Proposed Wetland Regions for Florida Freshwater Wetlands

By

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ABSTRACT

The Florida landscape was separated into greater than 140,000 unique 1000m by 1000m cells containing information about the type and percentage of freshwater palustrine wetlands within each cell. Two-way indicator species analysis (TWINSPAN) clustering algorithm hierarchically classified the rasterized landscape into groups that reflected generally unique community composition: forested deciduous, shrub scrub, and emergent marsh wetland types, and uplands (non-wetlands). The determinants of the spatial location for each group were examined using detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA). Based on the results of the DCA and CCA, as well as the literature available, it was determined that landscape hydrology determines, or at least is an important determinant of, the spatial location of different wetland types. A landscape water balance, which calculates the flow of water into and out of each cell, was calculated for January to April climatic inputs. The landscape was regionalized with the Landscape Water Balance Index into areas of similar critical depth of saturation for wetland plants. This study resulted in the creation of four wetland regions: South, Central, North, and Panhandle. These wetland regions were created based on the premise that the landscape water balance and all its manifestations (such as hydroperiod and depth of saturation) affect the biotic components of wetlands.

INTRODUCTION

Statement of the Problem

To assess the health of wetlands, environmental managers need to evaluate impacts on the wetland ecosystem. One method of assessing the health of wetland ecosystems that has come into recent favor is to utilize biological characteristics (Fennessy 1998, Karr 1997, USEPA 1997). Biological characteristics of wetlands, such as the macrophytes, macroinvertebrates, algae, and fish that compose the organismal wetland community, integrate impacts to the wetland over time. Synoptic water quality data, while useful, can lead to erroneous conclusions of wetland health as the water quality data often presents only a snapshot of the wetland's condition.

Wetland health is a relative phenomenon. In order to judge wetland health, ecological characteristics of a wetland must be compared to a benchmark or reference wetland of the same "type." The task of defining types and biological characteristics of Florida wetlands that might be used to evaluate wetland ecological condition is complicated by the fact that structurally (and probably functionally) wetlands vary across the state. While it is quite clear wetlands in the northern portions of the State are different from the same "kind" of wetlands in the southern reaches (Ewel 1990, 1998, Montague and Wiegert 1990, Brown 1984, Odum et al. 1982, Kushlan 1990), subtle differences might be evident along a gradient from north to south and could affect the use of biological indicators of ecological condition.

These observations lead to the following questions: Are there distinct wetland regions within the State that can be determined using major driving energies and landscape structural components? Are these regions significantly different from each other, such that physical and climatic variation within regions is less than the variation between regions?

Background

In 1972 the Federal Water Pollution Control Act (Clean Water Act) was passed in part to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters (Clean Water Act §101(a))." The Florida Department of Environmental Protection (FDEP) undertook the task of protecting the state's ecosystem health, initially for lakes and streams, by creating indicators of biological health (biometrics) for those ecosystems for each region of the state (Griffith et al.1997, Barbour et al. 1996). The FDEP recently began examining methods of protecting wetland ecosystem health using biometrics, which integrate stresses to the system over time (Karr and Chu 1997). One of the first steps in developing biometrics is to separate the state into regions (Omernik 1995, Davis and Simon 1995).

A regional approach to creating wetland bioassessment indices is necessary to account for natural variation in species assemblages due to spatial location (Hughes et al. 1990, National Research Council 1995). The regional approach allows for the development of a bioassessment framework that is appropriate for each wetland type and ecological region, or ecoregion. Ecoregions are defined as homogenous landscape patterns deduced from various climatic and geographic inputs (Griffith et al. 1994). The Environmental Protection Agency (EPA) defines ecoregions as areas "within which there is apparent homogeneity in a combination of geographic characteristic that are likely to be associated with resource quality, quantity, and types of stresses (Gibson 1994)." Variation within an ecoregion is typically less than variation between ecoregions (Hughes et al. 1990). By reducing landscape noise via wetland regionalization, a realistic biological framework for assessing wetland health can be constructed.

Review of the Literature

Several studies incorporating climatic and physiographic inputs have generated ecoregions at varying scales. Ecoregions have been created at the global (Woodward and Williams 1987, Prentice et al. 1992), country (Bailey 1983, Omernik 1987, Wiken 1986, Biggs et al. 1990), state (Griffith 1994, Perera et al. 1996), and local level (Yoke and Rennie 1996). Omernik's ecoregions have been utilized to stratify streams, create water quality parameters, set lake management goals, and develop biological criteria in several states (Griffith et al. 1994). Using Griffith's (1994) general regionalization map of Florida (Figure 1), FDEP has created maps of lake regions (Figure 2, Griffith et al. 1997) and stream regions (Figure 3, Barbour et al. 1996) to assist in the development of appropriate biological criteria for those ecosystems.

Additional studies have delineated Florida using physiographic or climatic characteristics. Agronomists have drawn a line between the thermic and hyperthermic temperature regimes in the northern peninsular section of the State (Carlisle 1995).
Thornthwaite (1941) delineated boundaries by differences in potential evapotranspiration (PET) and rainfall (Fernald and Purdum 1998). Bell and Taylor (1982) created a map to identify the range of Florida's flowering plants based on homogenous climate and soil types. The United States Department of Agriculture (USDA) created climatological divisions between regions of uniform climate (Fernald and Purdum 1998). The USDA has also created Land Resource Regions and Major Land Resource Areas of the United States that separate the landscape based on similar land use, elevation/topography, climate, water, soils, and potential natural vegetation (SCS 1981). Koppen's climate types split southern Florida between humid subtropical and tropical savanna (Visher 1954, Muller and Grymes 1998, pp. 87)." Omernik's (1987) ecoregions map of the United States separates Florida into three regions based on physiographic and climatic coincidences. These three regions were then subdivided into 13 sub-ecoregions by Griffith et al. (1994) for the Florida ecoregions map.

Multivariate Landscape Analysis

Wetland regions can be created using multifactor analysis of landscape characteristics. Multifactor landscape analysis of wetlands is appropriate as differences in landscape characteristics such as rainfall, evapotranspiration, soils, surficial geology, slope, and fire regime can determine both wetland type and species assemblages (Ewel 1990, Kushlan 1990, Odum et al. 1982, Ewel and Odum 1984, Duever 1982).
Several authors have utilized multivariate analysis of environmental variables to classify landscapes and examine environmental gradients. Host and Pregitzer (1991) used two-way indicator species analysis (TWINSPAN) and detrended correspondence analysis (DCA) to classify ecological species groups for upland forest ecosystems in northwestern Michigan. Vegetation in the Florida Keys was recognized to fall into 13 homogenous regions by Ross et al. (1992), who used TWINSPAN and DCA to classify the landscape. Frenzel (1996) used TWINSPAN to classify Nebraska streams into regions of homogenous macroinvertebrate assemblages. Tree communities in Tikal National Park, Guatemala, were classified into regions using TWINSPAN, DCA, and canonical correspondence analysis (CCA) by Schulze and Whitacre (1999). DCA, detrended DCA, and Stepwise Correspondence Analysis were used by Yoke and Rennie (1996) to create ecological regions in the Cherokee National Forest, North Carolina. Hix (1988) used TWINSPAN to delineate the upland hardwood forest ecosystem in southern Wisconsin into eleven "major ecosystem units." In Finland, a previous forest classification from 1949 was examined and corrected using TWINSPAN, DCA and CCA (Tonteri et al. 1990). Wetlands in Manitoba, Canada were regionalized into ecosystem units using TWINSPAN, DCA, and detrended CCA (Halsey et al. 1997).

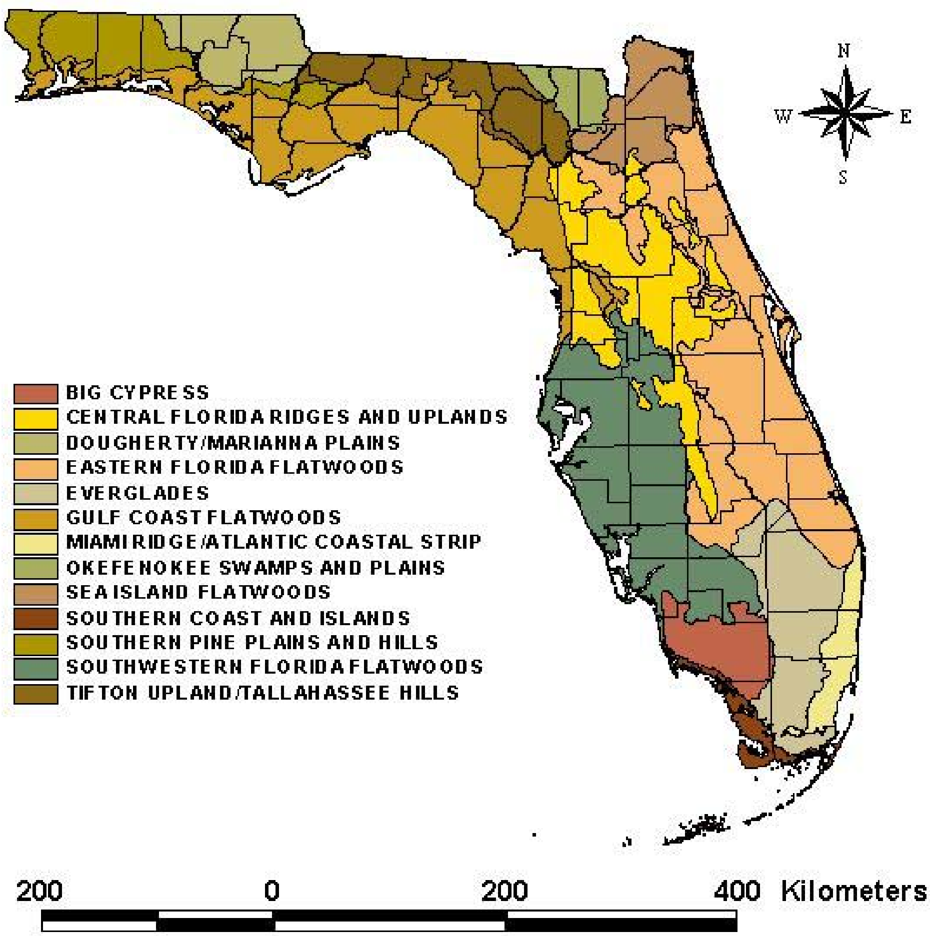

Figure 1. Sub-ecoregions of Florida (Griffith et al. 1994).

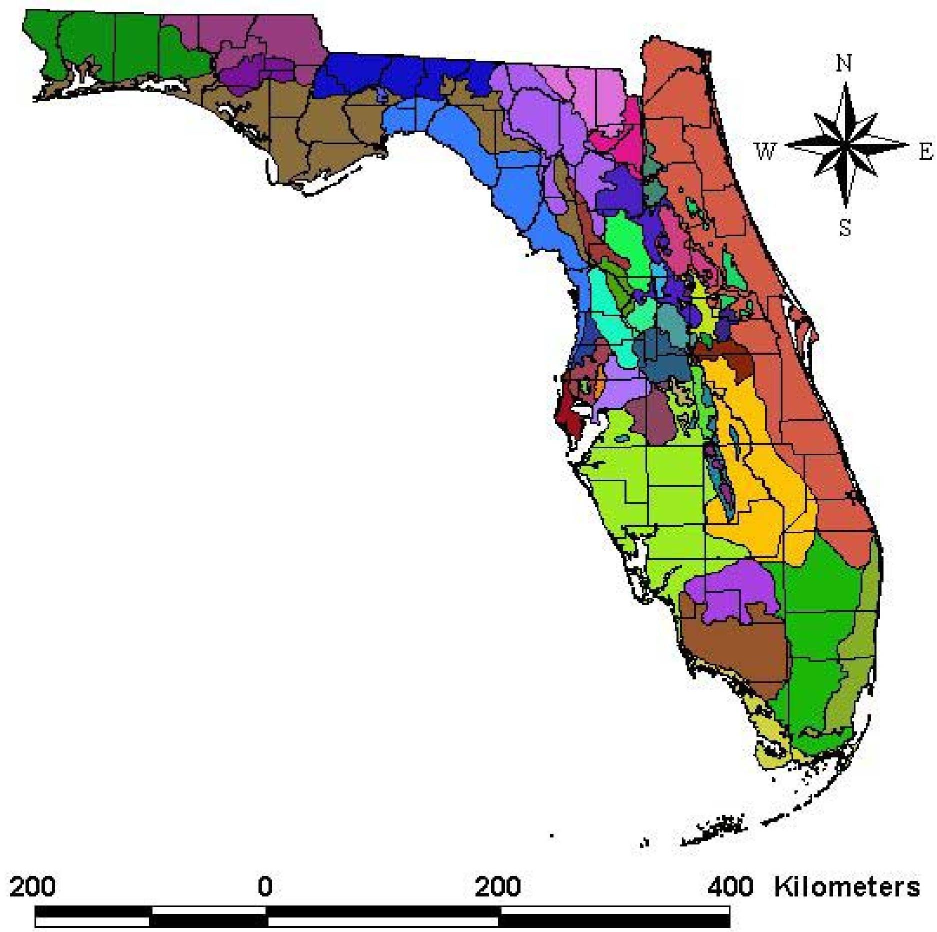

Figure 2. Griffith et al. (1997) delineated 47 lake regions for Florida.

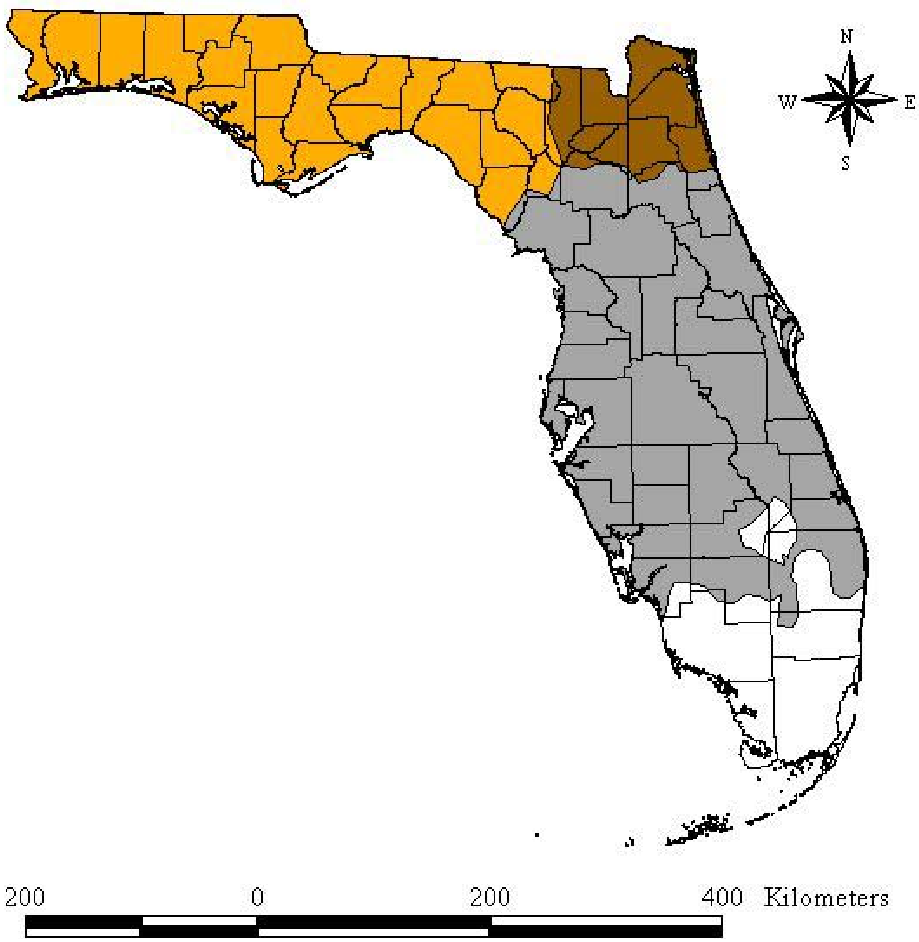

Figure 3. Barbour et al. (1996) created four stream regions based on the ordination of sampling data.

Others have used multivariate analysis to examine correlations between ecosystem units and environmental variables (Retuerto and Carballeira 1991, Allen and Peet 1990, Leland 1995, Anderson and Davis 1997, Nicholson et al.1996). The environmental determinants of ecosystems may be explored using DCA and CCA. Geostatistical applications such as TWINSPAN, DCA and CCA can assist in creating regions since ecosystem units that have similar environmental characteristics may also share similar organismal characteristics. Each environmental variable that is utilized to examine a wetland ecosystem type (i.e. emergent wetland) position on the landscape adds a dimension to the possible connections between wetland type and landscape position. For instance, examining the relationship between surficial geology, rainfall, and wetland type provides two dimensions (geology and rainfall) that may affect the wetland type. Adding more variables such as potential evapotranspiration and slope increases the dimensions (to four) and increases possible permutations of the data set. Multivariate statistics such as detrended correspondence analysis and canonical correspondence analysis can decrease the dimensionality of the data set by determining the importance of each variable to the wetland type (Gauch 1982).

Some researchers have cautioned against using TWINSPAN, DCA, and CCA to examine data. van Groenewoud (1992) suggested against using TWINSPAN analysis to separate vegetation data. His studies on simulated vegetation data indicated that TWINSPAN was not robust enough beyond the first division. However, Cao et al. (1997), responding to van Groenewoud, found the TWINSPAN performance acceptable and recommended its use in clustering field-collected river benthic communities. Westfall et al. (1997) found that the results of TWINSPAN analysis changed when the order of the input matrix changed. Tausch et al. (1995) found similar results for DCA. The current versions of TWINSPAN and DCA available through MjM Software (1998), which were used in this study, account for these potential errors (McCune and Mefford 1995, Oksanen and Minchin 1997).

Hydrologic Budget

The multiple landscape factors that dictate ecologically dissimilar regions have also been analyzed by others using the hydrologic budget equation. The inputs and outputs of the equation incorporate the landscape variability over the study area through the map algebra components. In Florida, water budgets have been completed statewide (Fernald and Purdum 1998), for southern Florida (Shih et al. 1983), the Everglades Agricultural Area (Omary and Izuno 1995), the Everglades (Fennema et al. 1994), Okeefenokee Swamp (Rykiel 1984, Yin and Brook 1992), the Green Swamp (Pride et al. 1966), Hillsborough County (Wiley 1997), Fakahatchee Strand (Burns 1984), St. Mark's River basin (Parker 1998), and many others parts of the state (e.g. Rushton 1996, Heimburg 1984, Fares et al. 1996, Riekerk 1989, Dolan et al. 1984). The water balance equation is particularly apropos to delineating wetland regions as it measures the flow of water through the landscape, which is well accepted as the most important factor to wetland formation and biological characterization (Hall and Penfound 1943, Ewel and Odum 1984, Mitsch and Gosselink 1993, Odum 1984, National Research Council 1995).

Wetland Differences in Florida

The wetland type and associated species composition in Florida is a function of landscape inputs. These inputs may include seasonal determinants such as timing, frequency, depth, and duration of flooding events, as well as static determinants such as soil type and spatial location (Brown 1984).

According to Ewel (1990, 1998), the climatic and physiographic landscape characteristics of Florida are reflected in structural and functional differences in cypress (*Taxodium distichum*) swamps, hardwood heads (*Nyssa sp., Acer sp., Quercus sp., others*), and mixed hardwood/conifer wetlands (including *Pinus serotina, P. elliottii, P. taeda, P. glabra, and Chamaecyparis thyoides,*) spatially located along a north to south axis. The most important variables on swamp structure and function are hydroperiod, fire frequency, organic matter accumulation, and water source (Ewel 1990, p. 283).

Kushlan (1990) described a similar distribution difference in Florida's marsh species assemblages and wetland function along a north to south axis. Topography and the movement of water on the landscape were found to be the most important factors in controlling marsh distribution in Florida. Associated factors included geology, rainfall, and evapotranspiration (Kushlan 1990).

Odum et al. (1982) discussed the debilitating effects of freezes on the northward propagation and distribution of mangrove wetlands in Florida. Mangrove distribution was thought to be dependent on climate, salt water, water fluctuation, runoff of nutrients, substrate and wave energy (p. 521). Montague and Wiegert (1990) reported that the distribution and extent of salt marsh species in Florida varies considerably, "… owing to a combination of a large latitudinal change and geographic differences in tidal range, local relief, and wave energy (p. 487)."

Duever (1975, 1982) explored the relationship between hydrology and plant communities in the Corkscrew Swamp (South Florida) and Okeefenokee Swamp (Florida - Georgia Border) respectively. He found that hydroperiod was the most important factor in determining wetland communities. Other factors included soil types, fire history, and successional sere.

Penfound (1952), in a thorough review of the literature to date, reported that water depth, timing of inundation and fire are the variables that determine community structure on the Southern United States wetland landscape. Brown et al. (1991) reported that a formative factor controlling wetland type on the Florida landscape was the spring season rainfall and associated water on the landscape.

Supporting the importance of hydrology in determining landscape assemblages, the National Research Council (1995) stated that the hydrologic threshold between upland and wetland plants is an inundation period of at least 14 days during the growing season. It follows, then, that a hydrologic threshold also exists for wetland plants that determines the maximum inundation period during the growing season that different wetland species will be able to tolerate.

Plan of Study

Palustrine wetland types demarcated on the Florida landscape by the National Wetlands Inventory were classified into areas of similar wetland type using a hierarchical classification technique (TWINSPAN). Map coverages of nine physical and climatic variables of the Florida landscape were obtained or created. The TWINSPAN groups were tested for similarity of the nine environmental factors at different hierarchical levels of division. The TWINSPAN classed landscape was subjected to ordination (detrended correspondence analysis and canonical correspondence analysis) to determine the importance of the measured environmental factors on wetland type and location.

Based on the ordination results and the well-supported theory that hydrology defines wetland types, map coverages of physical and climatic variables that affect the hydrology of the Florida landscape were acquired. A spatial landscape water balance model was solved using climatic inputs and physical characteristics of slope and infiltration to derive wetland regions that had different driving energies and landscape structures. Regions defined by the hydrologic model were tested for similarity and differences to determine if the between-region variation was greater than the within region variation in the characteristic driving energies and landscape structures.

METHODS

This study focused on acquiring data in a GIS (Geographic Information Systems) format and combining spatial data using geostatistical algorithms and spatial overlay analysis (Perera 1996). The general methodological approach was to first assemble the physiographic and climatic data sets and perform necessary rastorization and projection to produce data sets of like scale, resolution, and coordinate system. Secondly, the Florida landscape was classified and the determinant landscape properties of each wetland type were ascertained using geostatistical software. Finally, the hydrologic budget was calculated using GIS software to produce regions.

Detailed methods are given in succeeding sections in the following order: Description of Data Sets, Landscape Classification, Landscape Ordination, and Spatial Water Budget Modeling.

Description of Data Sets

Data acquired for wetland regionalization came from disparate sources and were organized into primary, secondary, and ancillary datasets. Primary layers included surficial geology, soils, and the digital elevation model. Secondary layers included precipitation, potential evapotranspiration, and annual days of freezing. Ancillary layers included the National Wetlands Inventory map (United States Fish and Wildlife Service, National Wetlands Inventory composite of maps from 1972-1994).

All data layers, if not already rasterized, were converted from polygons to grids for use with Arc/Info GRID. GRID is a cell-based method of analyzing data where the coverage, or map, is compartmentalized into equal area cells while maintaining the attribute data (ESRI 1991). Maps were analyzed with a cell size of 1000m x 1000m and all grids were projected to FDEP-standard Albers projection.

Primary Coverages

Primary data sets were of the physiographic type and included surficial geology, soils, and the digital elevation model.

Surficial Geology. This coverage was acquired as a pre-release draft from the Florida Geological Survey (FGS). The coverage describes Florida's surficial geology, from approximately 1m to 5m (Tom Scott, FGS, personal communication). There are ten types of geologic forms present in the coverage: clayey sand, dolomite, gravel and coarse sand, limestone, limestone/dolomite, medium fine sand and silt, sandy clay and clay, shell beds, shelly sand and clay, and peat. The scale of the original polygon map was 1:100,000.

Soils. The U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) published the State Soil Geographic (STATSGO) database at the 1:250,000 scale (USDA 1991). This file was obtained from the FDEP's digital library. The NRCS included extensive information associated with STATSGO polygons. For this analysis, Hydrogroup was selected from the database. Hydrogroup elements are either A, A/D, B, B/D, C, C/D, or D. "A" Hydrogroups are well-drained soils, and "D" Hydrogroups are poorly drained soils, and the slash value (i.e. B/D) refers to the drained/undrained condition of the soil (USDA 1991).

Digital Elevation Model. A digital elevation model (DEM) with a cell size of 92 meters and 1:250,000 scale was acquired from the University of Florida GeoPlan Center (based on United States Geological Survey 1972 elevation data) The cell size of 92 meters is the finest DEM that is currently available statewide. The range in elevation within the State was from 0m to 114m.

Secondary Coverages

Secondary maps of Florida were calculated from primary coverages or from point data that was modified to create a statewide coverage. Secondary coverages included slope, runoff, rainfall, potential evapotranspiration, and annual days at freezing.

Slope. Slope for each 1000m x 1000m cell in the State was calculated using the Arc/Info "slope" algorithm and the DEM. This algorithm determines the percent slope for each cell by comparing the elevation of the directly neighboring cells to that of the cell in question (ESRI 1991).

Runoff. Runoff coefficients were developed using the STATSGO database and landcover maps following Parker (1998) and Adamus and Bergman (1995). Each map unit, or cell, within the STATSGO database has a Hydrologic Group value that was utilized in assigning runoff values (NRCS 1998). The Hydrologic Group value is a measure of the drainage condition of each cell, and contains modifiers to acknowledge the effects of improved drainage on a cell. For instance, if a cell is classified as B/D, the "B" class refers to the improved drainage condition of the soil, perhaps due to ditching or tiling. The "D" modifier is what the cell would be like if the ditching or tiling did not occur. Since large-scale alteration of landscape drainage patterns began within the past 150 years and most landscape structures such as wetlands are likely older, all cells were reclassified to their unaltered condition for use in developing runoff coefficients (Adamus and Bergman 1995).

Runoff depends on a combination of landcover and soil type. The landcover map used (the National Wetlands Inventory map) labels cells as uplands, riverine, lacustrine, palustrine, estuarine, and marine. All wetlands and water bodies were assigned a runoff coefficient of 0.10 for all Hydrogroups, indicating that 10% of precipitation on the cell would become runoff and leave the cell. Landscape runoff coefficients for upland conditions were obtained by assigning Hydrogroup A a runoff coefficient of 0.10, Hydrogroup B a runoff coefficient of 0.17, Hydrogroup C a runoff coefficient of 0.23, and Hydrogroup D a runoff coefficient of 0.30. This follows the landcover/soil type classification of Adamus and Bergman (1995) for silviculture/upland forest and recreational/open space/range land.

Rainfall. Using monthly data for 175 stations between the years 1961-1990, average monthly rainfall coverages were generated. To create a full coverage of the State, inverse distance weighting (IDW) was used to interpolate, or spread, the space between all points. IDW estimates cell values by using a linearly weighted set of measurements (Watson and Philip 1985, ESRI 1991). Monthly maps were summed to create an annual rainfall coverage.

Potential Evapotranspiration. A potential evapotranspiration coverage was generated using the Thornthwaite Equation and the data from 52 stations reporting monthly temperature. The Thornthwaite Equation is as follows:

$$PET_i = 16\,(10T_i / I)^a \qquad (1)$$

Where:

PET_i is potential evapotranspiration in mm/month for month i

T_i is the temperature mean in Celsius for month i

I is the local heat index: $I = \sum (T_i / 5)^{1.514}$ (for each month)

$a = (0.675 \times I^3 - 77.1 \times I^2 + 492{,}390) \times 10^{-6}$

The Thornthwaite Equation has been alleged to over-estimate potential evapotranspiration, especially in summertime, as it does not take cloud cover into effect (Jones et al. 1984). However, studies have also supported the use of the Thornthwaite Equation as geographically representative for reporting potential evapotranspiration, especially when the data needed for other methods (Penman, Linacre, Blaney-Criddle, Holdrige) is not available or is sparsely available (Dolan et al. 1984, Muller and Grymes 1998, Yin and Brook 1992, Shih and Cheng 1991, Rykiel 1984, Mitsch and Gosselink 1993, Fernald and Purdum 1998). IDW was used to interpolate the space between the points for each month.

Annual Days at Freezing. Using data from 64 stations throughout Florida between 1951-1980, a coverage of mean annual days at freezing was created (Koss et al. 1988). Space between stations was interpolated using IDW.

Landscape Classification

A hybrid combination of GIS and statistics was used to classify the Florida landscape. Freshwater palustrine wetlands in Florida were initially located on the National Wetlands Inventory coverage. The clustering of wetland types was explored using a hierarchical classification algorithm (TWINSPAN) that clusters regions of similar wetland type and percent occurrence. Landscape characteristics of each TWINSPAN-determined region were explored using ordination methods (detrended correspondence analysis, canonical correspondence analysis), which places similar entities close together in ordination space and dissimilar entities farther apart. The relationships between wetland type and occurrence, and the landscape characteristics that drive those relationships, were discerned.

Percent occurrence of each wetland type for TWINSPAN analysis was obtained from the NWI coverage using the ArcInfo "blocksum" command. A working window size of 1020m x 1020m centered on the NWI 30m active cell was selected (Figure 4). This size was chosen to approximate the 1000m x 1000m working cell size. A wetland type (e.g. emergent marsh) was chosen and each NWI 30m cell that contained (for example) emergent marsh was recoded "1". All other data cells were recoded "0". The "blocksum" command then added all the "1's" that occurred in each 1020m x 1020m working rectangle about the active cell. The resultant value was divided by 1156 (the number of cells that made up the working window) to give landscape percent abundance in each approximately 1000m x 1000m cell. The process was iterated for each freshwater wetland type, and then the tables were joined and the cells resampled to 1000m x 1000m. The percent abundance was then simplified using a modified Bruan-Blanquet cover-abundance scale (Table 1). The result of this process was the approximate percent occurrence of each wetland type in each 1000m x 1000m cell in Florida.

a)

1	0	1	1
0	0	1	0
1	1	0	0
1	0	0	1

b)

8	8	8	8
8	8	8	8
8	8	8	8
8	8	8	8

Figure 4. The Arc Info "blocksum" process sums the values of the cells in the working window (a) above. Then the value of the entire working window is given to each of the cells in the working window (b). In this study, a "1" in (a) represents a particular wetland type, such as emergent marsh, on the landscape. The value of (b) would next be divided by the number of cells in (a) to get a percentage (in this instance, 50%). Finally, the cells would be resampled and the percentage given to the larger cell.

Table 7: Modified Bruan – Blanquet Cover Abundance Scale.

Percent Abundance	Recoded %
0	0%
0.1 – 16%	8%
16.1 – 32%	24%
32.1 – 48%	40%
48.1 – 64 %	56%
64.1 – 80%	72%
80.1 – 100%	90%

The polythetic divisive hierarchical classification technique TWINSPAN (two-way indicator species analysis) developed by Hill (1979) was used to cluster the cells into groups of similar wetland type and percent occurrence. TWINSPAN is a widely used program for classifying ecological data (Jongman et al. 1987). TWINSPAN begins with all the cells in a single group and divides the group into smaller and smaller clusters until an arbitrary stopping point is reached (Hill 1979). This is accomplished using reciprocal averaging, a type of weighted average ordination. Reciprocal averaging (also known as correspondence analysis) is an iterative ordination method whereby wetland type scores are the average of the percent wetland occurrence scores, and the percent wetland occurrence scores are the average of the wetland type scores (Gauch p. 144-152, 1982). The process is repeated until the scores stabilize, typically 20 to 100 iterations (Gauch 1982). To polarize the samples for the TWINSPAN dendrogram, the wetland type scores that represent the extremes after the scores have stabilized are emphasized and the ordination axis is divided in the middle to split the cluster into two groups (Pielou 1984). This complete process is repeated for each group to provide four groups, and so on until the groups have the maximum levels of division or the minimum number of cells. In this study, two levels of division were chosen, for a maximum of four groups. PC-ORD software (MjM Software 1998) was used to perform all geostatistical analysis.

TWINSPAN necessitates that wetland percentage abundance cut levels, or pseudospecies, are chosen. Pseudospecies cut levels of 0, 10, 30, and 50, were chosen for TWINSPAN analysis (McCune and Mefford 1995). Pseudospecies define the range of the abundance classes used in the TWINSPAN algorithm defined in the preceding paragraph and are a necessary component of TWINSPAN analysis, as TWINSPAN analyzes abundance data based on presence/absence (Gauch 1982). For instance, if a cell contains 15% emergent marsh, it would be classified as "present" for pseudospecies cut levels 0 and 10, and "absent" for pseudospecies cut levels of 30 and 50.

Once the dataset was clustered and the dendrogram constructed using TWINSPAN, new coverages were created to reflect the TWINSPAN hierarchical classification of the cells. For example, all cells were classified in the first dendrogram branching as "Group IA" or "Group IB." A statewide coverage was created to reflect this classification; every cell in Florida was classified as Group IA or Group IB. Group IA and Group IB were then split into two groups each by the next TWINSPAN branch of the dendrogram. A statewide coverage was also created that separated the state into four groups.

Using spatial statistics, the averages within each TWINSPAN group for each wetland type and percentage were obtained. For instance, TWINSPAN Group A could have hypothetical wetland type average values of 15% emergent marsh, 25% shrub scrub, 10% forested deciduous, 2% broad leafed evergreen, 8% needle leafed evergreen, and 40% upland. The average for the following environmental variables were also obtained: hydraulic conductivity of the surficial geology, percent slope, runoff, annual days of freezing temperature, soil Hydrogroup, January to April rainfall, January to April potential evapotranspiration, annual rainfall, and annual potential evapotranspiration. The averages for each of these environmental variables were statistically compared between groups to determine if there are differences in environmental variables that translate into differences in wetland type and abundance. The environmental variables for the first dendrogram division (two groups) were checked for similar means using student's t-test statistic (Zar 1984, Anderson and Davis 1997). Successive dendrogram divisions were compared using fixed-effects ANOVA statistic and the Tukey Multiple Comparison Test (Brand and Almendinger 1993, Shaltout et al. 1995, Zar 1984). The percentage and type of wetlands found in each TWINSPAN class were also tested for independence using the chi-squared test.

Landscape Ordination

TWINSPAN dendrogram group relationships with environmental variables were investigated using detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA). For both ordination methods, the second level dendrogram division was utilized (i.e. the Florida landscape was classified into 4 groups). As the data set contained over 140,000 samples, a randomly chosen sub set (n=8100) was selected for analysis of the second dendrogram groups. PC-ORD software was used for the analysis (MjM Software 1998).

Detrended Correspondence Analysis

DCA ordinates complex relationships between samples and environmental variables into low dimension space using reciprocal averaging (Gauch 1982). DCA was used to indirectly examine the environmental gradients that affect the location of wetland types on the landscape. Similar cells are ordinated in space closer than dissimilar cells. The axes were not rescaled and the number of segments was left at the recommended default value of 26.

Canonical Correspondence Analysis

Canonical correspondence analysis (CCA) was used in directly examining environmental gradients responsible for wetland distribution on the landscape. As in DCA, CCA ordinates the main matrix (wetland percentage distribution) using reciprocal averaging (McCune and Mefford 1995). The ordination of the main matrix in CCA, however, is constrained by multiple regression using variables present in the second matrix (environmental variables) (McCune and Mefford 1995). The output of CCA analysis is both ordination, were similar cells are clustered in space, and a vector plot, where vectors emanating from the origin visually indicate the importance of the environmental variables in determining wetland location on the landscape. The PC-ORD defaults were used for the CCA ordination: rows and columns scores standardized by centering and normalizing, scaling of ordination scores by optimizing columns, and graphing scores utilized a linear combination of environmental variables (McCune and Mefford 1995). Row values of zero in the main matrix were changed to 0.1, as null row values are not allowed.

Spatial Water Budget Modeling

Based on analysis of the preliminary TWINSPAN classification and DCA and CCA ordination, and on the preponderance of evidence in the literature, it was determined that landscape hydrology plays an important role in determining wetland position on the Florida landscape. It was therefore determined germane to wetland region creation to model the movement of water over the landscape, or to calculate the landscape water balance.

The landscape water balance was calculated for the period from January to April. The rational for using this period is related to the effects of water and drought on wetland structure and organization. Hydrology manifested through drought and flooding affects the vegetative community structure of wetlands. The affects are more pronounced during the early spring season from January to April. In Florida, most wetlands have standing water during the wet season, and wetlands generally have some standing water at some time on an annual basis. Brown (1991) suggested that a critical determining factor in wetland community organization is the length and severity of the early spring drought. This is the period when wetlands often dry down, yet it is the beginning of the growing season when plants experience their first flush of new growth. Additionally, this period of the year is also accompanied by increased incidence of fire from dry thunderstorms. The latter portion of the January to April time period also includes the beginning of the growing season when plants are susceptible to stresses from too much water on the landscape. As with too little water during the growing season, too much water can also influence wetland vegetative community structure. In essence, wetland structural organization may be determined by both the lack of rainfall in the early spring and by the abundance of rainfall in the early growing season.

The Landscape Water Balance Model

The landscape water balance model defined wetland regions based on a water budget for each cell. The water balance, or hydrologic budget equation, which describes the flow of water into or out of a cell, is given in equation 2, below.

$$\Delta V/\Delta T = (P + Si + Gi) - (PET + So + Go) \qquad (2)$$

Where:
V = volume of water (units^3)
T = time (t)
P = precipitation (units^3)
Si = surface inflow (units^3)
Gi = groundwater inflow (units^3)
PET = potential evapotranspiration (units^3)
So = surface outflow (units^3)
Go = groundwater outflow (units^3)

A modified water budget equation was applied as a spatial algorithm to the entire Florida landscape to calculate a "Landscape Water Balance Index" (LWBI). The concept was to apply a modified version of the basic hydrologic budget equation (equation 2) to each 1000m x 1000m cell, generating a coverage that was an index of the balance of precipitation and outflows. Groundwater inflows were not used in the LWBI equation, as the groundwater inflow is a function of the depth to the water table, which is synoptic information. The surface water inflow was also determined to be specious to the equation, as the particular direction and amount of surface water inflow from cell to cell is at a scale too fine for a regional water budget equation. The modified water budget equation is as follows:

$$Q = P - So - Go - PET \quad (3)$$

Where:

Q = cell moisture (m/cell)
P = precipitation (m/cell)
So = surficial outflow (m/cell)
Go = groundwater outflow determined by Darcy's Equation (m/cell)
PET = potential evapotranspiration (m/cell)

The result is a water budget driven by factors that are regional in scale and which was used to calculate the LWBI for the January - April time interval. The equation was applied to all cells in the Florida coverage. Cell values were grouped into classes based on the critical depth of soil saturation (beyond which wetland plants typically do not exist) and statistical clustering algorithms.

Surficial Hydrology

Pedogenic characteristics and slope regulate outflow from each cell via the equation:

$$So = P * RO_c * SL \quad (4)$$

Where:
So = surface outflow (m/cell)
P = precipitation (m/cell)
RO_c = runoff coefficient
SL = percent slope

The effect of higher percent slope on cell water is to move greater volumes of water off the cell per unit time. Therefore, *SL* values of zero will keep water on the cell for infiltration regardless of the RO_c, and slope values close to 100% will radically increase the potential outflow for each RO_c.

The precipitation remaining on each cell for flow after runoff and potential evapotranspiration is defined by:

$$Rm = P - (PET + So) \quad (5)$$

Where:
Rm = remaining moisture after runoff and potential ET (m/cell)
P = precipitation (m/cell)
PET = potential evapotranspiration (m/cell)
So = surface outflow (Eq. 4) (m/cell)

Groundwater Outflow

As infiltration describes the rate that water enters the soil, transmission describes the movement of water through soil horizons (Baver et al. 1972). The *Rm* value from equation 5 for each cell is assumed to flow downwards through the underlying layer until it reaches the water table. The rate and amount of flow through the semi-permeable layer is controlled by the effective hydraulic conductivity, K_e (Heath 1983) and the hydraulic gradient, $\Delta h/\Delta L$ (Baver et al. 1972). Effective conductivity is found by:

$$K_e = K * \lambda \quad (6)$$

Where:
K_e = effective conductivity (m/time)
K = hydraulic conductivity (m/time)
λ = conductivity coefficient based on fluid and particle properties (Baver et al. 1972)

Lacking K_e values for the surficial geology grid, the water balance for Florida was back- calculated to obtain a preliminary K_e. From the interpolated data, the total volume of rainfall on the state was obtained. This figure equates well with other reported values for rainfall (Odum et al. 1997). While Fernald and Purdum (1984) calculate a soil infiltration rate of 17% for Florida, Rykiel (1984) reported approximately 1% of the rainfall in the Okefenokee Swamp infiltrated through the surface into "deep seepage." This study utilized Rykiel's 1% infiltration, as the analysis concerns the water no longer available to the system. The λ coefficient was calculated:

$$\lambda = (1\% \text{ rain}) / [\ \Sigma\ (Ki * Ai)\ ] \quad (7)$$

Where:
λ = conductivity coefficient
1% rain = 2.2 E10 m^3 / yr
Ki = hydraulic conductivity K for each soil texture i (m/time)
Ai = area of each soil texture i (m^2)
λ is calculated to be approximately 4.6 E-5.

Hydraulic conductivity, K, is normally used to measure potential flow through saturated media. Saturation of the underlying media is a function of both infiltration from above and the depth to the water table. Depth to the water table is synoptic and unavailable information, which therefore necessitates the assumption that the media is unsaturated. This study assumes that the media is unsaturated throughout and uses K_e (effective conductivity). It is also assumes that there is no capillary rise in the media due to the same synoptic water table information.

The hydraulic gradient, $\Delta h/\Delta L$, is determined from (Baver et al. 1972):

$$\text{Hydraulic Gradient} = \Delta h/\Delta L \quad (8)$$

Where:
Δh = Remaining Moisture (m, from Equation 5) + depth (m) of porous media
ΔL = depth of porous media (m), assumed to be constant at 5m

These components are combined in Darcy's law, which describes the movement of water through porous media (Heath 1983):

$$Q/A = K_e\ (\Delta h/\Delta L) \quad (9)$$

Where:
Q/A = (potential flow m/time)/(area of flow m^2/time)

K_e = effective conductivity (m/time)
$\Delta h/\Delta L$ = hydraulic gradient, defined above

Landscape water balance is the difference between the water that remains on the cell following runoff (Eq. 5) and the amount of water that passes through the soil layer (Eq. 9):

$$\text{Landscape Water Balance} = Rm - Q/A \qquad (10)$$

Where:
Rm = water remaining after runoff and PET (m/cell/time) (Eq. 5)
Q/A = water which flows down through soil layer (m/cell/time) (Eq. 9)

The landscape water balance equation was applied to all cells on the Florida landscape.

RESULTS

In this section, the statistically derived determinants of wetland type and the results of the landscape water budget model are described. Firstly, the coverages generated and used to create the Landscape Water Balance Index (LWBI) are presented in the section titled "Spatial Modeling Data Layers." Secondly, the results of the geostatistical analysis, which determines the relative importance of each measured environmental variable to wetland location and type, are presented in the "Wetland Landscape Determinants" section. The results of the spatial water budget model are given in the "Landscape Water Balance Model Results" section, third. Fourthly, the regions defined by the LWBI model are in the "Description of the Landscape Water Balance Regions" section, which additionally includes the percentages of each wetland type and the average values for environmental variables within each region. Finally, the statistical differences between regions are given in the section titled "Statistical Analysis of the Wetland Regions."

Spatial Modeling Data Layers

The primary geographical information system datasets utilized in the water budget modeling included Surficial Geology (Figure 5), Hydrogroup (Figure 6), Slope (Figure 7), Runoff Coefficients (Figure 8), Rainfall (Figure 9), Potential Evapotranspiration (PET, Figure 10), and Annual Days of Freezing (Figure 11), each described in the Methods section. In the process of creating the Landscape Water Balance Index (LWBI), four new data layers were created. These coverages included the Surface Outflow (Equation 4, Figure 12), Remaining Moisture (Equation 5, Figure 13), Effective Hydraulic Conductivity (Equation 6, Figure 14), and Darcy's Law for percolation (Equation 9, Figure 15).

Wetland Landscape Determinants

The importance of unique measurable environmental inputs to wetland landscape position was determined through the use of TWINSPAN classification and DCA and CCA ordination.

Classification

The essence of TWINSPAN classification lies in the selection of samples. Whereas most users of vegetation classification models are constrained by the environment in which they work to select a "workable" number of samples (i.e. stratified random distribution, belt transects, releve plots), geographic information systems afford the selection of every single hectare of the Florida landscape for the classification algorithm. As other investigators have run transects along an environmental gradient (e.g. John and Dale 1990, Allen and Peet 1990) or used a random selection of plot locations to then plug into the TWINSPAN classification (e.g. Tonteri et al. 1990, Host and Pregitzer 1991), this study has been able to use each cell in Florida (n=143,326) as a sample plot to classify the landscape of Florida.

The TWINSPAN dendrogram of the Florida landscape is presented in Figure 16. The eigenvalues and indicators are given in Table 2. The hierarchical landscape classification by TWINSPAN analysis was limited to 2 levels of division, or 4 groups. Maps for wetland landscape classification with 2 and 4 classes are presented in Figures 17-18.

The TWINSPAN divisions were successful at differentiating the landscape of Florida into groups of similar wetland features. The eigenvalues, which define the amount of variance explained by each ordination axis (1 = an extremely tight correlation between

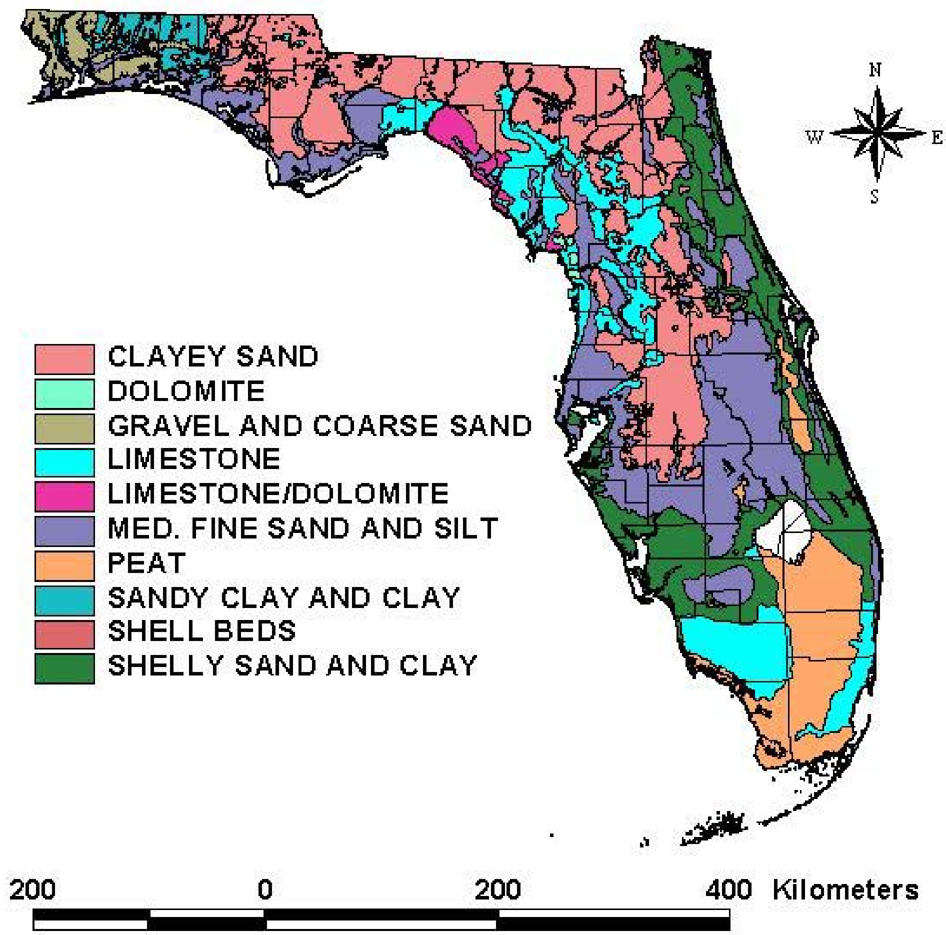

Figure 5. The surficial geology map was acquired from the Florida Geological Survey as a pre-release draft. This map represents the geology between 1 and 5 meters from the surface.

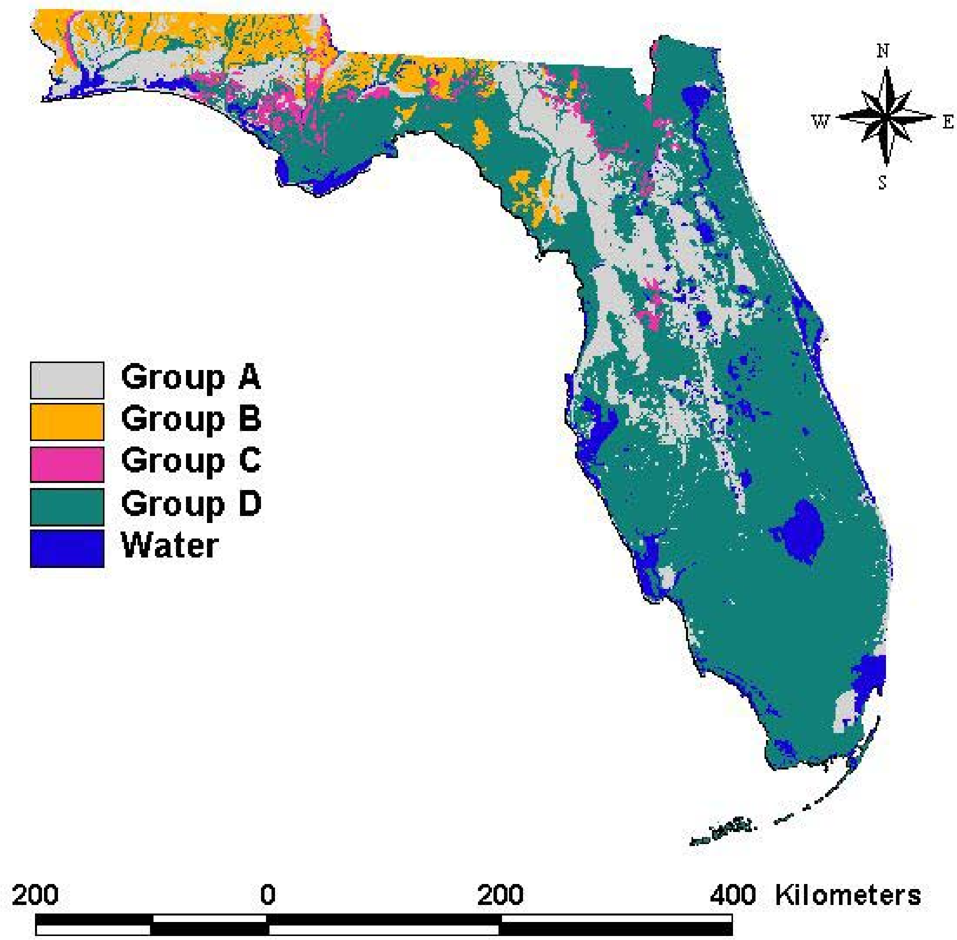

Figure 6. Hydrogroup classes were acquired from the STATSGO database (USDA 1991). The gradient is from well-drained soils (A) to poorly-drained soils (D).

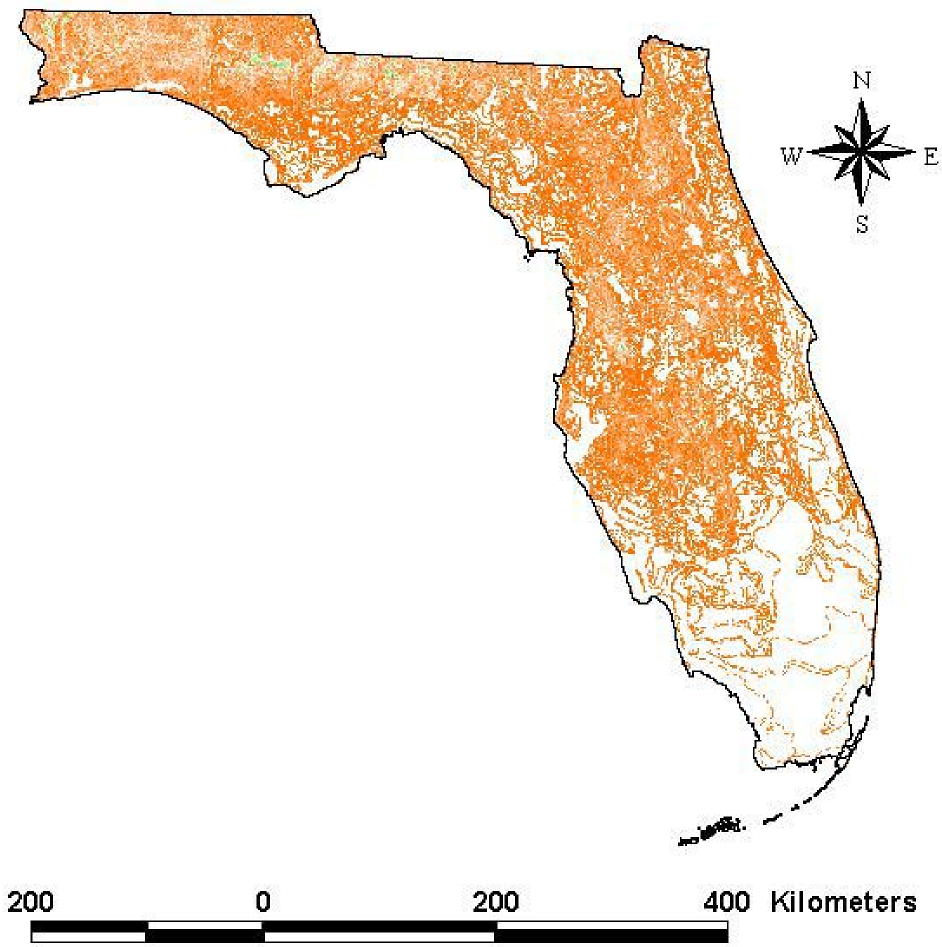

Figure 7. Slope was derived from USGS digital elevation models. The range in values is from -0.6% to 4.8%. The color ramp is white to orange to green (lowest to highest slope).

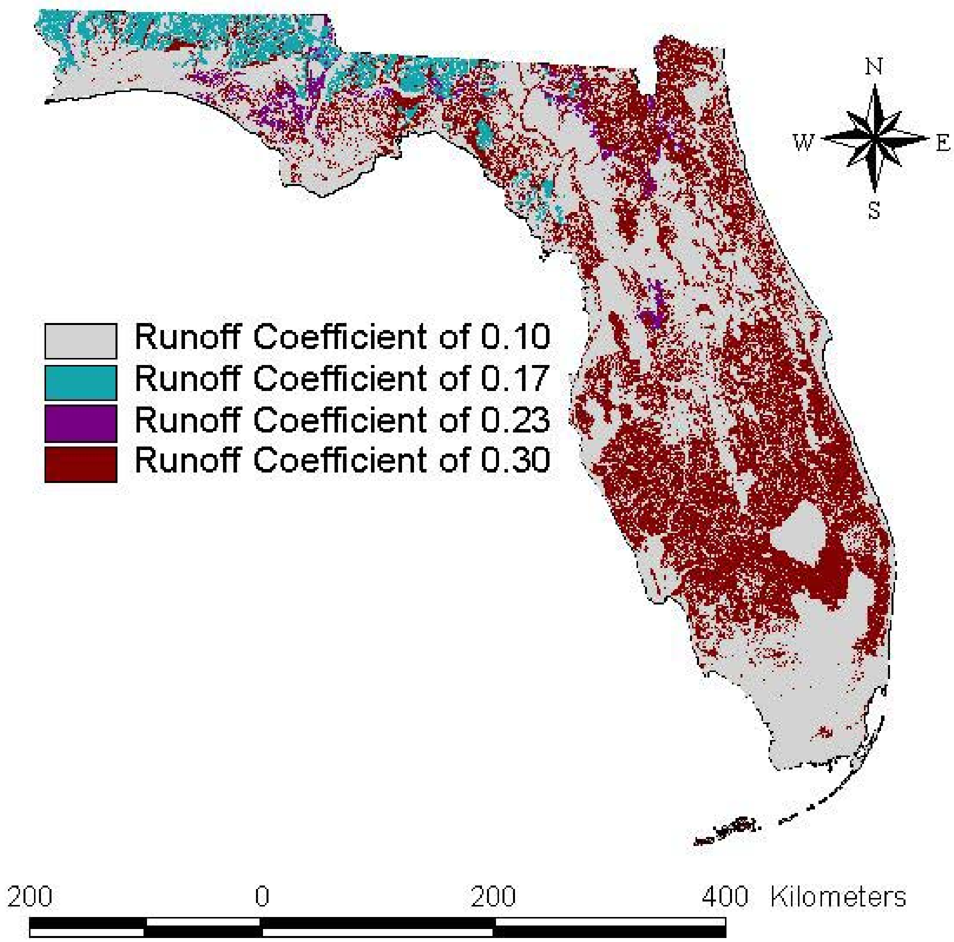

Figure 8. The runoff coefficients were determined from the land cover and soil type. Soil types were obtained from the STATSGO database, and the general land cover was obtained from the National Wetlands Inventory coverage.

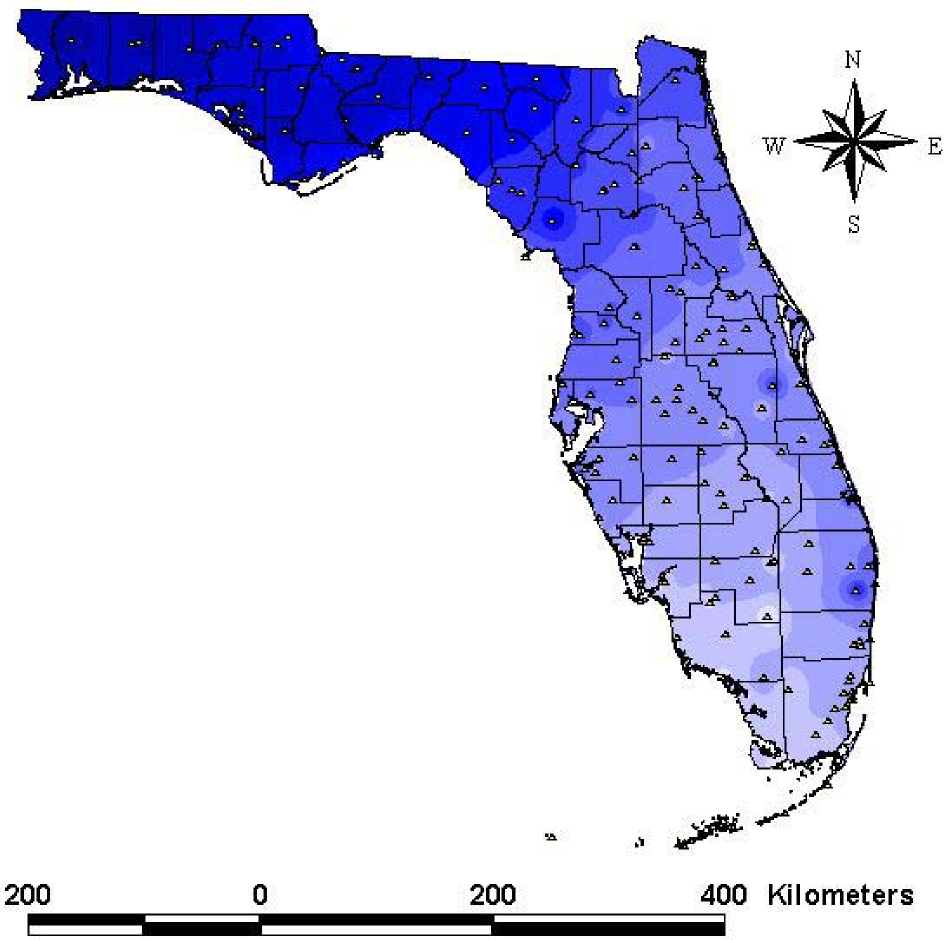

Figure 9. The average rainfall from 175 stations over 29 years was used to make this map. Inverse distance weighting was used to interpolate the space between the stations, represented as yellow triangles. The January – April range in rainfall is 0.17m (lighter blue) to 0.58m (darker).

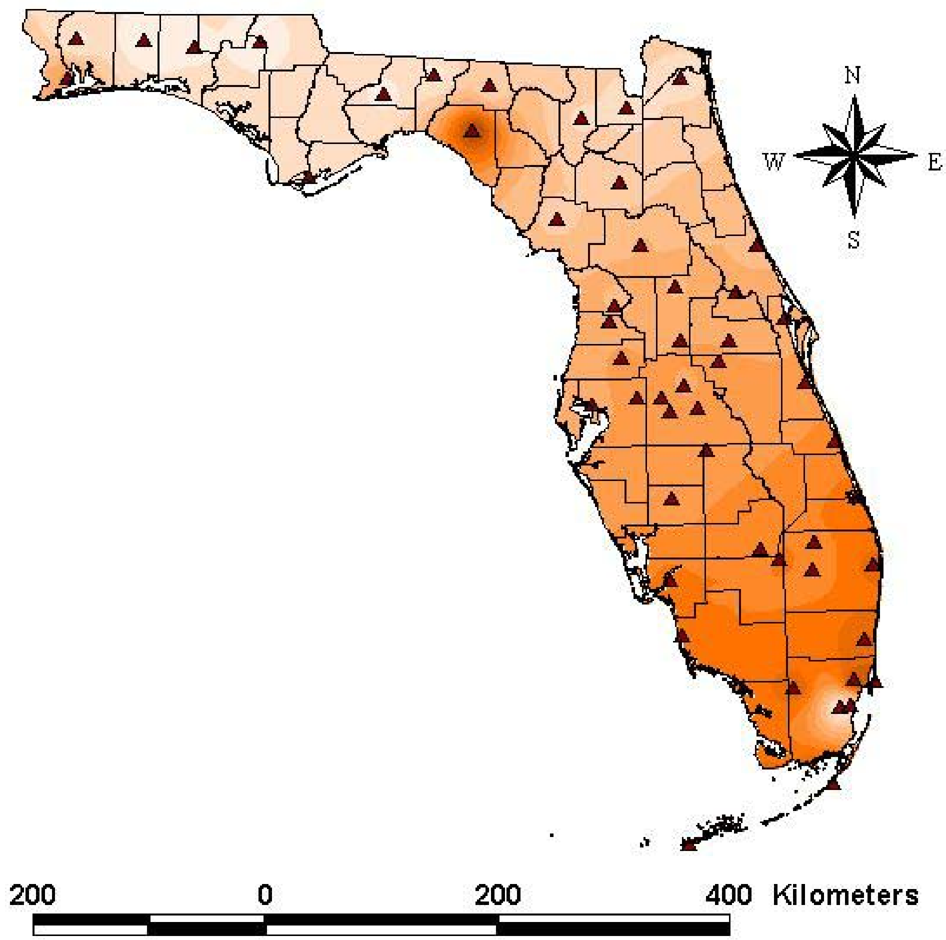

Figure 10. Thornthwaite's model was used to derive potential evaporation for January to April. Inverse distance weighting was used to interpolate the space between stations, represented as red triangles. The January – April range in PET is from 0.14m (lighter orange) to 0.33m (darker).

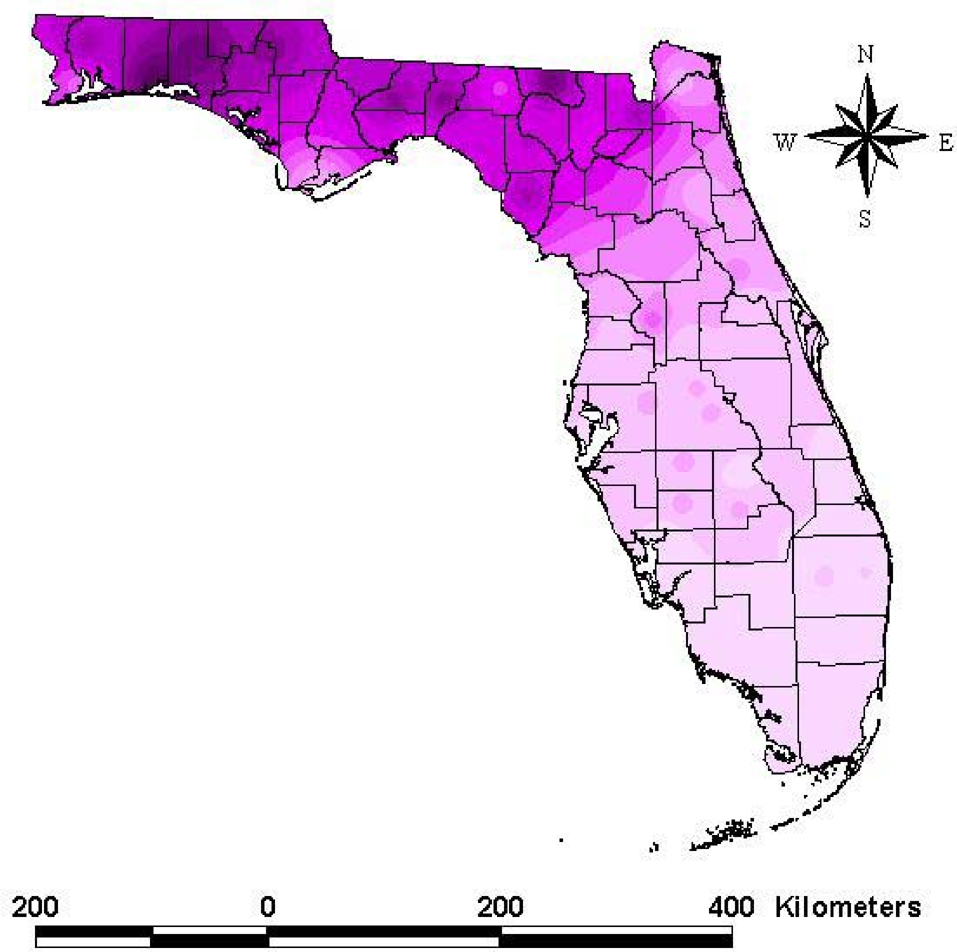

Figure 11. Coverage of the annual days at freezing for Florida. Lighter colors indicate fewer days where the temperature reaches freezing. Data is from NCDC Climate Normals from 1951 – 1980. The range is from 0 (lighter color) to 40 days/year (darker).

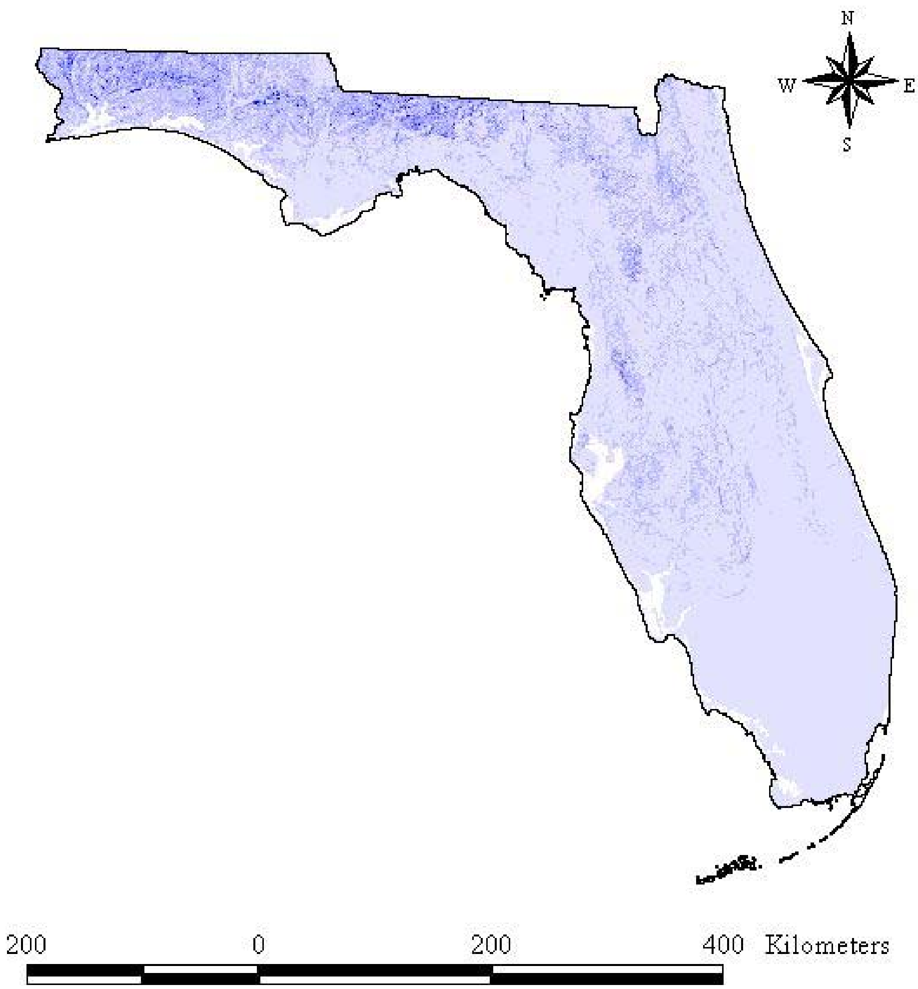

Figure 12. The surface water outflow map was created by multiplying the January – April precipitation by the slope and the runoff coefficient. The range in values is from 0.0004m (lighter color) to 0.0068m (darker color).

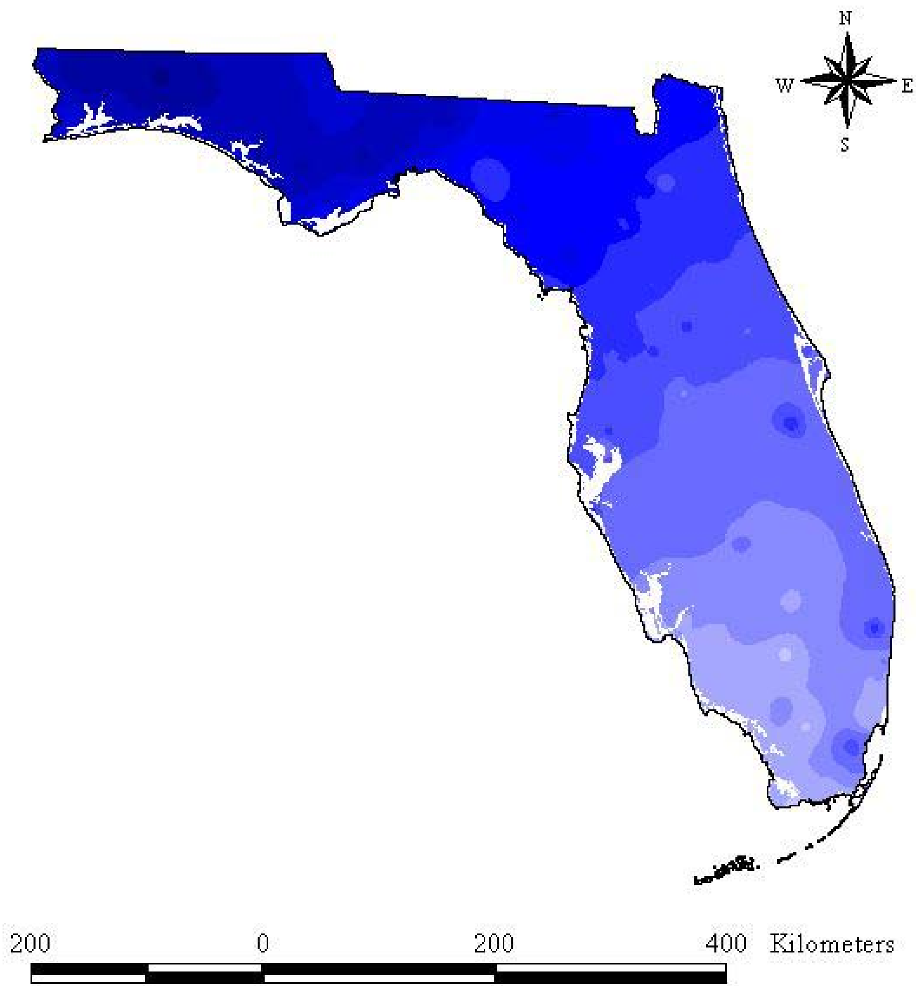

Figure 13. The remaining moisture is the amount of January to April precipitation left on the cell to percolate downward after the effects of the January to April potential evapotranspiration, slope, and runoff. The range in values is from -0.155m (lighter color) to 0.437m (darker colors).

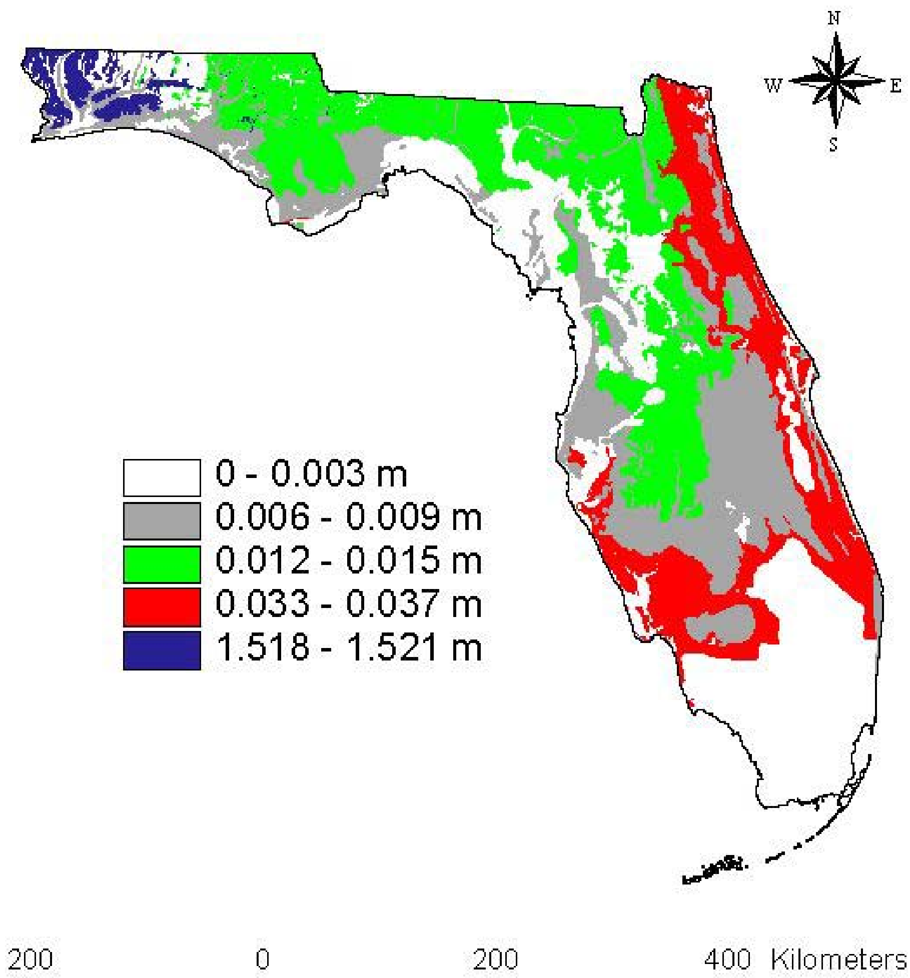

Figure 14. The effective conductivity for the January to April period. The range in values is from 0 to 1.521m / 4 months.

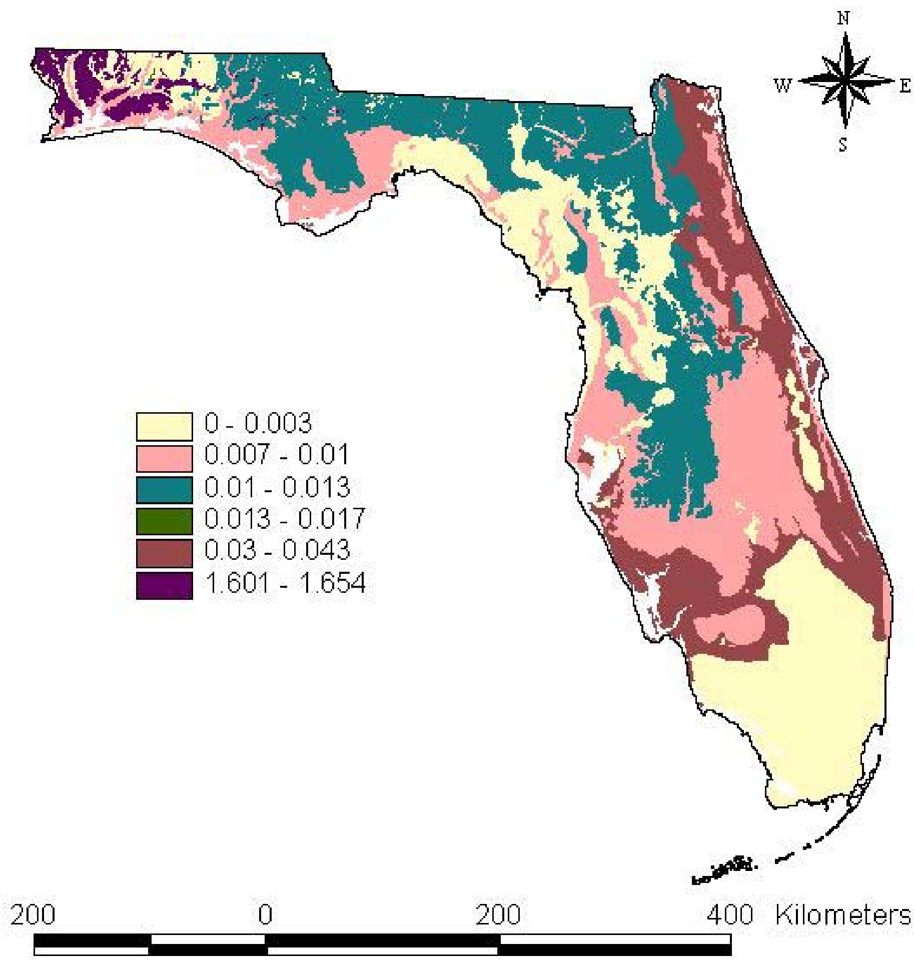

Figure 15. Darcy's law for the downward percolation of water. The values were found by multiplying the effective conductivity, Ke, by the hydraulic gradient. Data are given in m^2 for the January to April months.

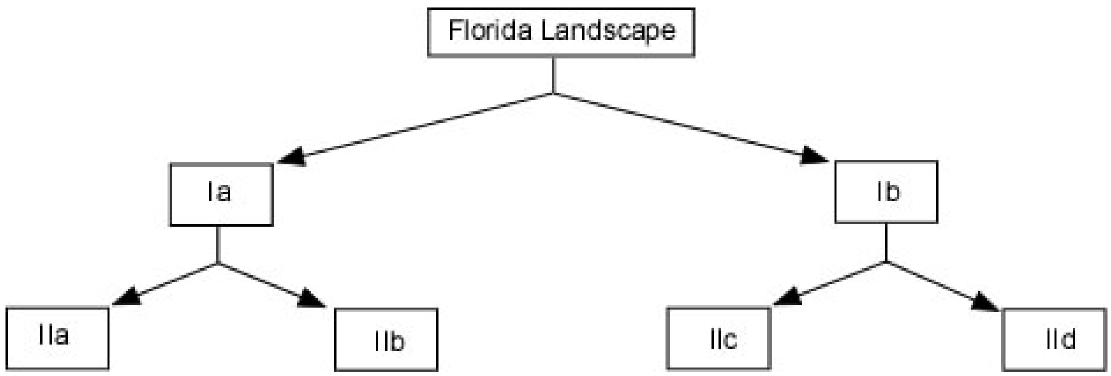

Figure 16. The TWINSPAN classification dendrogram for the Florida landscape. The main wetland type for each class in the first division is as follows: Ia – forested and uplands, Ib – shrub scrub and emergent marsh. The second division is: IIa – forested deciduous, IIb – uplands, IIc – shrub scrub, IId – emergent marsh.

Table 8. Eigenvalues and indicators of TWINSPAN classification levels one and two.

	Level One	Level Two
Eigenvalue	0.3150	0.3367
Positive Indicators	Emergent, Shrub Scrub	Needle Leafed Evergreen
Negative Indicators	Forested Deciduous, Needle Leafed Evergreen, Broad Leafed Evergreen	Broad Leafed Evergreen, Forested Deciduous

variance and ordination axis, McCune and Mefford 1995), are as follows: division one eigenvalues = 0.3150, and division two eigenvalues = 0.3367. Each level of TWINSPAN classification, with eigenvalues in the 0.30 – 0.40 range, represents relatively distinct landscape groupings (*sensu* Ross et al. 1992, Heikkinen 1991).

The initial TWINSPAN division separated Florida into two divisions: upland/forested deciduous (Ia) and emergent/shrub scrub (Ib) (see Figures 16 - 17). The forested and emergent/shrub scrub dichotomous clustering at the first classification is similar to results obtained by Ross et al. (1992), who used TWINSPAN to classify vegetation zones in the Florida Keys. The average percent of the wetland types for the first division is given in Table 3.

The second level of division separates Florida into four regions (see Figures 16, 18). The Ia class from the first TWINSPAN division is now split into two groups, forested deciduous (IIa) and uplands (IIb). The IIa class contains 36.3% forested deciduous, 11.0% needle-leafed evergreen, and less than 4% of emergent marsh, shrub scrub, and bread leafed evergreen (Table 4). The forested deciduous wetlands are clustered around the Apalachicola River delta in the panhandle, around Big Cypress National Preserve in South Florida, around the Green Swamp in Central Florida, and the headwaters of the St. John's River in the eastern part of central Florida. The uplands (IIb) are scattered throughout the state, but appear clustered in the far western Panhandle and along the Suwannee River floodplain in the Big Bend area of the Gulf Coast. There is a greater percentage of broad-leafed evergreens (2.5%) in this class than in any other class, and a very low percentage of needle-leafed evergreens (1.0%). Most lake areas present in the Florida landscape have been classified as IIb by TWINSPAN, and the areas of the state where the NWI was not complete (< 5%) have been classified as IIb.

Region Ib from level one TWINSPAN classification is now separated into shrub scrub (IIc) and herbaceous emergent communities (IId). The shrub scrub community (IId) is almost entirely located near the Everglades Agricultural Area, southwest of Lake Okeechobee. The average value for cells in this region for shrub scrub wetland type is 55.4%, by far the highest average wetland type for any class created by TWINSPAN. The emergent area (IId), like the uplands area (IIb), is scattered throughout the state. The emergent wetlands, though scattered, are mostly found in the peninsular area south of Cape Canaveral. Cells in this group average 21.5% emergent marsh, 2.1% shrub scrub, and less than 1% all other types of wetland communities.

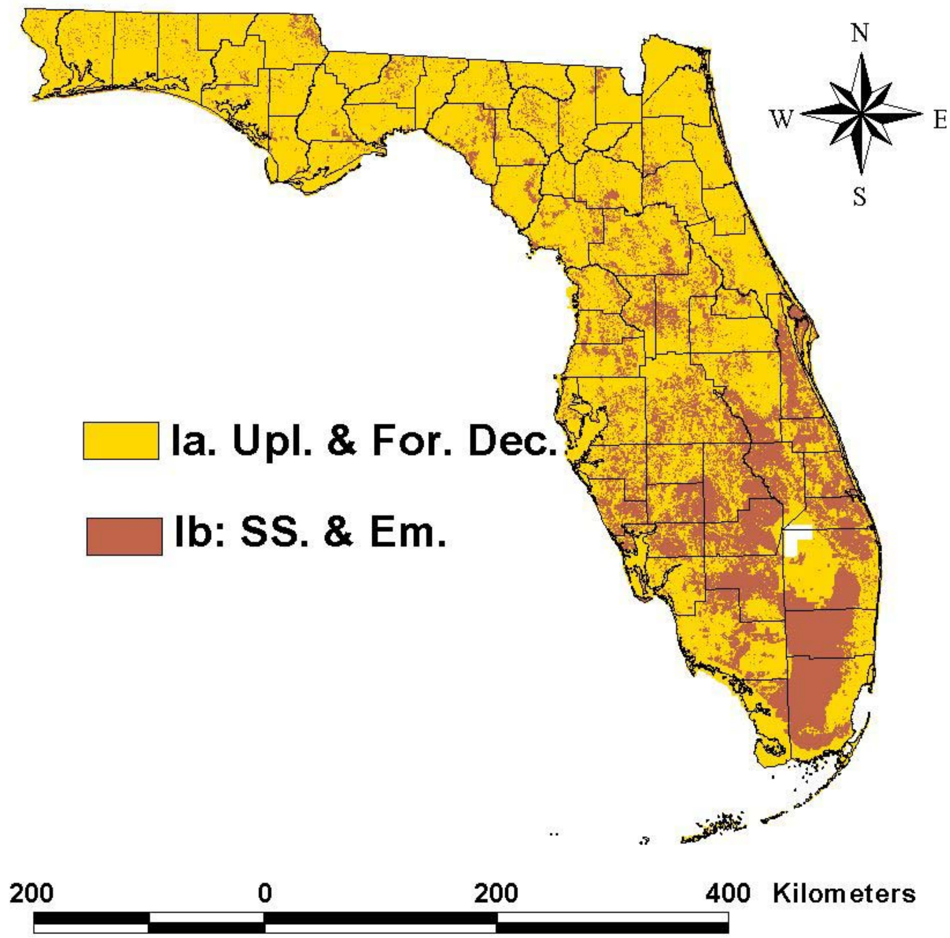

Figure 17. The TWINSPAN Classification First Division. Class Ia is mainly upland/forested wetland. Class Ib is mainly emergent/shrub scrub (see Table 3).

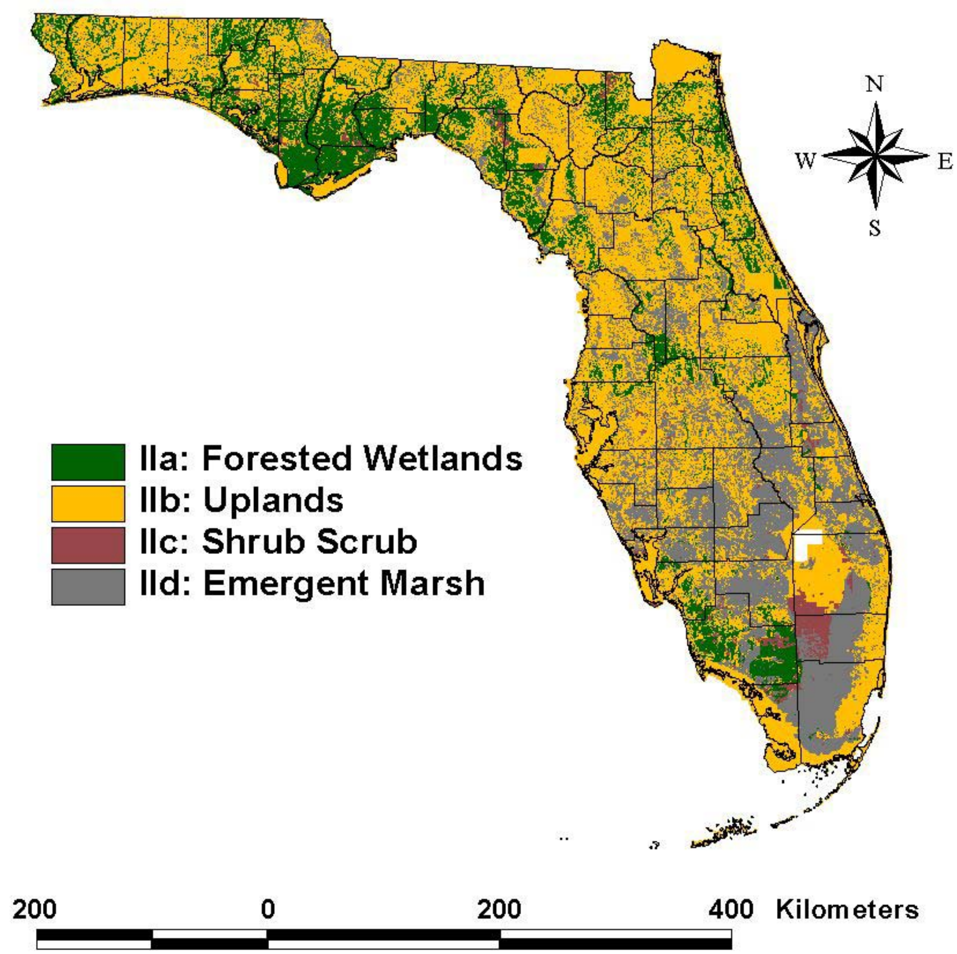

Figure 18. The TWINSPAN second division classification of the Florida landscape. The wetland type percentages for each class are given in Table 4.

Table 3. Average percent and extent of each wetland type for TWINSPAN, first division.

	Emer. Marsh	Shrub Scrub	For. Decid.	Br.Leafed Evrgn.	Ndle. Lfd. Evrgn.	Landscape Percent
Ia	3.804	1.769	10.786	1.723	3.392	0.252
Ib	33.688	19.846	2.906	1.281	1.644	0.748

Table 4. Average percent and extent for each wetland type in the second TWINSPAN division.

	Emer. Marsh	Shrub Scrub	For. Decid.	Br.Leafed Evrgn.	Ndle. Lfd. Evrgn.	Landscape Percent
IIa	3.433	2.300	36.327	0.851	10.988	0.184
IIb	2.977	1.486	5.291	2.447	0.968	0.563
IIc	6.643	55.391	4.339	1.914	3.537	0.025
IId	21.479	2.130	0.926	0.377	0.250	0.228

Comparison of TWINSPAN-Derived Landscape Groups

To determine if the TWINSPAN groups were unique with regard to the type and percentage of wetlands found in each group, the TWINSPAN-derived landscape groups (at the second level of classification) were subjected to the chi-squared test for independence. The test determined that the four landscape groups were unique with regard to wetland type and percentage (X^2 = 209.9446, p=0.0001).

A central premise to the geostatistical analysis of Florida's wetlands is that there are unique and measurable differences that exist in the environmental inputs that define wetland type and location in Florida, and that these differences can be minimized through regionalization. Using the TWINSPAN classification of wetland types, the means of nine environmental variables were examined for each TWINSPAN class to the second level (four groups). The environmental variables and the values for TWINSPAN divisions 1 and 2 are presented in Tables 5 and 6. A two-sample t-test was used to compare environmental means for class Ia and Ib (Table 7). The t-test revealed no similar means for the environmental values of the first TWINSPAN division. A fixed-effects ANOVA was employed to test for similar means of environmental values for the TWINSPAN second division (i.e. mean yearly rainfall for IIa = mean yearly rainfall for IIb = mean yearly rainfall for IIc, etc.). The results of the fixed-effects ANOVA are presented in Table 8. In every instance, at least one mean differed significantly from the others. To determine which means differed, the cells were then subjected to the Tukey Multiple Comparison Test, amongst the "most widely accepted and commonly used methods" for multiple comparisons (Zar 1984). The Tukey Test was chosen above other multiple comparison methods such as Kruskal-Wallis (Brand and Almendinger 1993), Wilcoxon rank-sum test (Frenzel 1996), Cochran's Q-Test (Zamora-Munoz and Alba-Tercedor 1996), Mann-Whitney U-Wilcoxon Rank W Test (Retuerto and

Table 5. Landscape averages for each of the TWINSPAN classes in the level one classification.

	Vertical Percolation Rate (m/day)	Yearly Rain (cm)	Yearly PET (cm)	% Slope	% Runoff	Annual Days at Freezing	Hydrogroup	January –April Rainfall (cm)	January – April PET (cm)
Ia	12149.758	139.776	104.261	0.347	14.772	14.565	2.954	35.822	18.933
Ib	2341.320	136.397	115.966	0.072	13.153	4.624	3.711	27.215	22.133

Table 6. Landscape averages for each of the TWINSPAN classes in the level two classification.

	Vertical Percolation Rate (m/day)	Yearly Rain (cm)	Yearly PET (cm)	% Slope	% Runoff	Annual Days at Freezing	Hydrogroup	January – April Rainfall (cm)	January – April PET (cm)
IIa	9625.008	144.007	101.465	0.272	14.299	17.741	3.452	39.205	18.064
IIb	14510.707	138.897	104.323	0.396	14.970	14.485	2.758	35.469	18.944
IIc	2532.499	139.959	111.199	0.102	12.106	9.334	3.671	31.155	21.268
IId	4660.533	134.701	112.234	0.184	14.280	6.147	3.208	28.522	21.414

Table 7. Results of the t-test statistic between TWINSPAN division one classes (Ia and Ib). In all instances, the means for each class were statistically different ($t_{0.05, inf.} = 1.96$).

Environmental Variables	t-Test Statistic
Vertical Percolation Rate	19.661
Yearly Rainfall	2.391
Yearly PET	-10.556
Slope	47.704
Runoff	10.240
Annual Days at Freezing	57.288
Hydrogroup	-22.586
January – April Rainfall	23.562
January – April PET	-16.203

Table 8. Results of the ANOVA test for TWINSPAN division two classes. The test compared the means of each environmental variable for each TWINSPAN division two class (IIa, IIb, IIc, IId). (The critical F 0.05, (1), 3, inf. = 2.61.) In all cases the means were significantly different.

Environmental Variables	f-Statistic
Vertical Percolation Rate	256.032
Yearly Rainfall	2834.979
Yearly PET	6399.968
Slope	1378.017
Runoff	298.998
Annual Days at Freezing	5823.562
Hydrogroup	1995.114
January – April Rainfall	6131.495
January – April PET	5981.620

Carballeira 1991), simple regressions (Bull and Hall 1992), and Newman-Keuls (Zar 1984) due to the very large number of cells in the sample (n=143,326) and the difficulty in ranking the order. The results of the Tukey Test for TWINSPAN's second division in Tables 9-17.

Ordination with Detrended Correspondence Analysis

The DCA ordination was completed for level 2 classification, with four clusters of TWINSPAN classes. Four classes were selected as these classes are more associated with definite wetland landscape types than level one classification (IIa: forested deciduous/needle leafed evergreen; IIb: upland; IIc: shrub scrub; IId: emergent marsh). The four classes are relatively unique with regard to environmental variables, with similar means between classes in only the following instances (vertical percolation: IIc = IId; runoff: IIa = IId; January – April PET: IIc = IId; annual days at freezing: IIc = IId; see Tables 9-17).

The DCA biplot is presented in Figure 19. The length of the un-scaled first axis (800 average standard deviation units, S.D.) indicates that there is substantial variance in the distribution of the samples along environmental gradients (Gauch 1982). The large number of samples, while excellent in providing insight into the correlation between samples and axes, hinders the interpretation of the biplot. Thus, for clarity the linear scores for the first axis are provided in Figure 20. The average ordination scores for all TWINSPAN classes for each axis are given in Table 18. The eigenvalues, which define the amount of variance explained by each ordination axis (McCune and Mefford 1995), are 0.294 for the first axis, 0.013 for the second axis, and 0005 for the third axis. From the eigenvalue for the first axis, it appears that the DCA ordination captured a gradient between the TWINSPAN classification and the environmental driving forces along the first axis. The low eigenvalues for axis 2 and 3 indicate that no determinants of wetland location may be inferred from these axes.

Axis 1 scores are negatively correlated for surficial geology, slope, runoff, freeze days, and January – April rainfall (Table 19). The scores for Axis 1 are positively correlated with yearly rainfall, yearly potential evapotranspiration, Hydrogroup, and January – April potential evapotranspiration (Table 19).

Ordination with Canonical Correspondence Analysis

CCA was used to directly analyze the environmental variables that define the location of wetland types in Florida. The first, second, and third axes have eigenvalues of 0.209, 0.042, and 0.009, respectively. These values are similar to the DCA eigenvalues (axis 1 = 0.294, axis 2 = 0.013, axis 3 = 0.005). The relative closeness of the axis 1 eigenvalues indicates that the CCA and DCA analyses may be accounting for the same environmental gradients along the first axis (Allen and Peet 1990). Monte Carlo results indicate a strong wetland type – environmental variable correlation for Axis 1 (correlation = 0.587, p=0.01, 99 Monte Carlo permutations). Ter Braks's (1986) "intraset" correlations indicate the relative importance of the environmental variables to determining wetland type (Table 20, Retuerto and Carballeira 1991). The first axis is negatively correlated with yearly potential evapotranspiration and January – April potential evapotranspiration, and Hydrogroup (higher Hydrogroup numbers indicate poorer drainage). Axis 1 is positively correlated with vertical percolation (from surficial geology), yearly rainfall, January – April rainfall, slope, runoff, and freeze days.

The biplot for axes 1 and 2 is presented in Figure 21. The diagram without the cells (for clarity) is given in Figure 22. The ordination location of the TWINSPAN groups along axis 1 is given in Figure 23. The average CCA ordination scores for each TWINSPAN class

Table 9. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were no similar means for yearly rainfall.

Yearly Rain Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
IIa vs. IId	9.305242489	0.04927853	188.8295	3.633	Reject
IIa vs. IIb	5.109886857	0.052578579	97.18572		Reject
IIa vs. IIc	4.048065608	0.058879096	68.75217		Reject
IIc vs. IId	5.257176881	0.06238609	84.26841		Reject
IIc vs. IIb	1.061821249	0.153976734	6.895985		Reject
IIb vs. IId	4.195355632	0.159464471	26.30903		Reject

Table 10. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were no similar means for yearly PET.

Yearly PET Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
IId vs. IIa	10.76923226	0.058921988	182.771	3.633	Reject
IId vs. IIb	7.91161364	0.051040407	155.0069		Reject
IId vs. IIc	1.035306946	0.130463881	7.935583		Reject
IIc vs. IIa	9.733925317	0.129368334	75.24195		Reject
IIc vs. IIb	6.876306695	0.125974158	54.58506		Reject
IIb vs. IIa	2.857618623	0.048171203	59.32214		Reject

Table 11. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were no similar means for slope.

Slope Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
IIb vs. IIc	2.94198	0.064079	45.91173	3.633	Reject
IIb vs. IId	2.119	0.015615	135.7037		Reject
IIb vs. IIa	1.241726	0.015382	80.7253		Reject
IIa vs. IIc	1.700254	0.067215	25.29567		Reject
IIa vs. IId	0.877275	0.030614	28.65583		Reject
IId vs. IIc	0.822979	0.063935	12.87209		Reject

Table 12. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were no similar means for January - April Rainfall.

January – April Rainfall Comparison	Difference Between Regional Means	Standard Error	Test q-vs.alue	$q_{0.05, inf., 4}$	Conclusion
IIa vs. IId	10.68366	0.057186	186.821827	3.633	Reject
IIa vs. IIc	8.049815	0.043414	185.4184258		Reject
IIa vs. IIb	3.736393	0.038981	95.85241637		Reject
IIb vs. IId	6.947272	0.027061	256.7263057		Reject
IIb vs. IIc	4.313422	0.032687	131.9619273		Reject
IIc vs. IId	2.633849	0.11963	22.01669719		Reject

Table 13. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were statistically similar means for January - April Rainfall between TWINSPAN classes IId and IIc.

January – April PET Comparison	Difference Between Regional Means	Standard Error	Test q-vs.alue	$q_{0.05, inf., 4}$	Conclusion
IId vs. IIa	3.34967212	0.019089	175.4792	3.633	Reject
IId vs. IIb	2.469146609	0.016535	149.3253		Reject
IId vs. IIc	0.146057664	0.042266	3.45569		Similar Means
IId vs. IIa	3.203614455	0.041911	76.43865		Reject
IId vs. IIb	2.323088945	0.040811	56.92265		Reject
IId vs. IIa	0.88052551	0.015606	56.42288		Reject

Table 14. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were statistically similar means for annual days at freezing between TWINSPAN classes IId and IIa.

Annual Days at Freezing Comparison	Difference Between Regional Means	Standard Error	Test q-vs.alue	$q_{0.05, inf., 4}$	Conclusion
IIa vs. IId	11.59362425	0.506267	22.90021	3.633	Reject
IIa vs. IIc	8.406731717	1.111659	7.562328		Reject
IIa vs. IIb	3.255016476	0.413823	7.865726		Reject
IIb vs. IId	8.33860777	0.438605	19.01166		Reject
IIb vs. IIc	5.151715241	1.082522	4.758993		Reject
IIc vs. IId	3.186892528	1.121121	2.842596		Similar Means

Table 15. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were statistically similar means for vertical percolation rates between TWINSPAN classes IId and IIc.

Vertical Percolation Rate Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
IIb vs. IIc	11978.21	676.2896113	17.71165483	3.633	Reject
IIb vs. IId	9850.174	274.0093497	35.94831305		Reject
IIb vs. IIa	11978.21	258.606087	46.31835352		Reject
IIa vs. IIc	7092.509	694.5111765	10.21223201		Reject
IIa vs. IId	4964.475	316.3214498	15.69439883		Reject
IId vs. IIc	2128.034	700.3925969	3.038344905		Similar Means

Table 16. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were no similar means for hydrogroup.

Hydrogroup Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
IIc vs. IIb	0.913204376	0.018467	49.45172	3.633	Reject
IIc vs. IId	0.463290112	0.000366	1266.666		Reject
IIc vs. IIa	0.219219273	0.018964	11.55968		Reject
IIa vs. IIb	0.693985102	0.007061	98.27828		Reject
IIa vs. IId	0.244070839	0.008637	28.25748		Reject
IId vs. IIb	0.449914264	0.007482	60.13268		Reject

Table 17. The Tukey multiple comparison test was used to examine similar means between TWINSPAN classes. There were statistically similar means for runoff coefficients between TWINSPAN classes IIa and IId.

Runoff Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
IIb vs. IIc	2.863423895	0.079251592	36.13081	3.633	Reject
IIb vs. IId	0.690231105	0.032110026	21.49581		Reject
IIb vs. IIa	0.670318769	0.030304981	22.1191		Reject
IIa vs. IIc	2.193105126	0.081386902	26.94666		Reject
IIa vs. IId	0.019912337	0.037068407	0.537178		Similar Means
IId vs. IIc	2.173192789	0.082076122	26.47777		Reject

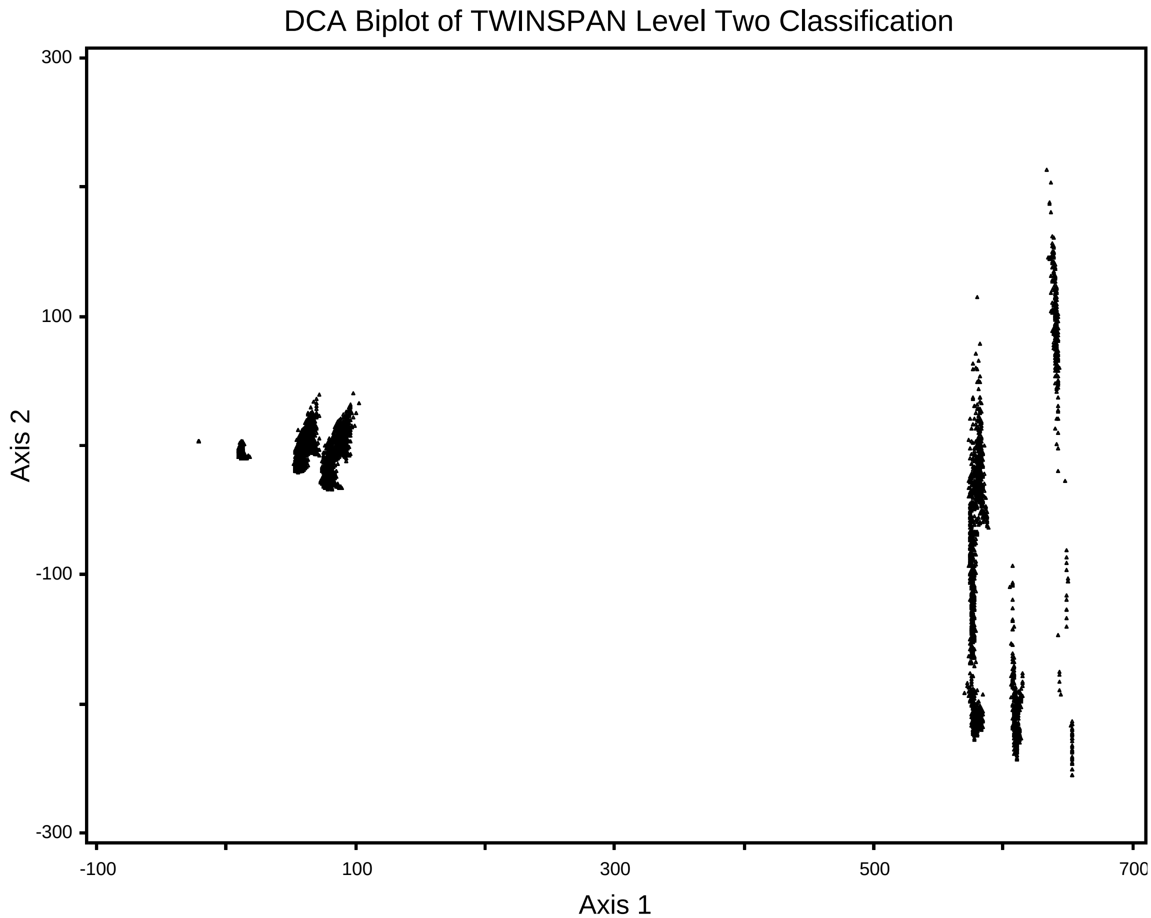

Figure 19. Biplot of the DCA ordination of 8100 cells classified with TWINSPAN. While the number of cells obfuscates the biplot, analysis of the biplot reveals an ordination along a hydrological gradient from shorter to longer hydroperiod.

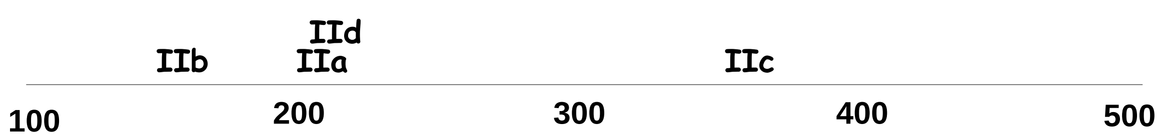

Figure 20. Biplot of the DCA ordination and the linear representation of Axis 1. The biplot reveals an ordination along a hydrological gradient from shorter to longer hydroperiod. The ordination of the TWINSPAN classes results in an order, from left to right, of uplands, forested deciduous, emergent marsh, and shrub scrub (IIb, IIa, IId, and IIc, respectively).

Table 18. DCA Ordination Scores for TWINSPAN Level Two Classification. Standard deviations are in paranthesis.

	Class IIa	Class IIb	Class IIc	Class IId
Axis One	202.532 (236.54)	169.465 (223.665)	363.924 (266.848)	206.651 (246.485)
Axis Two	-26.73 (69.363)	-20.168 (59.154)	-116.878 (101.646)	-59.193 (81.132)
Axis Three	-25.959 (66.402)	-22.502 (56.011)	-114.000 (99.853)	-33.896 (79.940)

Table 19. DCA Correlations with the Main Axis. Coefficients with two asterisks are significant at p=0.001.

	Axis 1	Axis 2	Axis 3
Environmental Variables	Correlation Coefficient	Correlation Coefficient	Correlation Coefficient
Surficial Geology	-0.184**	0.105**	0.113**
Yearly Rain	0.161**	0.176**	0.164**
Yearly PET	0.131**	-0.583**	-0.577**
Slope	-0.083**	0.375**	0.283**
Runoff	-0.071**	0.130**	0.128**
Annual Freeze Days	-0.007	0.541**	0.541**
Hydrogroup	0.002	-0.173**	-0.142**
Jan-Apr. PET	0.136**	-0.539**	-0.529**
Jan-Apr. Rain	-0.053**	0.547**	0.540**

Table 20. Ter Brak's (1986) "intraset" Correlations Amongst CCA Environmental Variables. Correlations with two asteriks are significant at p=0.001.

	Axis 1	Axis 2	Axis 3
Environmental Variables	Correlation Coefficient	Correlation Coefficient	Correlation Coefficient
Surficial Geology	0.161**	-0.418**	-0.418**
Yearly Rain	0.607**	-0.586**	-0.586**
Yearly PET	-0.903**	-0.106**	-0.106**
Slope	0.276**	-0.094**	-0.094**
Runoff	0.079**	0.115**	0.115**
Annual Freeze Days	0.888**	0.189**	0.189**
Hydrogroup	-0.065**	0.251**	0.251**
Jan-Apr. PET	-0.886**	0.002	0.002**
Jan-Apr. Rain	0.947**	-0.106**	-0.106

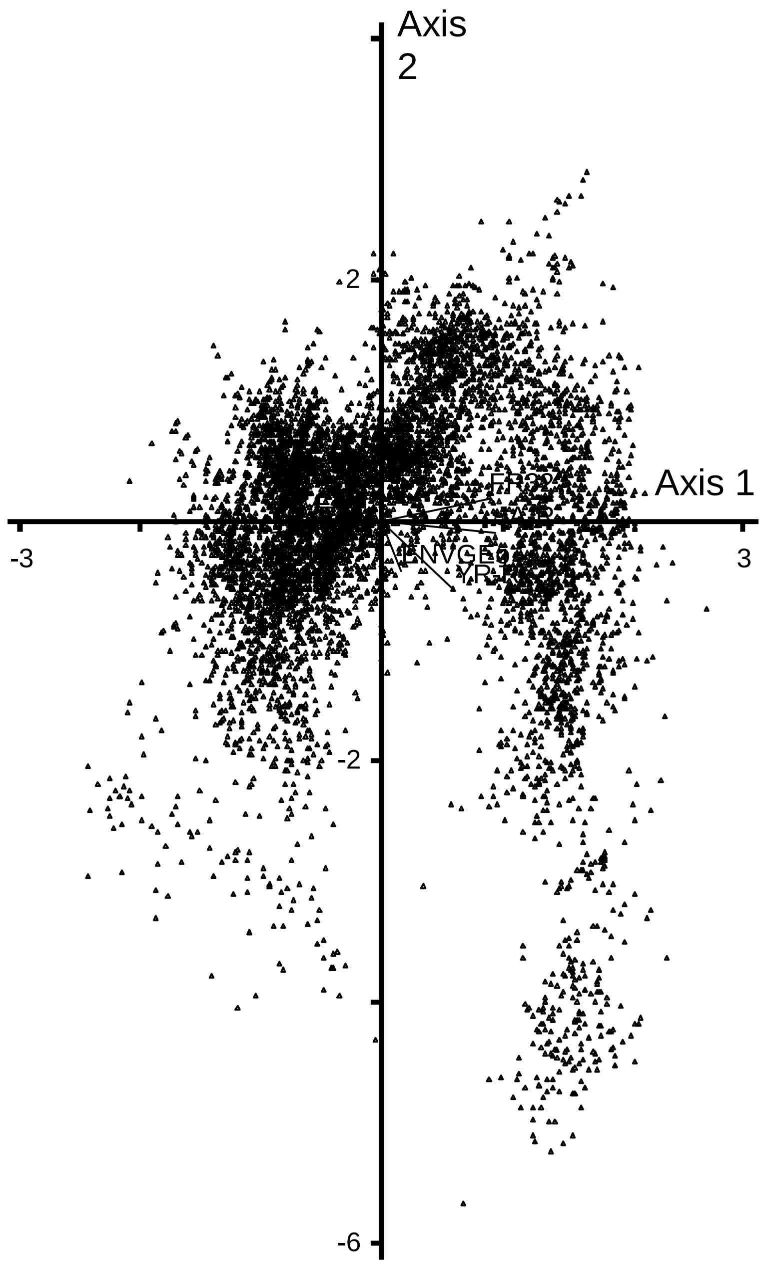

Figure 21. CCA Ordination of TWINSPAN Classes and Environmental Variables. The number of cells (8100) and the gross spatial extent of the environmental data set together obstruct the graphical analysis of the biplot.

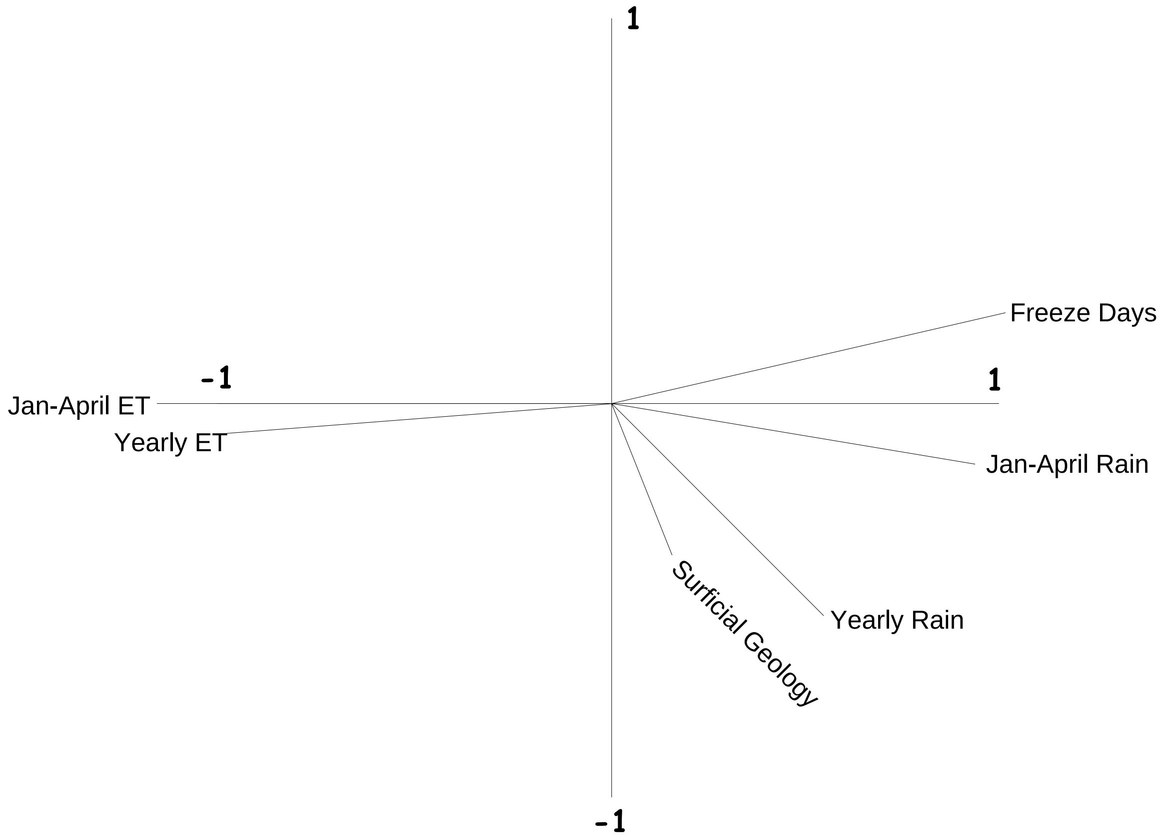

Figure 22. Graphical Representation of the CCA Ordination biplot showing the vectors that affect the ordination of the TWINSPAN classes. The vectors point in the direction of maximum variation and the length is proportional to the rate of change.

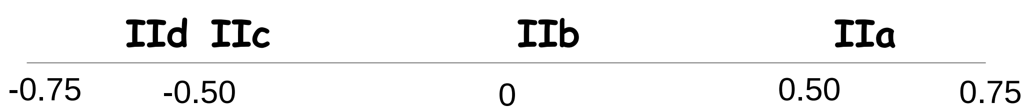

Figure 23. Linear representation of the CCA ordination of TWINSPAN level two classification along the first axis.

for axis 1, 2, and 3 are given in Table 21. In the CCA vector analysis, the environmental variables are indicated by arrows emanating from the center of the CCA diagram. They point in the direction of maximum variation within the data and the length is proportional to the rate of change. The ordination of the TWINSPAN classes indicates that the first axis reflects a moisture gradient, with the TWINSPAN classes that receive high amounts of January – April rainfall (IIa - forested and IIb- uplands) on the right and TWINSPAN classes with lower amounts of January – April rainfall on the left (IIc - shrub scrub and IId – emergent marsh). The potential evapotranspiration gradient is also reflected along the first axis, with

January – April PET and yearly PET higher in the TWINSPAN classes on the left. Annual days of freezing also appear to determine TWINSPAN location in ordination space, with the forested (IIa) and uplands (IIb) classes receiving a higher number of freezing days. Axis 1 is correlated strongest with January – April rainfall, yearly potential evapotranspiration, annual days of freezing, and January – April potential evapotranspiration (see Table 20).

Axes 2 and 3, like DCA axes 2 and 3, have spurious eigenvalues (Gauch 1982). These axes were thus not used to interpret underlying gradients important to wetland formation and classification in Florida.

<u>Landscape Water Balance Model Results</u>

Results for the January to April period are given in Figure 24. It is important to note that the values for water within each cell are from a mathematical model and do not represent an amount of water to actually be found on the landscape at any given time. Small-scale isolated heterogeneous "peaks" and "sinks" on the output maps do not necessarily indicate localized highs and lows of water storage -- interpolating the climate data with inverse distance weighting allows for an accurate representation of the landscape but may also cause isolated highs and lows as the algorithm fits a plane through the data points (Robeson 1997).

The results for the January to April landscape water balance (Figure 24) were scaled to reflect the critical depth of saturation for wetland plants. It is generally accepted that 30 cm is the approximate critical depth of saturation for most wetland plants, beyond which there is not enough oxygen for plant respiration (National Research Council 1995, Whigham and Simpson 1978). To distinguish zones of soil saturation at less than the critical depth (< 30 cm), the range of the LWBI was separated into a first order map with values greater than or equal to 0.30 m and values less than 0.30 m (Figure 25). To provide a hydrologic gradient within the zones above and below the critical depth of saturation, the values were then further separated into 0.10 m intervals in the second order map (Figure 26). This allowed the model to initially distinguish zones above the critical depth and below the critical depth, and on a hierarchically finer scale, to reflect a hydrologic gradient within each of the groups above and below the critical depth of saturation.

The non-scaled numeric results of the landscape water balance (Figure 24) were also subjected to an agglomerative hierarchical clustering procedure, average linkage. This iterative method measures the Euclidian distances between values and merges the closest values into a single cluster (SAS Institute Inc. 1989). Based on the peaks and troughs in the cubic clustering criterion, the pseudo-F statistic, and the pseudo-t statistic (Table 22), the output of the spatial hydrologic budget was separated into statistical regions (Figure 27 and Figure 28). The clustering algorithm appeared to have difficulty at the hierarchical level shown in Figure 27 with placing contiguous spatial water budget values in the same cluster. For instance, the hydrologic budget values for cluster four are –0.01, 0.01, 0.02, 0.03, 0.06, 0.09, and 0.12 cm (see Table 23). Values for 0, 0.04, 0.05, 0.07, and 0.08 cm were clustered with disparate groups. To alleviate this situation the clustering was reclassified and mapped to a hierarchical level above the original clustering output (i.e. the data was reclassified from

Table 21. CCA Ordination Scores for TWINSPAN Level Two Classification. Standard Deviations are in parentheses.

	Class IIa	Class IIb	Class IIc	Class IId
Axis One	0.595 (0.978)	0.083 (0.949)	-0.451 (0.945)	-0.597 (0.586)
Axis Two	-0.019 (1.176)	-0.079 (1.200)	-0.059 (0.867)	-0.042 (0.837)
Axis Three	-0.059 (1.210)	-0.749 (1.236)	0.338 (0.764)	-0.244 (0.899)

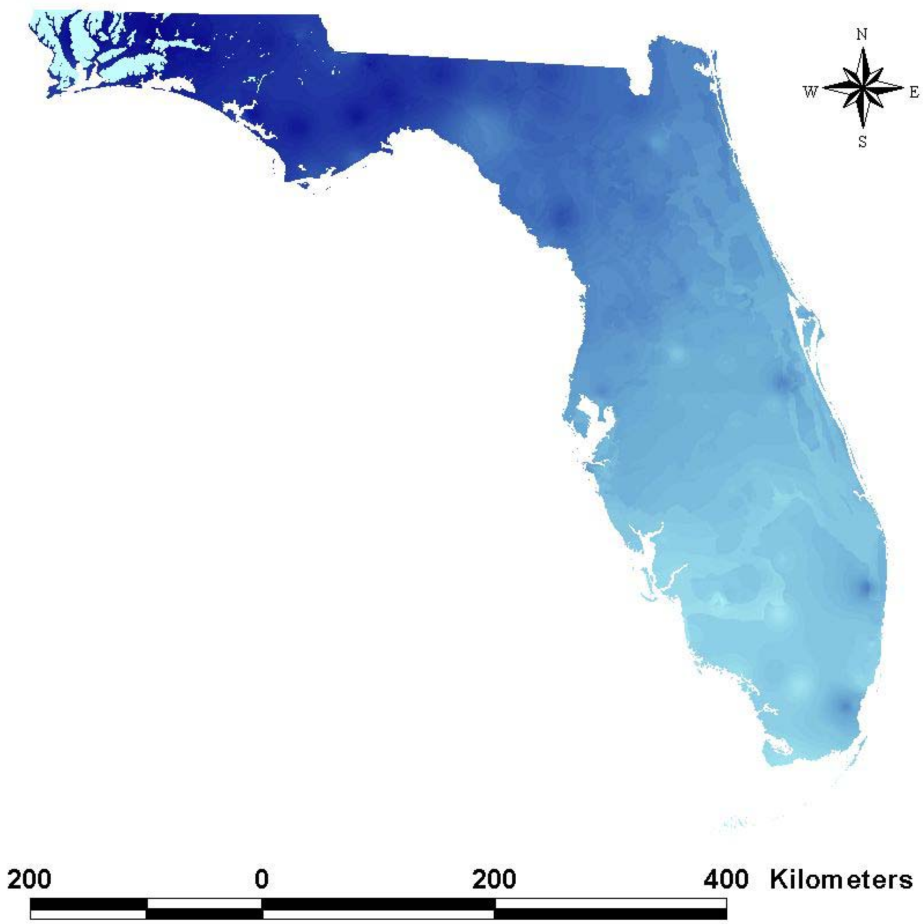

Figure 24. The results of the landscape water balance spatial hydrologic model. The range is from -1.27m to 0.43m. Lighter colors indicate a lower landscape water balance value than darker colors.

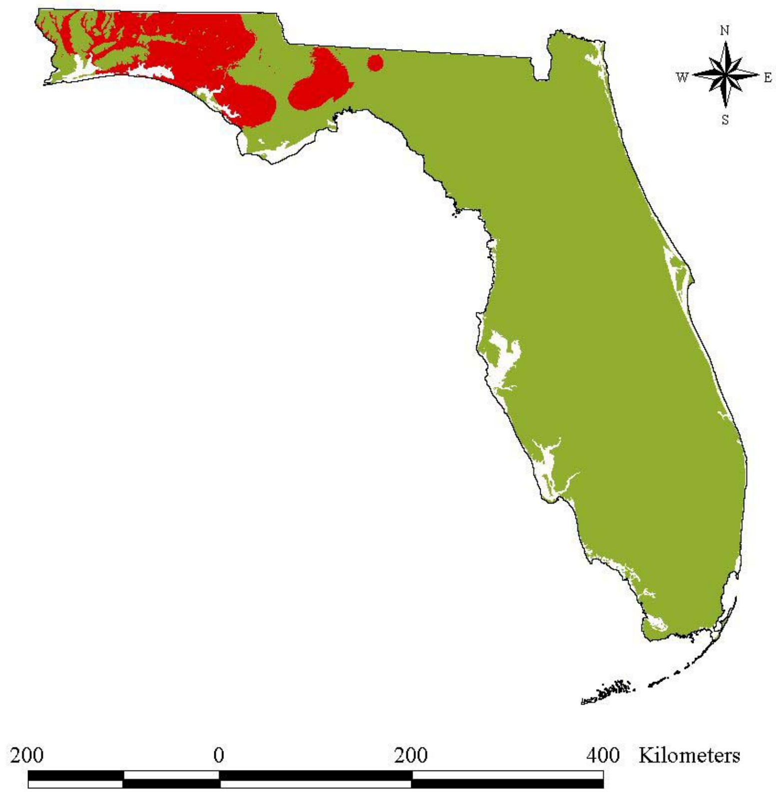

Figure 25. The Landscape Water Balance Index separated into values less than or equal to 30cm and values greater than 30cm. Values greater than 30cm (in red) indicate depths of saturation beyond the critical depth for wetland plants.

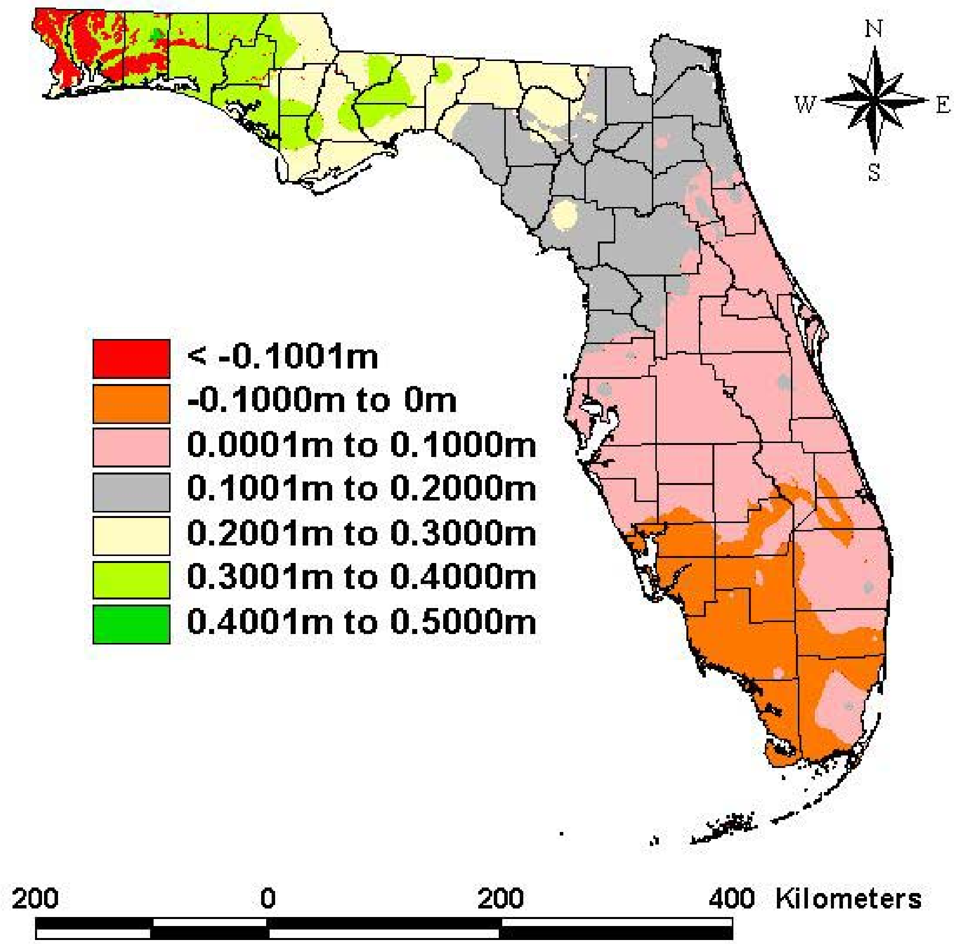

Figure 26. A 0.10m hydrologic gradient within the critical depth of saturation. This scale delineates six zones along the hydrologic gradient.

Table 22. Based on peaks and troughs in the cubic clustering criterion, pseudo - f, and pseudo-t statistics, the PSMI was separated between Cluster 6 and 7. This created 6 statistical regions.

Cluster Name	Cubic Clustering Criterion	Pseudo - F Statistic	Pseudo - t Statistic
Cluster 10	1.715	1249.7	4.8
Cluster 9	0.394	900.1	71.6
Cluster 8	-0.245	717.4	35.6
Cluster 7	-1.01	552.4	57.1
Cluster 6	0.019	562.7	35.2
Cluster 5	-4.714	214.1	177.1
Cluster 4	-4.027	195.9	62.5
Cluster 3	-3.504	167.2	35.9
Cluster 2	-9.656	21.8	239.4
Cluster 1	0	n/a	21.8

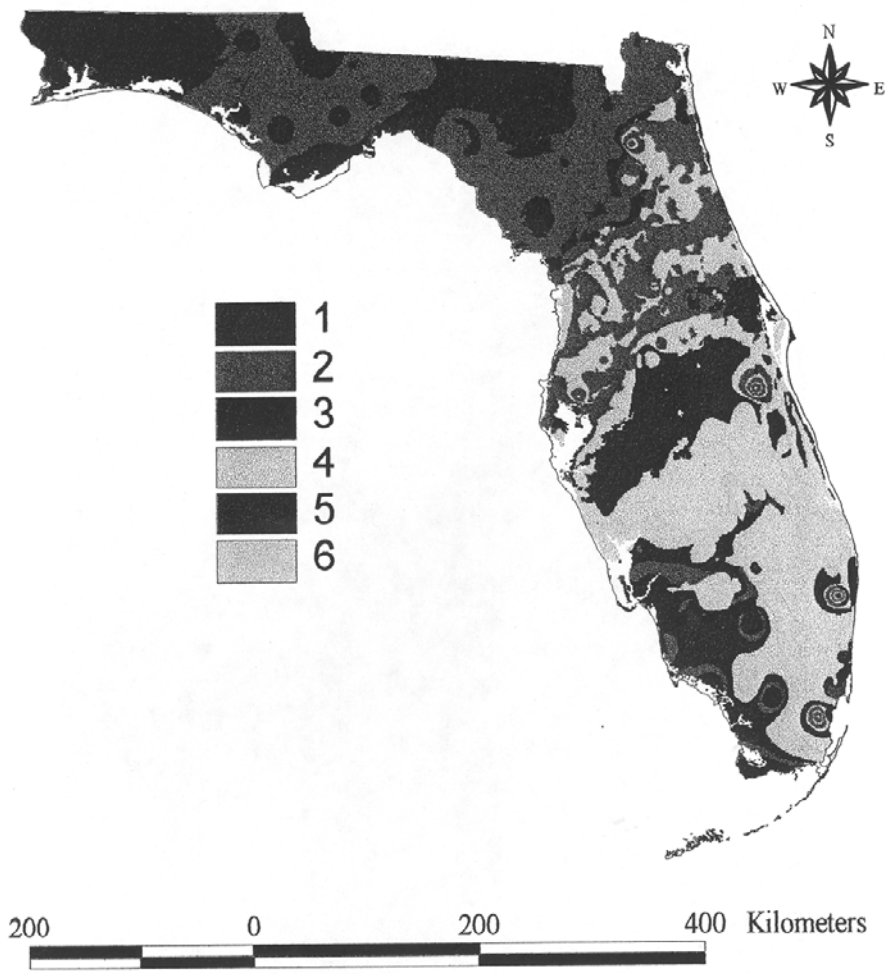

Figure 27. The SAS average-linkage clustering procedure created six groups based on Euclidean distance between LWBI values.

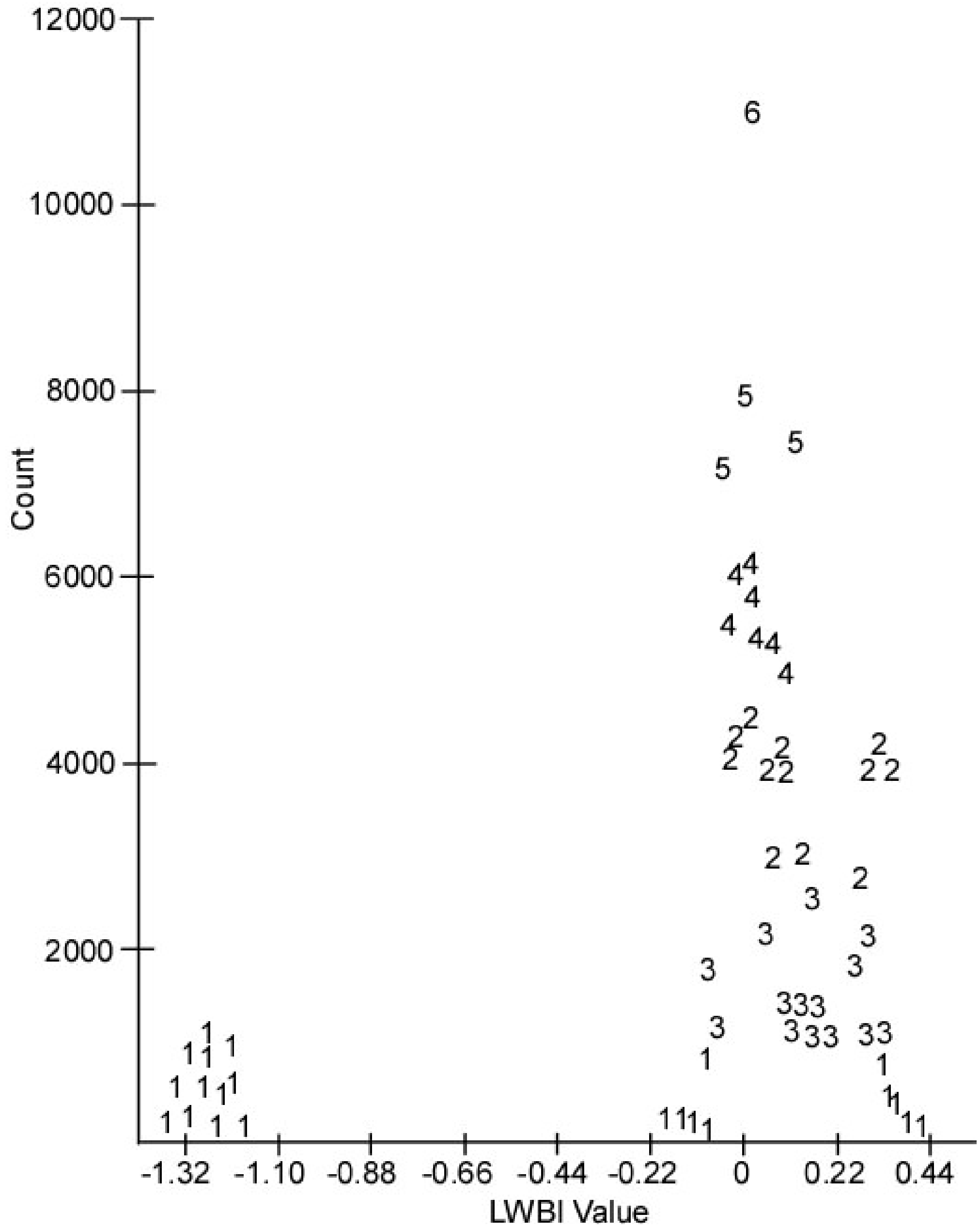

Figure 28. The plot from the average linkage clustering algorithm. The plotted values are the clusters to which the LWBI values (X-axis) have been prescribed.

Table 29. The assignments for each of the LWBI values based on the clustering algorithm.

LWBI Value	Cluster Assignment	LWBI Value (continued)	Cluster Assignment (continued)
-1.27	1	0.07	2
-1.26	1	0.08	2
-1.25	1	0.09	4
-1.24	1	0.10	2
-1.23	1	0.11	2
-1.22	1	0.12	4
-1.21	1	0.13	2
-1.20	1	0.14	3
-1.19	1	0.15	2
-1.18	1	0.16	2
-1.17	1	0.17	2
-1.16	1	0.18	2
-1.15	1	0.19	3
-1.14	1	0.20	3
-1.13	1	0.21	3
-1.12	1	0.22	3
-1.11	1	0.23	3
-0.12	1	0.24	3
-0.11	1	0.25	3
-0.10	1	0.26	3
-0.09	1	0.27	3
-0.08	1	0.28	2
-0.07	1	0.29	2
-0.06	1	0.30	2
-0.05	3	0.31	2
-0.04	3	0.32	3
-0.03	2	0.33	3
-0.02	5	0.34	3
-0.01	4	0.35	3
0.00	6	0.36	3
0.01	4	0.37	1
0.02	4	0.38	1
0.03	4	0.39	1
0.04	5	0.40	1
0.05	5	0.41	1
0.06	4	0.42	1
		0.43	1

a finer second order map to a coarser first order map). The first order map clustering was reclassified in a logical fashion according to the actual results from the hydrologic budget equation and the cluster assigned to each value (see Table 23). Hence, values between 0.07 and 0.36 m (clusters two and three, with two instances of cluster four at 0.09 and 0.12 m) were clustered together; and values between –0.05 and 0.06 m (clusters four, five, and six, with outliers for clusters two and three at –0.05, –0.04 and –0.03 m) were clustered together. The outliers for cluster one, 0.37 to 0.43 m, make up 0.6% of the data set and are spatially located adjacent to both the cluster one region and the cluster three region. Based on the spatial location on the clustering plot and the positive value of the outliers, those cells were reclassified and joined to cluster three. The resultant map, which could be considered a first order map since it is a hierarchical level above (coarser) than the statistical clustering, is given in Figure 29.

The landscape mosaic created by applying the critical depth of saturation scale to the spatial hydrologic model, as previously mentioned, contains localized cell water highs and lows. The resultant patchwork output when the first order critical depth LWBI (< 0.30m and ≥ 0.30m, Figure 25) was separated into a second order map (Figure 26, 0.10m scale) was further reduced in complexity into the final output map (Figure 30) by use of the sensitivity analysis (Figure 31), described below.

The sensitivity analysis was conducted by adding and subtracting 50% of the value for each of the components in the LWBI model (precipitation, PET, slope, runoff, K_e). The model was then run multiple times and changes in categorical cell values were noted. For example, all cells with the LWBI value between –0.10m and 0m (cells mostly located in South Florida) were given the categorical value of “2.” The sensitivity analysis was run using the 50% increased and 50% decreased input components, and the resulting continuous values between were scaled according to the 0.10m scale in Figure 26 and given the corresponding categorical value (i.e. –0.10m and 0m were reclassified as “2.”) The number of times a cell changed in categorical value (out of a total of ten iterations) was then summed to create the sensitivity analysis output map, Figure 31. Based on the sensitivity analysis, areas of the state that changed the most during the analysis were considered to represent border conditions between wetland regions. Linear boundaries for the final wetland regions map approximate the geographic mid-point of the areas of the highest categorical change. Hence, the boundary line between the Central and North and the Central and South regions closely follows the extent of the area of “Moderate Changes.” Note, however, that the boundary between the North and the Panhandle regions was delineated with the use of areas of “Moderate Changes” and areas of “Few Changes.” The northward bend of the North – Panhandle border was delineated to reflect the narrow and unique extent of the “Few Changes” area. The northward delineation is also a result of the connectedness between the areas of “Moderate Changes” and “Few Changes.” Due to the complexity of the Panhandle’s LWBI, the Panhandle has been simplified into a single region until field verification can delineate additional regional boundaries.

Description of the Landscape Water Balance Regions

The following section describes each of the regions created with the landscape water balance model and scaled according to the critical depth of saturation for wetland plants. The wetland region descriptions include the percent of each wetland type found in the region, and the averages for the landscape variables.

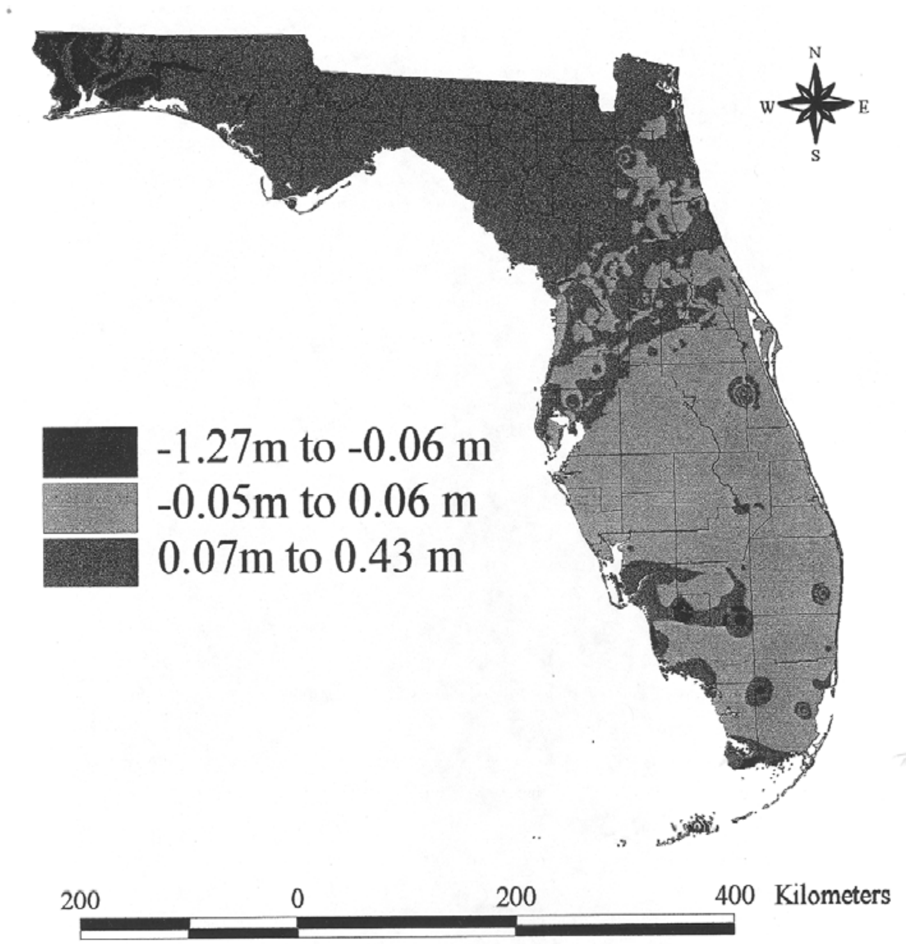

Figure 29. The results of the statistical clustering of the hydrologic model values were agglomerated at a hierarchical level that resulted in three groups.

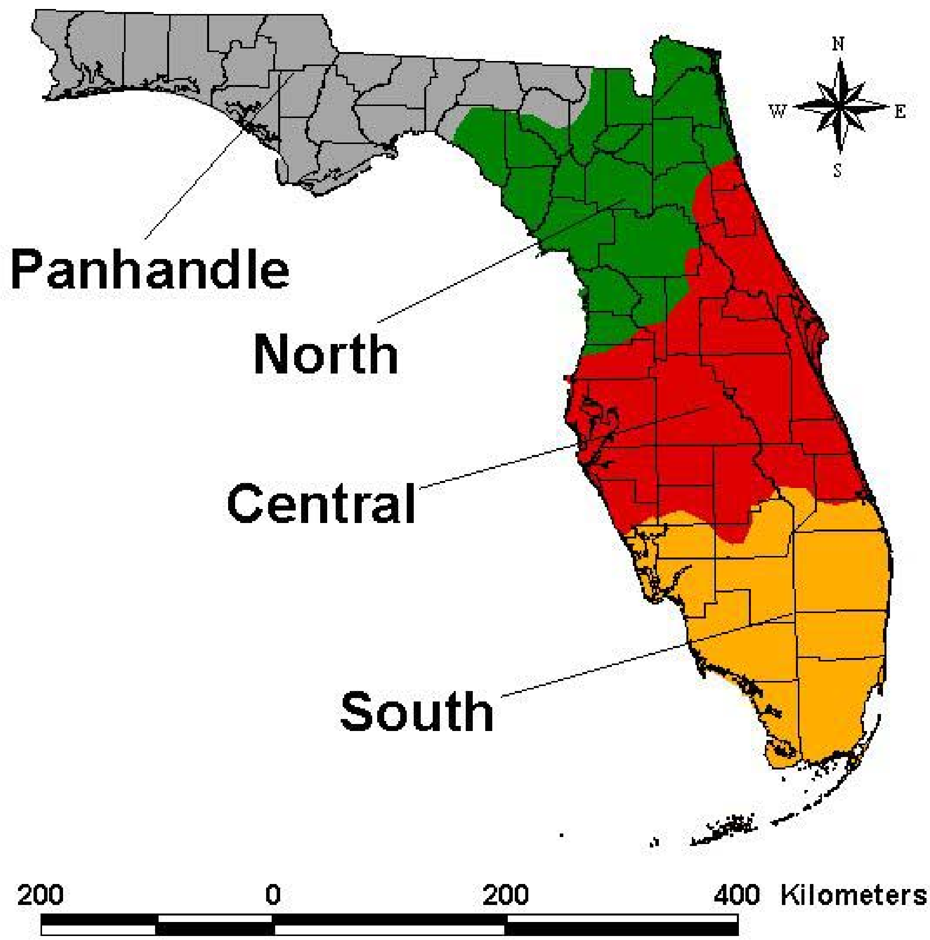

Figure 30. Wetland regions of Florida derived through the use of a spatial hydrological model. The regions were scaled based on the critical depth of saturation.

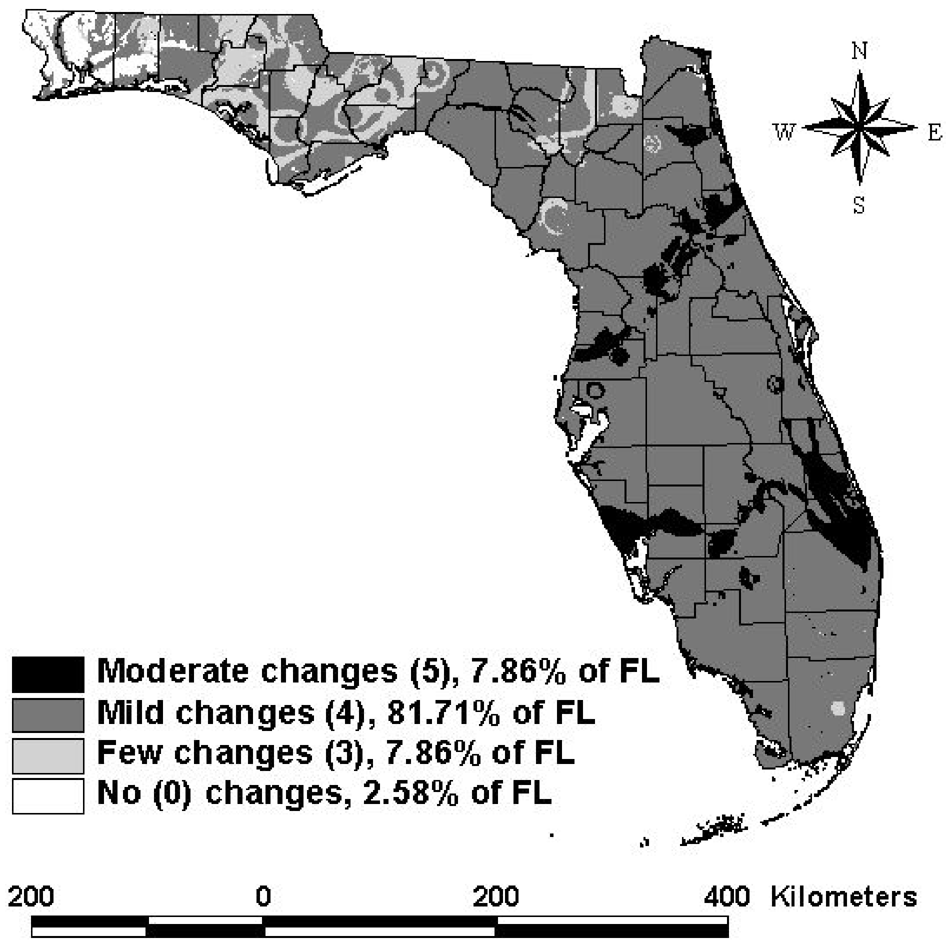

Figure 31. The sensitivity analysis of the spatial hydrologic model was used to demarcate the borders between wetland regions. The number of times a cell changed in categorical value is given in parenthesis.

South Region

This region runs from just north of Lake Okeechobee to the Florida Keys. The percentage of each palustrine wetland type, according to the National Wetland Inventory, is presented in Table 24. The extent of each of the wetland types can be seen in Figure 32(a-e). Non-wetland areas are 64.6% of the landscape. Of the 35.4% of the south region that is wetland, 60.8% is emergent marsh, 17.3% is shrub scrub, 16.4% is forested deciduous, and < 5% needle leafed and broad leafed evergreen.

The South Region is an extraordinarily level part of Florida, with an average slope of 0.029%. The yearly rainfall averages 1.377m and potential evapotranspiration for the same period averages 1.204m. The majority (60.0%) of the soil is classed group B ("Moderate infiltration rates") and 25.1% is classified as group D ("very slow infiltration rates," NRCS 1994, pp. C-11 to C-12). The soil is underlain by peat (37.4%), shelly sand and clay (28.3%), and limestone (21.0%). On average, the region is annually subjected to 1.72 days where the temperature reaches freezing. The average environmental variables for the region are given in Tables 25-27.

Central Region

The Central Region extends from the South Region boundary to just north of Tampa Bay on the west coast, and angles diagonally in a meandering SW/NE direction from Tampa Bay to St. Augustine. The landscape is 83.7% upland, and of the 16.3% that is palustrine wetland, 41.4% is emergent, 39.8% is forested deciduous, and less than 10% is shrub scrub, needle leafed evergreen, and broad leafed evergreen (Table 28, Figure 33(a-e)). 1.317m of rainfall falls yearly, with 1.118m potentially evapotranspirating. The slope is minor, with 0.204% the average. The region is composed of 66.7% B Hydrogroup ("Moderate infiltration rates") and 21.3% is group A ("high infiltration rates," NRCS 1994, pg. C-11). The Florida sand ridge is a unique landscape artifact in this region, with 49.0% of the surficial geology medium fine sand and silt, 23.7% shelly sand and clay, and 21.7% sandy clay. Occasional freezes average 5.4 days per year in the Central Region. The environmental averages are presented in Tables 25-27.

North Region

Only 16% of this region is classified as palustrine wetlands. Table 29 lists the percentage of each wetland type found in the North Region and Figure 34(a-e) shows their extent. The western boundary follows a SW/NE diagonal from the Ochlocknee River near Tallahassee to the St. Mary's River at the Florida/Georgia border. The forested deciduous wetland type stands out at 62.7%. The emergent marshes are found in 13.3% of the cells,

Table 210. The percentage and extent of the South Region's wetland types.

South Region	Emergent	Shrub Scrub	Forested Deciduous	Broad Leafed Evergreen	Needle Leafed Evergreen	Total % Wetlands
% Landscape	21.544	6.133	5.803	0.717	1.227	35.4
% of Wetlands	60.818	17.313	16.381	2.023	3.464	

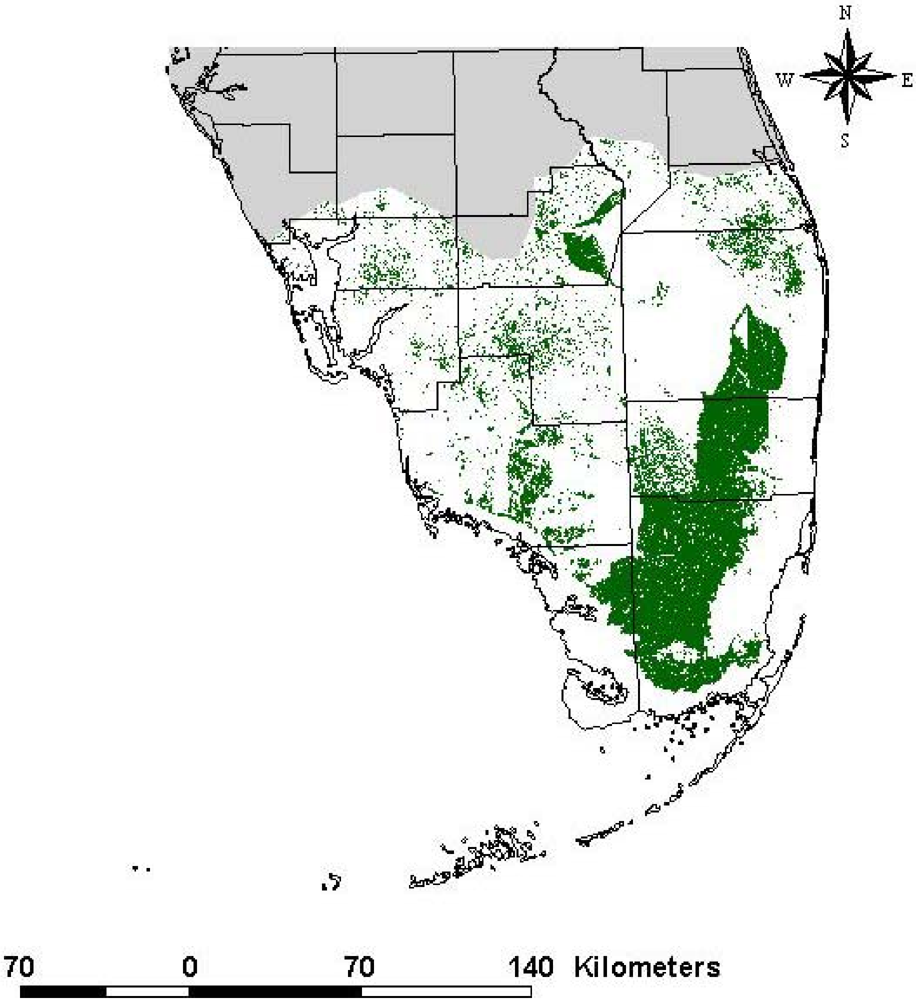

Figure 32. Wetlands of the South Region: a) 60.8% of the wetlands in this region are of the emergent marsh wetland class.

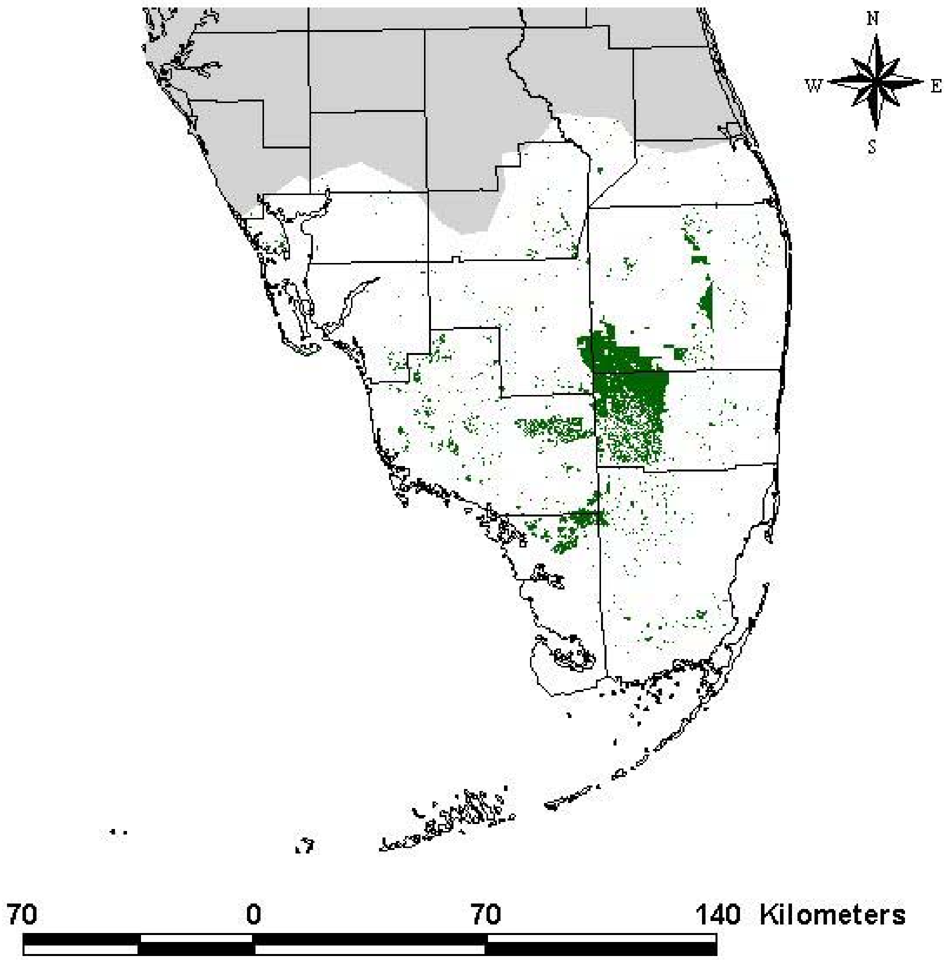

Figure 32. Wetlands of the South Region: b) 17.3% of the wetlands in this region are of the shrub scrub wetland class.

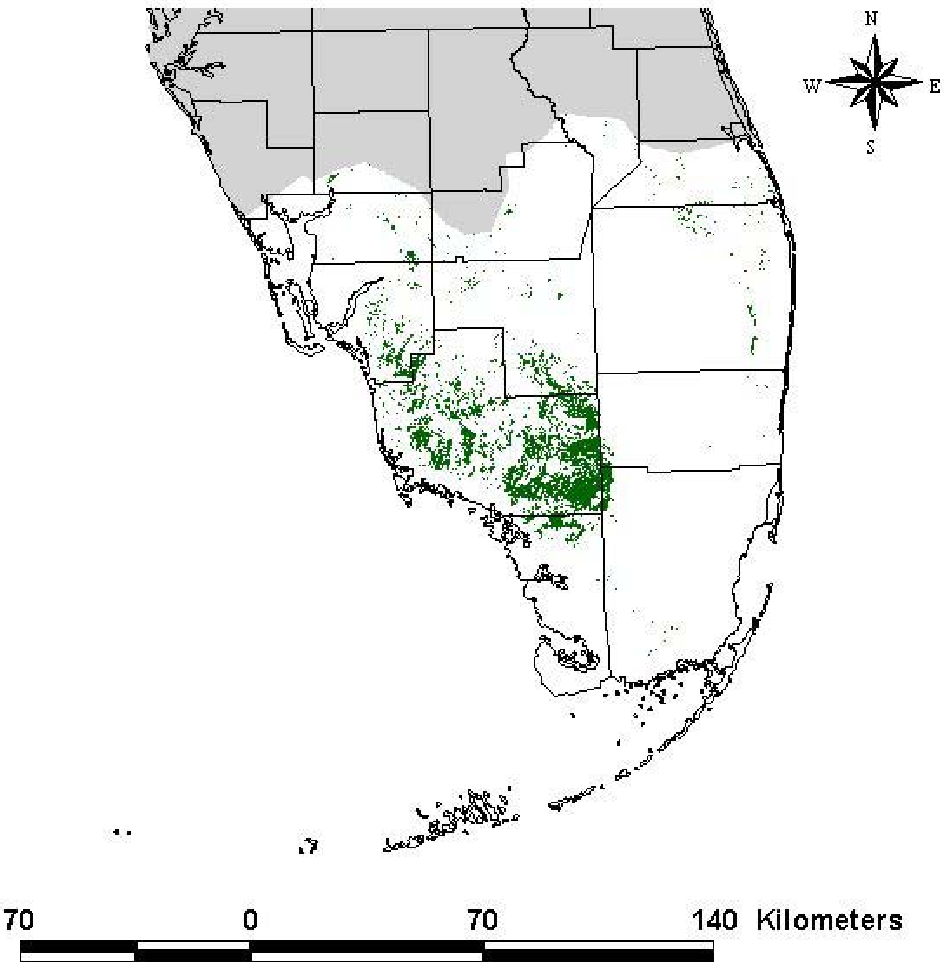

Figure 32. Wetlands of the South Region: 16.4% of the wetlands in this region are of the forested deciduous wetland class.

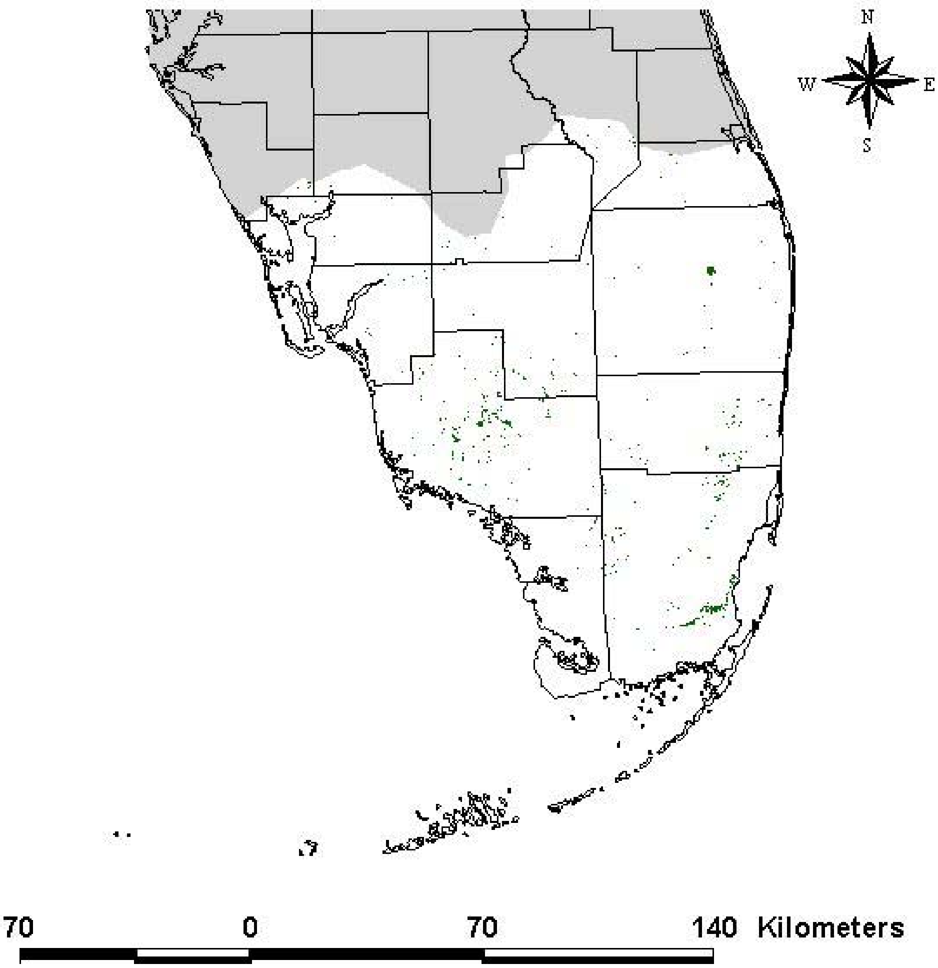

Figure 32. Wetlands of the South Region: d) 2.0% of the wetlands in this region are of the broad leafed evergreen wetland class.

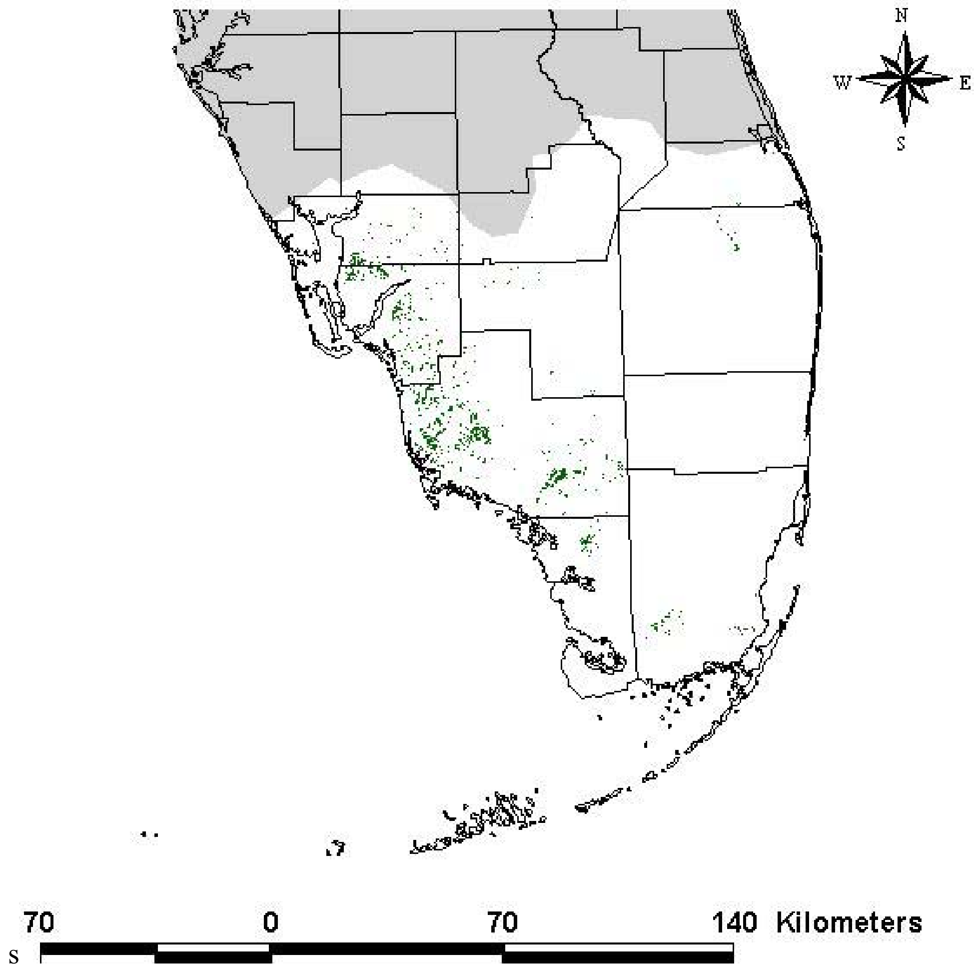

Figure 32. Wetlands of the South Region: e) 3.5% of the wetlands in this region are of the needle leafed evergreen wetland class.

Table 25. The means and standard deviation (in parentheses) of landscape variables for each of the four wetland regions.

	Yearly Rain	Yearly PET	% Slope	Runoff	Annual Days at Freezing	January - April Rain	January - April PET
South	1.377m (0.085)	1.204m (0.042)	0 (0.1)	17.565 (9.699)	1.720 (1.084)	0.242m (0.026)	0.242m (0.02)
Central	1.317m (0.035)	1.118m (0.031)	0.2 (0.3)	20.404 (9.988)	5.388 (1.901)	0.284m (0.20)	0.215m (0.01)
North	1.363 (0.054)	1.027m (0.052)	0.3 (0.3)	17.642 (9.505)	15.993 (5.928)	0.352m (0.031)	0.191m (0.02)
Panhandle	1.512m (0.097)	0.958m (0.041)	0.6 (0.6)	15.773 (7.570)	40.147 (5.692)	0.475m (0.035)	0.166m (0.01)

Table 211. Categorical means for each hydrogroup class, for each of the wetland regions.

	Hydrogroup Class A	Hydrogroup Class B	Hydrogroup Class C	Hydrogroup Class D
South	5.6%	60.0%	9.3%	25.1%
Central	21.3%	66.7%	8.2%	3.8%
North	32.5%	42.4%	9.1%	15.9%
Panhandle	24.9%	45.0%	16.2%	13.8%

Table 27. Categorical means for each surficial geology class, for each wetland region.

	Dolomite	Sandy Clay and Clay	Peat	Limestone	Medium Fine Sand and Silt	Clayey Sand	Shelly Sand and Clay	Gravel and Coarse Sand
South	0.0%	0.0%	37.4%	21.0%	8.3%	0.0%	28.3%	0.0%
Central	0.0%	0.1%	3.2%	2.3%	49.0%	21.7%	23.7%	0.0%
North	0.8%	0.0%	0.5%	34.9%	15.0%	36.8%	12.0%	0.0%
Panhandle	0.1%	10.3%	0.0%	6.4%	24.3%	48.1%	0.1%	10.7%

Table 28. The percentage and extent of the Central Region's wetland types.

Central Region	Emergent	Shrub Scrub	Forested Deciduous	Broad Leafed Evergreen	Needle Leafed Evergreen	Total % Wetlands
% Landscape	6.748	1.416	6.491	1.273	0.365	0.163
% of Wetlands	41.418	8.689	39.843	7.812	2.239	

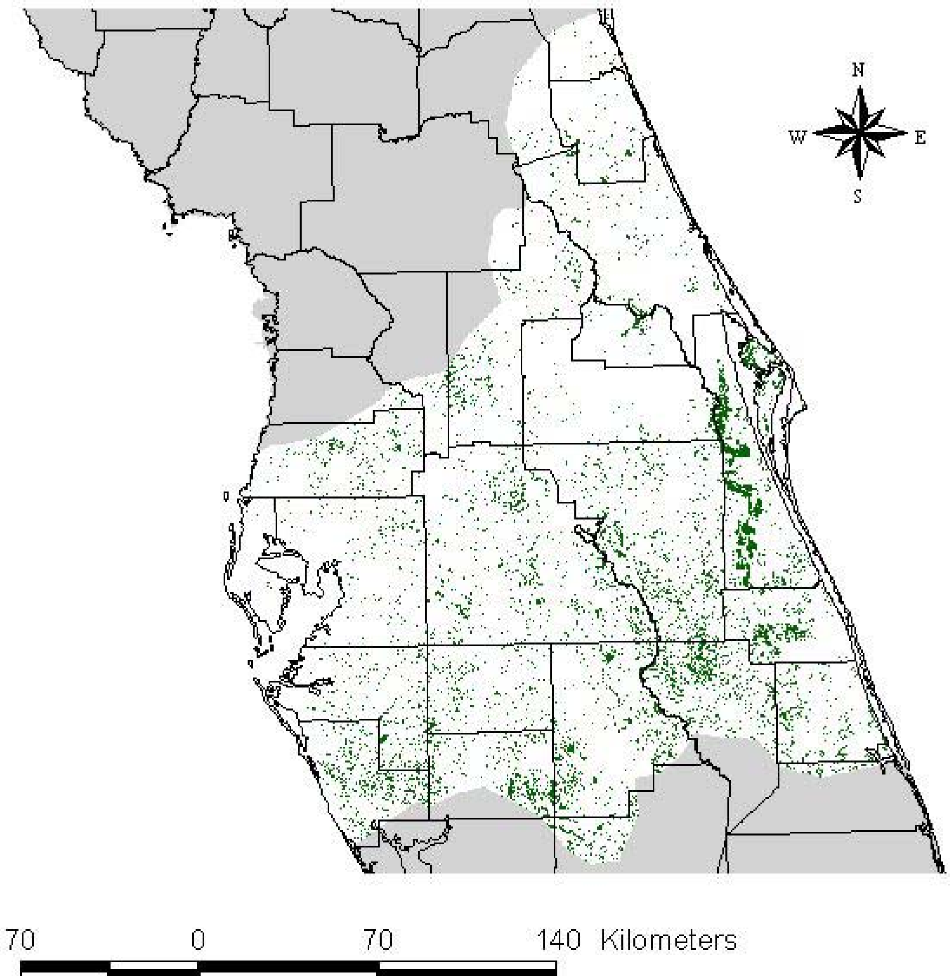

Figure 33. Wetlands of the Central Region: a) 41.4% of the wetlands in this region are of the emergent marsh wetland class.

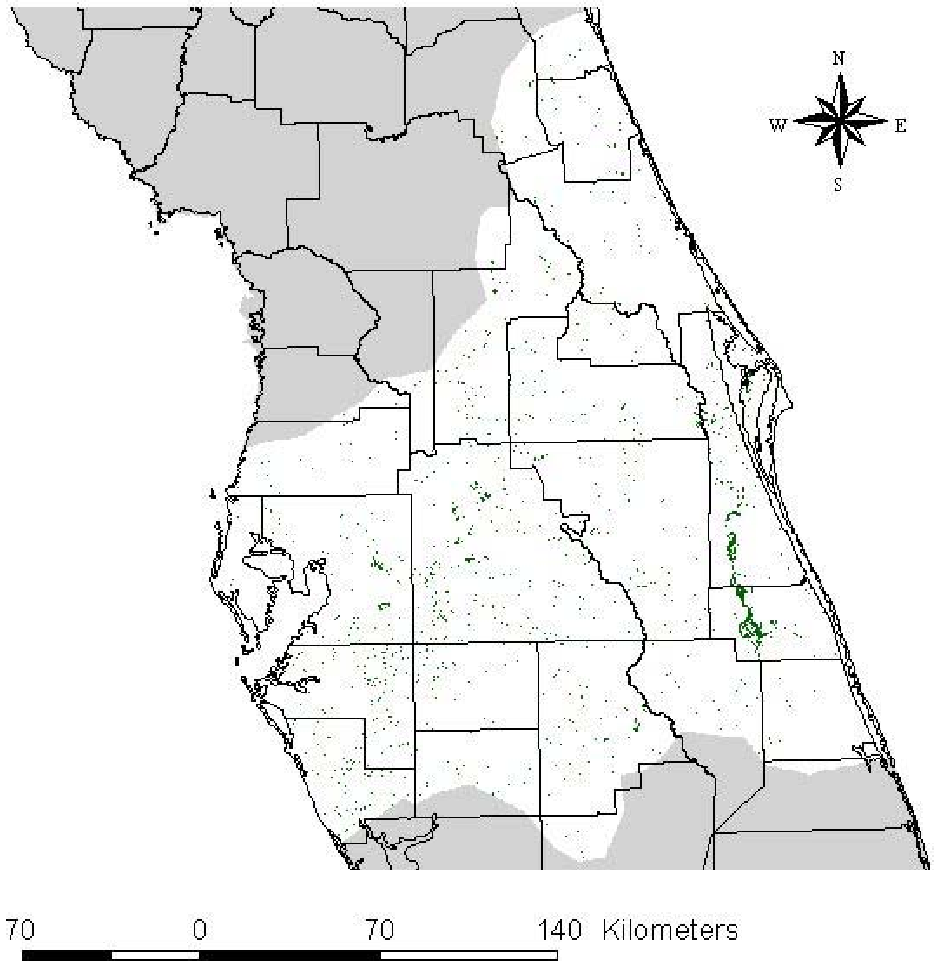

Figure 33. Wetlands of the Central Region: b) 8.7% of the wetlands in this region are of the shrub scrub wetland class.

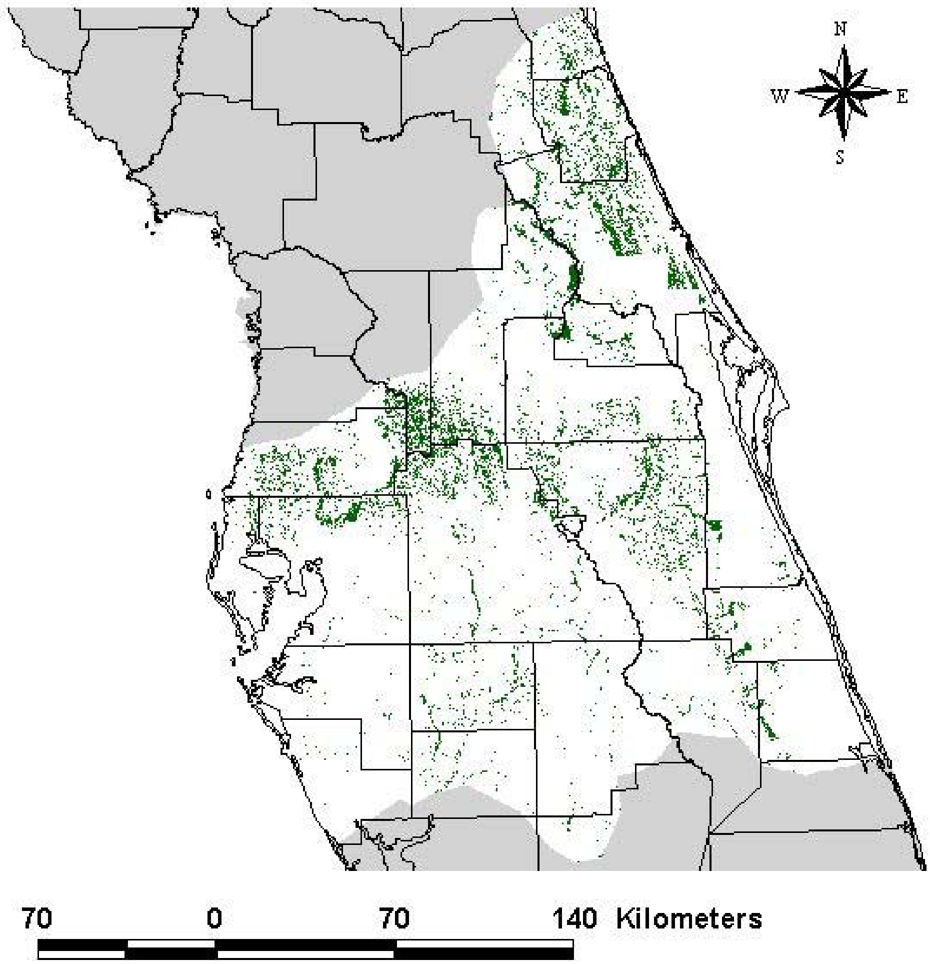

Figure 33. Wetlands of the Central Region: c) 39.8% of the wetlands in this region are of the forested deciduous wetland class.

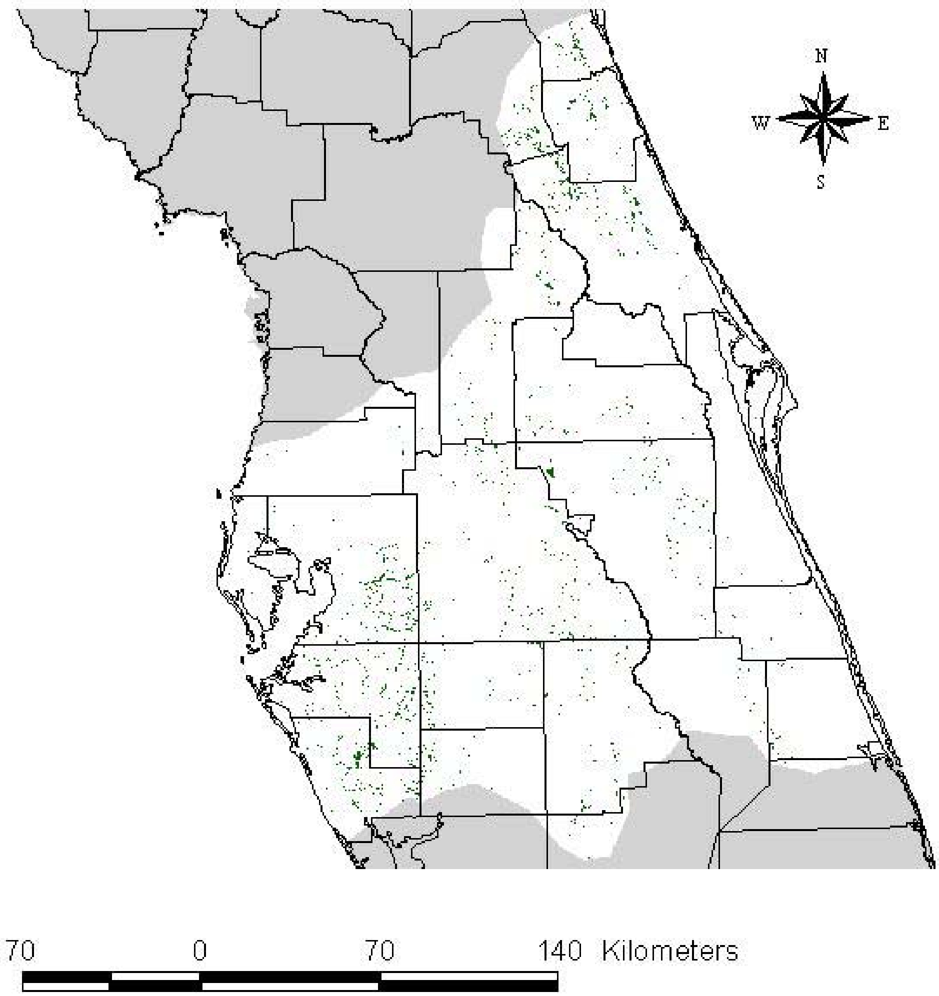

Figure 33. Wetlands of the Central Region: d) 7.8% of the wetlands of this region are of the broad leafed evergreen wetland class.

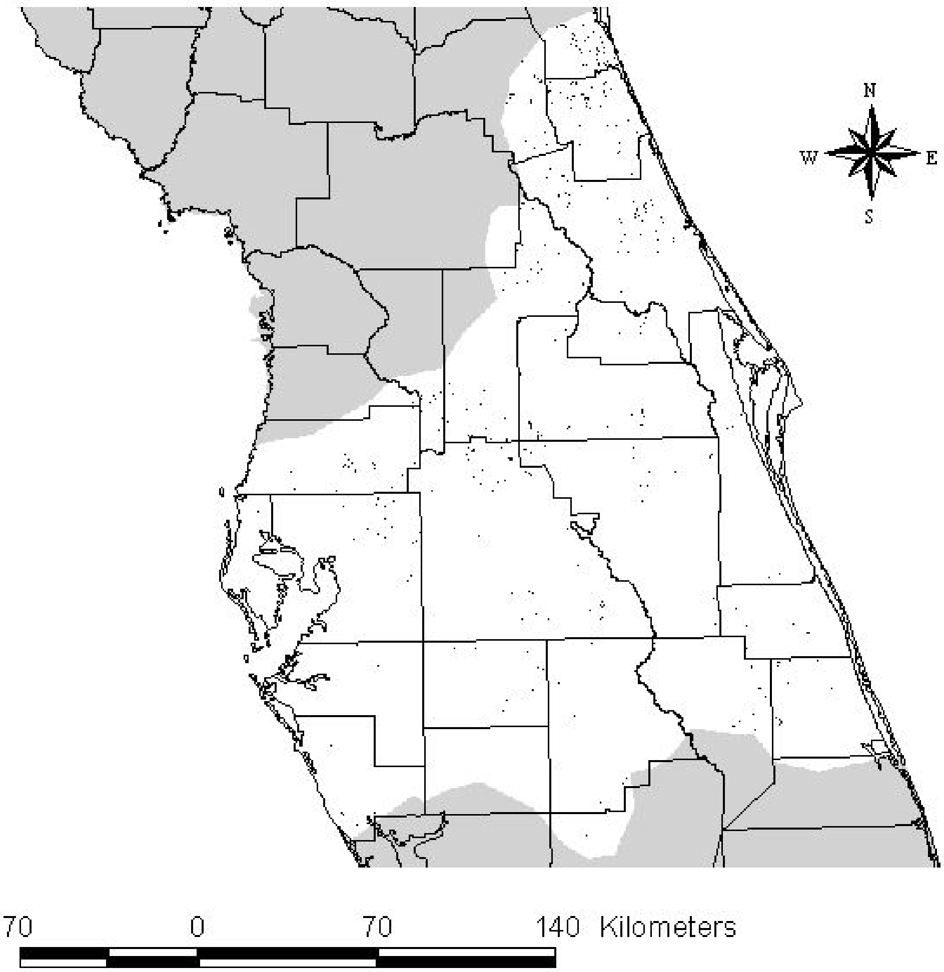

Figure 33. Wetlands of the Central Region: e) 2.2% of the wetlands in this region are of the needle leafed evergreen wetland class.

Table 29. The percentage and extent of the North Region's wetland types.

North Region	Emergent	Shrub Scrub	Forested Deciduous	Broad Leafed Evergreen	Needle Leafed Evergreen	Total % Wetlands
% Landscape	2.117	1.367	10.010	1.024	1.455	0.160
% of Wetlands	13.254	8.559	62.665	6.411	9.111	

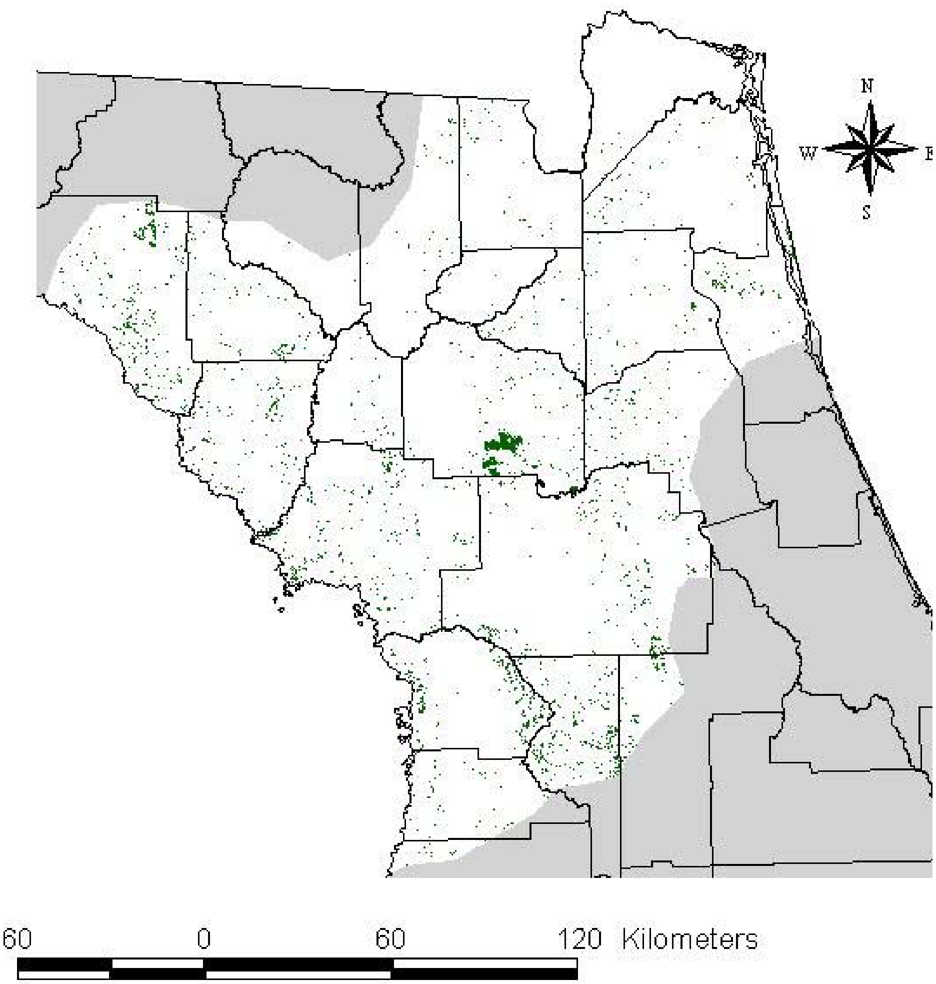

Figure 34. Wetlands of the North Region: a) 13.3% of the wetlands in this region are of the emergent marsh wetland class.

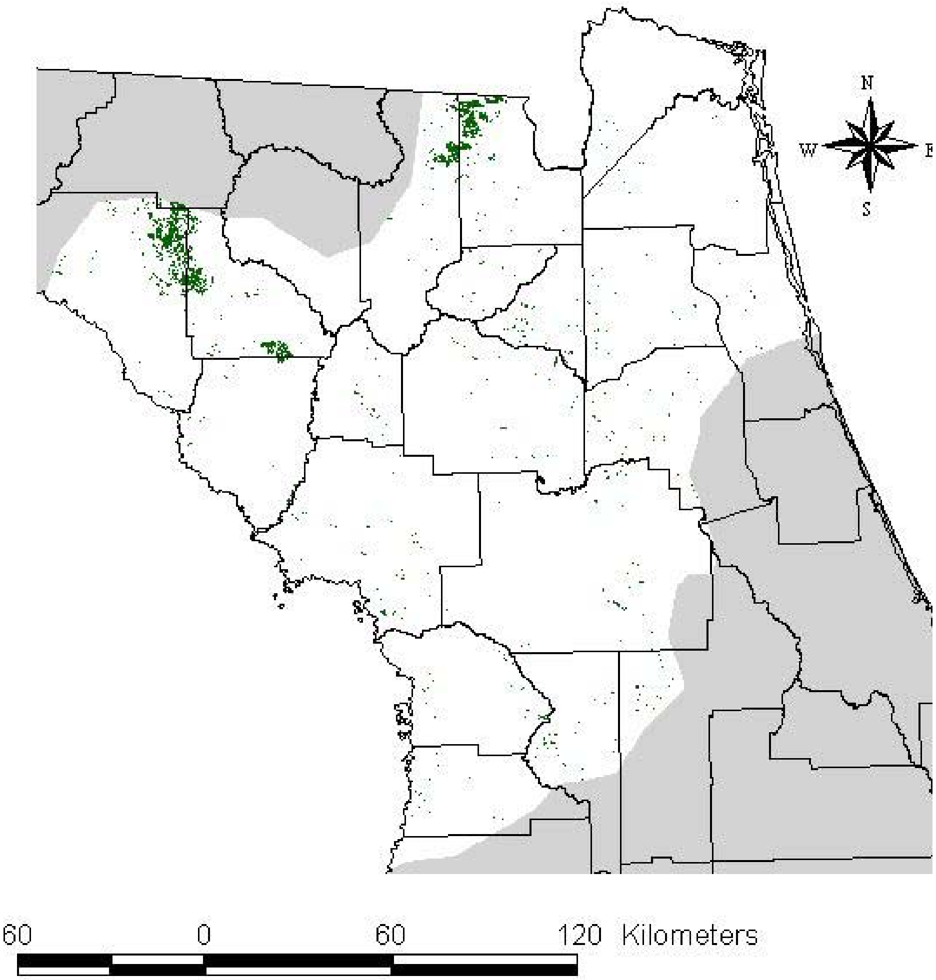

Figure 34. Wetlands of the North Region: b) 8.6% of the wetlands in this region are of the shrub scrub wetland class.

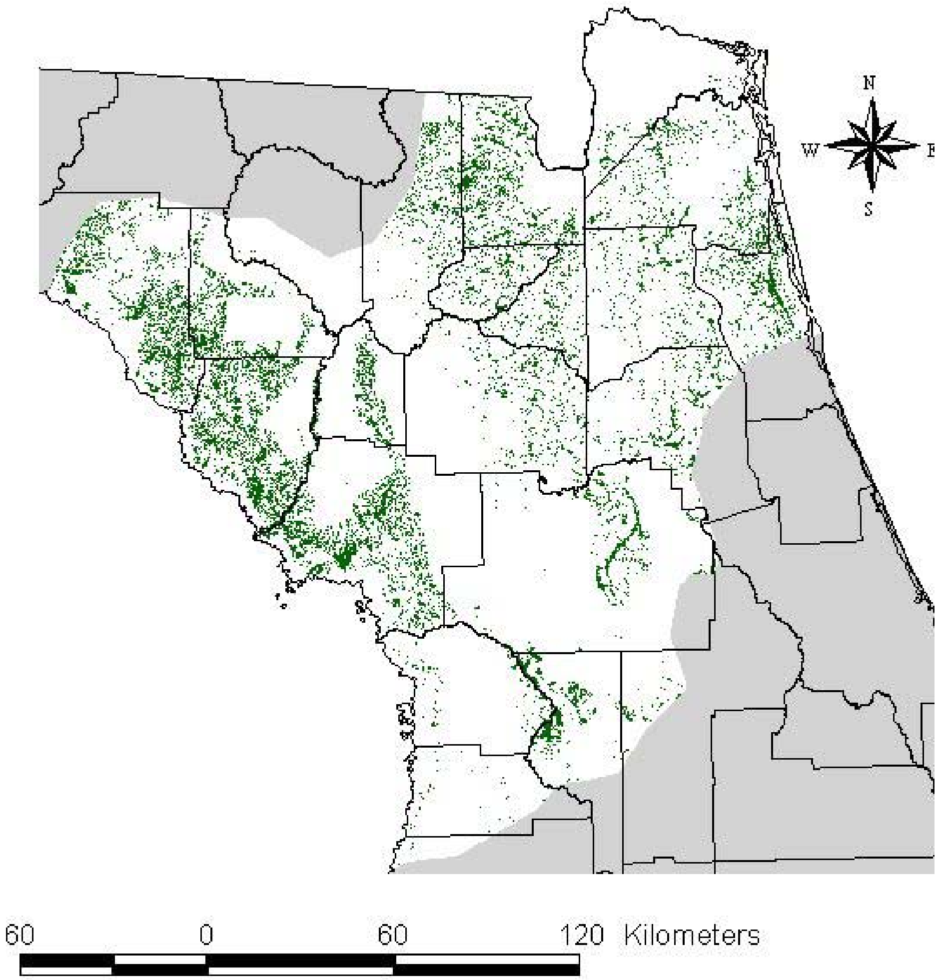

Figure 34. Wetlands of the North Region: c) 62.7% of the wetlands in this region are of the forested deciduous class.

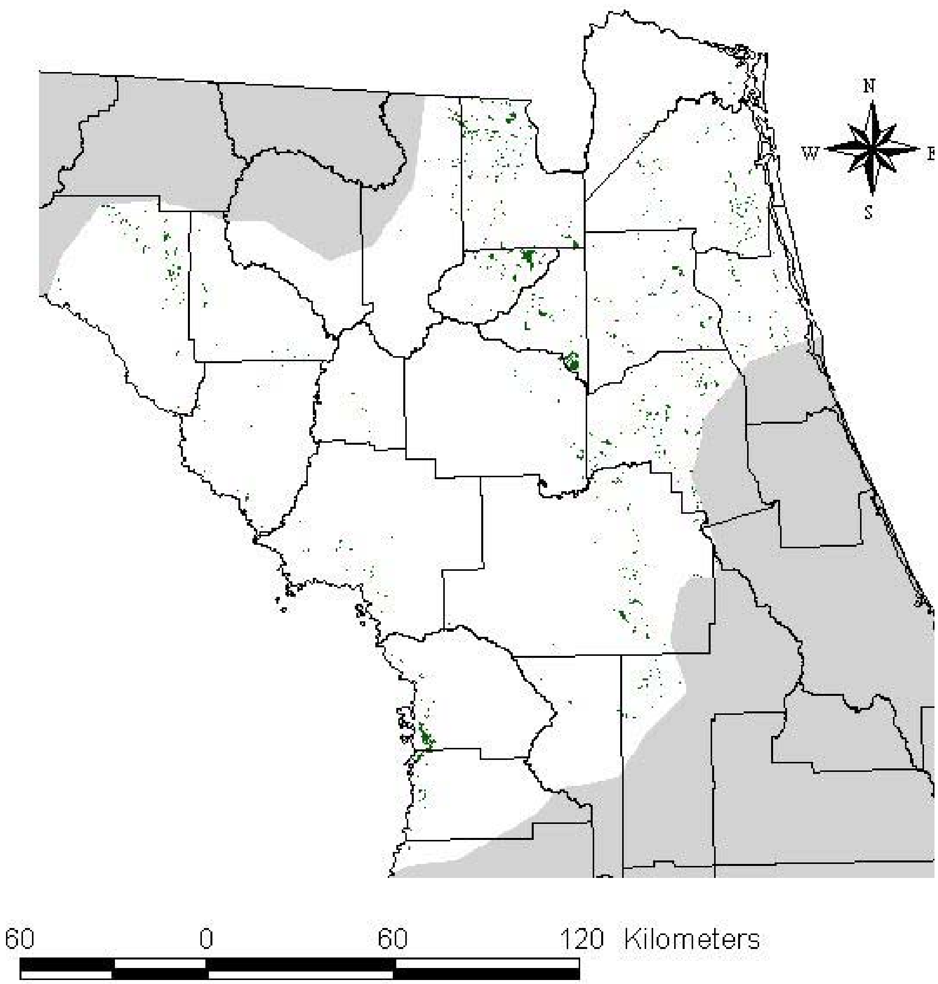

Figure 34. Wetlands of the North Region: d) 6.4% of the wetlands in this region are of the broad leafed evergreen wetland class.

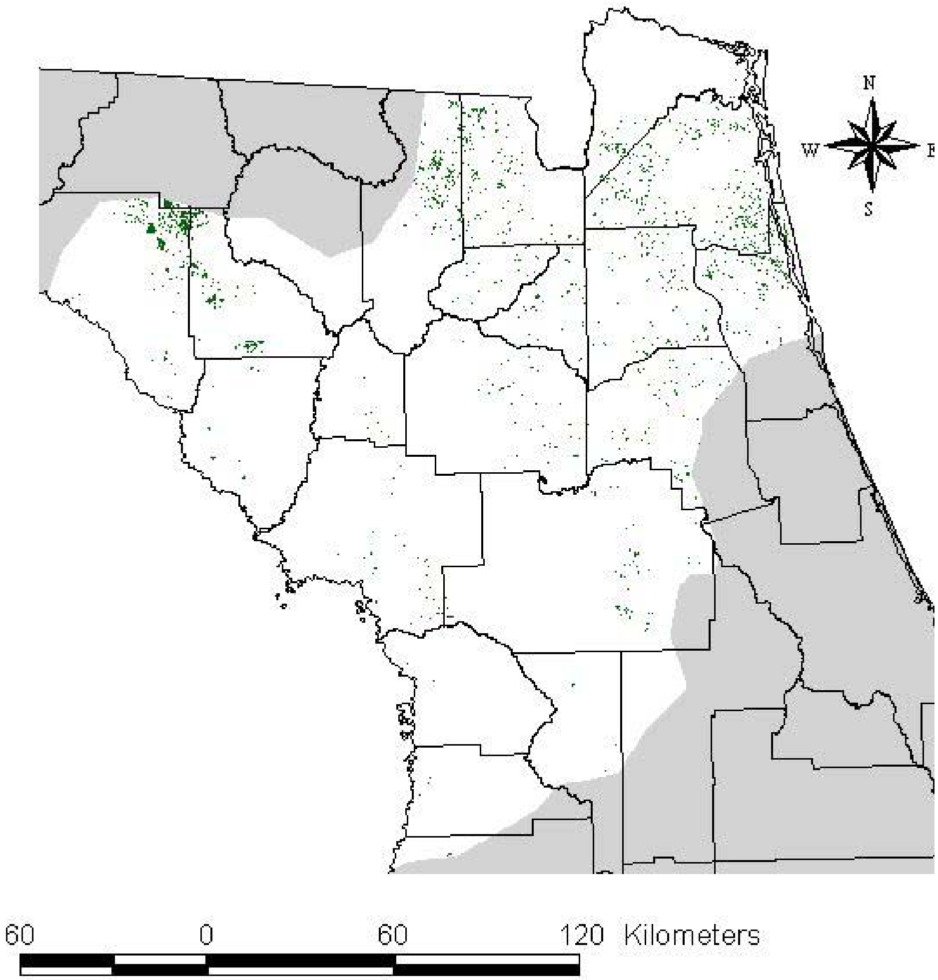

Figure 34. Wetlands of the North Region: e) 9.1% of the wetlands in the North Region are of the needle leafed evergreen wetland class.

needle-leafed evergreens in 9.1%, shrub scrub at 8.6%, and broad-leafed evergreens at 6.4%. Rainfall averages 1.363m per year, and potential evapotranspiration 1.027m. The slope increases to an average of 0.286% in this region. There is a diverse array of Hydrogroups: 32.5% group A (high infiltration), 42.4% group B (moderate infiltration), 9.1% group C (slow infiltration), and 15.9% group D (very slow infiltration) (USDA 1991). Clayey sand comprises 36.8% of the surficial geology, limestone 34.9%, and shelly sand and clay 12.0%. The number of days where the temperature reaches freezing averages 16.0 days per year. Tables 25-27 list the averages for all environmental values.

Panhandle Region

This region covers the Panhandle from the North Region boundary to Alabama. The extent of the wetland types is presented in Table 30 and Figure 35(a-e). The forested deciduous class is found in 51.6% of the wetland cells, and the needle-leafed evergreens are found in 32.3%. Wetlands make up 21.7% of the landscape. The Panhandle Region has the highest average slope, at 0.581%, and days at freezing temperature, averaging 40.147 days per year. Rainfall averages 1.512m and potential evapotranspiration 0.958m per year. The Panhandle has the most diverse Hydrogroup classes: group A 24.9%, group B 45.0%, group C 16.2%, and group D 13.8%. Clayey sand makes up 48.1% of the surficial geology, medium fine sand and silt 24.3%, gravel and coarse sand 10.7%, and sandy clay and clay 10.3%. Averages can be found in Tables 25 - 27.

Statistical Analysis of the Wetland Regions

The four wetland regions delineated by the spatial water budget and described above were subjected to the chi-squared test for independence. The test determined that the four wetland regions were unique with regard to the type and percentage of wetlands found in each region ($X^2 = 37.961$, d.f. = 12, p=0.0001).

The landscape inputs characteristic to each spatial water budget wetland region were also analyzed by region to determine if differences in environmental variables may translate into differences in wetland type and abundance. The environmental inputs to each region were initially compared using the fixed-effects ANOVA statistic to determine if the means were equal (Table 31). Failing to have equal means, the landscape inputs to each region were then compared using the Tukey Multiple Comparison Test (Brand and Almendinger 1993, Shaltout et al. 1995, Zar 1984). The results of the landscape similarity tests indicate very little similarity amongst wetland regions: just as the types and percentage of wetlands are unique for each region, so, too, are the landscape driving characteristics unique for each region. Of the nine variables measured (yearly rain, yearly potential evapotranspiration, January – April rain, January – April potential evapotranspiration, slope, runoff, Hydrogroup, vertical percolation rate, and annual days at freezing), there were similar means between the

Table 30. The percentage and extent of the Panhandle Region's wetland types.

Panhandle Region	Emergent	Shrub Scrub	Forested Deciduous	Broad Leafed Evergreen	Needle Leafed Evergreen	Total % Wetlands
% Landscape	0.689	1.468	11.195	1.337	7.004	0.217
% of Wetlands	3.177	6.767	51.605	6.163	32.288	

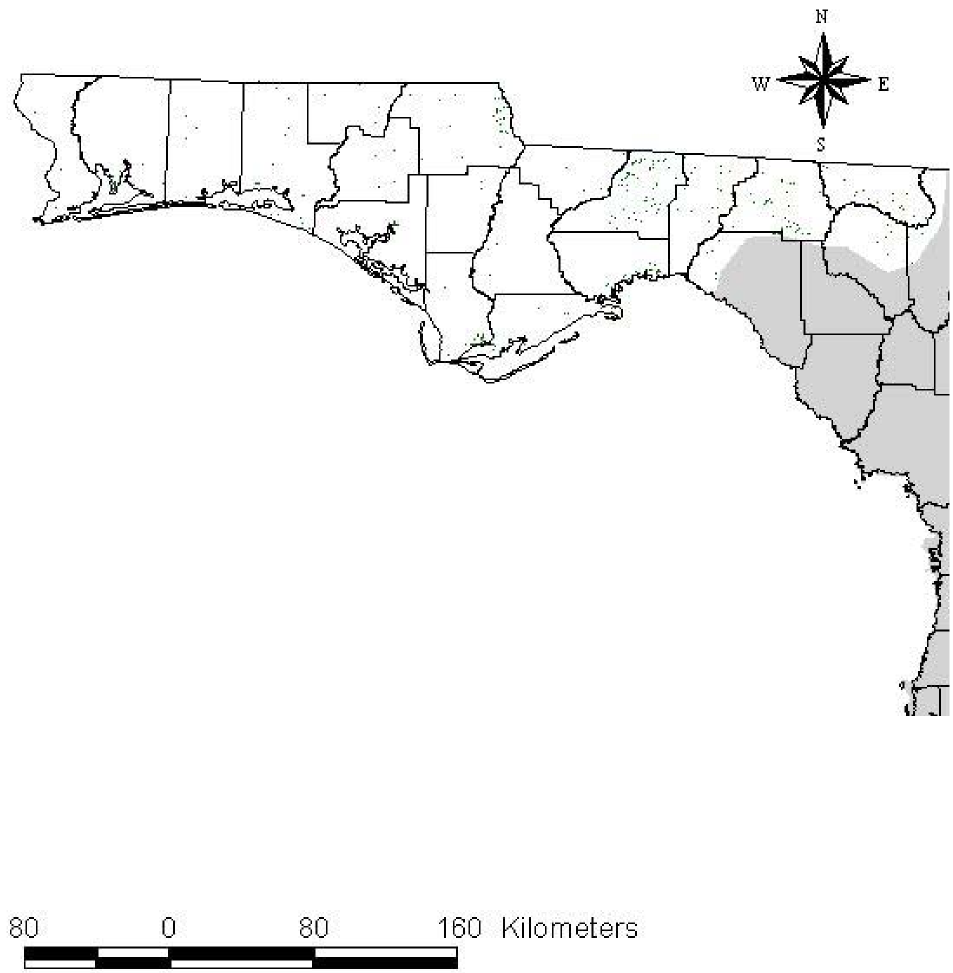

Figure 35. Wetlands of the Panhandle Region: a) 3.2% of the wetlands of this region are of the emergent marsh wetland class.

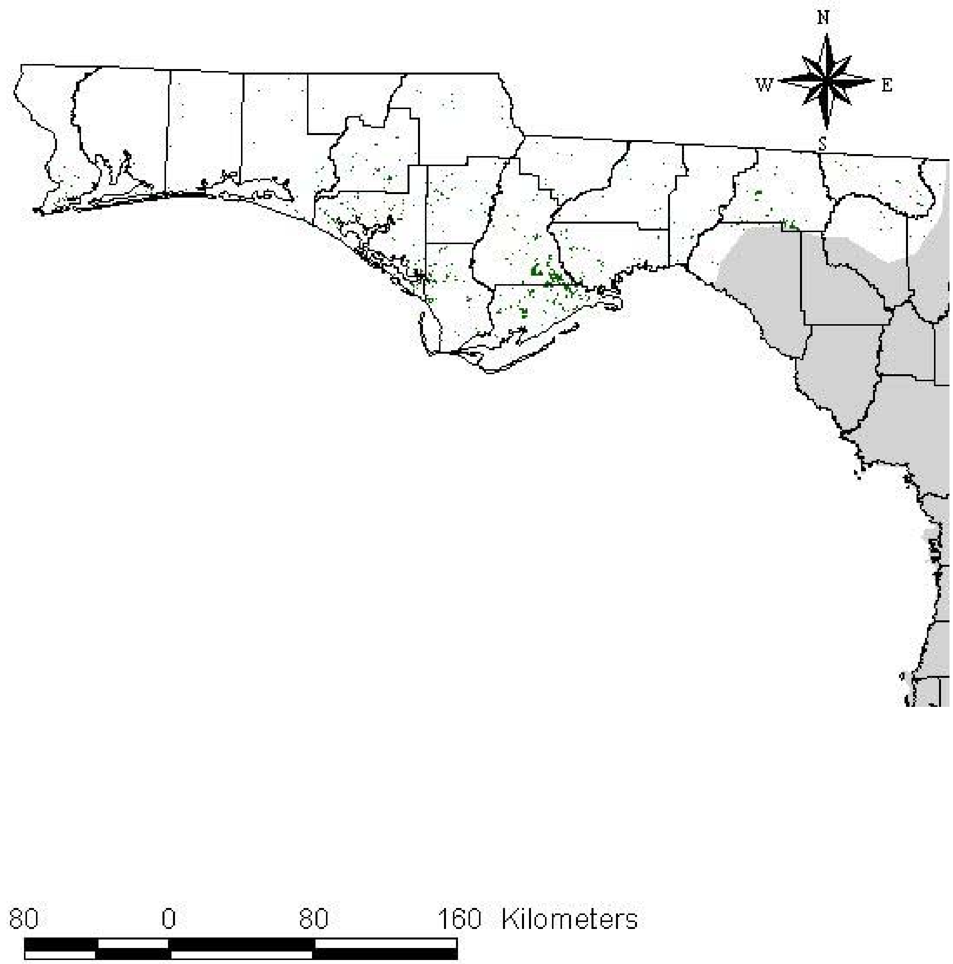

Figure 35. Wetlands of the Panhandle Region: b) 6.8% of the wetlands of this region are of the shrub scrub wetland class.

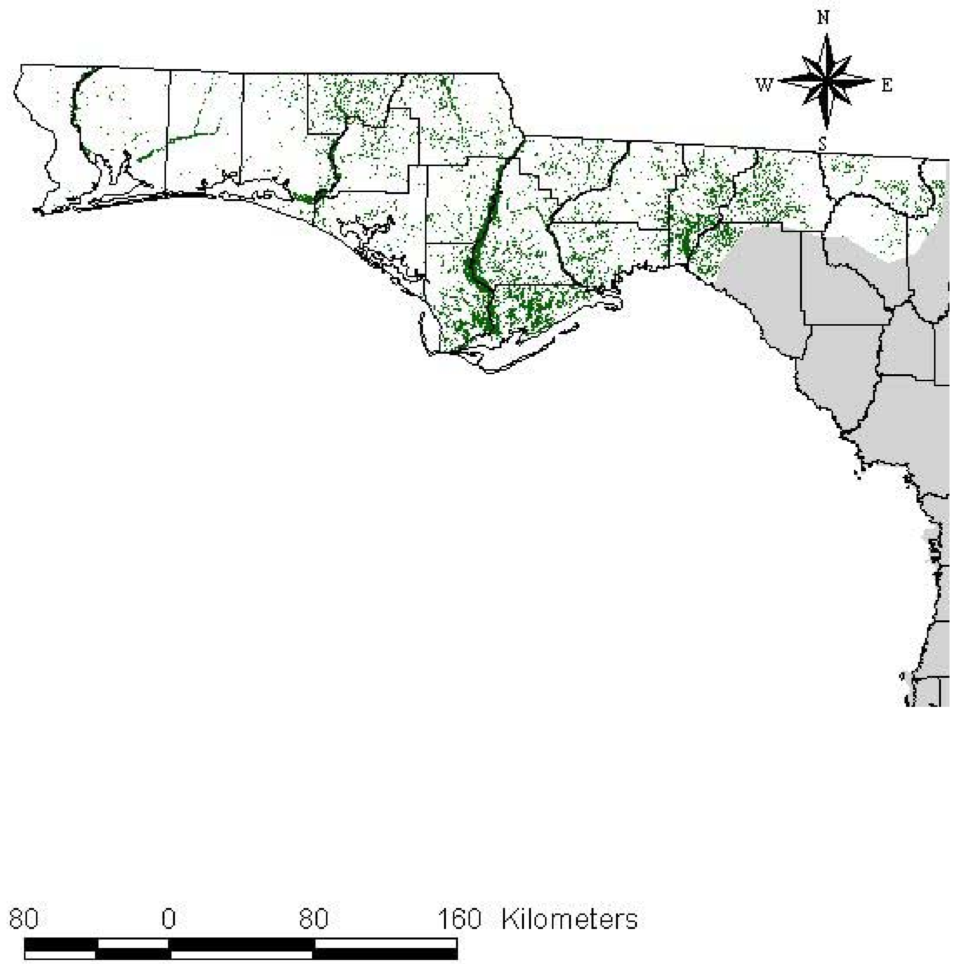

Figure 35. Wetlands of the Panhandle Region: c) 51.6% of the wetlands of this region are of the forested deciduous wetland class.

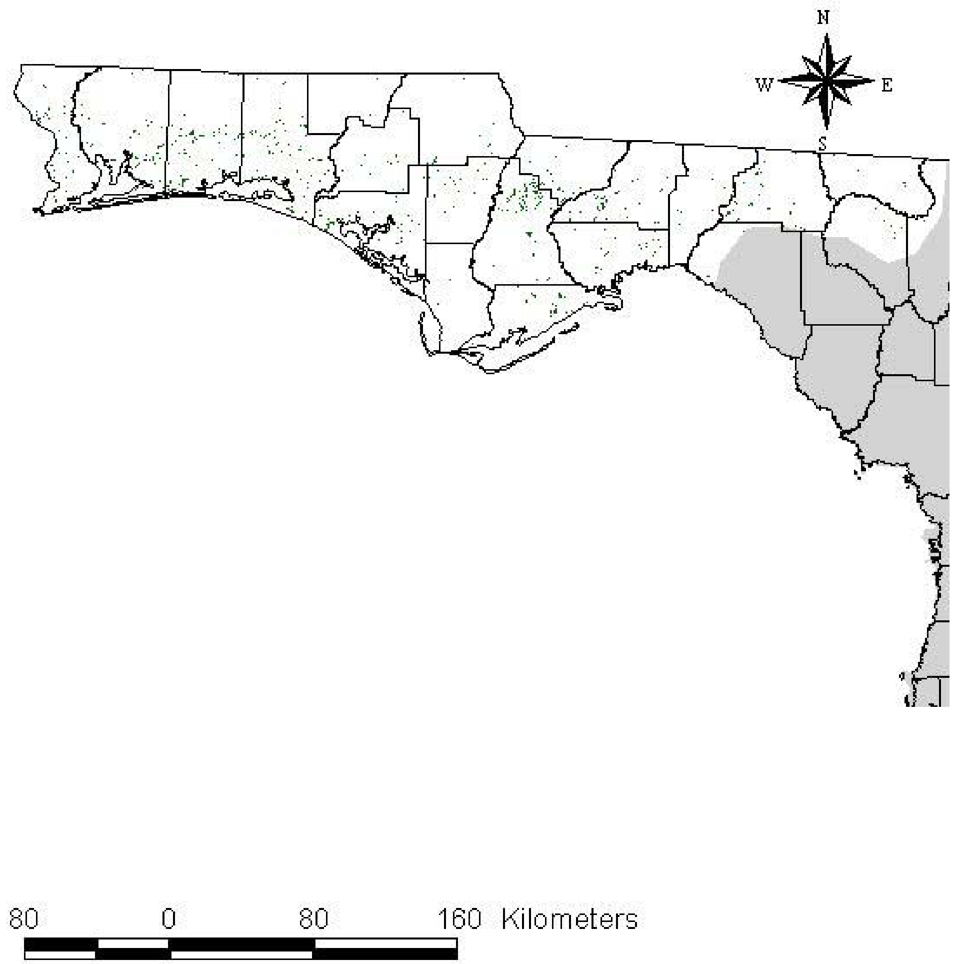

Figure 35. Wetlands of the Panhandle Region: d) 6.2% of the wetlands of this region are of the broad leafed evergreen wetland class.

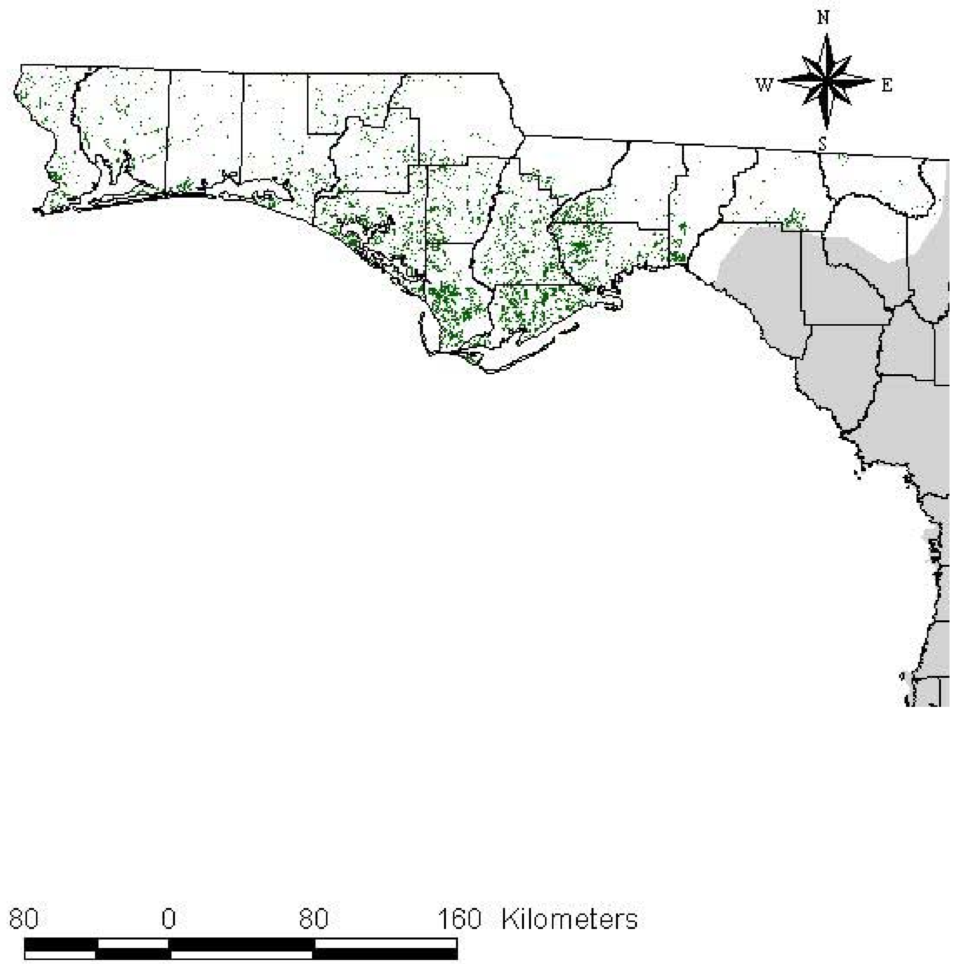

Figure 35. Wetlands of the Panhandle Region: e) 32.3% of the wetlands of this region are of the needle leafed evergreen wetland class.

Table 31. Results of the ANOVA test. The test compared the means of each environmental variable for each wetland region. (The critical $F_{0.05, (1), 3, inf.} = 2.61$.) In all cases the means were significantly different.

Environmental Variables	f-statistic
Runoff	1778.76
January - April Rainfall	462822.6
January - April PET	151538.1
Yearly Rainfall	52807.95
Yearly PET	227657.3
Hydrogroup Class	3173.11
Slope	12503.28
Annual Freeze Days	252165
Vertical Percolation Rate	4306.719

wetland regions in only two instances: the South, Central, and North regions (Peninsular regions) were similar to each other and differed from the Panhandle region in vertical percolation rate; and the North and South regions had similar means for the runoff value (Tables 32-40).

The first order statistical clustering regionalization (Figure 29), was analyzed to determine similarities in the percentage and type of wetland communities found. At the landscape level, the driving forces behind the position of the wetlands on the landscape were also checked for similar means. Based on Figure 29, the State is separated into three groups: Mainland, Peninsula, and Far-Western. In analyzing the first order statistical regions, the area in the far western part of the State, (cluster one) was not included in the similarity analysis. The excluded Far-Western Region (approximately 2.5% of the State) is underlain by gravel and coarse sand and the percolation rate of the media, coupled with highly localized slope, resulted in model values a full order of magnitude greater (and 1m lower in LWBI) than the rest of the State.

The independence of the "Mainland" and "Peninsular" derived wetland regions were tested using the chi-squared statistic. The results indicate that the two regions are unique for wetland type and percentage ($X^2 = 12.8644$, d.f. = 4, p = 0.0001). The regions were also tested for similar landscape driving inputs using the two-sample t-test (Table 41). In all cases, the "Mainland" and "Peninsular" regions were unique with regard to environmental driving forces.

Table 32. Tukey multiple comparison test for equal means between wetland regions for the runoff value (q 0.05, inf., 4). North and South had statistically similar means for runoff.

Runoff Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
Central vs. Panhandle	4.631921745	0.064887	71.38443	3.633	Reject
Central vs. South	2.839725969	0.065855	43.12119		Reject
Central vs. North	2.762740729	0.06642	41.59482		Reject
North vs. Panhandle	1.869181016	0.069816	26.77294		Reject
North vs. South	0.07698524	0.070716	1.088651		Similar means
South vs. Panhandle	1.792195776	0.069278	25.86962		Reject

Table33. Tukey multiple comparison test for equal means between wetland regions for the vertical percolation value (q 0.05, inf., 4). The South, Central, and North regions all had statistically means for vertical percolation rates (from the surficial geology coverage).

Vertical Percolation Rate Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
Panhandle vs. South	28674.43834	309.1071481	92.765368	3.633	Reject
Panhandle vs. North	28661.26633	310.2472957	92.382002		Reject
Panhandle vs. Central	27711.85075	291.1566328	95.178497		Reject
Central vs. South	962.5875982	292.8690224	3.2867512		Similar Means
Central vs. North	949.4155809	294.0721337	3.2285126		Similar Means
North vs. South	13.17201729	311.8548764	0.0422377		Similar Means

Table 34. Tukey multiple comparison test for equal means between wetland regions for the January - April PET value (q 0.05, inf., 4). There were no similar means for January – April PET.

January to April PET Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
South vs. Panhandle	760.5380754	1.191546	638.2783	3.633	Reject
South vs. North	511.6913852	1.202462	425.5364		Reject
South vs. Central	267.2133404	1.129161	236.6478		Reject
Central vs. Panhandle	493.324735	1.117209	441.569		Reject
Central vs. North	244.4780448	0.00727	33628.97		Reject
North vs. Panhandle	248.8466902	1.191246	208.8962		Reject

Table 35. Tukey multiple comparison test for equal means between wetland regions for the Yearly Rain value (q 0.05, inf., 4). There were no similar means for January – April Rainfall.

January to April Rain Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
Panhandle vs. South	2329.083779	2.148816	1083.892	3.633	Reject
Panhandle vs. Central	1907.995524	2.014757	947.0102		Reject
Panhandle vs. North	1228.925602	2.148275	572.0524		Reject
North vs. South	1100.158177	2.168502	507.3356		Reject
North vs. Central	679.0699222	2.03574	333.5741		Reject
Central vs. South	421.0882552	2.036311	206.7898		Reject

Table 36. Tukey multiple comparison test for equal means between wetland regions for the yearly PET value (q 0.05, inf., 4). There were no similar means for yearly PET.

Yearly PET Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
South vs. Panhandle	24.5497315	0.031884	769.9608	3.633	Reject
South vs. North	17.68053789	0.032198	549.1263		Reject
South vs. Central	8.609573093	0.030234	284.7603		Reject
Central vs. Panhandle	15.9401584	0.02988	533.4651		Reject
Central vs. North	9.0709648	0.030214	300.2201		Reject
North vs. Panhandle	6.869193605	0.031865	215.5694		Reject

Table 37. Tukey multiple comparison test for equal means between wetland regions for the yearly rain value (q 0.05, inf., 4). There were no similar means for yearly rainfall.

Yearly Rain Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
Panhandle vs. Central	19.51283176	0.050456	386.7265	3.633	Reject
Panhandle vs. North	14.92313941	0.001723	8663.593		Reject
Panhandle vs. South	13.52727218	0.05384	251.2478		Reject
South vs. Central	5.985559579	0.051054	117.2392		Reject
South vs. North	1.395867229	0.054369	25.67386		Reject
North vs. Central	4.58969235	0.05102	89.95807		Reject

Table 38. Tukey multiple comparison test for equal means between wetland regions for the annual days at freezing value (q 0.05, inf., 4). There were no similar means for annual days at freezing.

Annual Days at Freezing Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
Panhandle vs. South	2453.276160	3.1815849	771.0861944	3.633	Reject
Panhandle vs. Central	2086.456446	2.9816179	699.7732473		Reject
Panhandle vs. North	1025.954284	3.1796852	322.6590785		Reject
North vs. South	1427.321876	3.2128361	444.2560476		Reject
North vs. Central	1060.502162	3.0149426	351.7487036		Reject
Central vs. South	366.819713	3.0169461	121.5864339		Reject

Table 39. Tukey multiple comparison test for equal means between wetland regions for the slope value (q 0.05, inf., 4). There were no similar means for slope.

Slope Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
Panhandle vs. South	5.216050744	0.027912	186.8779	3.6333	Reject
Panhandle vs. Central	3.684254951	0.026206	140.5866		Reject
Panhandle vs. North	2.914141507	0.028197	103.3479		Reject
North vs. South	2.301909237	0.028511	80.73798		Reject
North vs. Central	0.770113444	0.026844	28.68879		Reject
Central vs. South	1.531795793	0.026543	57.70932		Reject

Table 40. Tukey multiple comparison test for equal means between wetland regions for the hydrogroup value (q 0.05, inf., 4). There were no similar means for hydrogroup value.

Hydrogroup Comparison	Difference Between Regional Means	Standard Error	Test q-value	$q_{0.05, inf., 4}$	Conclusion
South vs. Panhandle	0.991388278	0.007488137	132.3945	3.633	Reject
South vs. North	0.627256382	0.01081271	58.01102		Reject
South vs. Central	0.352710779	0.010066255	35.03893		Reject
Central vs. Panhandle	0.638677498	0.009936217	64.27773		Reject
Central vs. North	0.274545602	0.010173433	26.98653		Reject
North vs. Panhandle	0.364131896	0.010691755	34.05726		Reject

Table 41. Results of the t-test statistic between the "Mainland" and "Peninsular" regions as defined by clustering algorithms. In all instances, the means for the Mainland and Peninsular regions were statistically different ($t_{0.05, inf.} = 1.96$).

Environmental Variables	t-Test Statistic
January – April Rainfall	-34.8257
January – April PET	63.56757
Yearly PET	-21.9075
Yearly Rainfall	9.44876
Annual Days at Freezing	172.1089
Slope	85.05498
Vertical Percolation Rate	-16.0318
Runoff	-23.1847
Hydrogroup	-29.6617

DISCUSSION

In this study, the Florida landscape was separated into greater than 140,000 unique cells containing information about the type and percentage of wetlands within each cell. During the TWINSPAN analysis, the rasterized landscape was hierarchically classified into groups that reflected generally unique wetland community composition: Forested Deciduous, Uplands, Shrub Scrub, and Emergent Marsh wetland types. The determinants of the spatial location for each of these wetland groups were examined using detrended correspondence analysis and canonical correspondence analysis. Based on the results of the DCA and CCA, as well as the literature available, it was determined that the landscape hydrology determines, or at least is an important determinant of, the spatial location of different wetland types.

With the results of the geostatistical analysis demonstrating the importance of hydrology in determining wetland type and location, a landscape water balance was calculated for January to April climatic inputs. The landscape was regionalized with the Landscape Water Balance Index into areas of similar critical depth of saturation for wetland plants. This study resulted in the creation of four wetland regions: South, Central, North, and Panhandle.

These wetland regions were created based on the premise that the landscape water balance and all its manifestations (such as hydroperiod and depth of saturation) affect the biotic components of wetlands. It is therefore reasonable to assume during the creation of wetland bioassessment indicators that the same type of wetland having a different landscape water balance will have a different characteristic species assemblage.

These regions and the processes that were used to create them are discussed here in the following sections: Landscape Classification and Wetland Ecosystem Determinants, Landscape Water Balance Regionalization, and Model Improvements.

Landscape Classification and Wetland Ecosystem Determinants

While detrended correspondence analysis and canonical correspondence analysis are typically used for gradient analysis, the TWINSPAN divisions, which are based on percent occurrence of different wetland types, appear to also reflect a hydrologic gradient between TWINSPAN classes. The relationship between hydrology and plant composition is shown in Figure 36. The wetland vegetation that typifies the first TWINSPAN group (Ia) is uplands and forested deciduous, while that which typifies the second TWINSPAN group (Ib) is emergent and shrub scrub wetlands. The relationship between forested wetlands and hydroperiod is such that forested wetlands typically have shorter hydroperiods that non-forested wetlands (Ewel 1998, Kuslan 1990, Duever 1982). The means of the TWINSPAN classes at the first level of division seem to indicate that while the group Ia (uplands/forested deciduous) receives more yearly and January – April rainfall and has a smaller yearly and January – April potential evapotranspiration than Ib (emergent and shrub scrub wetlands), the very high mean rates of vertical percolation and slope, coupled with the higher rates of runoff and better drainage move the water off the landscape very quickly (Table 5). Annual days at freezing may also be a landscape driving force that is reflected in the classification, as group Ia averages many more days at freezing each year.

The influence of hydroperiod continues in the second TWINSPAN division, with the upland class (IIb) having the highest mean higher hydraulic conductivity, slope, runoff, and drainage, which likely shunt water off the landscape quickly (Table 6). The scrub shrub (IIc) and emergent marsh (IId) have the lowest mean percolation rates, slope, and runoff, all of which would increase amount of time water stays on the landscape.

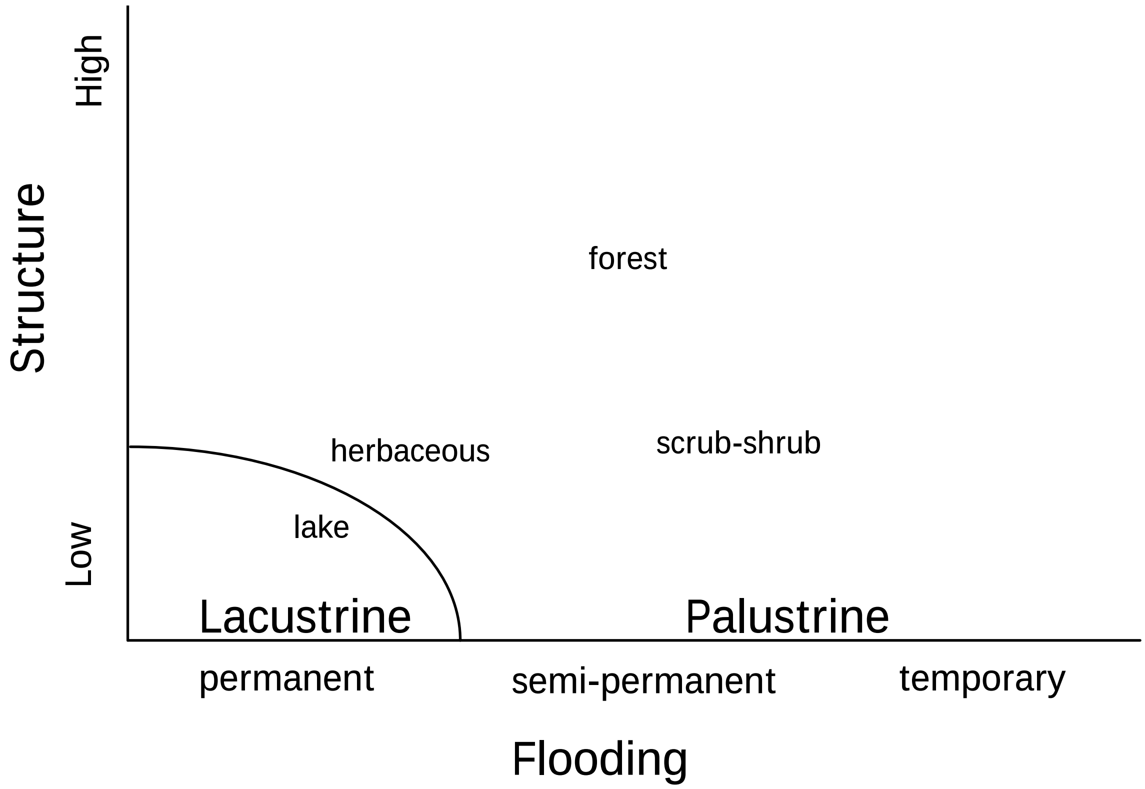

Figure 36. The relationship between hydroperiod and plant communities/structure (modified from Sharitz and Gresham (1998)). A longer hydroperiod is more conducive to herbaceous vegetation assemblages.

TWINSPAN Group Comparisons

During the TWINSPAN analysis, the measured environmental inputs to the unique TWINSPAN groups (classes IIa, IIb, IIc, and IId) demonstrated no significant relationship between TWINSPAN groups in the first division and a significant relationship in only four of fifty-four possible instances in the second division (Tables 9-17). Clusters IIc and IId (majority shrub scrub and emergent marsh, respectively), had similar means for vertical percolation rate, January – April potential evapotranspiration, and annual days at freezing. The clusters are both part of the Ib class from the first TWINSPAN division (i.e. emergent marsh and shrub scrub), and the majority of the cells are located in south Florida, with IIc (shrub scrub) occurring almost exclusively in the northern section of the Everglades. The surficial geology of the South region is rich in peat resources, which may explain the similar low means for percolation rates (from surficial geology). The similar potential evapotranspiration values are likely also explained by their spatial proximity to one another, as the potential evapotranspiration figure was obtained from temperature, which is likely to be very similar in areas that are abutting. The proximity of the two classes is likely to account for the similar means in annual days at freezing, as well.

Class IIb, with very small percentages of wetland types (see Table 4), is considered uplands. The class was unique in not having a similar mean with any other TWINSPAN class for any of the environmental variables. This follows logically for if a landscape were classified as upland, it would likely mean that few environmental variables would be the same as an area classified as a wetland landscape due to the driving forces that create wetlands. By the same logic, perhaps all lands characterized as wetlands (IIa, IIc, IId) should demonstrate similar means for a measured environmental value. The expected statistical relationship between all lands classified as wetlands and measured environmental values (e.g. rainfall, potential evapotranspiration, annual days of freezing, etc.) is not present in this analysis, due perhaps to the scale of the research, the lack of accuracy in the NWI maps or because a driving force, such as fire regime, was not incorporated into the study. Note, though, while a direct relationship between measured environmental values and wetland groups does not exist, a synergistic relationship does exist between all lands characterized as wetlands that separates them from the upland class. The physiographic characteristics (such as slope, runoff, vertical percolation rate) act synergistically to maintain more water on the landscape in wetland groups than in upland groups.

Gradient Examination through Ordination

The importance of hydrology in defining the locations of wetland types and associated species assemblages on the Florida landscape is sustained by the DCA ordination of the TWINSPAN groups. The ordination of the first four TWINSPAN classes reveals that the uplands landscapes ordinate at the far left side of the axis, followed to the right by forested deciduous, emergent wetlands, then shrub scrub wetlands (Figure 20). The first axis, which is the main gradient in interpreting ordination results (Tonteri et al. 1990), appears to separate wetland types along a hydrological gradient similar to the first division of the TWINSPAN analysis with shorter hydroperiod classes on the left of the biplot and longer hydroperiod classes on the right. The left side of Axis 1 is negatively correlated with rainfall during the period January – April, meaning that there is higher rainfall during the January – April period on cells that are predominantly forested deciduous (IIa) and uplands (IIb). Yet, just as with the TWINSPAN division two, there is also high runoff of those cells as the slope, runoff, and vertical percolation (from surficial geology coverage) are negatively correlated with the first axis.

The DCA ordination of the TWINSPAN clusters and correlation for emergent wetlands (IId) and shrub scrub (IIc) reveals a positive correlation for yearly rainfall. Slope, runoff, and vertical percolation are negatively correlated with the ordination location of classes IIc and IId. The combination of high yearly rainfall and low movement of water off the landscape (as indicated by the low slope, runoff, and vertical percolation) maintains water on the landscape and creates conditions for emergent and shrub scrub wetland formation.

The shrub scrub community (IIc) is located on the right side of axis 1 in Figure 20. The large Euclidian distance between the shrub scrub (IIc) and the emergent wetland type (IId) along the hydrological gradient may not be due to the increased hydrology. Rather, the distance may be due to the small and clustered spatial extent of the shrub scrub wetland type in comparison to other wetland types and the relatively low variance in environmental conditions that follows a limited spatial extent.

The CCA separated the TWINSPAN groups as the DCA did, into a left group and a right group, although the number of cells in the analysis (n=8100) obfuscated the diagram. While in the DCA they are plotted on the right, in the CCA the left cluster is comprised mainly of TWINSPAN classes IIc and IId, which are the scrub shrub and emergent wetland types. The environmental conditions that CCA analysis determined are indicative of class IIc and IId wetland types (shrub scrub and emergent marsh, from Table 4) are low slope, low runoff, poor drainage, and a low number of freezing days. High values for annual and January – April potential evapotranspiration are found for these classes (see Table 20). The forested deciduous (IIa) and uplands complex (IIb), on the right side of the first axis ordination, are subject to higher vertical percolation rates, high slope, high runoff, high January – April and yearly rainfall, and a high number of days at freezing. It appears from the CCA ordination vectors that the strongest correlations belong to the January – April rainfall, the annual freeze days, January – April PET, and yearly PET.

The CCA ordination supports the hypothesis that the distribution of wetland regions in Florida is related to the hydrology of the landscape, with emergent and shrub scrub wetland types found in areas that maintain higher landscape water balances. TWINSPAN classes IIa and IIb, which in the DCA were correlated with high January – April rainfall, but also correlated with high slope, runoff, and vertical percolation rates, are again defined by the CCA as areas that receive high amounts of rainfall (January – April and annual) but become less hydric as the water leaves the cell through runoff, high slope, or high percolation rates. The high correlation for yearly and January – April potential evapotranspiration for IIc and IId may be more a remnant of the spatial location of the scrub shrub and emergent marsh wetland types, and not what actually defines their spatial location as the vegetation type drives the potential evapotranspiration, and not vice versa.

To summarize the ordination of the TWINSPAN clusters, some generalizations can be made from the DCA and CCA results. It appears that the landscape hydrology does influence the spatial location of wetland types. While the rainfall during the January – April period on the upland (IIb) and forested (IIa) classes is higher than on the emergent (IId) and shrub scrub (IIc) communities, the rain appears to leave the cells more quickly in the upland and forested classes, thereby minimizing hydrologic stress. The rapid movement of rainfall off the landscape is due to the high soil drainage capacity, the high surficial geology percolation rates, high slopes, and high runoff values of uplands and forested wetland classes (IIb and IIa). Landscape characteristics of the emergent and shrub scrub classes that affect the movement of rain on the landscape (and thus the landscape water balance) are low soil drainage capacity, low surficial geology percolation rates, low slopes, and low runoff values. The number of annual days of freezing also appears to have an impact on wetland community profiles, with the uplands and forested deciduous classes having many more days of freezing temperatures than the emergent and shrub scrub classes

Landscape Water Balance Regionalization

The results of the landscape water balance model, when statistically clustered using the average linkage process and then reclassified based on the actual LWBI values of the cells, appear to separate the State into a first order map with two main classes: a Mainland Region and a Peninsular Region, and a third, outlying Far-Western Region (Figure 29). The distinction worthy of discussion between the Mainland and Peninsular regions is the ecological appeal of the division. The Florida Peninsula juts approximately 350 miles into the Atlantic Ocean and Gulf of Mexico. The influence from the surrounding seas affects almost every aspect of the Florida peninsula's natural history, from the underlying limestone and sand to the rainfall and ocean-moderated temperature extremes. It is ecologically and geographically appealing to consider how the influence from the mainland landscape driving forces (of particular note are the slope and annual days of freezing) would be expected to diminish as the distance from the mainland increases, while the influence of the driving forces of the oceans surrounding much of Florida (such as rainfall) would conversely increase.

At a coarse resolution, the separation of the State into Peninsular and Mainland wetland ecological regions follows bio-geographical and ecological canons. These regions, though, must be considered on a hierarchical basis. For just as there are climatic and physiologic (and latitudinal) gradients that separate the Florida peninsula from the rest of the coastal southeast, there exist landscape gradients that drive wetland ecology at a finer scale, notably the timing, depth, and duration of flooding on the landscape. By utilizing a hydrological gradient along the critical depth of saturation to determine wetland regions, a finer scale is used that may more accurately reflect the effects of landscape variables on the species composition of wetland communities.

Regionalization Using the Landscape Water Balance Index

Based on model results, as one travels south through peninsular Florida during the January to April model period, the landscape water balance decreases. The decrease in the landscape water balance follows the north to south decrease in seasonal rainfall and the increase in temperature-based potential evapotranspiration. The slope, which on average decreases along a north – south gradient and is characteristically less in peninsular Florida than in the relatively hilly areas of the Panhandle, would tend to increase the landscape water balance in southern peninsular Florida, as more moisture would remain on each cell. The low runoff value for wetlands would also tend to maintain the landscape water balance in southern Florida, as large expanses of wetlands are present. However, both the slope and the runoff components of the model are multiplied by the estimated rainfall. The rainfall decreases along a north – south gradient, and thus the effects of slope and runoff on maintaining the landscape water balance are likewise lessened along the north – south axis.

The premise that drives the model is that the landscape water balance affects the biotic components of wetlands, and the study assumes that the same type of wetland having a different landscape water balance will have a different characteristic species assemblage. This model-derived hydrologic regime may determine wetland landscape community composition, as hydrology is a major factor in controlling the species that will be found on wetland landscapes through hydroperiod, timing, frequency, and depth of inundation (Figure 36, Penfound 1952, Cowardin et al. 1979, Duever 1982, O'Brien and Motts 1980, McKevlin et al. 1998, Wigley and Lancia 1998, Hoover and Kilgore 1998, Breder and Rosen 1966). Due to differences in model-derived regional hydrology during the January to April period, wetlands that may be of the same type (i.e. depressional emergent marshes) but located in different regions of the state as defined by this study may have different species assemblages (Ewel 1990, Ewel 1998, Kushlan 1990, Odum et al.1982, Duever 1975, and Duever 1982).

Comparisons with Published Regionalizations

Supporting the robustness of the model and the critical depth of saturation scale, the Landscape Water Balance Index-derived peninsular regions approximate several published floristic and climatic regions in Florida. The isopleth separating peninsular Florida from the mainland (North from the Panhandle) approximates a region known to agronomists as the separation between the thermic and hyperthermic temperature regimes (Figure 37, Carlisle 1995). This boundary separates the growing season months for Florida and the vegetation assemblages that can withstand freezes and extreme temperature fluctuations. The growing season is defined as, "the portion of the year when soil temperatures are above biologic zero (5 degrees C) as defined by Soil Taxonomy (USDA 1985, p. 1)." South of the line, the

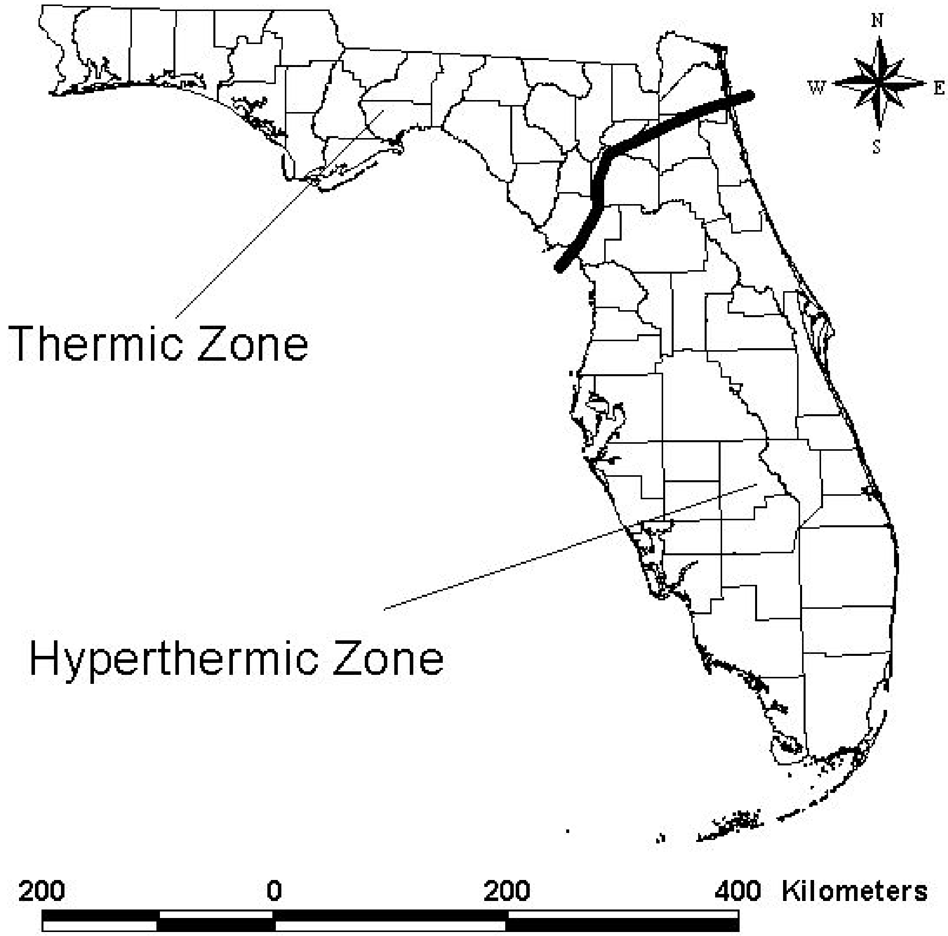

Figure 37. A map of the separation between the Thermic and Hyperthermic Temperature Zones (Carlisle 1995). The line separates growing seasons and vegetation assemblages.

growing season is assumed to be February to December; north of the boundary has a growing season of March to October (USDA 1985).

The split between the North Region and the Central represents the approximate boundary between Thornthwaite's "humid mesothermal" and "subhumid mesothermal" zones (Figure 38, Thornthwaite 1941). The Thornthwaite boundaries represent regions where flora types will respond to differences in available water (precipitation minus potential evapotranspiration) to create homogenous vegetation regions (Thornthwaite 1941). Thornthwaite's "subhumid mesothermal" and "humid tropical" represents another split captured in the model, where climatic differences in precipitation and potential evapotranspiration form homogenous vegetation regions (Fernald and Purdum 1998).

Bell and Taylor (1982) created a map to identify the range of Florida's flowering plants. This map, based on both homogenous climate and soil types, corroborates very well with the Landscape Water Balance Index map. The DEP currently utilizes Bell and Taylor's map of Florida (Figure 39) to separate wetland floristic regions (Tobe et al. 1998). Bell and Taylor's map follows county boundaries, and is very similar to this study's hydrological map in separating Florida into southern peninsular, central peninsular, northern peninsular and western (Panhandle) regions.

Figure 40 represents the USDA's climatological division between regions of uniform climate (Fernald and Purdum 1998). This map matches well with the South Region, and separates Florida into seven regions. The central peninsula is separated into two regions, which if combined, closely match the Central Region of this study. Both the North Region and the Panhandle Region also closely match regions identified by the USDA.

The USDA's Land Resource Regions (LRA's, Figure 41) and Major Land Resource Areas (MLRA's, Figure 42) of the United States separate the Florida landscape into regions and then further divides the regions into "areas" based on expert opinions of zones of similar landuse, elevation/topography, climate, water, soils, and potential natural vegetation (SCS 1981). The LRA boundary at the Big Bend region of Florida approximates the Land Resource Region boundary between "Atlantic and Gulf Coast Lowland Forest and Crop Region (North)" and the Florida Subtropical Fruit, Truck Crop, and Range Region (South) (SCS 1981)." This is also approximates the hydrologic budget Panhandle/North Florida Regional boundary. These MLRA map polygons are similar to Griffith's (1994) sub-ecoregions (see Figure 1). The MLRA Florida Everglades boundary corresponds well with the South Region boundary and the Landscape Water Balance Index North/Central boundary is similar to the South-Central Florida Ridge/Southern Florida Flatwoods MLRA boundary.

Omernik's (1987) ecoregions map of the United States (Figure 43) separates Florida into three regions. Omernik's divisions are similar to the Landscape Water Balance Index map. The South Regions, Central Region, and the Panhandle Region are present in both maps. The maps differ in that this analysis splits the Central Peninsula region it two parts, a North and Central region.

The South Region contains the Big Cypress and Everglades areas. These uniquely vegetated lands are underlain by limestone and peat, respectively, and contain vast zones of similar vegetation not found in such breadth and extent elsewhere in Florida (Davis and Ogden 1994). Koppen's classification of climate types splits southern Florida between humid subtropical, which is described as a "forested climate with cool winters and warm to hot summers" and tropical savanna, characterized by "very mild to warm, dry winters, and rainy, hot summers (Figure 44, Visher 1954, Muller and Grymes 1998, pp. 87)."

The regions located in the Panhandle do not follow known regions as well as the peninsular zones, with the exception of the USDA climatological division and the MLRA maps described in Figures 40 and 42. The landscape complexity evident in the Panhandle may be related to the Appalachian Mountain chain topography and the orographic effect on rainfall and temperature. The dichotomy between the coastal zone climate and the remnant

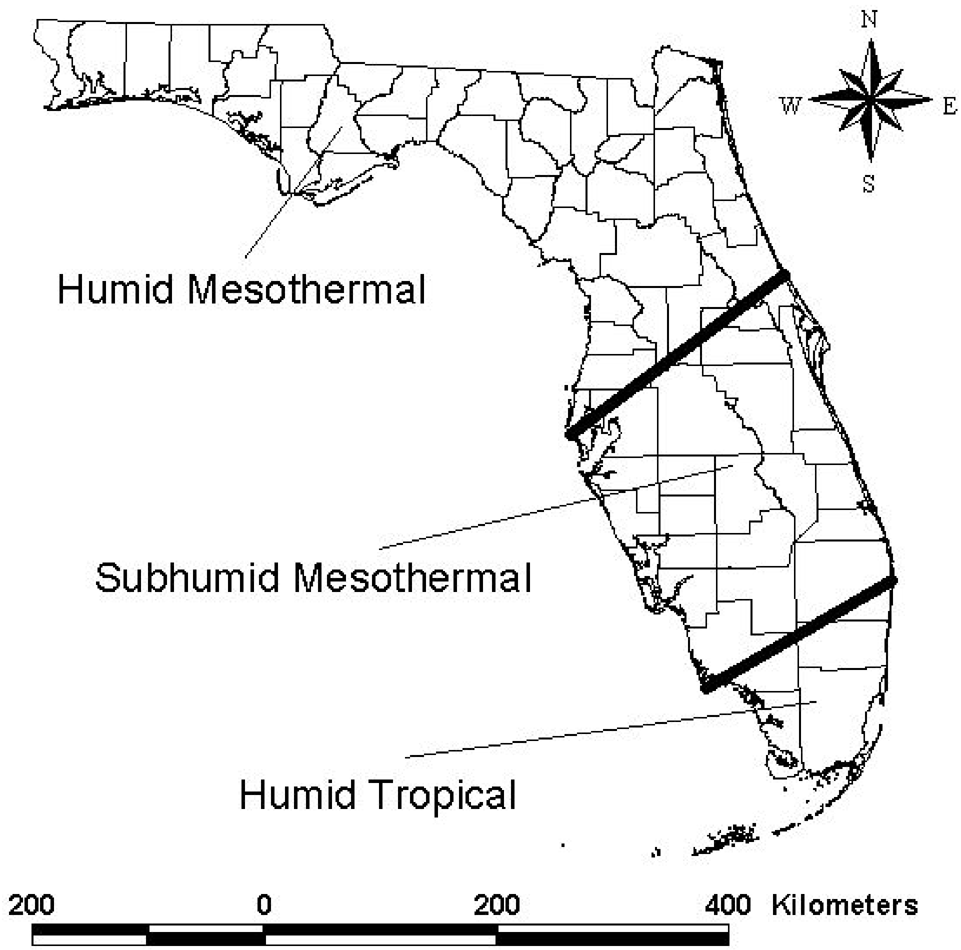

Figure 38. A map of the Thornthwaite's Climatological Zones. Different zones represent changes in water availability for vegetation (Thornthwaite 1941).

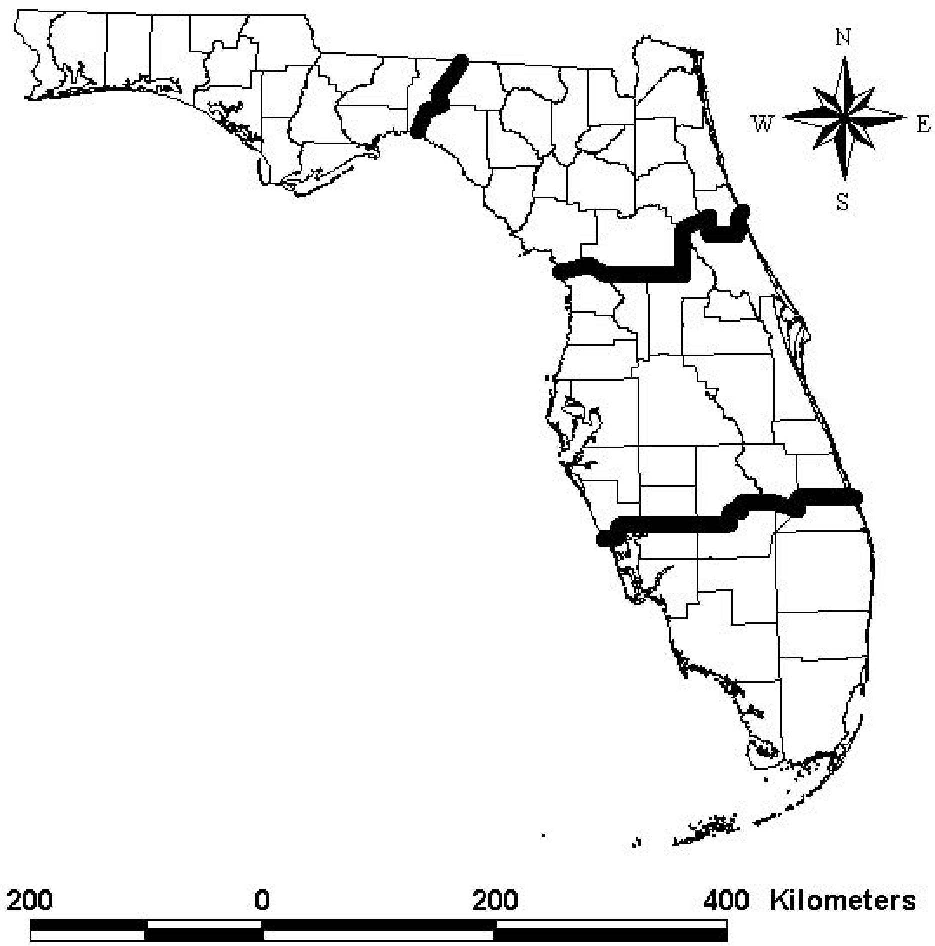

Figure 39. A map of the Floristic Regions of Florida. Bell and Taylor created these regions of similar vegetation and soils foro their Flowering Plants of Florida (1982) field guide.

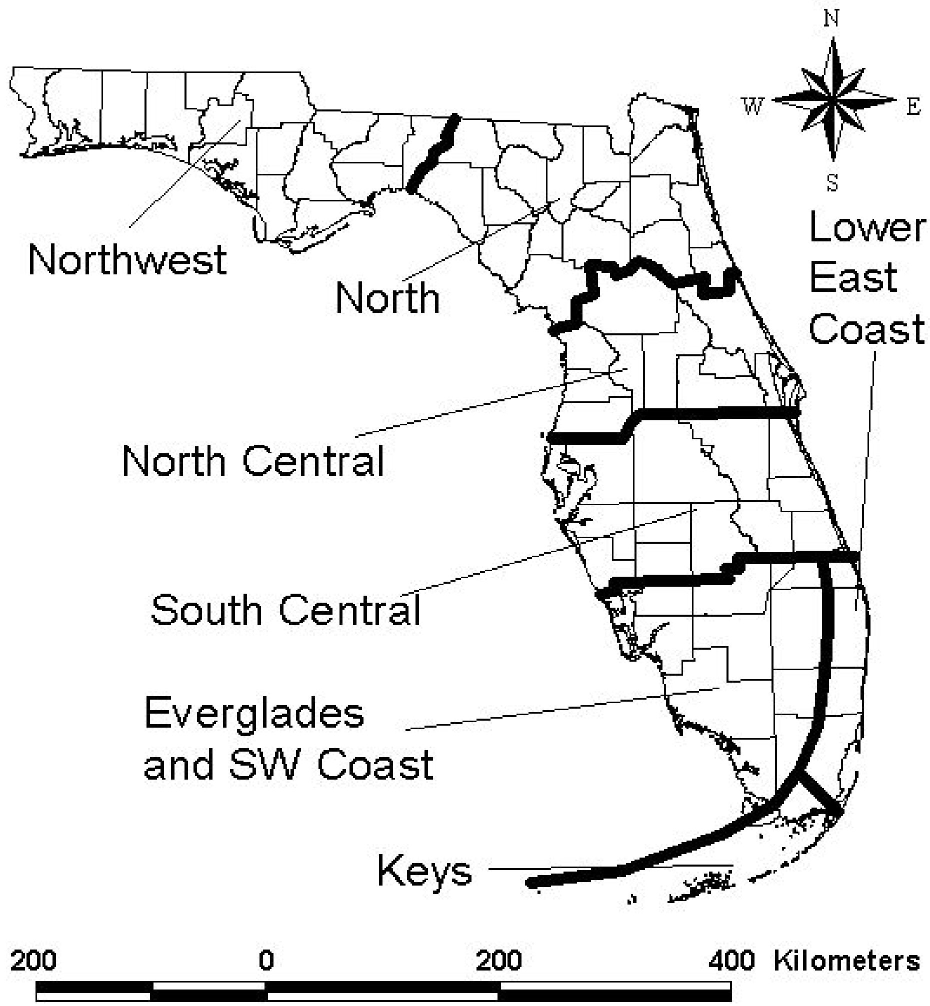

Figure 40. Florida has seven delineations of USDA Climatological Divisions. Regions of uniform climates are delineated by the USDA (Fernald and Purdum 1998).

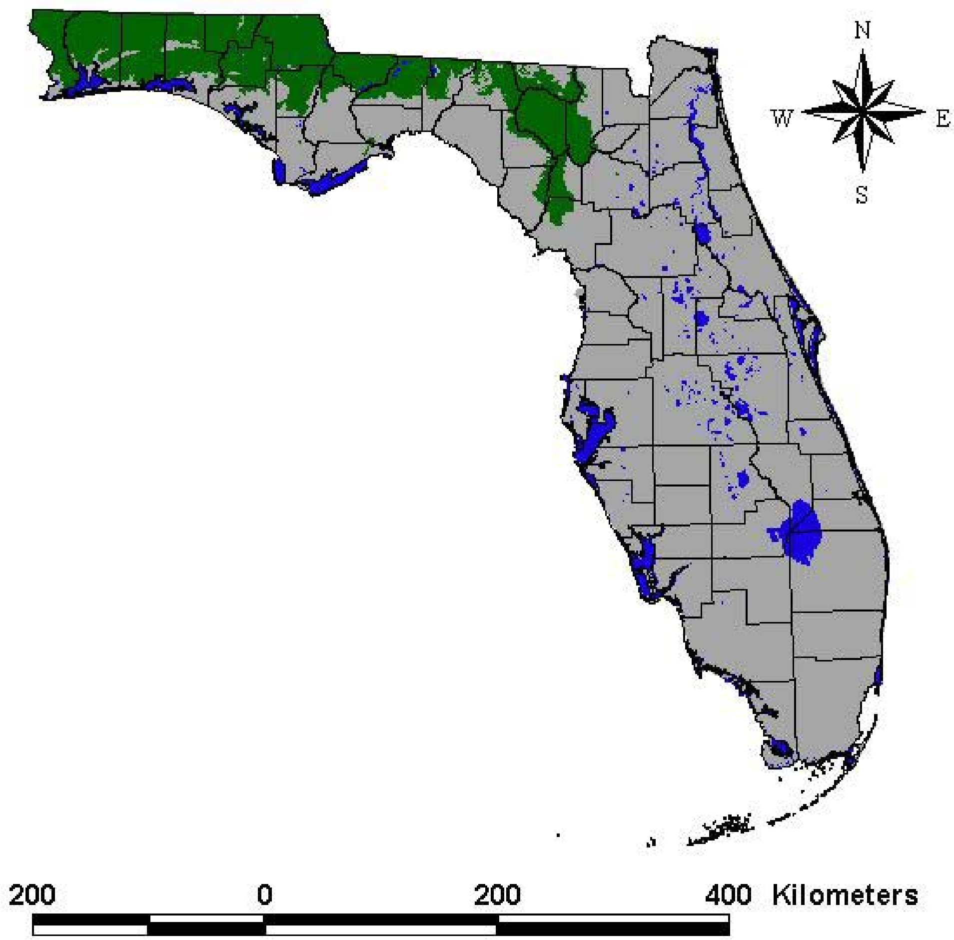

Figure 41. A map of the USDA's Land Resource Regions. The USDA separated the Florida landscape into two Land Resource Regions of similar elevation/topography, climate, water, soil, natural vegetation, and land use. The north region is the "Atlantic and Gulf Coast Lowland Forest and Crop Region" and the south region the "Florida Subtropical Fruit, Truck Crop, and Range Region (USDA 1981).

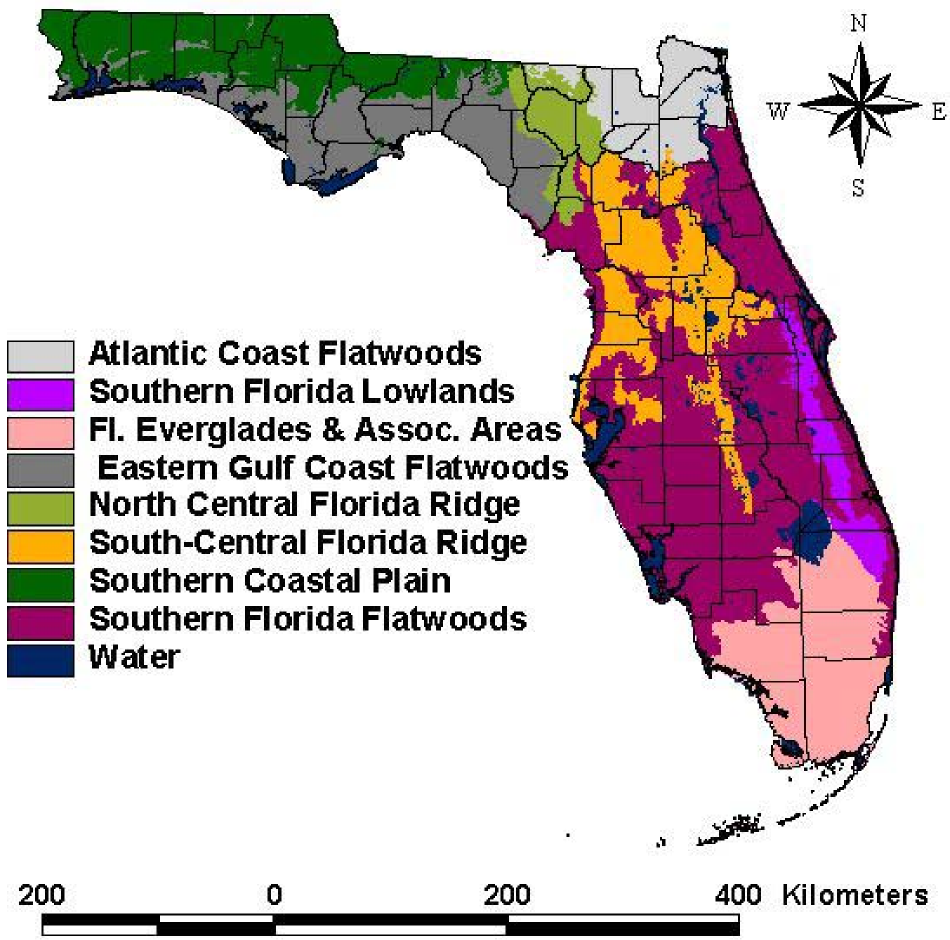

Figure 42. The USDA's Major Land Resource Areas (MLRA's). The LRA's (Figure 37) are further divided into homogenous climatic and landscape units (USDA 1981).

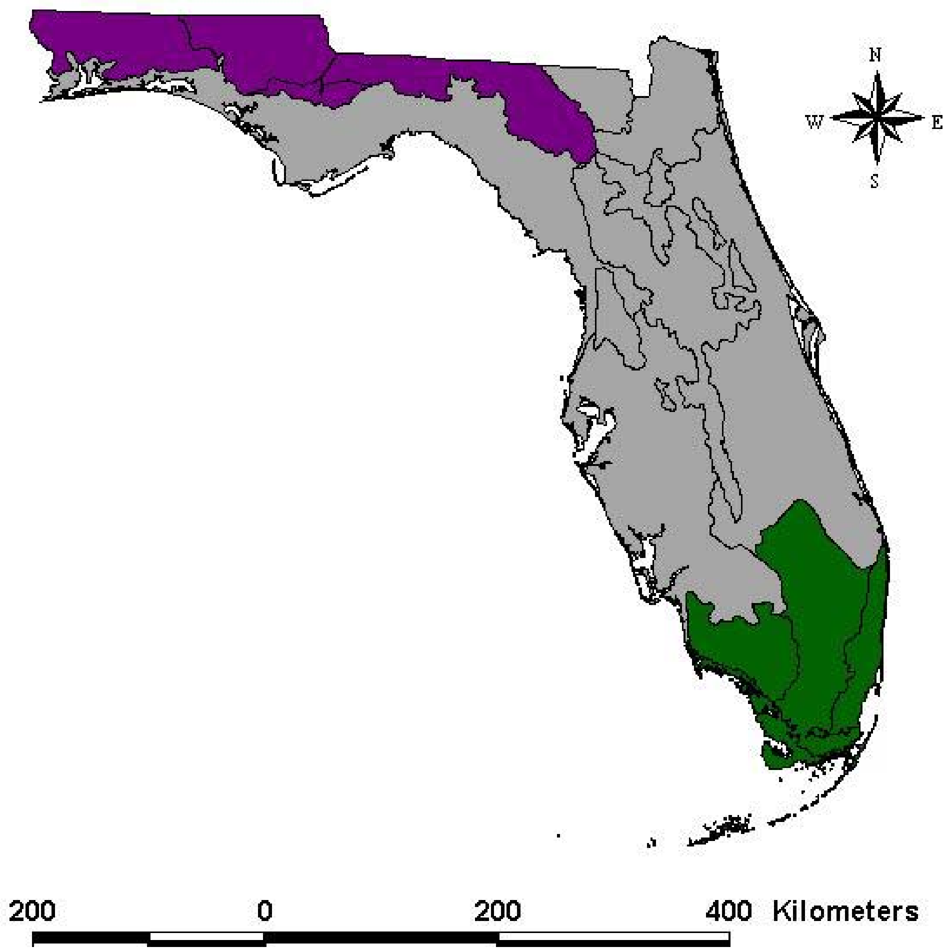

Figure 43. Omernik's (1987) Ecoregions of the United States. These regions represent homogenous landscape units. This map was further divided by Griffith et al. (1994) to create the subecoregions of Florida (these polygons are visible).

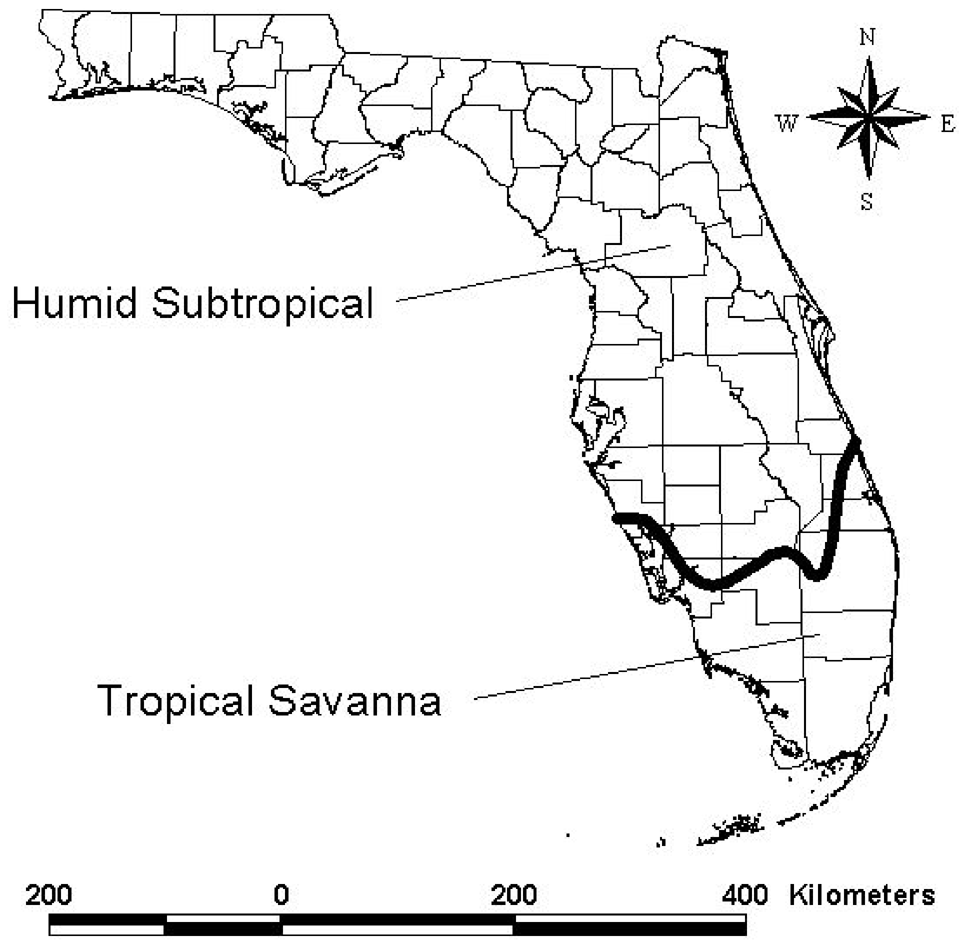

Figure 44. Koppen Climate Classification. Humid Subtropoical is defined as "forested climate with cool winters and warm to hot summers (Muller and Grymes1998)." Tropical Savanna is characterized by "very mild to warm, dry winters, and rainy, hot summers (Muller and Grymes 1998)."

hills in the region could also create localized heterogeneity that is captured by the model. It is possible that the Panhandle, with its complexity, will necessitate several small regions.

Statistical Discussion of the Between Variation amongst Wetland Regions

The chi-squared tests indicate that the type and percentage of wetlands found in the two analyzed regions (Mainland and Peninsula) delineated using the LWBI and the average-linkage clustering algorithm are dependent upon the region (i.e. the wetland type and percentage are different within each region). Chi-squared results also indicate that the regions delineated using the LWBI and the critical depth of saturation (South, Central, North, Panhandle) are also dependent upon the region.

The chi-squared tests support the hypothesis that there are (in general) different types of wetlands that will be found in the particular regions. The two-sample t-test results appear to indicate that there are different landscape driving forces at work between the Mainland Region and the Peninsular Region, as none of the means for the nine measured environmental variables were statistically similar. However, at what appears to be on a hierarchical finer scale, the regions delineated by the critical depth of saturation have similar means for some driving forces between the four regions. In particular, the North, Central, and South all have the same mean for the rate of percolation resulting from the surficial geology of each region (see Table 33). The similarity for the North, Central, and South regions may be a result of the similar pelagic original of their basement materials. The Panhandle, likely due to its unique gravel surficial geology in the far western portion of the State and complex LWBI values, is dissimilar to the North, Central, and South regions for percolation rate.

The only other statistical similarity comes between the second-order North and South Regions and the mean runoff value (see Table 32). With no obvious reason for the similarity, it may be explained by the relationship between the runoff coefficient, the land cover, and the Hydrogroup classification. Over thirty percent of the South Region is wetlands, which are given 0.10 for a runoff coefficient. While the North Region does not have nearly the same percent of the land as wetlands, it does have, on average, 25% more land classified as Hydrogroup "A", which is also given 0.10 for a runoff coefficient. This may be a averaging phenomenon.

Model Improvements

While the multivariate landscape analysis included many of the features on the Florida landscape, the input list was not exhaustive. As fire has been a part of the natural Florida landscape, it would certainly play a part in determining the landscape composition. Ewel (1990) and Kushlan (1990) both note the importance of fire in wetland formation. It would be difficult, though, to create a map of annual wildfires that would be accurate and useful. Additionally, the fire itself could range from a small fire to a huge conflagration. The difference in intensity could affect the resilience and composition of the landscape, as would the timing. In seasons of water stress, fires would paint the landscape with a much larger brush than in periods of adequate moisture.

The scale of the model, with cells of 1000m by 1000m, resulted in wetland regions that closely match previous published regional maps of Florida. While regions may be created at a smaller scale for the landscape water balance, the improvement in resolution may not be reflected in the improvement of the regions. The smaller scale would be useful, however, in the TWINSPAN analysis and subsequent DCA and CCA. The smaller cell size may allow for a more accurate relationship between wetland type and the underlying environmental gradients.

Maps that accurately portray the vegetation would be an asset to regionalization models as well. The Florida Gap Analysis Program is currently creating vegetation alliance maps at 30m cell size (Scott 1996). The use of the Gap Analysis Program product in addition to the environmental landscape inputs, may result in a description of the underlying gradients not only to wetland plant formation, but to all ecological assemblages on the Florida landscape.

The final improvement on the map will come from the field. The regions developed by this study presume to derive regions of landscape heterogeneity. The actually heterogeneity of the wetland species assemblages found in each region will determine the appropriateness of each region. Additional studies may determine that the regional boundaries will change, depending on the type of wetland in question.

Conclusions

Several conclusions can be reached based on this study's efforts to characterize the Florida landscape into wetland regional units.

1. The use of geographic information systems allows for the analysis of several layers of environmental data in the creation of homogenous landscape regions. In this study, the landscape hydrology was modeled and four unique wetland regions were delineated based a combination of physiographic and climatic inputs.
2. The use of geographic information systems allows for the spatial analysis of landscape driving forces when coupled with spatial data that reflects vegetative communities. The more accurate and finer-scaled the vegetative communities are mapped, the better the analysis of the driving forces will be.
3. Wetland vegetative communities respond to gradients in hydrologic driving forces. While rainfall is important in determining community structure, the actual effect of rainfall is related to the hydroperiod. The study supports the results of Duever (1982), Ewel (1990), Kushlan (1990), and others who have determined through field studies that gradients of hydrology manifested in the hydroperiod drive wetland community structure.
4. January – April potential evapotranspiration and yearly potential evapotranspiration are both strongly correlated to the axis in the DCA analysis and even more so in the CCA analysis. The effects of these environmental variables on driving wetland community structure should be discounted, however, as evapotranspiration is an effect of different wetland vegetation types, not a cause.
5. The results of the detrended correspondence analysis indicate that the ordination of the TWINSPAN wetland community groups is most influenced by the rate of vertical percolation. Those areas with lesser rates of vertical percolation through the sub-soil sediment are likely to maintain landscape water balance amounts that would exclude most forested wetland communities. DCA ordination also indicates that yearly rainfall is also a factor in the ordination of the TWINSPAN wetland community groups. While more rainfall logically would indicate a higher propensity to support vegetation communities that evolved with high rainfall amounts, other landscape characteristics of forested wetlands in Florida such as high slope, runoff, and soil drainage often counteract the effects of higher rainfall amounts.
6. Canonical correspondence analysis concludes that January – April rainfall is the main driving energy for wetland community composition in Florida. The number of days

each year that the temperature drops below freezing was also indicated as a main wetland community driving energy. The effects of slope, runoff, soil drainage, and vertical percolation rates were also significantly correlated with the ordination of the TWINSPAN wetland classes, though not as strongly as the January – April rainfall.

7. The weaker correlation of the non-rainfall landscape variables may be related to the scale of the study. Rainfall is a large-scale phenomenon, and rainfall over a 1000m x 1000m landscape cell is likely a daily occurrence in Florida. However, slope, runoff, and soil drainage are landscape characteristics that typically operate on a much smaller scale than the study size in this project. At a time when the spatial data is at a scale that more accurately reflects the true impact of slope, runoff, and soil drainage, (and to a lesser degree vertical percolation rates, a more wide-scale phenomena) on an ecosystem, the correlations between those spatial datasets and wetland communities on the landscape will no doubt increase markedly.

8. The main conclusion of this study that can be reached from examining the results of the DCA and the CCA are that while the amount of rainfall (be it yearly or during the January – April season) plays an important part in determining wetland community structure, perhaps more important than the amount of rainfall an area receives is the effect of the area's physiographic landscape characteristics on the movement of the rainfall.

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