Area 2008	Area in 2030 (ha)	Percent Area 2030	Difference 2008 to 2030 (ha)
High Potential	507729.60	0.15	524948.42	0.12	17218.816
Medium Potential	1856934.02	0.54	2668614.40	0.60	811680.384
Low Potential	1076522.37	0.31	1229824.77	0.28	153302.4

Table 4.11: The area (hectares) and percentage of land use pixels with high (value 7, 8 or 9), medium (4, 5, or 6) or low (1, 2, or 3) potential for improving wetland functions between the year 2008 and 2030 for the Change in Potential Wetland Restoration Site Index (CPWRS).

Potential for Mitigation	Potential Area between 2008 and 2030 (ha)	Percent Area between 2008 and 2030
High Potential	1905894.02	0.44
Medium Potential	2068387.20	0.47
Low Potential	406281.60	0.09

Table 4.12: The area (hectares) and percent of land use pixels with high (value 7, 8 or 9), medium (4, 5, or 6) or low (1, 2, or 3) potential for improving wetland functions between the year 2008 and 2030 for the Change in Wetland Site Index (CWSI).

Potential for Mitigation	Potential Area between 2008 and 2030 (ha)	Percent Area between 2008 and 2030
High Potential	1085644.80	0.32
Medium Potential	1888855.17	0.55
Low Potential	459918.02	0.13

Table 4.13: Trend lines for the total area of high, medium, and low potential for restoration sites shown in Figure 4.13 and the percentage of area shown in Figure 4.14.

Measure of Potential	Risk Assessment Index	Trendline	R-Square
Percentage of Area:	PWRS 2008	$y = 0.0297x^2 – 0.1045x +0.4036$	1
	PWRS 2030	$y = 0.0835x^2 – 0.3363x + 0.616$	1
	WSI 2008	$y = -0.3094x^2 + 1.3204x – 0.8634$	1
	WSI 2030	$y = -0.4049x^2 + 1.6995x – 1.1758$	1
	CPWRS	$y = -0.2083x^2 +0.6619x – 0.0185$	1
	CWSI	$y = -0.325x^2 + 1.2088x – 0.5677$	1
Total Area:	PWRS 2008	$y = 122463x^2 - 430378x + 2E+06$	1
	PWRS 2030	$y = 330820x^2 - 1E+06x + 2E+06$	1
	WSI 2008	$y = -1E+06x^2 + 5E+06x - 3E+06$	1
	WSI 2030	$y = -2E+06x^2 + 8E+06x - 5E+06$	1
	CPWRS	$y = -912299x^2 + 3E+06x – 81198$	1
	CWSI	$y = -1E+06x^2 + 4E+06x - 2E+06$	1

Table 4.14: Range of the percent difference between the 2008 GLUT and the 2008 estimated wetland position file created using SLAMM in Chapter Three, component one per 12 Digit Hydrologic Unit Code. The lowest measure of deviance corresponds with the value closest to zero, and the largest measure of deviance of the 2008 GLUT from the 2008 SLAMM land use file is the highest value. * - 'upland' includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

Land Use Type	Lowest Value	Highest Value
Beach/mud/dune	0.0242	8.8590
Water	0.0486	8.8313
Developed Land	0.0238	3.6696
Forested Wetland	0.0150	4.1182
Saltwater Wetland	0.0022	9.6953
Freshwater Wetland	0.0361	7.3405
Upland*	0.0900	8.7480

Table 4.15: Analysis of the percentage of the length of the GLUT created Jekyll Island shoreline within a specified buffer of the LIDAR, elevation or aerial photo created Jekyll Island shoreline for the year 1974 (Jackson 2010).

Total Length of GLUT shoreline: 29008.06 m

Buffer (m)	Length within Buffer (m)	Percentage within Buffer
60	25544.78	88.06
120	2597.71	8.96
180	680.40	3.25
240	185.18	0.64

Table 4.16: Sensitivity of the PWRS index to the individual layers for the year 2008. All area measurements are hectares of the mean patch area of high priority (value 7, 8, or 9) pixels in the PWRS.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
WQQI (Layer 2.1)	45.26	78.22	123.48	1.64	1.73
BIO (Layer 2.2)	45.26	72.67	117.93	1.56	1.61
Reduce FC (Layer 2.3)	45.26	30.14	75.40	1.00	0.67

Table 4.17: Sensitivity of the PWRS index to the individual layers for the year 2008. All area measurements are hectares of the total area of high priority (value 7, 8, or 9) pixels in the PWRS.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
WQQI (Layer 2.1)	1057190.40	1868882.43	2926072.83	1.33	1.77
Reduce FC (Layer 2.3)	1057190.40	1224774.14	2281964.54	1.04	1.16
BIO (Layer 2.2)	1057190.40	1135105.02	2192295.42	1.00	1.07

Figure 4.18: Sensitivity of the PWRS index to the individual layers for the year 2030. All area measurements are hectares of the mean patch area of high priority (value 7, 8, or 9) pixels in the PWRS.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
WQQI (Layer 2.1)	42.91	75.73	118.64	1.72	1.76
BIO (Layer 2.2)	42.91	69.81	112.72	1.63	1.63
Reduce FC (Layer 2.3)	42.91	26.12	69.03	1.00	0.61

Table 4.19: Sensitivity of the PWRS index to the individual layers for the year 2030. All area measurements are hectares of the total area of high priority (value 7, 8, or 9) pixels in the PWRS.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
WQQI (Layer 2.1)	1068621.31	1903068.90	2971690.22	1.33	1.78
BIO (Layer 2.2)	1068621.31	1208023.04	2276644.35	1.02	1.13
Reduce FC (Layer 2.3)	1068621.31	1163394.05	2232015.36	1.00	1.09

Table 4.20: Sensitivity of the WSI to the individual layers for the year 2008. All area measurements are hectares of the mean patch area of high priority (value 7, 8, or 9) pixels in the WSI.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Dev Ref (Layer 5.1)	13.73	19.29	33.02	1.05	1.40
BIO (Layer 5.2)	13.73	17.83	31.56	1.00	1.30
Reduce FC (Layer 5.3)	13.73	17.80	31.53	1.00	1.30

Table 4.21: Sensitivity of the WSI to the individual layers for the year 2008. All area measurements are hectares of the total area of high priority (value 7, 8, or 9) pixels in the WSI.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
BIO (Layer 5.2)	1943029.76	4030008.83	5973038.59	2.65	2.07
Dev Ref (Layer 5.1)	1943029.76	3431210.50	5374240.26	2.38	1.77
Reduce FC (Layer 5.3)	1943029.76	310899.61	2253929.37	1.00	0.16

Table 4.22: Sensitivity of the WSI to the individual layers for the year 2030. All area measurements are hectares of the mean patch area of high priority (value 7, 8, or 9) pixels in the WSI.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Reduce FC (Layer 5.3)	12.51	22.42	34.92	1.35	1.79
BIO (Layer 5.2)	12.51	14.23	26.74	1.03	1.14
WQQI (Layer 5.1)	12.51	13.39	25.89	1.00	1.07

Table 4.23: Sensitivity of the WSI to the individual layers for the year 2030. All area measurements are hectares of the total area of high priority (value 7, 8, or 9) pixels in the WSI.

Layers	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
BIO (Layer 5.2)	1661139.84	4029998.96	5691138.80	2.89	2.43
Dev Ref (Layer 5.1)	1661139.84	2303650.94	3964790.78	2.01	1.39
Reduce FC (Layer 5.3)	1661139.84	310899.58	1972039.42	1.00	0.19

Table 4.24: Sensitivity of the CPWRS index to its individual layers. All area measurements are hectares of the mean patch area of high priority (value 7, 8, or 9) pixels in the CPWRS.

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Reduce FC (Layer 4.3)	5.81	8.38	14.18	1.89	1.44
WQQI (Layer 4.1)	5.81	7.44	13.24	1.76	1.28
BIO (Layer 4.2)	5.81	5.72	11.52	1.54	0.98
ShoreStable (Layer 4.4)	5.81	1.70	7.50	1.00	0.29

Table 4.25: Sensitivity of the CPWRS index to its individual layers. All area measurements are hectares of the total area of high priority (value 7, 8, or 9) pixels in the CPWRS.

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Reduce FC (Layer 4.3)	950588.10	3666841.41	4617429.50	4.70	3.86
ShoreStable (Layer 4.4)	950588.10	63104.38	1013692.48	1.03	0.07
BIO (Layer 4.2)	950588.10	40089.60	990677.70	1.01	0.04
WQQI (Layer 4.1)	950588.10	32317.18	982905.28	1.00	0.03

Table 4.26: Sensitivity of the CWSI to its individual layers. All area measurements are hectares of the mean patch area of high priority (value 7, 8, or 9) pixels in the CWSI.

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
Reduce FC (Layer 6.3)	20.03	55.84	75.87	3.59	2.79
BIO (Layer 6.2)	20.03	12.32	32.35	1.53	0.62
ShoreStable (Layer 6.4)	20.03	10.84	30.87	1.46	0.54
Dev Ref (Layer 6.1)	20.03	1.10	21.13	1.00	0.05

Table 4.27: Sensitivity of the CWSI to its individual layers. All area measurements are hectares of the total area of high priority (value 7, 8, or 9) pixels in the CWSI.

Layer	Standard Output	Change	Weighted Output	Indexed Effect	Direct Effect
ShoreStable (Layer 6.4)	521020.80	1262336.38	1783357.18	3.34	2.42
Reduce FC (Layer 6.3)	521020.80	745336.83	1266357.63	2.37	1.43
BIO (Layer 6.2)	521020.80	63230.40	584251.20	1.09	0.12
Dev Ref (Layer 6.1)	521020.80	13179.62	534200.42	1.00	0.03

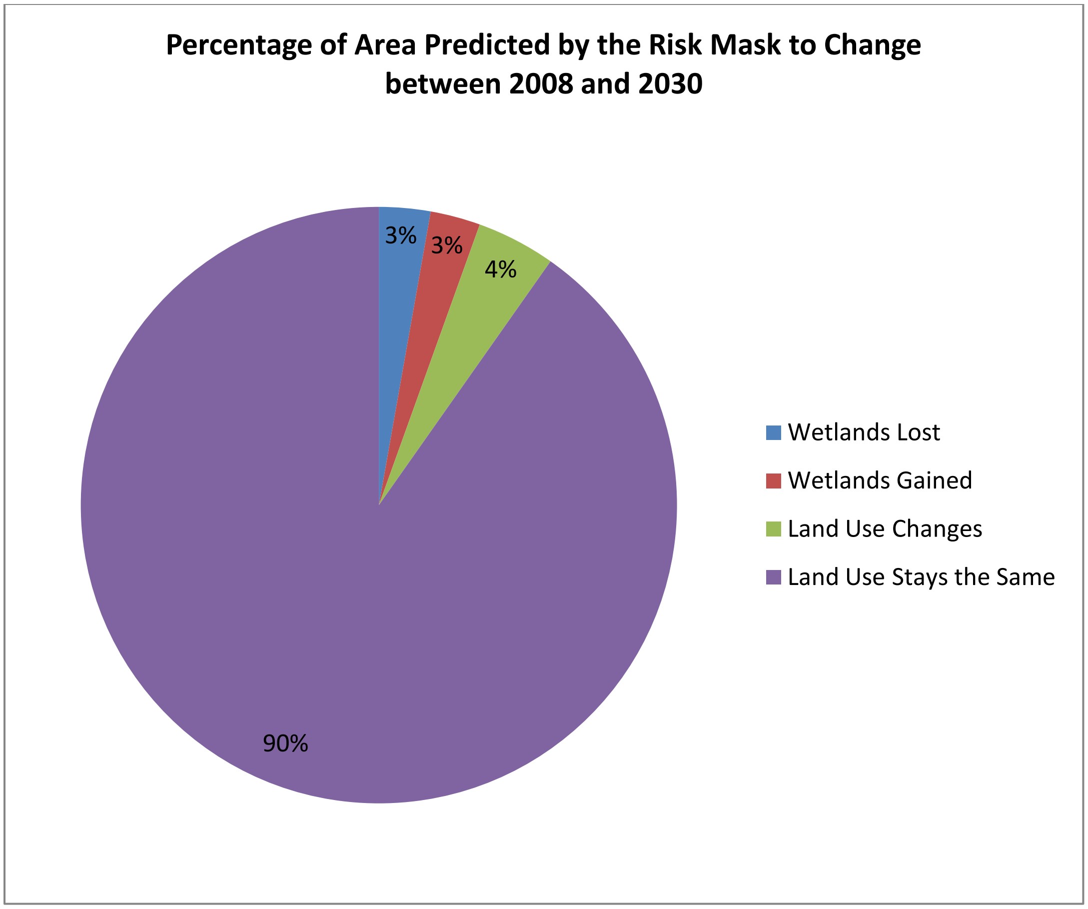


Figure 4.1: The percentage of area that is predicted to change between the years 2008 and 2030 using the Risk Mask created in Chapter Three, component three.

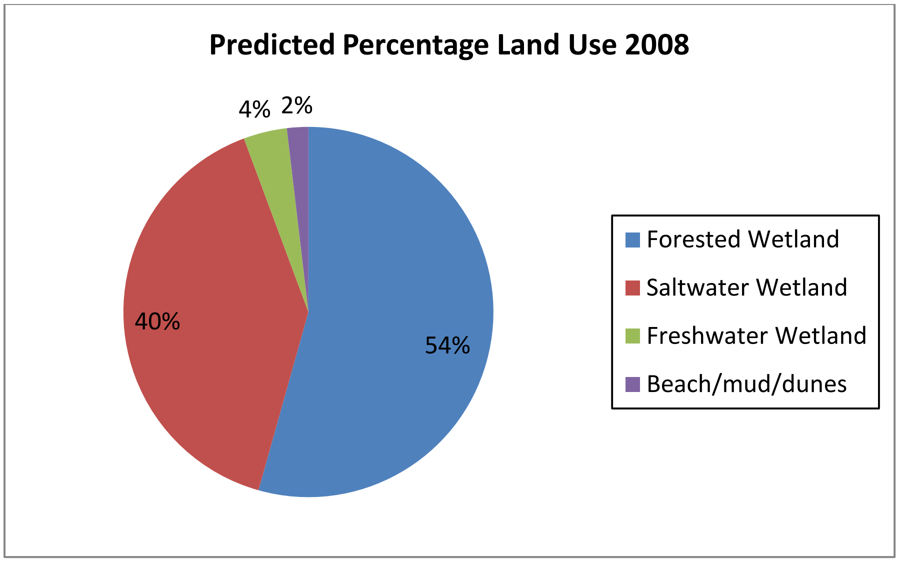


Figure 4.2: Diagram showing the percentage of land use area in 2008 as predicted using the Sea-Level Rise Affecting Marshes (SLAMM) model in Chapter Three, component one.

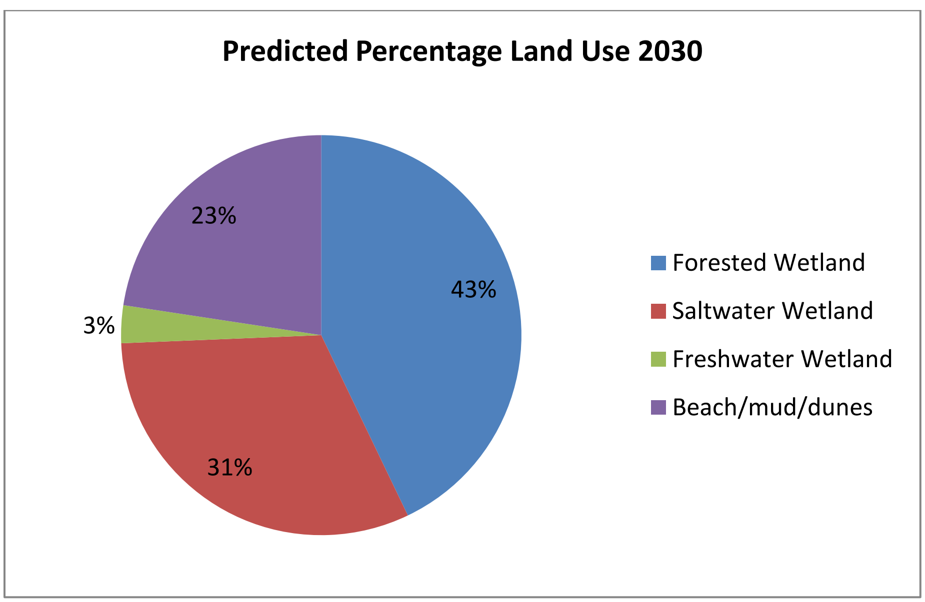


Figure 4.3: Diagram showing the percentage of land use area in 2030 as predicted using the Sea-Level Rise Affecting Marshes (SLAMM) model in Chapter Three, component one.

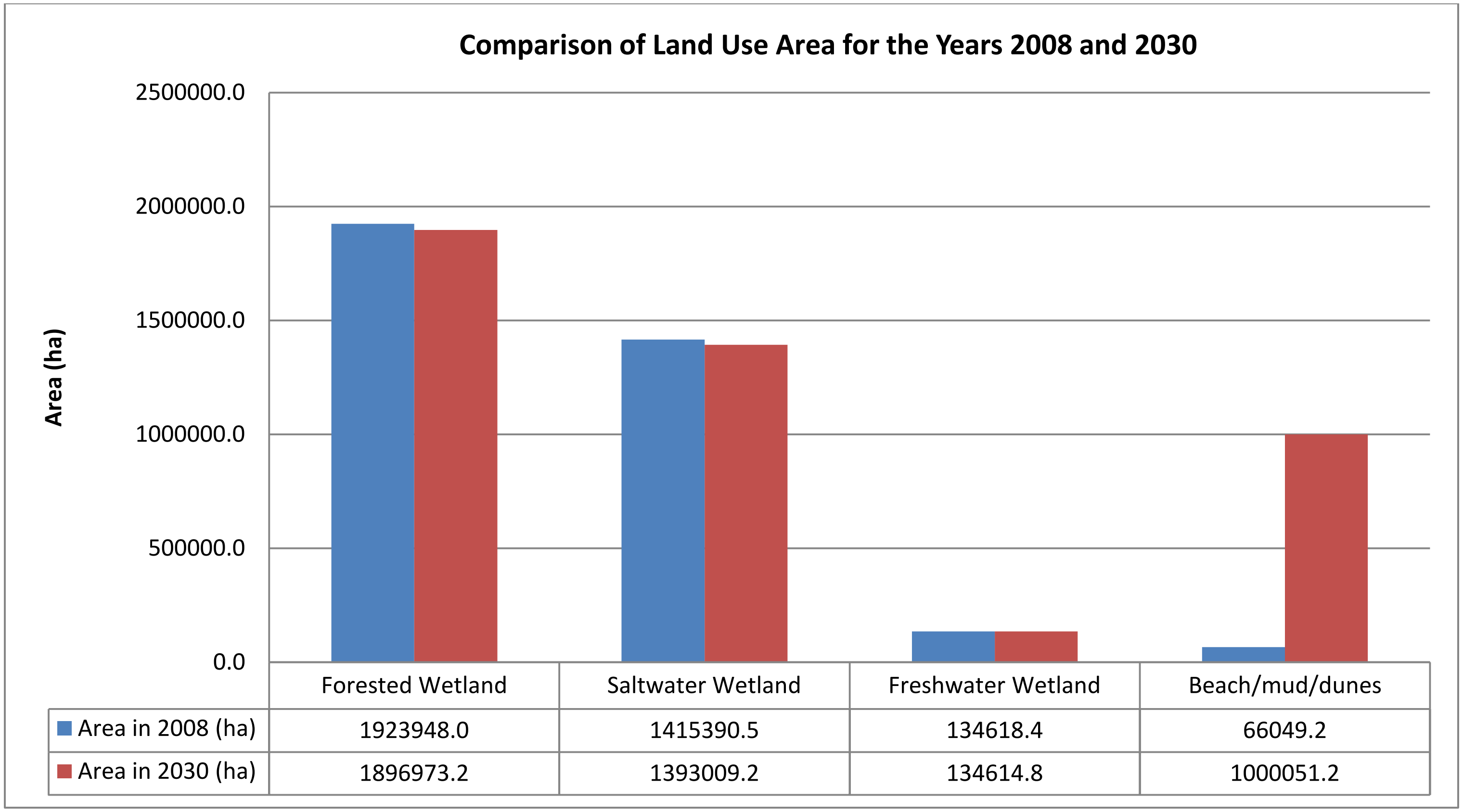


Figure 4.4: Graph comparing the total area of forested wetlands, saltwater wetlands, freshwater wetlands, and beach/mud/dune areas for the years 2008 and 2030 from the files created using the Sea-Level Rise Affecting Marshes Model (SLAMM).

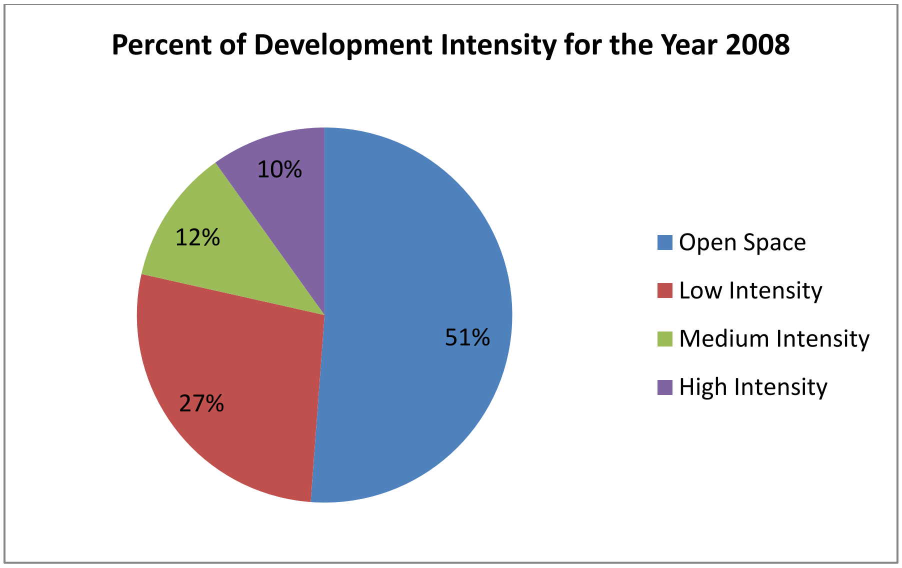


Figure 4.5: Percentage of land use development intensity (open space, low intensity, medium intensity and high intensity) for the year 2008 from the 2008 Georgia Land Use Trends (GLUT) file.

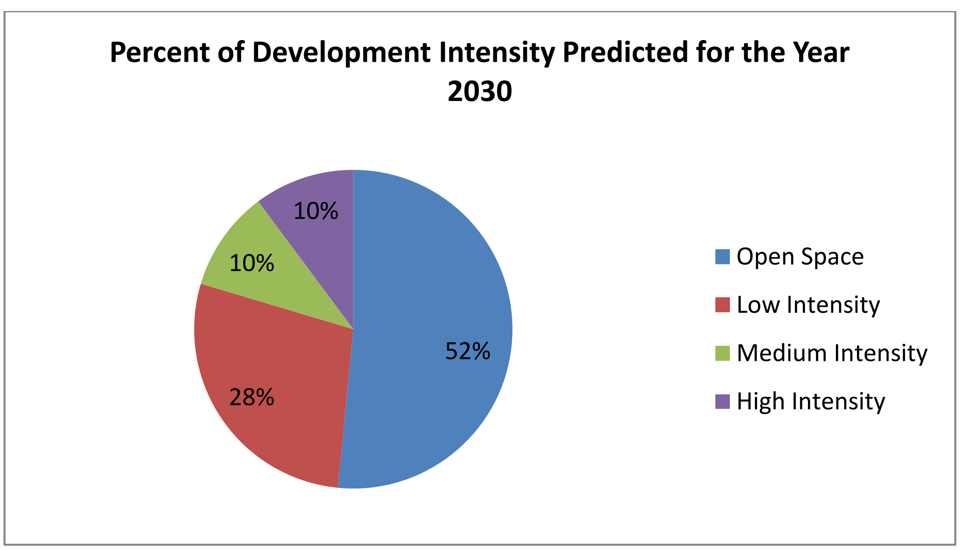


Figure 4.6: Percentage of land use development intensity (open space, low intensity, medium intensity and high intensity) for the projected developed areas in 2030 that is determined using the program SLEUTH in Chapter Three, component one.

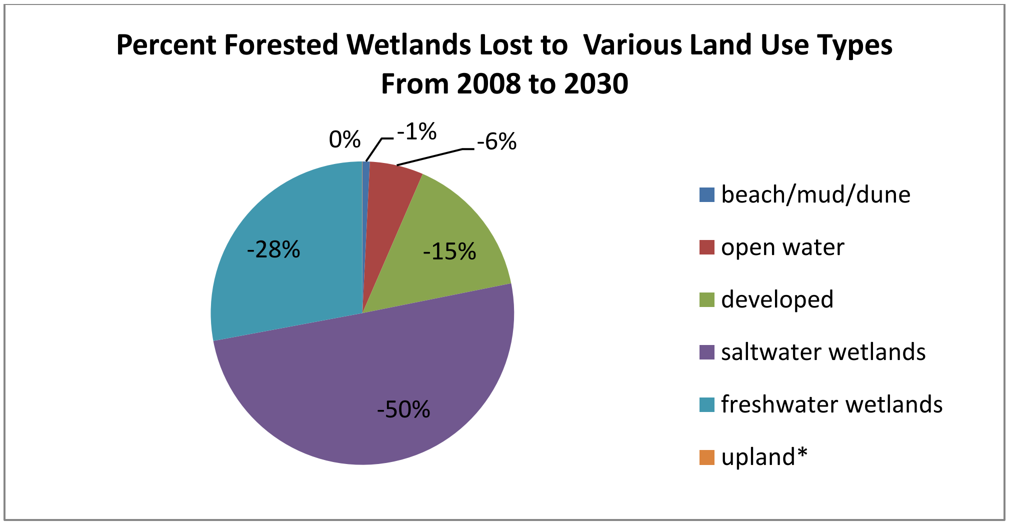


Figure 4.7: Projected percentage of land use area that is converted from forested wetlands to another land use type from 2008 to 2030. * - 'upland' includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

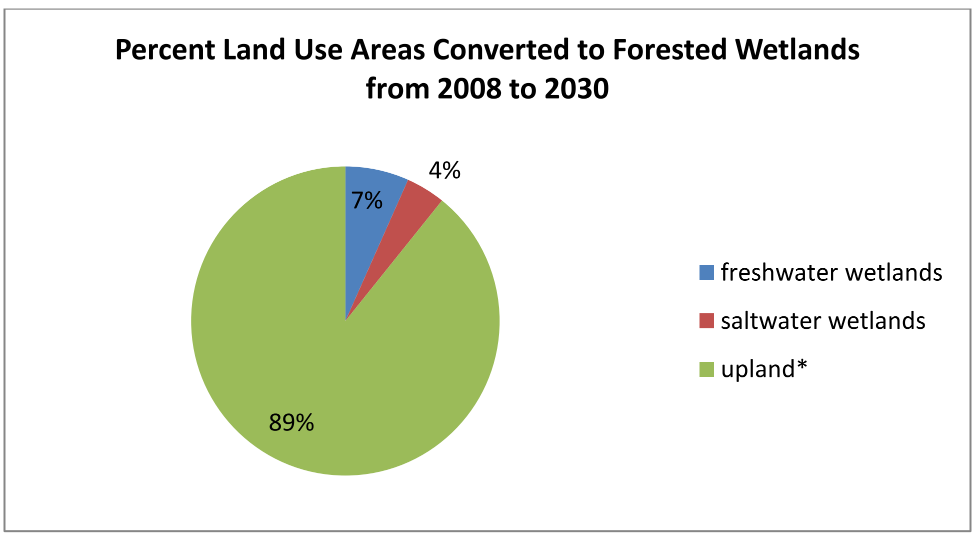


Figure 4.8: Projected percent of land use that is converted from to forested wetlands from the years 2008 and 2030. * - 'upland' includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

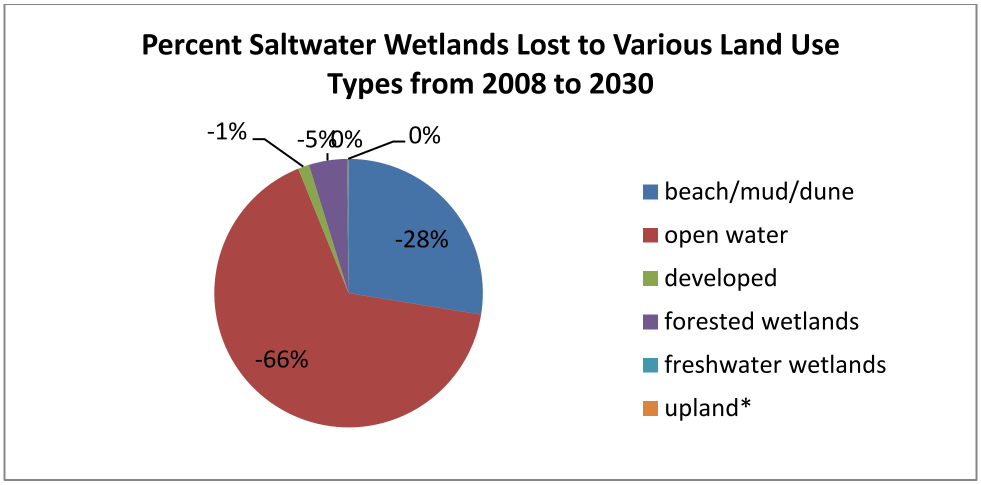


Figure 4.9: Projected percent area of saltwater wetlands that are lost from the years 2008 to 2030. * - ‘upland’ includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

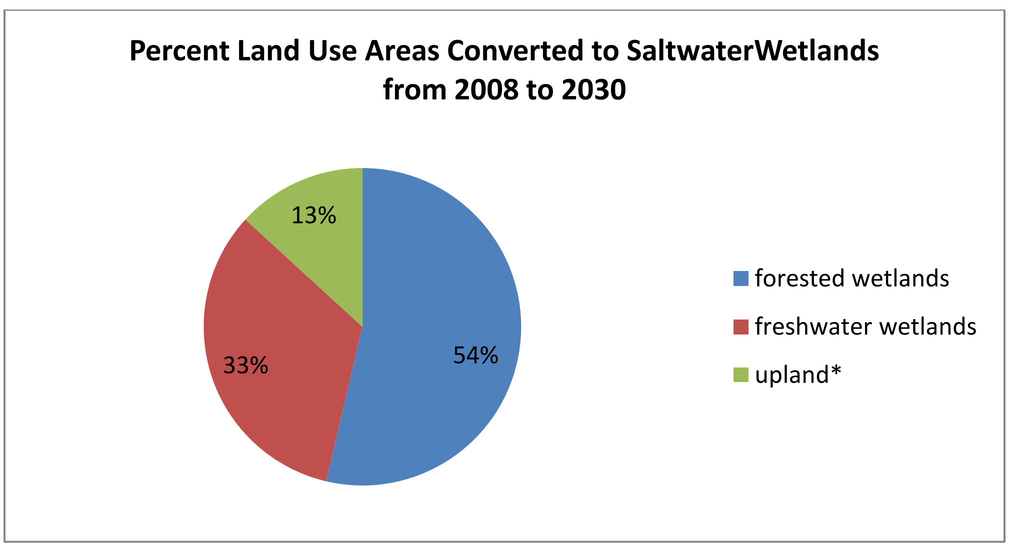


Figure 4.10: Projected percent of land use that is converted from to saltwater wetlands from the years 2008 and 2030. * - ‘upland’ includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

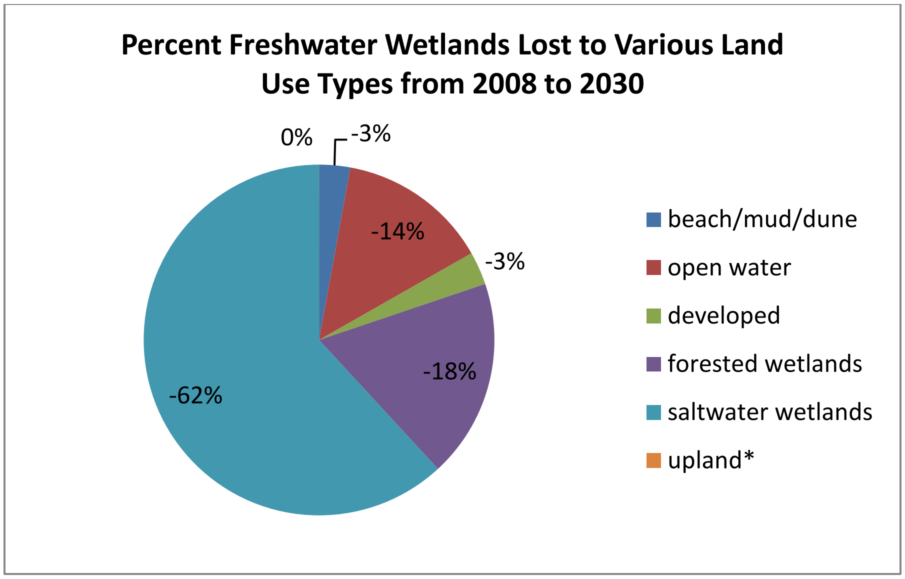


Figure 4.11: Projected percent area of freshwater wetlands that are lost from the years 2008 to 2030. * - ‘upland’ includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.

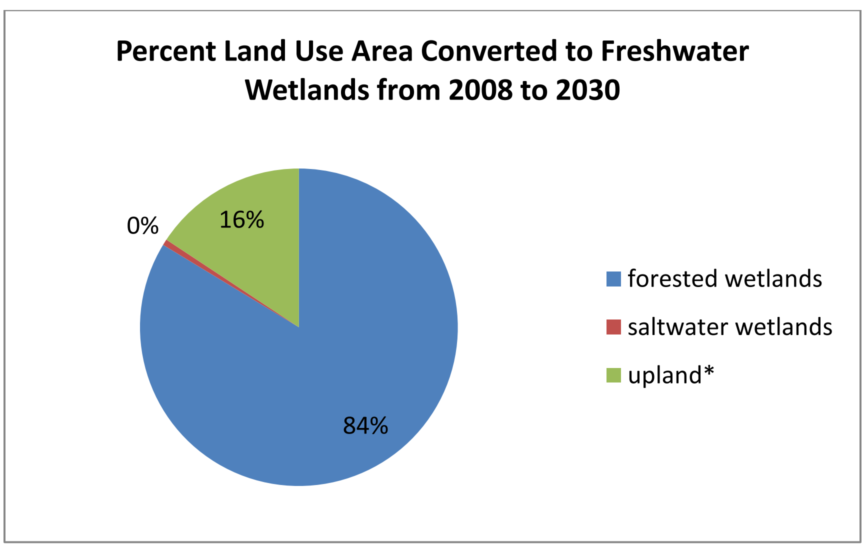
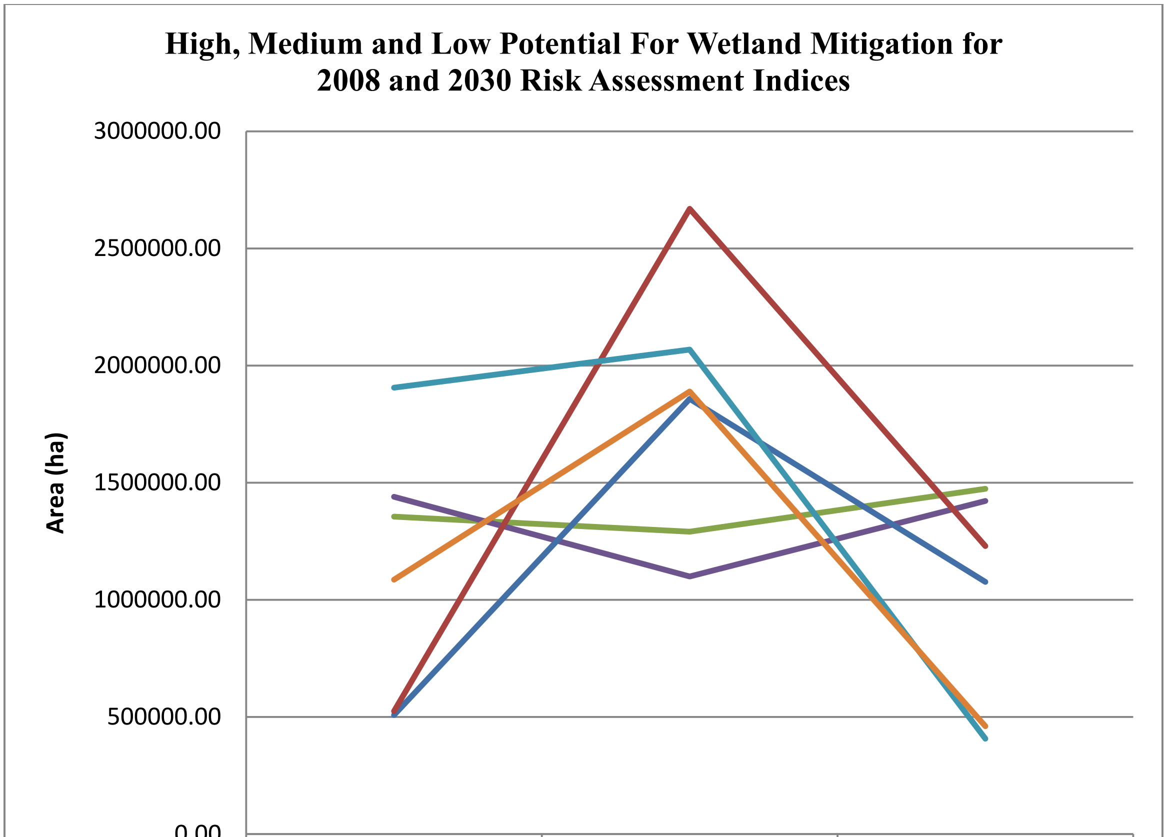
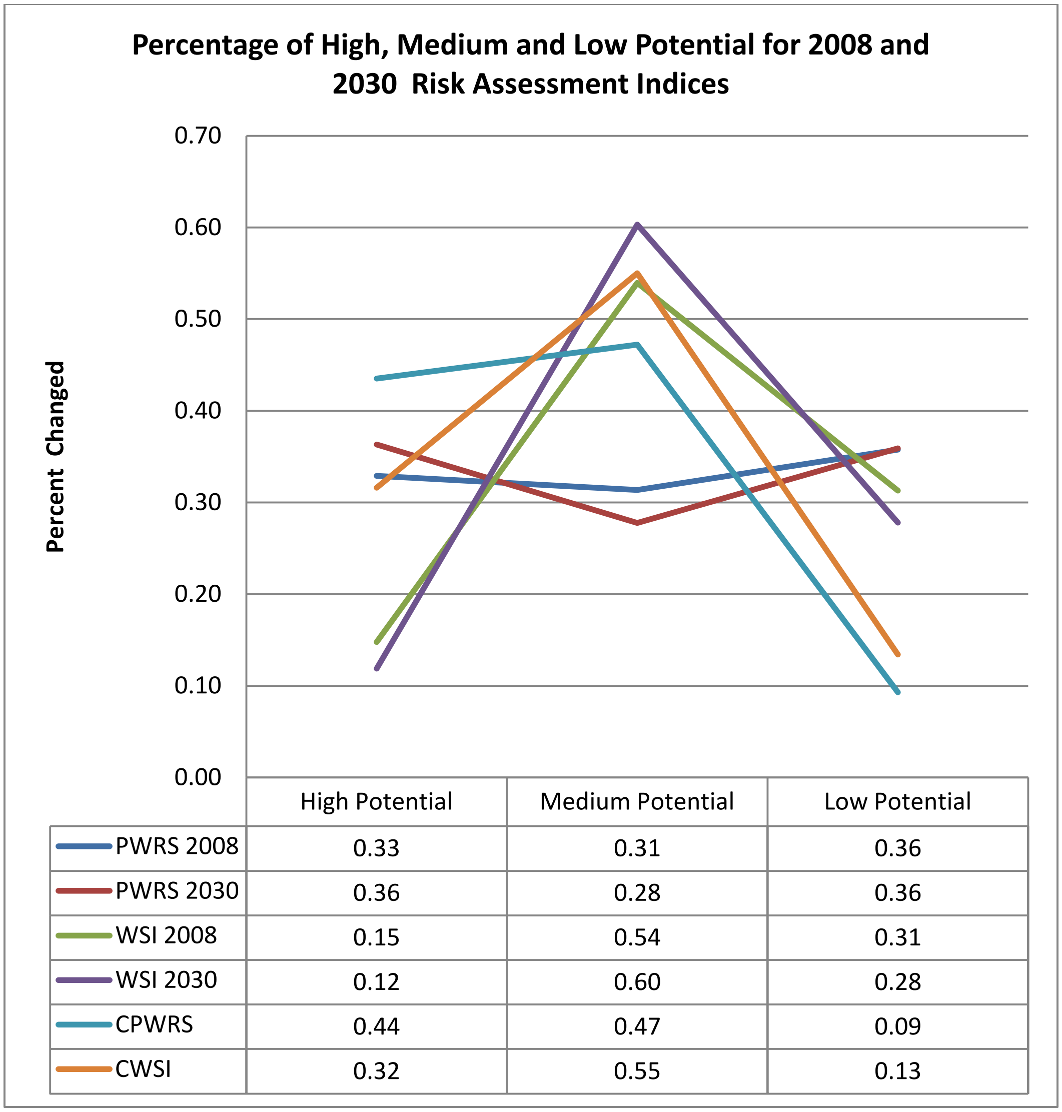


Figure 4.12: Projected percent of land use that is converted to freshwater wetlands from the years 2008 and 2030. * - ‘upland’ includes agriculture, forested, golf courses, mines, sparse/barren and utility swaths landcover types.



	High Potential	Medium Potential	Low Potential
PWRS 2008	1354287.62	1291298.43	1473235.20
PWRS 2030	1439308.80	1099987.20	1422306.05
WSI 2008	507729.60	1856934.02	1076522.37
WSI 2030	524948.42	2668614.40	1229824.77
CPWRS	1905894.02	2068387.20	406281.60
CWSI	1085644.80	1888855.17	459918.02

Figure 4.13: Projected Change in the distribution of acreage between high, medium and low potential for wetland indices (PWRS, WSI, CPWRS, CWSI) from 2008 to 2030.



	High Potential	Medium Potential	Low Potential
PWRS 2008	0.33	0.31	0.36
PWRS 2030	0.36	0.28	0.36
WSI 2008	0.15	0.54	0.31
WSI 2030	0.12	0.60	0.28
CPWRS	0.44	0.47	0.09
CWSI	0.32	0.55	0.13

Figure 4.14: Projected Change in the percentage of acreage that are identified as high, medium and low potential for wetland indices (PWRS, WSI, CPWRS and CWSI) from 2008 to 2030.

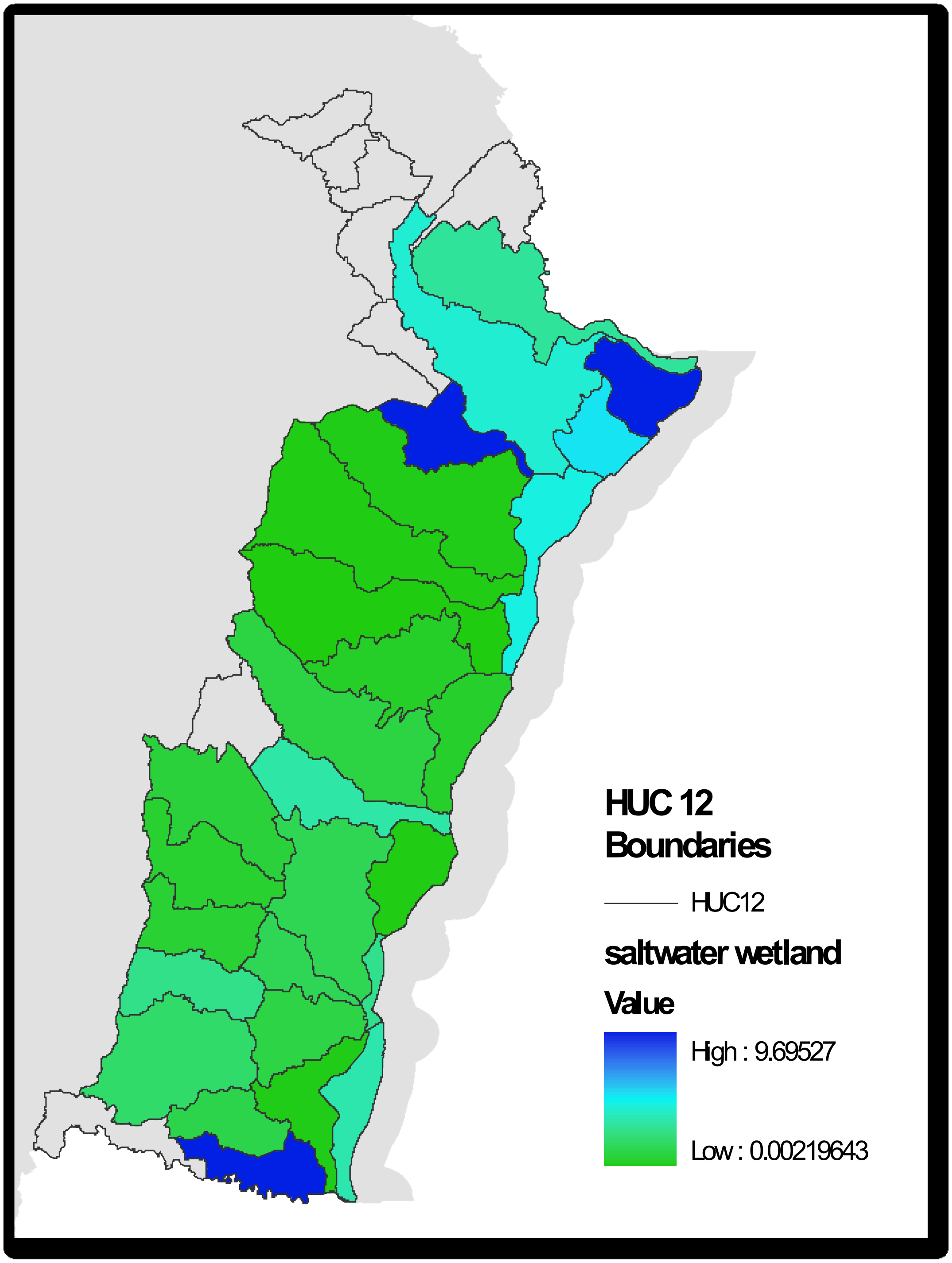


Figure 4.15 : SLAMM Descrepancy Analysis- the percent difference of saltwater wetlands between the glut created by SLAMM and that created by NARSAL. The empty 12 Digit Hydrologic Units are where there are no identified saltwater wetlands in either the 2008 SLAMM land use file of the 2008 GLUT file.

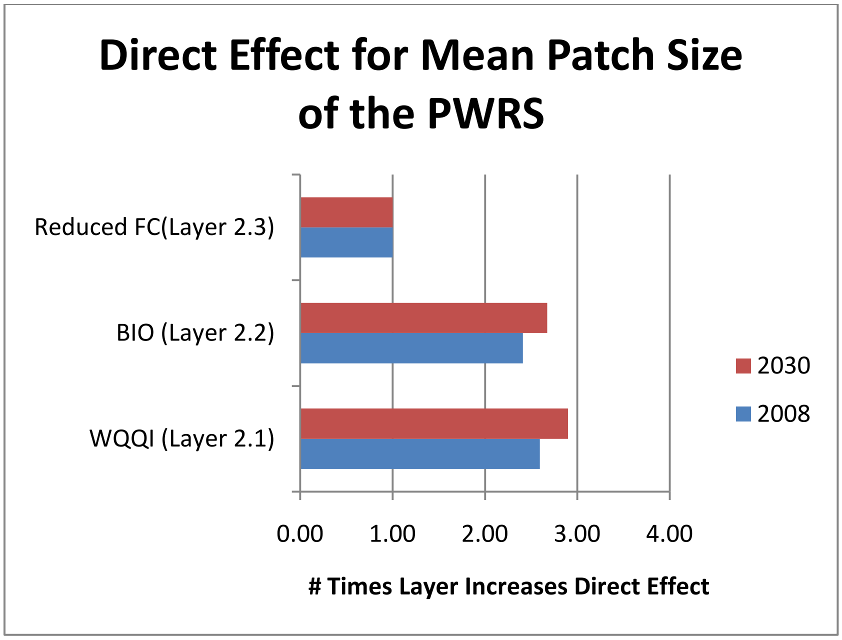


Figure 4.16: The number of times a layer increases their direct effect on the ability of a high priority mean patch area to benefit the wetland functions in the PWRS Index.

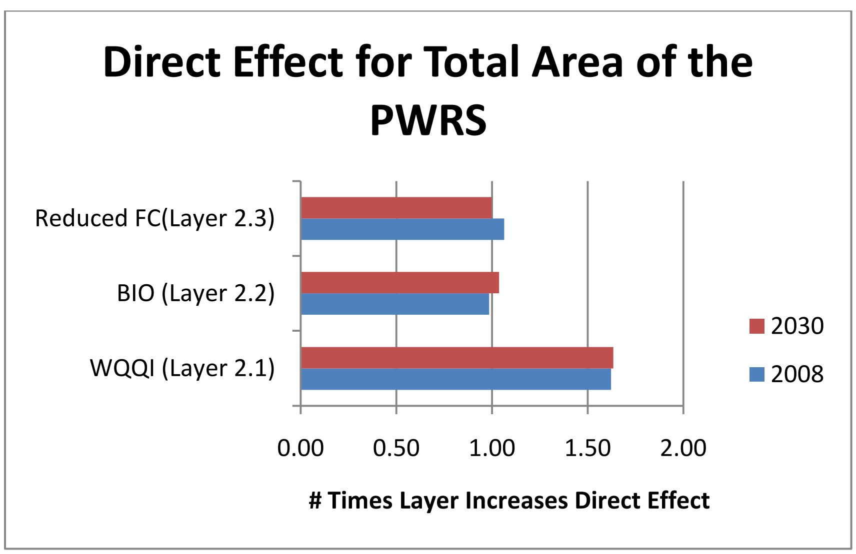


Figure 4.17: The number of times a layer increases their direct effect on the ability of the total area of high prioritysites to benefit the wetland functions in the PWRS Index.

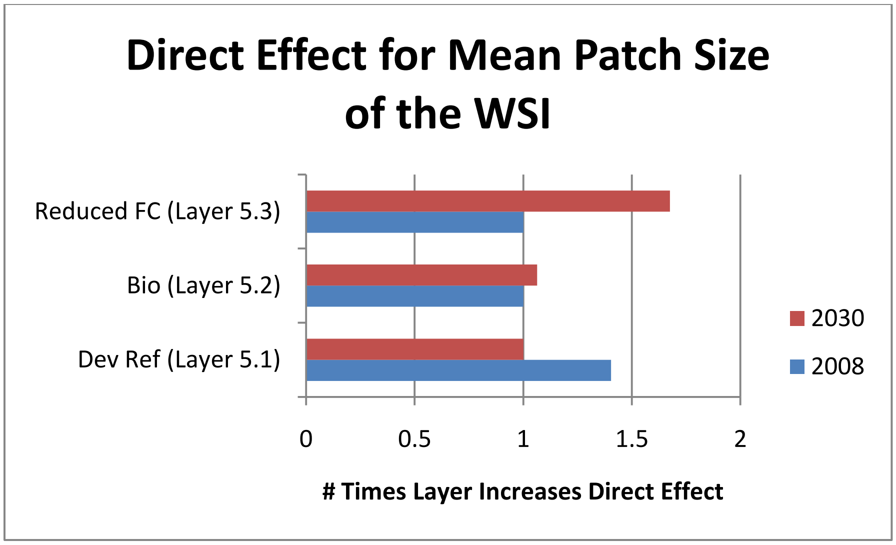


Figure 4.18: The number of times a layer increases their direct effect on the ability of a high priority mean patch area to benefit the wetland functions in the Wetland Site Index.

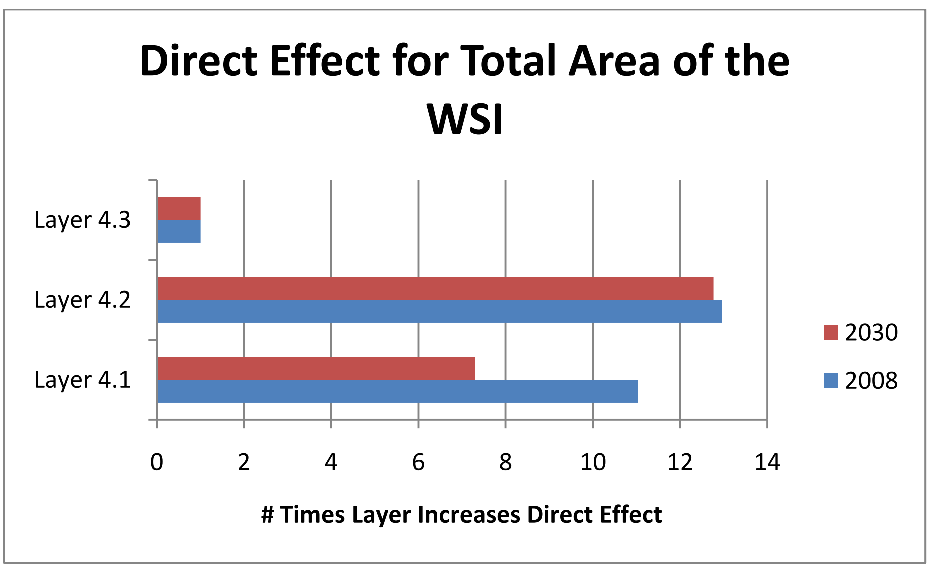


Figure 4.19: The number of times a layer increases their direct effect on the ability of the total area of high prioritysites to benefit the wetland functions in the Wetland Site Index.

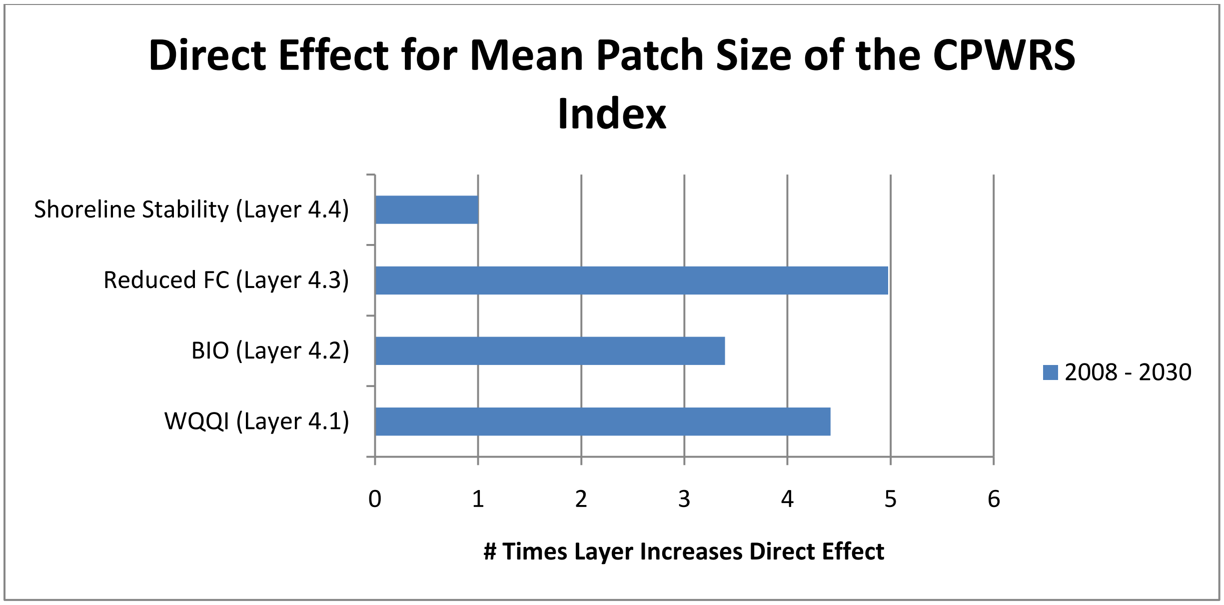


Figure 4.20: The number of times a layer increases their direct effect on the ability of a high priority mean patch area to benefit the wetland functions in the CPWRS Index.

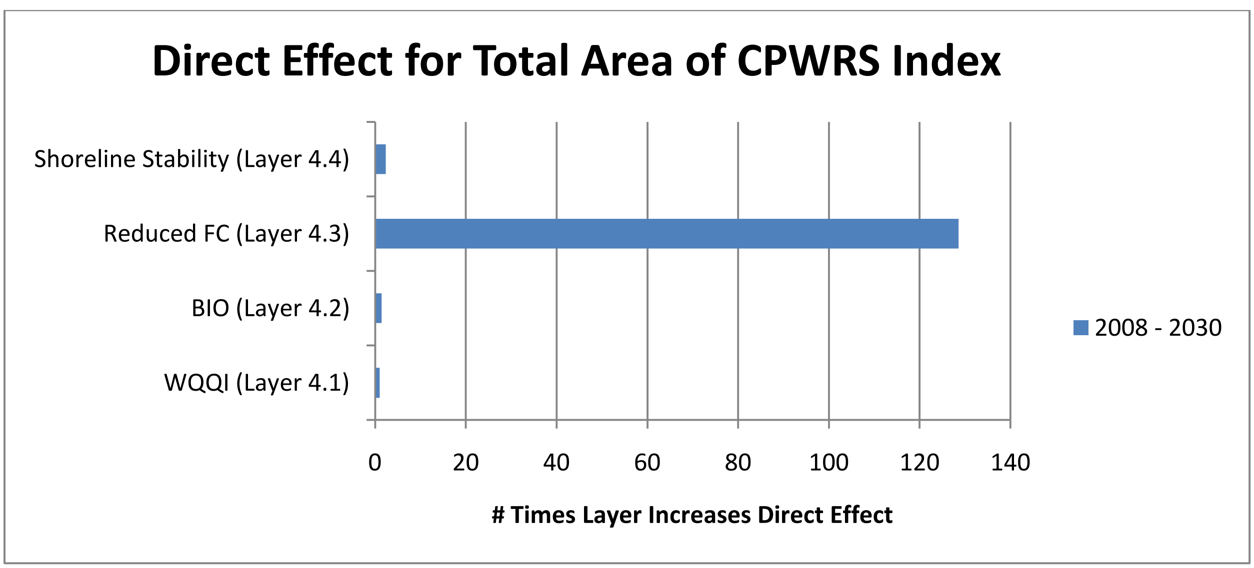


Figure 4.21: The number of times a layer increases their direct effect on the ability of the total area of high prioritysites to benefit the wetland functions in the CPWRS Index.

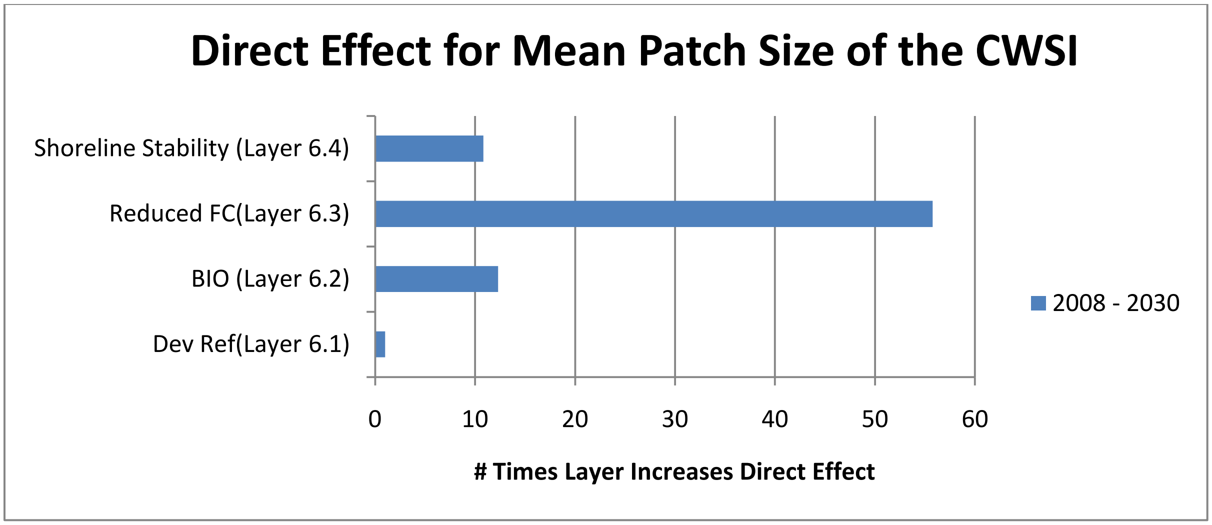


Figure 4.22: The number of times a layer increases their direct effect on the ability of a high priority mean patch area to benefit the wetland functions in the CWSI.

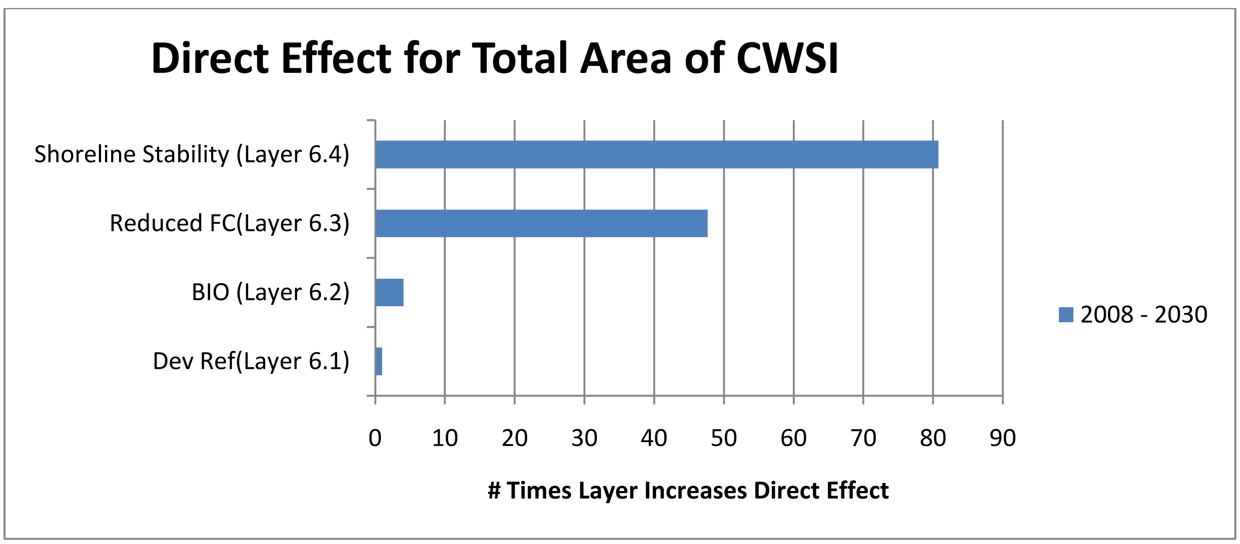


Figure 4.23: The number of times a layer increases their direct effect on the ability of the total area of high prioritysites to benefit the wetland functions in the CWSI.

CHAPTER 5

DISCUSSION

Coastal wetlands are always experiencing geomorphic and land use changes as a result of the influence of sea-level rise, coastal storms and human alterations (Woodworth et al. 2005). Compared to wetlands in other areas of the state of Georgia, these changes are very rapid although they might not be evident when looking at the coast of Georgia as a whole. At the local scale dramatic changes are shown to occur, considering that in this study land use change is only predicted for approximately 20 years in the future. Specifically, the Risk Mask shows that there is an estimated loss of 262,358 ha of wetlands and a gain of 255,510 ha of wetlands between the years 2008 and 2030 and the future land use map shows an increase of 219101 ha of developed land. These changes in the landscape are shown by the PWRS, WSI, CPWRS and CWSI to change the relative potential that a land use pixel has of performing the wetland functions of improving water quality and quantity, conserving biodiversity in high priority streams, reducing the levels of fecal coliform that reach beaches and potential shellfish nursery areas, and the stabilization of the shoreline from coastal storm events. The change in land use identified by the Risk Mask as well as the potential and change in potential identified in the four indices used in the risk assessment can be used by natural resource managers to aide in the selection of compensatory wetland mitigation sites as described in the introduction of the Methodologies chapter.

FUTURE LAND USE MAP

All the changes in landscape that are identified by the Risk Mask, PWRS, WSI, CPWR and CWSI are based on the prediction of land use change made through the creation of the future land use map for the year 2030. The general trends of the future land use map when compared to the 2008 GLUT are an increase in the total area of beach, open water, urban areas and forested wetlands along the coast of Georgia and a decrease in the total area of saltwater and freshwater wetlands. The uplands of the coast of Georgia also decreased in total area due to the conversion to urban land use, forested wetlands, saltwater wetlands or freshwater wetlands. The general trends for the changes in landcover types fits the descriptions found in several studies (Adam 2002; Hoozemans et al. 1999) on how coastal regions change in response to a rise in sea-level, increased storm surge events, the movement of barrier islands and anthropogenic alterations of the landscape.

As in every prediction model, there are going to be errors in the final output that are associated with the parameters chosen, the accuracy of the initial data, and in the way that the analysis is performed. In an effort to determine the extent of the errors and where they occur, a couple different analysis techniques are performed to highlight regions of concern. The first analysis evaluated the variance per 12 Digit HUC of landcover types between the 2008 GLUT and the projected 2008 land use map predicted using SLAMM. From the analysis (Table 4.14), it is found that the largest difference between the two maps occurs when comparing the percentage of saltwater wetlands. The deviation of this land use type is most likely an artifact of the National Wetland Inventory (NWI) file used to determine the spatial location of wetlands in SLAMM. The NWI file is outdated and in comparing this file with the 1974 GLUT, it was found that for the 12 Digit HUC that shows the most variance (Figure 4.15) that a large region of it is identified as being saltwater wetland in the NWI but in the 1974 GLUT it is identified as being freshwater wetland. While it is difficult to determine which land use file is the most accurate in its delineation of wetland areas, using a newer NWI file, such as the one that is now being created for the coastal counties (Kramer, *pers. Comm.)* will hopefully limit the discrepancies that occur in the creation of this future land use map.

For the risk assessment, the functions that wetlands provide, and not their structure, are of interest, so all wetland types can be looked at as a single category, thus removing any discrepancies that may arise from different land use files assigning different wetland types to the same spatial location. Doing this does not account for discrepancies in the identification of beach and water areas in the NWI and GLUT files, which have the third and fourth highest values for variance. The 12 Digit HUCS identified as having the highest values of variance are those that include barrier islands such as Tybee Island. The parameters used and the low resolution of the elevation data most likely led to the SLAMM model not predicting the fragmentation and loss of beach area and the increase in water area that is shown to occur in the 2008 GLUT (Figure 3.5). To offset this, the computer program AMBUR is used to predict the spatial location of the barrier islands for the coast of Georgia. The accuracy of the output of AMBUR depends on the accuracy of the shoreline files used in the program. In Table 4.15, it is calculated that 88% of the Jekyll Island shoreline file that is created using the 1974 GLUT file is within 60 meters of the Jekyll Island file created using more traditional and accurate means. Since the spatial resolution of the 1974 GLUT file is 60 meters and the spatial resolution of the maps used in the four risk assessment indices are 30 meters, the resulting position of the barrier islands predicted using AMBUR are determined to be accurate enough to fix the discrepancies of the SLAMM output for the beach and water landcover categories.

RISK MASK

The Risk Mask, which identifies the areas which have the highest probability of land use change between the years 2008 and 2030, is used to weight the layers in the CPWRS Index and CWSI. The predicted total area of wetlands lost due to coastal stresses (262,358 ha) is close to the predicted total area of wetlands gained (255,510 ha). There is a net loss of 6,875 ha for the coast of Georgia, which is very small when compared to the 8,502,312 ha of land that never changes landcover classification during the 22 year time period. To use the Risk Mask in selecting possible wetland mitigation sites, the wetland areas that are predicted to be lost between 2008 and 2030 are regions in the landscape where it is not advisable to attempt wetland mitigation owing to the high potential of wetland loss from to the predicted effect of coastal stresses. The 255,510 ha of coastal areas that are classified as new wetlands in 2030 are the most opportune locations for wetland mitigation. These new wetland areas have a high probability of being able to sustain conditions suitable to support wetlands over the specified time span and they are also areas where there is the least risk of mitigated wetlands to fail based on the future risks described previously. In the Risk Map, those areas that are identified as having land use changes are locations where the land use changes from one land use type to another within the 22 year time frame. The Risk Mask does not distinguish between the types of land use changes that occur, such as the transition of one wetland type to another or from an upland land cover to an urban landcover, so natural resource managers need to be careful when selecting sites in these areas for the purpose of compensatory wetland placement. The best way to distinguish a difference between the two types of land use change is to compare the areas where land use changes with the CPWRS and the CWSI outputs because the CPWRS would pertain to transitions that do not involve wetlands and the CWSI would correlate with wetland transitions.

POTENTIAL WETLAND RESTORATION SITE INDEX

The PWRS Index identifies the spatial location of non-wetland sites that will provide the most benefit to the wetland ecosystem functions of improving water quality and quantity, conserving biodiversity in high priority streams and reducing fecal coliform to areas of concern through the mitigation processes of restoration and establishment. The index is developed for the years 2008 and 2030. In general, the total area of land use pixels with a high potential value (value is 7, 8 or 9) increased between the two years, and the total area of land use pixels with a medium (value is 4, 5 or 6) and low potential (value is 1, 2 or 3) for enhancing wetland functions decreased over time. This change in the overall mitigation potential of the landscape shows that with the predicted change in land use comes an increased ability for non-wetland sites to improve wetland functions through mitigation. Since all of the wetland functions in the analysis are related to water quality and the quality of water is linked to the amount of amount of impervious surface in a watershed ((Kelsey et al. 2004; Mallin et al. 2001; Mallin et al. 2000), it is not surprising that an increase in urbanization (219101 ha) leads to an increased need to improve water quality. When selecting sites for wetland mitigation, choosing a site that has a high potential for improving wetland benefits in 2008 and 2030 will help to ensure that the sites will be in the location that will provide the most benefit to wetland functions not only at this point in time, but also in the future.

The layer with the most influence on the PWRS index for the years 2008 and 2030 is the Water Quality and Quantity layer (Layer 3.1). What this means is that when a site with a high potential for improving wetland functions is selected for mitigation, that the function of water quality and quantity will be 1.65 times more likely to be improved in 2008 when compared to the function of conserving biodiversity, and 2.89 times more likely to be improved in 2030 when compared to the function of reducing the levels of fecal coliform (Tables 4.18 and 4.19). The ranking of the direct effect of the mean patch size that the layers have on the PWRS is the same for both of the landscape scales (mean patch size and total area) evaluated and for both 2008 and 2030, except when considering the total area of high priority areas in 2008. In this instance, the conservation of biodiversity had the smallest influence on the PWRS instead of the reduction of fecal coliform. The results of the sensitivity analysis show that the PWRS index is not sensitive to the landscape scale of the analysis and that the potential for wetland mitigation to perform improve wetland functions is stable between the years 2008 and 2030.

The results of this analysis correlate with the results of the PWRS performed by Carpenedo (2008). In the study of the potential for restoration for the entire state of Georgia, the water quality and quantity layer was found to have the most influence on the final index and the conservation of biodiversity had the second highest influence. This ranking of potential also corresponds with the two most desired wetland functions identified in a survey conducted by Carpenedo (2008).

HOW THE RESULTS OF THE PWRS INDEX CAN BE USED TO SELECT SITES FOR THE ESTABLISHMENT AND RESTORATION OF COASTAL WETLANDS

When using the results of the PWRS Index for the coast to select sites for the restoration or establishment of wetlands, it is important to also consider the results of the Risk Mask. Even though a land use pixel is identified as having a high potential for mitigation in 2008 and 2030, if it is close to regions where there is predicted to be a loss of wetlands or change in land use types, then it is at a higher risk of also being lost or affected by the land use changes. Conversely, selecting mitigation sites in areas where wetlands are predicted to be created in 2030 can improve the success of wetland mitigation by increasing their chance of remaining a wetland in future.

WETLAND SITE INDEX

The WSI prioritizes the condition of existing wetland sites to perform the functions of improving water quality and quantity, conserving biodiversity in high priority streams and reducing fecal coliform levels for the years 2008 and 2030. In 2008 15% of the wetlands have a high potential of performing wetland functions, 54% have a medium potential and 31 % have a low potential (Table 4.10). While the total area for the three potential mitigation classifications increase between 2008 and 2030, the percent of high potential areas actually decreases by 3% and the percent of medium potential areas increases by 6%. A higher percentage of sites with a medium potential rather than a high potential is expected owing to the difficulty of wetlands to perform all three of the identified wetland functions well and because the spatial location and land use types within a watershed does not always allow for all of the functions to be utilized (Zedler 2006).

The sensitivity analysis performed for the years 2008 and 2030 show that the influence of a layer on the WSI depends on the landscape scale of the analysis and the time that the analysis is performed. When analyzing sensitivity based on the mean patch size, The Deviation from Reference layer (Layer 5.1), which determines the condition of water quality for a wetland, has the most influence on the WSI for the year 2008 and the Reduced FC layer (Layer 5.3) has the most influence in 2030 (Tables 4.20 and 4.22). In 2008, the Deviation from Reference layer is only 1.08 times more likely to be performed by a wetland when compared to the BIO (Layer 5.2) and Reduced FC (Layer 5.3) layers and in 2030 the Reduced FC layer had 1.67 times more influence on the WSI than the Deviation from Reference. This flipping of the ranking of influence suggests that the WSI is the most sensitive to the change in patch size which changed from 2008 and 2030. This means that the function that will be the most improved through enhancement is dependent on the patch size and the spatial position of landcover types at that moment in time. The dynamic nature of coastal wetlands is reflected in the results of the sensitivity analysis for mean patch size because the influence of a wetland function is highly sensitive the changes in land use. To perform wetland mitigation practices on existing wetlands in such an environment means that a future perspective of how the landscape will change needs to be kept in order to ensure that even if there is no loss of wetland acreage that there is also no net loss of wetland function(2008).

When considering the total area of those pixels ranked with high potential, the Conservation of Biodiversity layer has the most influence in 2008 and 2030. In 2008, it is 1.17 times more likely to be performed by a wetland when compared to the Deviation from Reference layer and it is 12.9 times more likely than the Reduced FC layer (Table 4.21). The influence of the Conservation of Biodiversity layer changes in 2030, with it having 1.75 times more influence than the Deviation from Reference Layer and 12.79 times more influence than the Reduced Fecal Coliform layer (Table 4.23). This suggests that the WSI is not sensitivity to changes in land use over time when looking at the total area of high priority pixels for the coast of Georgia.

HOW THE RESULTS OF THE WSI CAN BE USED TO SELECT SITES FOR THE PRESERVATION AND ENHANCEMENT OF COASTAL WETLANDS

Overall, a wetland site has a better chance of successfully preserving wetland functions for those sites that are identified as having a high potential of performing wetland functions in 2008 and 2030 and are also not identified by the Risk Mask as being a wetland area that is lost or a land use area that changes. For enhancement purposes, those wetland areas that have a low potential of performing wetland functions in 2008 and 2030 and are also identified as not being lost in the future due to coastal risks should be the areas targeted by resource managers.

CHANGE IN POTENTIAL WETLAND RESTORATION SITE INDEX

The CPWRS index ranks the potential of a non-wetland site to change in its potential to improve the wetland functions of water quality and quantity, conservation of biodiversity, reduction of fecal coliform and shoreline stability between the years 2008 and 2030. The results from the index show that 44% of the sites that are identified as being restorable in either 2008 or 2030 have a high potential for improving in their potential for wetland mitigation and 47% of the sites have a medium potential for improving potential. A medium potential represents those land use areas that have almost no change in their potential between 2008 and 2030, while the low potential areas tend to have a negative change in potential between 2008 and 2030. For the coast of Georgia, there are only 9% of wetland areas (406281.6 ha) that are identified as having a low potential, which is approximately equal to the area of land use pixels that are identified by the Risk Mask to change in their land use classification over the 22 year period (Tables 4.1and 4.11). This means that those areas that are identified as having a low potential in the CPWRS are more than likely the non-wetland areas that experience a change land use between the years 2008 and 2030.

The layer that has the most influence on the results of the CPWRS Index for the mean patch and the total area of high potential sites analyses is the Reduced Fecal Coliform layer (Layer 4.3). The influence of the Reduced FC layer is much greater than the other layers when looking at the total area of high potential sites (128.67) than looking at the mean patch size (1.13) (Tables 4.24 and 4.25). There are several explanations for this. First, when looking at the figures in Chapter Three for the layers used in the creation of the CPWRS index (Figures 3.19 to

3.22), almost the entire coast of Georgia is considered to have a high potential for wetland restoration whereas for the other three layers, there are only small areas that are considered to have a high potential. This may be due to the fact that the Reduced FC Layer is weighted by the percentage of developed area in a watershed, and this increased between the years 2008 to 2030 by 219101.4 ha, which also increases the need for wetland mitigation in the year 2030. Also looking at these figures, the areas that have a high potential for the WQQI, BIO and Shoreline Stability layers are all grouped into patches. For the Reduced Fecal Coliform layer, these patches are fragmented in the landscape, which reduces the direct effect of this layer on the CPWRS in comparison to the other three layers.

From the CPWRS analysis it seems that the WQQI and BIO layers are relatively stable in their mitigation potential between the years 2008 and 2030 because they have a similar influence on the CPWRS Index (1.28 and 0.98, respectively) and the majority of their potential for mitigation over times is within the classification of medium potential (Table 4.2). When using the CPWRS Index final output for aiding in the process of selecting a location for the restoration or establishment of a wetland, it is important to remember that the land use pixels that are identified as having a high priority are those regions in the landscape that have a low potential for mitigation in 2008 but improve in their potential by the year 2030. For this analysis, the Reduced FC layer had the highest potential for improvement, so selecting a high potential site from this index will more than likely see the greatest increase of wetland functions in the ability of the site to reduce fecal coliform.

HOW THE RESULTS OF THE CHANGE IN POTENTIAL WETLAND RESTORATION SITES INDEX CAN BE USED TO SELECT SITES FOR THE PRESERVATION AND ENHANCEMENT OF COASTAL WETLANDS

The results of the CPWRS Index can be used in conjunction with the PWRS Index and the Risk Mask to select sites for the restoration or establishment of wetlands. The PWRS Index identifies the spatial location where a restored or established wetland site will most likely benefit wetland functions within a watershed while the Risk Mask identifies the regions in the coast that are the most likely to be degraded or lost by coastal stresses. The CPWRS Index highlights the non-wetland areas in the landscape that are the most likely to improve in their ability to improve wetland functions based solely on the predicted change in land use over time. By comparing the results of the PWRS Index, the Risk Mask, and the CPWRS Index, a resource manager will be able to make better informed decisions on the placement of mitigated wetland sites in the landscape by being able to select the areas that have a high potential for providing a wetland function, a low potential of degradation or loss over time, and a high potential that the mitigated site will continue or improve in its ability to perform the wetland functions in the future. Using the results of the PWRS Index, Risk Mask and CPWRS Index in this manner will increase the probability that a restored or established wetland site will perform the desired wetland functions today and also in the future.

CHANGE IN WETLAND SITE INDEX

The CWSI prioritizes the change in the potential of the condition of existing wetland sites based on the difference of those wetland sites to perform the wetland functions of improving water quality, conserving biodiversity, reducing fecal coliform and improving shoreline stability between the years 2008 and 2030. The wetland areas with a high potential for improving their condition compose 32 % of the coast of Georgia, while there are 55% of the sites identified as being medium potential and 13% of the sites considered as low potential. The wetland sites with the lowest potential are those wetlands that become either degraded or lost over time due to the stresses afflicted on them from sea-level rise, storm surge or anthropogenic alterations. Those wetland sites that are identified as having a medium potential are considered to be areas where the potential condition of the wetland does not change over time and the areas with a high potential are regions where there is an increase in the potential of existing wetlands to perform wetland functions. The high potential sites would be the best sites for performing the compensatory wetland mitigation method of preservation (2008) because these sites are already identified as improving over time.

In the sensitivity analysis, the CWSI is sensitive to the landscape level that the analysis is performed, just as the WSI was also found to be sensitive. At the patch level, the Reduced FC layer (Layer 6.3) has the greatest direct influence on the CWSI (2.79) and the Deviation from Reference Conditions layer (Layer 6.1) has the least influence (0.05) (Table 4.26). When analyzing the sensitivity for the total area of high prioritized pixels, the Shoreline Stability layer (Layer 6.4) has the highest direct effect (2.42) and the Reduced FC layer has the second greatest effect (1.43) on the CWSI (Table 4.27). The change in the influence on the CWSI between the patch and total area analysis is due to the amount and distribution of the potential for improving wetland conditions for each layer, which can be seen in Figures 3.30 to 3.33. The Deviation from Reference Conditions (Layer 6.1, Figure 3.30) has the smallest amount of wetland area identified as having a high potential for improving. This is mainly due to there being little difference between the potential for mitigation between 2008 and 2030, and where a difference does occur, it is usually negative. The only difference between the 2008 and 2030 BIO layers (Layer 5.2) that are used to create the BIO layer for the CWSI is that there is a slight increase in the potential for most land use pixels except for those that are identified as being lost by the Risk Mask, which are given a low potential for improving. Overall, when a high priority site is chosen for the purpose of preservation using the CWSI, the functions that are the most likely to be improved are the reduction of fecal coliform and shoreline stability, which are the same functions that are identified by the CPWRS Index.

HOW THE RESULTS OF THE CHANGE IN WETLAND SITE INDEX CAN BE USED TO SELECT SITES FOR THE PRESERVATION AND ENHANCEMENT OF COASTAL WETLANDS

Natural resource managers have a very powerful suite of tools to aid in the selection of wetland sites which should be preserved or enhanced through processes of wetland mitigation. These tools are the WSI, the CWSI, and the Risk Mask. When the results of these three methodologies are compared, resource managers will be able select wetland sites that need to be enhanced based on whether they have a low potential for performing wetland conditions in the WSI, a high potential of improving their ability of performing wetland functions over time in the CWSI, and having a low risk of becoming degraded or lost, as identified by the Risk Mask. Selecting wetland sites for the purpose of preservation is the same as selecting a site for enhancement, except that wetland areas which have a high potential for performing wetland functions should be selected instead of those that have a low potential. An enhanced or preserved wetland mitigation site that is selected in this manner will have a higher probability of successfully performing desired wetland functions now and in the future.

CHAPTER 6

CONCLUSION

The risk assessment for coastal wetlands created in this thesis is an important tool for natural resource managers to use when selecting mitigation sites for either the restoration/establishment of new coastal wetlands or the preservation/enhancement of existing coastal wetlands. Previous methodologies used to aide in the selection of wetland mitigation sites (PWRS Index and the WSI) did not include functions that are specific to coastal areas, nor did they account for how future risks will affect the success of mitigated wetlands over time. Coastal wetlands are dynamic and constantly changing regions that perform the important functions of shoreline stability, improving water quality, and providing safe habitats for a variety of aquatic and terrestrial species that are specific to coastal regions. By not including an analysis that specifically looks at coastal wetlands, their functions and their stresses, these important resources are in danger of becoming lost and degraded. Models that have recently been created, such as the Sea-Level Affecting Marshes Model (SLAMM), the urban growth model Slope, Land cover, Elevation, Urban areas, Transportation and Hill-slope (SLEUTH), and the shoreline stability model Analyzing Moving Boundaries Using R (AMBUR), make it possible to predict where land use changes will occur in a coastal regions, and thus enable future risk assessments for wetlands to be performed. Previous to the research performed in this paper, no other wetland mitigation analysis presented a way to select wetland mitigation sites based on future events, even though a need to protect our wetlands from future risks has been expressed (Hoozemans et al. 1999; Titus 2000). By creating this wetland risk assessment tool, the success of wetland mitigation in regions of rapid change and elevated stresses can be improved by avoiding those areas that are identified as having a high risk of being degraded or lost in the future.

The results of the risk assessment can be used to improve the success of wetland mitigation sites in coastal areas by taking into account the risks that are associated with the coast and looking at the potential for mitigation sites over a projected time frame. The final results of the risk assessment are maps which portray the spatial position in the landscape where wetland mitigation would have the most benefit to wetland functions currently and in the future, as well those areas that would have the greatest potential to improve in their ability to benefit wetland functions over time. The things that are specifically learned from performing the risk assessment for coastal wetlands in the state of Georgia are shown below.

1. Between the years 2008 and 2030, there is projected to be a loss of 262, 358 ha of wetlands and a gain of 255,510 ha of wetland. The change in wetland acreage occurs as a result of the influence of the coastal risks of sea-level rise, storm surge, barrier island migration and population growth that are predicted to cause the land use changes depicted in the future land use map for 2030 and the Risk Mask.
2. There is an increase in the areas identified as having a high potential for mitigation between the years 2008 and 2030. The projected increase in area is 85021 ha for the final output of the PWRS Index and 17219 ha for the final output of the CWI. The wetland function is most likely to be improved when a high potential mitigation site is selected from the results of these indices is the ability of a wetland to improve water quality and quantity.
3. From 2008 to 2030, the percentage of areas that had a low potential for mitigation is approximately 10%. This means that over the 22 year period, most of the coast of

Georgia either maintains or improves in its potential for mitigation. The two wetland functions that have the highest potential for improvement over time are the ability of wetlands to reduce fecal coliform and improve shoreline stability.

4. The results of the WSI and CWSI show that the influence of a layer on the output depends on the spatial scale of the sensitivity analysis. Since these two indices employ the wetland mitigation methods of preservation and enhancement to improve existing wetlands, this means that resource managers need to be careful when selecting mitigation sites to improve a specific function for existing wetlands because the function that is chosen to be improved today might not be the function that is improved in the future.

There is plenty of room for improvement or adaptation of the risk assessment model for coastal Georgia presented in this paper. The main way to improve the results of the analysis is to improve the accuracy and quality of the data that are being used. In the case of the NWI file causing discrepancies between the projected and actual land use for the year 2008, an updated NWI file could have greatly improved the results. An updated file is currently being made for the coastal counties of Georgia (Kramer, *pers. Comm.)* and should be used in future analysis projects to hopefully reduce the variances discovered in the results chapter. The use of a higher quality elevation dataset would also improve the accuracy of the predictions made by SLAMM. A new dataset that is created by the Coastal Georgia Regional Development Center (CGRDC) using Light Detection and Ranging (LiDAR), which can get a more accurate measurement of elevation for flat topographies such as the Georgia coast, is expected to soon be released to the general public (Coastal Georgia Regional Development Center 2009). The adaptation of the risk assessment for use in other coastal environments or for other types of mitigation is encouraged. There is no other analysis available that predicts the potential for mitigation at a future point in time, and by having other states use all or even a portion of the methodologies presented in this paper, will enable resource managers to make better informed decisions on where to place wetland mitigation sites that will have a higher success of performing the desired wetland functions over time.

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APPENDIX A

LIST OF EQUATIONS

APPENDIX B

LIST OF ACRONYMS

AML	Arc Macro Language
AMBUR	Analyzing Moving Boundaries Using R
BIO	Conservation of Biodiversity in High Priority Streams
CFCI	Coastal Fecal Coliform Index
CGRDC	Coastal Georgia Regional Development Center
CN	Curve Number
CPWRS	Change in Potential Wetland Restoration Sites
CWA	Clean Water Act of 1972
CWSI	Change in Wetland Site Index
CZMA	Coastal Zone Management Act
DEM	Digital Elevation Model
DHPSI	Distance to High Priority Stream
DII	Distance to Impairment Index
DNR	Department of Natural Resources
EPD	Environmental Protection Agency
FWPCA	Fedearl Water Pollution Control Act
GIS	Geographical Information Systems
GLUT	Georgia Land Use Trends Database
GT	Great diurnal Tide Range

HSG	Hydrologic Soil Group
HUC	Hydrologic Unit Codes
IWS	Indexed Wetland Size
LiDAR	Light Detection and Ranging
LUDI	Land Use Distance Index
NAVD88	North American Vertical Datum of 1988
NARSAL	Natural Resources Spatial Analysis Laboratory
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natsional Resouces Conservation Service
NRDC	Natural Resources Defense Council
NWI	National Wetlands Inventory
MLLW	Mean Lower Low Water
MHHW	Mean Higher High Water
MTL	Mean Tide Level
PRI	Potential Runoff Index
PWRS	Potential Wetlands Restoration Site
RHA	Rivers and Harbors Act
SLAMM	Sea-Level Affecting Marsh Migration
SLEUTH	Slope, Land cover, Elevation, Urban areas, Transportation and Hill-slope
SS	Shoreline Stability
USACE	United States Army Corp of Engineers
USFWS	United States Fish and Wildlife Services

WSI	Wetland Site Index
WQQI	Water Quality and Quantity Index

APPENDIX C

COMPUTER SCRIPTS DEVELOPED FOR MITIGATION ANALYSIS

```
/*-----------------------------------------------------------------------------------------------------------
/* ******PROJECT AML*********
/*
/*This aml converts the sea-level rise file from the SLAMM output ASC file, the SLEUTH file,
        and the projected barrier island file create the future GLUT Base layer
/*
/* This is done in three steps: the First step converts from SLAMM to GLUT Classification
/*      the Second step adds the slueth and the agricultural growth to the projected GLUT layer
/*      the Third stepsdetermines where barrier islands erode and accrete based on the AMBUR
/*      WLR forecast shapefiles
/*
/* COMMAND TO RUN:  &r F:\Risk\amls\SLAMM_to_projected.aml
F:\Risk\Future_Risk_Base_Map\Projection\Final_projection_2030 Project_2030
/*-----------------------------------------------------------------------------------------------------------
&args .wrk .out
&severity &error &fail
&echo &on
w %.wrk%
/* Future SLAMM model
```

```
/* Need to rename file in ArcCatalog to a shorter file name
/* File was:ga_SLR, 2030, Scenario A1B Maximum_GIS.ASC but changed it to 2030_slr.ASC
/*&sv slamm_future = K:\Coastal_Wetlands\Library\Projection\2030\2030_slr.ASC
/*&sv slamm_future = K:\Coastal_Wetlands\Library\Projection\2050\2050_slr.ASC
/*&sv slamm_future = K:\Coastal_Wetlands\Library\Projection\2075\slr_2075.ASC
&sv slamm_future = K:\Coastal_Wetlands\Library\Projection\2008\2008_slr.ASC
/*&sv slamm_future = K:\Coastal_Wetlands\Library\Projection\2100\2100_slr.ASC
/* Future impervious surface and agricultural growth
&sv imperv_fut = K:\Coastal_Wetlands\Library\Projection\2030\urban_ag2030
/* Mask of the coast
&sv mask =  K:\Coastal_Wetlands\Library\mask
/* Polygon from barrier islands for the current year
&sv isl_mask = F:\Risk\Barrier_Islands\Base_Files\shoreline_08.shp
/* Mask of the rivers that are to be removed from the barrier islands
&sv streams = F:\Risk\Barrier_Islands\Projection_2030\stream_mask.shp
/* Projected Shoreline
&sv barrier_proj = F:\Risk\Barrier_Islands\Projection_2030\ga_isl_30_poy.shp
grid
setwindow %mask% %mask%
/* Part One: Reclassifies from SLAMM to GLUT
conv = asciigrid(%slamm_future%)
cn = con(conv eq 15 OR conv eq 16 OR conv eq 17 OR conv eq 18 or conv eq 19, 11, 0)
cn1 = con(conv eq 10 OR conv eq 11 OR conv eq 12, 7, cn)
```

```
cn2 = con(conv eq 3 OR conv eq 4 OR conv eq 7 OR conv eq 9 OR conv eq 23, 91, cn1)
cn3 = con(conv eq 8 OR conv eq 20 OR conv eq 22, 92, cn2)
cn4 = con(conv eq 5 OR conv eq 6, 93, con(conv eq 1, 22, con(conv eq 2, 41, cn3)))
glut = con(%mask% ge 0, cn4)
/*For part two, the impervious layer needs to reclassify the class value 25 to either equal 21, 22,
23 or 24 based on the
/*focal majority of the area and then this is added to the glut file
impv = con(%imperv_fut% eq 21 OR %imperv_fut% eq 22 OR %imperv_fut% eq 23 or
%imperv_fut% eq 24, %imperv_fut%)
impv_fmj = FocalMajority(impv, CIRCLE, 17, DATA)
impv_fmjrcl = con(%imperv_fut% eq 25, impv_fmj, %imperv_fut%)
imp_wetforst = con(impv_fmjrcl eq 41 OR impv_fmjrcl eq 42 OR impv_fmjrcl eq 43 OR
impv_fmjrcl eq 91 OR impv_fmjrcl eq 92 OR impv_fmjrcl eq 93, 0, impv_fmjrcl)
man_slr = con(imp_wetforst gt 0, imp_wetforst, glut)
imp_proj = con(man_slr eq 41, %imperv_fut%, man_slr)
/* For part three, the barrier island migration is taken into account
/* The barrier project file needs to be a raster file with the same cell size as the land use files
barrier = shapeGrid(%barrier_proj%, Id, 30)
c_mask = shapeGrid(%isl_mask%, GRIDCODE, 30)
stream_remove = shapeGrid(%streams%, Id, 30)
dist_water = eucdistance(barrier, #, #, 300)
remove_land = con((c_mask gt 0 && dist_water gt 0), 11)
dist_beach = eucdistance(c_mask, #, #, 1000)
```

```
add_land = con(isnull(stream_remove) eq 1 && barrier eq 0 && dist_beach gt 0, 7)

barrier_move = con(isnull(remove_land) eq 0, 11, add_land)

%.out% = con(isnull(barrier_move) eq 1, imp_proj, barrier_move)

/* Clean up of files

kill conv

kill cn

kill cn1

kill cn2

kill cn3

kill cn4

kill glut

kill impv

kill impv_fmj

kill impv_fmjrcl

kill imp_wetforst

kill man_slr

kill barrier

kill c_mask

kill stream_remove

kill dist_water

kill dist_beach

q
```

```
/*--------------------------------------------------------------------------------------------------------------
/*
/* *********SHORELINES AML****************
/*
/*creates barrier island shoreline files from land use data to use in AMBUR
/*
/* Need to create masks of the coastal areas that include the islands of interest before running
        this aml
/*
/* COMMAND TO RUN: &r F:\Risk\amls\Shoreline.aml F:\Risk\Barrier_Islands\Base_Files
shoreline_85
/*--------------------------------------------------------------------------------------------------------------
&args .wrk .out
&severity &error &fail
&echo &on
w %.wrk%
/* glut_74
/*&sv glut = K:\Coastal_Wetlands\Library\glut_1974
/* glut_1985
/*&sv glut = K:\Coastal_Wetlands\Library\glut_1985
/* glut_1992
/*&sv glut = K:\Coastal_Wetlands\Library\glut_1992
/* glut_1998
/*sv glut = K:\Coastal_Wetlands\Library\glut_1998
/* glut_2001
/*&sv glut = K:\Coastal_Wetlands\Library\glut_2001
/* glut_2005
/*&sv glut = K:\Coastal_Wetlands\Library\glut_2005
/* glut_2008
&sv glut = K:\Coastal_Wetlands\Library\glut_2008
/* mask barrier islands
&sv mask = F:\Risk\Barrier_Islands\Migration\gaBarrier_mask.shp
grid
mask = shapegrid(%mask%, #, 30)
setwindow mask mask
island = con(mask ge 0, %glut%)
water = con(island eq 11, 1)
w_group = regiongroup(water, #, eight, #, #, nolink)
area_water = zonalarea(w_group)
small_water = con(area_water lt 18000, 1)
```

```
isl_rcl1 = con((island eq 7 OR island gt 11), 1)
null_w = isnull(small_water)
isl_rcl2 = con(null_w eq 1, isl_rcl1, 1)
%.out% = gridshape(isl_rcl2, weed)
kill island
kill water
kill w_group
kill area_water
kill small_water
kill isl_rcl1
kill null_w
kill isl_rcl2
q
&stop
/* Need to add the shoreline year to the attribute table to keep track of shorelines
/* The final poly line for each year will need to be converted to a polyline before performine step two
```

```
# ---------------------------------------------------------------------------

# baseline.py

# Created on: Sun Jul 10 2011 10:51:31 PM

#   (generated by ArcGIS/ModelBuilder)

# Usage: baseline <shoreline_08> <shoreline_05> <shoreline_01> <shoreline_98>

<shoreline_92> <shoreline_85> <shoreline_74> <Output_File__Baseline_Onshore> <shoreline>

<Output_File__Baseline_Offshore>

# ---------------------------------------------------------------------------

# Import system modules

import sys, string, os, arcgisscripting

# Create the Geoprocessor object

gp = arcgisscripting.create()

# Set the necessary product code

gp.SetProduct("ArcInfo")
```

```
# Check out any necessary licenses
gp.CheckOutExtension("spatial")
# Load required toolboxes...
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst
Tools.tbx")
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Data Management
Tools.tbx")
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Conversion
Tools.tbx")
# Script arguments...
shoreline_08 = sys.argv[1]
if shoreline_08 == '#':
 shoreline_08 = "shoreline_08" # provide a default value if unspecified
shoreline_05 = sys.argv[2]
if shoreline_05 == '#':
 shoreline_05 = "shoreline_05" # provide a default value if unspecified
shoreline_01 = sys.argv[3]
if shoreline_01 == '#':
 shoreline_01 = "shoreline_01" # provide a default value if unspecified
shoreline_98 = sys.argv[4]
if shoreline_98 == '#':
 shoreline_98 = "shoreline_98" # provide a default value if unspecified
```

```
shoreline_92 = sys.argv[5]
if shoreline_92 == '#':
 shoreline_92 = "shoreline_92" # provide a default value if unspecified


shoreline_85 = sys.argv[6]
if shoreline_85 == '#':
 shoreline_85 = "shoreline_85" # provide a default value if unspecified
shoreline_74 = sys.argv[7]
if shoreline_74 == '#':
 shoreline_74 = "shoreline_74" # provide a default value if unspecified
Output_File__Baseline_Onshore = sys.argv[8]
if Output_File__Baseline_Onshore == '#':
 Output_File__Baseline_Onshore =
"F:\\Risk\\Barrier_Islands\\Migration\\RasterT_Con_Plu1_MultipleRin1.shp" # provide a default
value if unspecified
shoreline = sys.argv[9]
if shoreline == '#':
 shoreline = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_FeatureToLine_M.shp" #
provide a default value if unspecified
Output_File__Baseline_Offshore = sys.argv[10]
if Output_File__Baseline_Offshore == '#':
```

```
Output_File__Baseline_Offshore =
"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_Union_MultipleR2.shp" # provide a default
value if unspecified
# Local variables...
Output_Raster_Dataset = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_011.img"
Output_Raster_Dataset__4_ = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_081.img"
Output_Raster_Dataset__5_ = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_051.img"
shoreline_981_img = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_981.img"
Output_Raster_Dataset__3_ = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_921.img"
Output_Raster_Dataset__6_ = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_851.img"
Output_Raster_Dataset__7_ = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_741.img"
Output_polygon_features = "F:\\Risk\\Barrier_Islands\\Migration\\RasterT_Con_Plu1.shp"
Con_Weighte_1 = "F:\\Risk\\Barrier_Islands\\Migration\\Con_Plus_Plu1"
Inner_Baseline = "F:\\Risk\\Barrier_Islands\\Migration\\RasterT_Con_Plu1_MultipleRin.shp"
Input_true_raster_or_constant_value__2_ = "1"
Output_raster = "F:\\Risk\\Barrier_Islands\\Migration\\Plus_Plus_Pl3"
Output_raster__2_ = "F:\\Risk\\Barrier_Islands\\Migration\\Plus_shoreli1"
Output_raster__3_ = "F:\\Risk\\Barrier_Islands\\Migration\\Plus_Plus_sh1"
Output_raster__4_ = "F:\\Risk\\Barrier_Islands\\Migration\\Plus_Plus_Pl1"
Output_raster__5_ = "F:\\Risk\\Barrier_Islands\\Migration\\Plus_Plus_Pl2"
Output_raster__6_ = "F:\\Risk\\Barrier_Islands\\Migration\\Plus_Plus_Pl4"
Cellsize = "30"
Cellsize__2_ = "30"
```

Cellsize__3_ = "30"

Cellsize__4_ = "30"

Cellsize__5_ = "30"

Cellsize__6_ = "30"

Cellsize__7_ = "30"

Output_Feature_Class = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_Union.shp"

Output_File__Baseline_off =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_Union_MultipleR.shp"

Output_file = "F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_Union_MultipleR1.shp"

Output_File__Base =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_Union_MultipleR2.shp"

Output_Feature_Class__9_ =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_FeatureToLine.shp"

Output_Feature_Class__7_ =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_08_FeatureToLine.shp"

Output_Feature_Class__8_ =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_01_FeatureToLine.shp"

Output_Feature_Class__6_ =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_98_FeatureToLine.shp"

Output_Feature_Class__3_ =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_92_FeatureToLine.shp"

Output_Feature_Class__4_ =

"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_85_FeatureToLine.shp"

```
Output_Feature_Class__2_ =
"F:\\Risk\\Barrier_Islands\\Migration\\shoreline_74_FeatureToLine.shp"
shoreline_05__2_ = "shoreline_05"
shoreline_05__3_ = "shoreline_74"
shoreline_05__4_ = "shoreline_85"
shoreline_05__5_ = "shoreline_92"
shoreline_05__6_ = "shoreline_98"
shoreline_05__7_ = "shoreline_01"
shoreline_05__8_ = "shoreline_08"
shoreline_05__9_ = "shoreline_05"
shoreline_08__4_ = "shoreline_08"
shoreline_01__2_ = "shoreline_01"
shoreline_98__3_ = "shoreline_98"
shoreline_92__3_ = "shoreline_92"
shoreline_85__2_ = "shoreline_85"
shoreline_74__2_ = "shoreline_74"
RasterT_Con_Plu1_MultipleRin_shp =
"F:\\Risk\\Barrier_Islands\\Migration\\RasterT_Con_Plu1_MultipleRin.shp"
# Process: Polygon to Raster (4)...
gp.PolygonToRaster_conversion(shoreline_08, "FID", Output_Raster_Dataset__4_,
"CELL_CENTER", "NONE", Cellsize__2_)
# Process: Polygon to Raster (5)...
```

```
gp.PolygonToRaster_conversion(shoreline_05, "FID", Output_Raster_Dataset__5_,
"CELL_CENTER", "NONE", Cellsize)
# Process: Plus (2)...
gp.Plus_sa(Output_Raster_Dataset__4_, Output_Raster_Dataset__5_, Output_raster__2_)
# Process: Polygon to Raster...
gp.PolygonToRaster_conversion(shoreline_01, "FID", Output_Raster_Dataset,
"CELL_CENTER", "NONE", Cellsize__3_)
# Process: Plus (3)...
gp.Plus_sa(Output_raster__2_, Output_Raster_Dataset, Output_raster__3_)
# Process: Polygon to Raster (2)...
gp.PolygonToRaster_conversion(shoreline_98, "FID", shoreline_981_img, "CELL_CENTER",
"NONE", Cellsize__4_)
# Process: Plus (4)...
gp.Plus_sa(Output_raster__3_, shoreline_981_img, Output_raster__4_)
# Process: Polygon to Raster (3)...
gp.PolygonToRaster_conversion(shoreline_92, "FID", Output_Raster_Dataset__3_,
"CELL_CENTER", "NONE", Cellsize__5_)
# Process: Plus (5)...
gp.Plus_sa(Output_raster__4_, Output_Raster_Dataset__3_, Output_raster__5_)
# Process: Polygon to Raster (6)...
gp.PolygonToRaster_conversion(shoreline_85, "FID", Output_Raster_Dataset__6_,
"CELL_CENTER", "NONE", Cellsize__6_)
# Process: Plus...
```

```
gp.Plus_sa(Output_raster__5_, Output_Raster_Dataset__6_, Output_raster)
# Process: Polygon to Raster (7)...
gp.PolygonToRaster_conversion(shoreline_74, "FID", Output_Raster_Dataset__7_,
"CELL_CENTER", "NONE", Cellsize__7_)

# Process: Plus (6)...
gp.Plus_sa(Output_raster, Output_Raster_Dataset__7_, Output_raster__6_)
# Process: Con...
gp.Con_sa(Output_raster__6_, Input_true_raster_or_constant_value__2_, Con_Weighte_1, "",
"\"Value\" > 0")
# Process: Raster to Polygon...
gp.RasterToPolygon_conversion(Con_Weighte_1, Output_polygon_features, "SIMPLIFY",
"VALUE")
# Process: Multiple Ring Buffer...
gp.MultipleRingBuffer_analysis(Output_polygon_features, Inner_Baseline, "-5", "Default",
"distance", "ALL", "FULL")
# Process: Add Field (8)...
gp.AddField_management(Inner_Baseline, "ID", "SHORT", "8", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
# Process: Feature To Line...
gp.FeatureToLine_management("F:\\Risk\\Barrier_Islands\\Migration\\RasterT_Con_Plu1_Multi
pleRin.shp", Output_File__Baseline_Onshore, "", "ATTRIBUTES")
# Process: Add Field...
```

```
gp.AddField_management(shoreline_05, "Time_fram", "TEXT", "", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
# Process: Calculate Field...
gp.CalculateField_management(shoreline_05__2_, "Time_fram", "2005", "VB", "")
# Process: Feature To Line (3)...
gp.FeatureToLine_management("shoreline_05", Output_Feature_Class__9_, "",
"ATTRIBUTES")
# Process: Add Field (7)...
gp.AddField_management(shoreline_08, "Time_fram", "TEXT", "", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
# Process: Calculate Field (5)...
gp.CalculateField_management(shoreline_05__8_, "Time_fram", "2008", "VB", "")
# Process: Feature To Line (4)...
gp.FeatureToLine_management("shoreline_08", Output_Feature_Class__7_, "",
"ATTRIBUTES")
# Process: Add Field (6)...
gp.AddField_management(shoreline_01, "Time_fram", "TEXT", "", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
# Process: Calculate Field (2)...
gp.CalculateField_management(shoreline_05__7_, "Time_fram", "2001", "VB", "")
# Process: Feature To Line (5)...
gp.FeatureToLine_management("shoreline_01", Output_Feature_Class__8_, "",
"ATTRIBUTES")
```

```
# Process: Add Field (5)...
gp.AddField_management(shoreline_98, "Time_fram", "TEXT", "", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
# Process: Calculate Field (4)...
gp.CalculateField_management(shoreline_05__6_, "Time_fram", "1998", "VB", "")
# Process: Feature To Line (6)...
gp.FeatureToLine_management("shoreline_98", Output_Feature_Class__6_, "",
"ATTRIBUTES")
# Process: Add Field (4)...
gp.AddField_management(shoreline_92, "Time_fram", "TEXT", "", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
# Process: Calculate Field (6)...
gp.CalculateField_management(shoreline_05__5_, "Time_fram", "1992", "VB", "")
# Process: Feature To Line (7)...
gp.FeatureToLine_management("shoreline_92", Output_Feature_Class__3_, "",
"ATTRIBUTES")
# Process: Add Field (3)...
gp.AddField_management(shoreline_85, "Time_fram", "TEXT", "", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
# Process: Calculate Field (7)...
gp.CalculateField_management(shoreline_05__4_, "Time_fram", "1985", "VB", "")
# Process: Feature To Line (8)...
```

gp.FeatureToLine_management("shoreline_85", Output_Feature_Class__4_, "", "ATTRIBUTES")

Process: Add Field (2)...

gp.AddField_management(shoreline_74, "Time_fram", "TEXT", "", "", "50", "", "NON_NULLABLE", "NON_REQUIRED", "")

Process: Calculate Field (3)...

gp.CalculateField_management(shoreline_05__3_, "Time_fram", "1974", "VB", "")

Process: Feature To Line (9)...

gp.FeatureToLine_management("shoreline_74", Output_Feature_Class__2_, "", "ATTRIBUTES")

Process: Merge...

gp.Merge_management("F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_FeatureToLine.shp;F:\\Risk\\Barrier_Islands\\Migration\\shoreline_08_FeatureToLine.shp;F:\\Risk\\Barrier_Islands\\Migration\\shoreline_01_FeatureToLine.shp;F:\\Risk\\Barrier_Islands\\Migration\\shoreline_98_FeatureToLine.shp;F:\\Risk\\Barrier_Islands\\Migration\\shoreline_92_FeatureToLine.shp;F:\\Risk\\Barrier_Islands\\Migration\\shoreline_85_FeatureToLine.shp;F:\\Risk\\Barrier_Islands\\Migration\\shoreline_74_FeatureToLine.shp", shoreline, "ID 'ID' true true false 10 Double 0 10 ,First,#,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_FeatureToLine.shp,ID,-1,-1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_08_FeatureToLine.shp,ID,-1,-1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_01_FeatureToLine.shp,ID,-1,-1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_98_FeatureToLine.shp,ID,-1,-1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_92_FeatureToLine.shp,ID,-1,-1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_85_FeatureToLine.shp,ID,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_74_FeatureToLine.shp,ID,-1,-1;GRIDCODE

'GRIDCODE' true true false 10 Double 0 10

,First,#,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_FeatureToLine.shp,GRIDCODE,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_08_FeatureToLine.shp,GRIDCODE,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_01_FeatureToLine.shp,GRIDCODE,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_98_FeatureToLine.shp,GRIDCODE,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_92_FeatureToLine.shp,GRIDCODE,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_85_FeatureToLine.shp,GRIDCODE,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_74_FeatureToLine.shp,GRIDCODE,-1,-1;Year

'Year' true true false 4 Short 0 4

,First,#,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_FeatureToLine.shp,Year,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_08_FeatureToLine.shp,Year,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_01_FeatureToLine.shp,Year,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_98_FeatureToLine.shp,Year,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_92_FeatureToLine.shp,Year,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_74_FeatureToLine.shp,Year,-1,-1;Time_fram

'Time_fram' true true false 50 Text -1 -2

,First,#,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_FeatureToLine.shp,Time_fram,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_08_FeatureToLine.shp,Time_fram,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_01_FeatureToLine.shp,Time_fram,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_98_FeatureToLine.shp,Time_fram,-1,-

1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_92_FeatureToLine.shp,Time_fram,-1,-

```
1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_85_FeatureToLine.shp,Time_fram,-1,-
1,F:\\Risk\\Barrier_Islands\\Migration\\shoreline_74_FeatureToLine.shp,Time_fram,-1,-1")
# Process: Union...
gp.Union_analysis("shoreline_05 #;shoreline_08 #;shoreline_01 #;shoreline_98 #;shoreline_92
#;shoreline_85 #;shoreline_74 #", Output_Feature_Class, "ALL", "", "GAPS")
# Process: Multiple Ring Buffer (2)...
gp.MultipleRingBuffer_analysis(Output_Feature_Class, Output_File__Baseline_off, "5",
"Default", "distance", "ALL", "OUTSIDE_ONLY")
# Process: Feature To Line (2)...
gp.FeatureToLine_management("F:\\Risk\\Barrier_Islands\\Migration\\shoreline_05_Union_Mul
tipleR.shp", Output_file, "", "ATTRIBUTES")
# Process: Erase...
gp.Erase_analysis(Output_file, Output_Feature_Class, Output_File__Base, "")
# Process: Add Field (9)...
gp.AddField_management(Output_File__Base, "ID", "SHORT", "8", "", "50", "",
"NON_NULLABLE", "NON_REQUIRED", "")
/* ---------------------------------------------------------------------------------------------
/*
/* Fecal Coliform analysis for shellfish and beach conservation
/*
/* Created 6/2011
/*		Heather Ashby
/*		Natural Resources Spatial Analysis Labratory
```

```
/*              Institute of Ecology, University of Georgia
/*              Athens, GA 30606
/*
/*  This layer determines where potential mitigation sites will improve fecal coliform
concentrations
/*  by relating the amount of impervious surface in a basin and the distance to the impervious
surface to the
/*  amount of fecal coliform. The higher the percentage of impervious surface and the closer to
impairment,
/*  the higher the potential of fecal coliform contamination
/*
/*  Further processing is necessary to complete this layer, including, reclassifying the final
layers.
/*
/*  INPUT FILES: .wrk is the workspace F:\Risk\Mitigation\Layer3
/*
/*        MASK:  located K:\Coastal_Wetlands\Library
/*
/*  WORKSPACE:  Workspace for this aml is F:\Risk\Mitigation\Layer3_5and4_5
/*              and all files generated are in that folder.
/*
/*  COMMAND TO RUN:  &r F:\Risk\Final_amls\habitat_beach.aml F:\Risk\Mitigation\Layer3
/*
```

```
/* -------------------------------------------------------------------------------------------

&args .wrk .out

&severity &error &fail

&echo &on

w %.wrk%

/* snapped statewide grid

&sv mask = K:\Coastal_Wetlands\Library\new_mask

/* 13 class landcover Current

&sv glutlc = K:\Coastal_Wetlands\Library\glut_2008

/* 13 class landcover future

&sv glut2030 = F:\Risk\Future_Risk_Base_Map\Projection\Final_projection_2030\Project_2030

/* 12 digit huc for the coast

&sv huc = K:\Coastal_Wetlands\Library\HUC12

/* PRI for GLUT 2008 from Mitgation layer 4

&sv pri_08 = F:\Risk\Mitigation\Layer1\PRI_2008

/* PRI for GLUT from Mitigation Layer4

&sv pri_30 = F:\Risk\Mitigation\Layer1\pri_2030

grid

setwindow %mask% %mask%

/*Classifies out impervious surface from glut

impv_2008 = con(%glutlc% eq 21 OR %glutlc% eq 22 OR %glutlc% eq 23 OR %glutlc% eq 24,
%glutlc%, 0)
```

impv_2030 = con(%glut2030% eq 21 OR %glut2030% eq 22 OR %glut2030% eq 23 OR %glut2030% eq 24, %glut2030%, 0)

/*Assign mean impervious percentage for GLUT impervious surface classification: 21 is 10%, 22 is 34.5%, 23 is 64.5%, 24 is 90%

/*Area for each pixel based on the pixel's percent impervious is calculated to give the impervious area for each pixel

imparea_08 = con(impv_2008 eq 24, .9 * 900, con(impv_2008 eq 23, .645 * 900, con(impv_2008 eq 22, .345 * 900, con(impv_2008 eq 21, .1 * 900))))

imparea_30 = con(impv_2030 eq 24, .9 * 900, con(impv_2030 eq 23, .645 * 900, con(impv_2030 eq 22, .345 * 900, con(impv_2030 eq 21, .1 * 900))))

/*Calculates the percent impervious surface per 12 digit HUC

imphucsum_08 = zonalsum(%huc%, imparea_08)

imphucsum_30 = zonalsum(%huc%, imparea_30)

huc_area = zonalarea(%huc%)

imp_perc08 = imphucsum_08 / huc_area

imp_perc30 = imphucsum_30 / huc_area

/* In ArcGIS (by hand) need to reclassify using Natural Breaks(Jenks) with 9 classes where high impervious surface = 9 and low impervious surface = 1

/* SET 1: POTENTIAL RUNOFF INDEX for impervious surface areas

imp_PRI_2008 = con(%mask% ge 0, con(impv_2008 gt 0, %pri_08%, 1))

imp_PRI_2030 = con(%mask% ge 0,con(impv_2030 gt 0, %pri_30%, 1))

kill impv_2030

kill imparea_08

kill imparea_30

kill imphucsum_08

kill imphucsum_30

kill impv_2008

q

/*To finish analysis, reclassify imp_pri similar to mitigation layer 4 and then multiply by the relcassified dii from layer 4 = Imp_wqqi

/*fecal_protection = imp_perc*imp_wqqi and then mask with the mitigation mask

/*reclassify with Natural Breaks where the highest value=9 and lowest value=1

/*Mask the result with the risk_mit_mask

/*Run the Final Risk Mask (Risk_mask.aml)

/*---

/*

/* ************ **WETLANDS MIGRATION AML** *****************

/*

/* This aml shows where changes in wetland location occur due to sea-level rise and storm surges

/* This aml only uses maps produced by SLAMM

/*

/* COMMAND TO RUN: &r F:\Risk\amls\wet_migration.aml F:\Risk\Migration

/*

/*---

&args .wrk .out

```
&severity &error &fail
&echo &on
w %.wrk%
/* glut 2008
&sv g08 = K:\Coastal_Wetlands\Library\Projection\2008\glut_slr2008
/* glut 2030
&sv g30 = K:\Coastal_Wetlands\Library\Projection\2030\glut_slr2030
/* glut 2050
&sv g50 = K:\Coastal_Wetlands\Library\Projection\2050\glut_slr2050
/* Pglut 2075
&sv g75 = K:\Coastal_Wetlands\Library\Projection\2075\glut_slr2075
/* glut 2100
&sv g100 = K:\Coastal_Wetlands\Library\Projection\2100\glut_slr2100
/* wetlands 2030
&sv wet30 = K:\Coastal_Wetlands\Library\Projection\wet_coast30
/* coastal mask
&sv mask = K:\Coastal_Wetlands\Library\new_mask
grid
setwindow %mask% %mask%
/* Shows difference in wetlands from 2008 to 2030
con1 = con((%g08% eq 91 && %g30% eq 93) OR (%g08% eq 91 && %g30% eq 92) OR
(%g08% eq 92 && %g30% eq 93) OR (%g08% eq 92 && %g30% eq 91) OR (%g08% eq 93
&& %g30% eq 91) OR (%g08% eq 93 && %g30% eq 92), 3, 0)
```

```
migrate08_30 = con((%g30% eq 91 or %g30% eq 92 OR %g30% eq 93) && %g08% lt 91, 1,
con(%g08% ge 91 && %g30% lt 91, 2, con((%g08% eq 91 && %g30% eq 91) OR (%g08% eq
92 && %g30% eq 92) OR (%g08% eq 93 && %g30% eq 93), 4, con1)))
kill con1
/* Difference in wetlands from 2008 to 2050
con1 = con((%g08% eq 91 && %g50% eq 93) OR (%g08% eq 91 && %g50% eq 92) OR
(%g08% eq 92 && %g50% eq 93) OR (%g08% eq 92 && %g50% eq 91) OR (%g08% eq 93
&& %g50% eq 91) OR (%g08% eq 93 && %g50% eq 92), 3, 0)
migrate08_50 = con((%g50% eq 91 or %g50% eq 92 OR %g50% eq 93) && %g08% lt 91, 1,
con(%g08% ge 91 && %g50% lt 91, 2, con((%g08% eq 91 && %g50% eq 91) OR (%g08% eq
92 && %g50% eq 92) OR (%g08% eq 93 && %g50% eq 93), 4, con1)))
kill con1
/* Difference in wetlands from 2008 to 2075
con1 = con((%g08% eq 91 && %g75% eq 93) OR (%g08% eq 91 && %g75% eq 92) OR
(%g08% eq 92 && %g75% eq 93) OR (%g08% eq 92 && %g75% eq 91) OR (%g08% eq 93
&& %g75% eq 91) OR (%g08% eq 93 && %g75% eq 92), 3, 0)
migrate08_75 = con((%g75% eq 91 or %g75% eq 92 OR %g75% eq 93) && %g08% lt 91, 1,
con(%g08% ge 91 && %g75% lt 91, 2, con((%g08% eq 91 && %g75% eq 91) OR (%g08% eq
92 && %g75% eq 92) OR (%g08% eq 93 && %g75% eq 93), 4, con1)))
kill con1
/* Difference in wetlands from 2008 to 2100
```

```
con1 = con((%g08% eq 91 && %g100% eq 93) OR (%g08% eq 91 && %g100% eq 92) OR
(%g08% eq 92 && %g100% eq 93) OR (%g08% eq 92 && %g100% eq 91) OR (%g08% eq 93
&& %g100% eq 91) OR (%g08% eq 93 && %g100% eq 92), 3, 0)
migrate08_100 = con((%g100% eq 91 or %g100% eq 92 OR %g100% eq 93) && %g08% lt 91,
1, con(%g08% ge 91 && %g100% lt 91, 2, con((%g08% eq 91 && %g100% eq 91) OR
(%g08% eq 92 && %g100% eq 92) OR (%g08% eq 93 && %g100% eq 93), 4, con1)))
kill con1
q
/* 0 = Not wetland
/* 1 = Wetland gain
/* 2 = Wetland loss
/* 3 = Wetland change to different wetland classification
/* 4 = Wetland stays the same
/* -------------------------------------------------------------------------------------------
/*
/* ****************HABITAT AND BEACH AML*****************
/*
/* Fecal Coliform analysis for shellfish and beach conservation
/*
/* Created 6/2011
/*              Heather Ashby
/*              Natural Resources Spatial Analysis Labratory
/*              Institute of Ecology, University of Georgia
```

/* Athens, GA 30606

/*

/* This layer determines where potential mitigation sites will improve fecal coliform concentrations

/* by relating the amount of impervious surface in a basin and the distance to the impervious surface to the

/* amount of fecal coliform. The higher the percentage of impervious surface and the closer to impairment,

/* the higher the potential of fecal coliform contamination

/*

/* Further processing is necessary to complete this layer, including, reclassifying the final layers.

/*

/* INPUT FILES: .wrk is the workspace F:\Risk\Mitigation\Layer3

/*

/* MASK: located K:\Coastal_Wetlands\Library

/*

/* WORKSPACE: Workspace for this aml is F:\Risk\Mitigation\Layer3_5and4_5

/* and all files generated are in that folder.

/*

/* COMMAND TO RUN: &r F:\Risk\Final_amls\habitat_beach.aml F:\Risk\Mitigation\Layer3

/*

/* ---

```
&args .wrk .out
&severity &error &fail
&echo &on
w %.wrk%
/* snapped statewide grid
&sv mask = K:\Coastal_Wetlands\Library\new_mask
/* 13 class landcover Current
&sv glutlc = K:\Coastal_Wetlands\Library\glut_2008
/* 13 class landcover future
&sv glut2030 = F:\Risk\Future_Risk_Base_Map\Projection\Final_projection_2030\Project_2030
/* 12 digit huc for the coast
&sv huc = K:\Coastal_Wetlands\Library\HUC12
/* PRI for GLUT 2008 from Mitgation layer 4
&sv pri_08 = F:\Risk\Mitigation\Layer1\PRI_2008
/* PRI for GLUT from Mitigation Layer4
&sv pri_30 = F:\Risk\Mitigation\Layer1\pri_2030
grid
setwindow %mask% %mask%
/*Classifies out impervious surface from glut
impv_2008 = con(%glutlc% eq 21 OR %glutlc% eq 22 OR %glutlc% eq 23 OR %glutlc% eq 24,
%glutlc%, 0)
impv_2030 = con(%glut2030% eq 21 OR %glut2030% eq 22 OR %glut2030% eq 23 OR
%glut2030% eq 24, %glut2030%, 0)
```

/*Assign mean impervious percentage for GLUT impervious surface classification: 21 is 10%, 22 is 34.5%, 23 is 64.5%, 24 is 90%

/*Area for each pixel based on the pixel's percent impervious is calculated to give the impervious area for each pixel

imparea_08 = con(impv_2008 eq 24, .9 * 900, con(impv_2008 eq 23, .645 * 900, con(impv_2008 eq 22, .345 * 900, con(impv_2008 eq 21, .1 * 900))))

imparea_30 = con(impv_2030 eq 24, .9 * 900, con(impv_2030 eq 23, .645 * 900, con(impv_2030 eq 22, .345 * 900, con(impv_2030 eq 21, .1 * 900))))

/*Calculates the percent impervious surface per 12 digit HUC

imphucsum_08 = zonalsum(%huc%, imparea_08)

imphucsum_30 = zonalsum(%huc%, imparea_30)

huc_area = zonalarea(%huc%)

imp_perc08 = imphucsum_08 / huc_area

imp_perc30 = imphucsum_30 / huc_area

/* In ArcGIS (by hand) need to reclassify using Natural Breaks(Jenks) with 9 classes where high impervious surface = 9 and low impervious surface = 1

/* Use the PRI from the WQQI analysis

kill impv_2030

kill imparea_08

kill imparea_30

kill imphucsum_08

kill imphucsum_30

kill impv_2008

q

/*To finish analysis, reclassify imp_pri similar to mitigation layer 4 and then multiply by the relcassified dii from layer 4 = Imp_wqqi

/*fecal_protection = imp_perc*imp_wqqi and then mask with the Restorability mask

/*reclassify with Natural Breaks where the highest value=9 and lowest value=1

/* For the WSI, Mask the result with the Risk mask and reclassify so that lowest value = 1 and

/* the highest value = 9

/* --

/*

/**********************SHORELINE STABILITY AML****************

/*

/* Created 6/2011

/*   Heather Ashby

/*   Natural Resources Spatial Analysis Labratory

/*   Institute of Ecology, University of Georgia

/*   Athens, GA 30606

/* This layer determines the stability of the shoreline based on the size of new wetlands

/* identified in the future land use map, as well as the distance the wetland may be located

/* from existing wetlands and the shoreline

/*

/* Further processing is necessary to complete this layer, including, reclassifying the final layers.

/*

```
/*  INPUT FILES: .wrk is the workspace F:\Risk\Final_layers\Layer5_1
/*
/*        MASK:  located K:\Coastal_Wetlands\Library
/*
/*  WORKSPACE:  Workspace for this aml is F:\Risk\Existing\Layer5
/*                     and all files generated are in that folder.
/*
/*  COMMAND TO RUN:  &r F:\Risk\Final_amls\shoreline_stability.aml
F:\Risk\Final_layers\Layer5_1
/* ---------------------------------------------------------------------------------------------
&args .wrk .out
&severity &error &fail
&echo &on
w %.wrk%
/* snapped coastal grid
&sv mask = K:\Coastal_Wetlands\Library\new_mask
/* landcover Current
&sv glut08 = K:\Coastal_Wetlands\Library\glut_2008
/* landcover future
&sv glut30 = F:\Risk\Future_Risk_Base_Map\Projection\Final_projection_2030\Project_2030
/* 12 digit huc for the coast
&sv huc = K:\Coastal_Wetlands\Library\HUC12
/* statewide dem
```

```
&sv dem = K:\2008_GLUT_wetlands\1_4_quality_quantity\ned_u17
/* wetlands for 2008
&sv wetmask08 = K:\Coastal_Wetlands\Library\coast_wet2008
/* wetlands for 2030
&sv wetmask30 = K:\Coastal_Wetlands\Library\coast_wet2030
grid
setwindow %mask% %mask%
/* Compares the land use for 2008 and 2030 to determine where wetland areas were created
glut08 = con(%mask% ge 0, %glut08%)
wet30 = con((%glut30% eq 91 OR %glut30% eq 92 OR %glut30% eq 93) && glut08 lt 91, 1)
/* Part one calculates the size of the new wetland areaa
wetgrp30 = regiongroup(wet30, #, eight, #, #, nolink)
new_wetarea30 = zonalarea(wetgrp30)
/* Part two calculates the Euclidean Distance between a land use pixel and the closest existing
wetland pixel and shoreline pixel
existing_wet = con(glut08 ge 91, 1)
dist_wetland = EucDistance(existing_wet)
/* To distinguish the difference between open ocean water and lakes, only water areas larger than
100 pixels are selected
water08 = con(glut08 eq 11, 1)
watergrp08 = zonalarea(water08)
dist_water = EucDistance(con(watergrp08 gt 90000, 1))
q
```

```
&stop
/* The final processing for this layer for the PWRS includes reclassifying the new_wetarea30 ->
9 = infinity, 1 = 9000
/* To calculate the LUDI, the reclassified dist_wet and dist_water(9->smallest value, 1->largest
value) are multiplied together and the LUDI is then reclassified (9->shortest distance, 1->longest
distance)
/*-----------------------------------------------------------------------------------------------------------
/*
/* ***************SENSITIVITY ANALYSIS AML**********************
/*
/* COMMAND TO RUN: &r F:\Risk\Final_amls\Sensitivity_analysis.aml
F:\Risk\Final_Layers\PWRS\Analysis\difflayer
/*-----------------------------------------------------------------------------------------------------------
&args .wrk .out
&severity &error &fail
&echo &on
w %.wrk%
/* snapped coastal grid
&sv mask = K:\Coastal_Wetlands\Library\mask
/* Final Layer files of the analysis
&sv l4 = F:\Risk\Final_Layers\Layer5_1\corr_l_5_rc
&sv l3 = F:\Risk\Final_Layers\PWRS\DiffPWRS\difflayer3_rc
&sv l2 = F:\Risk\Final_Layers\PWRS\DiffPWRS\difflayer2_rc
```

```
&sv l1 = F:\Risk\Final_Layers\PWRS\DiffPWRS\difflayer1_rc

grid

setwindow %mask% %mask%

/* Selects the high priority areas (7,8,9) and sets their value to 900

l4_hp = con(%l4% ge 7, 900)

l3_hp = con(%l3% ge 7, 900)

l2_hp = con(%l2% ge 7, 900)

l1_hp = con(%l1% ge 7, 900)

/* Calculates the standard output for each layer and overall(total area)

l4_st_area = zonalsum(%mask%, l4_hp)

l3_st_area = zonalsum(%mask%, l3_hp)

l2_st_area = zonalsum(%mask%, l2_hp)

l1_st_area = zonalsum(%mask%, l1_hp)

stand_totarea = con(isnull(l4_st_area) eq 0, l4_st_area, 0) + con(isnull(l3_st_area) eq 0,

l3_st_area, 0) + con(isnull(l2_st_area) eq 0, l2_st_area, 0) + con(isnull(l1_st_area) eq 0,

l1_st_area, 0)

/* Weights each of the layers by a factor of five

l4_x5 = l4_st_area * 5

l3_x5 = l3_st_area * 5

l2_x5 = l2_st_area * 5

l1_x5 = l1_st_area * 5

/* Computes the weighted total area for each layer

l4_weight = l4_x5 + l3_st_area + l2_st_area + l1_st_area
```

```
l3_weight = l4_st_area + l3_x5 + l2_st_area + l1_st_area

l2_weight = l4_st_area + l3_st_area + l2_x5 + l1_st_area

l1_weight = l4_st_area + l3_st_area + l2_st_area + l1_x5

/* Calculates the Change between weight and standard

l4_change = l4_weight - stand_totarea

l3_change = l3_weight - stand_totarea

l2_change = l2_weight - stand_totarea

l1_change = l1_weight - stand_totarea

/* Calculates the direct effect

l4_direct = l4_change / stand_totarea

l3_direct = l3_change / stand_totarea

l2_direct = l2_change / stand_totarea

l1_direct = l1_change / stand_totarea

q

&stop

/*-----------------------------------------------------------------------------------------------------------

/*

/* *************SENSITIVITY PATCH AML***************************

/*

/* COMMAND TO RUN: &r F:\Risk\Final_amls\Sensitivity_patch.aml

F:\Risk\Final_Layers\PWRS\Analysis\difflayer_patch

/*-----------------------------------------------------------------------------------------------------------

&args .wrk .out
```

```
&severity &error &fail
&echo &on
w %.wrk%
/* snapped coastal grid
&sv mask = K:\Coastal_Wetlands\Library\mask
/* Final Layer files of the analysis
&sv l4 = F:\Risk\Final_Layers\Layer5_1\corr_l_5_rc
&sv l3 = F:\Risk\Final_Layers\PWRS\DiffPWRS\difflayer3_rc
&sv l2 = F:\Risk\Final_Layers\PWRS\DiffPWRS\difflayer2_rc
&sv l1 = F:\Risk\Final_Layers\PWRS\DiffPWRS\difflayer1_rc
grid
setwindow %mask% %mask%
/* Selects the high priority areas (7,8,9) and sets their value to 900
l4_hp = con(%l4% ge 7, 900)
l3_hp = con(%l3% ge 7, 900)
l2_hp = con(%l2% ge 7, 900)
l1_hp = con(%l1% ge 7, 900)
/* Calculates the standard output for each layer and overall(total area)
l4_patch = regiongroup(l4_hp, #, eight, #, #, nolink)
l3_patch = regiongroup(l3_hp, #, eight, #, #, nolink)
l2_patch = regiongroup(l2_hp, #, eight, #, #, nolink)
l1_patch = regiongroup(l1_hp, #, eight, #, #, nolink)
l4_st_area = zonalmean(%mask%, l4_patch)
```

```
l3_st_area = zonalmean(%mask%, l3_patch)
l2_st_area = zonalmean(%mask%, l2_patch)
l1_st_area = zonalmean(%mask%, l1_patch)
stand_totarea = con(isnull(l4_st_area) eq 0, l4_st_area, 0) + con(isnull(l3_st_area) eq 0,
l3_st_area, 0) + con(isnull(l2_st_area) eq 0, l2_st_area, 0) + con(isnull(l1_st_area) eq 0,
l1_st_area, 0)
/* Weights each of the layers by a factor of five
l4_x5 = l4_st_area * 5
l3_x5 = l3_st_area * 5
l2_x5 = l2_st_area * 5
l1_x5 = l1_st_area * 5
/* Computes the weighted total area for each layer
l4_weight = l4_x5 + l3_st_area + l2_st_area + l1_st_area
l3_weight = l4_st_area + l3_x5 + l2_st_area + l1_st_area
l2_weight = l4_st_area + l3_st_area + l2_x5 + l1_st_area
l1_weight = l4_st_area + l3_st_area + l2_st_area + l1_x5
/* Calculates the Change between weight and standard
l4_change = l4_weight - stand_totarea
l3_change = l3_weight - stand_totarea
l2_change = l2_weight - stand_totarea
l1_change = l1_weight - stand_totarea
/* Calculates the direct effect
l4_direct = l4_change / stand_totarea
```

```
l3_direct = l3_change / stand_totarea

l2_direct = l2_change / stand_totarea

l1_direct = l1_change / stand_totarea

q

&stop
```