VISUALIZING FUTURE LAND USE: FACING CLIMATE HAZARD IN

THE COASTAL AREA OF GLYNN COUNTY, GA

By

ZHAN SHI

(Under the Direction of Rosanna G. Rivero)

ABSTRACT

In recent years, rapid development of land and frequent climate hazard pose two challenges to Coastal Georgia. Both the natural resources and the property of coastal residents have become vulnerable to sea level rise and flooding risk. Using Glynn County, GA, as a case study, based on a Geographic Information System (GIS) platform, this study attempt to identify a land-use preference and conflict by Land-Use Conflict Identification Strategy (LUCIS) model, and then propose sustainable land-use scenarios for 2030 by means of future land-use allocation. Furthermore, comparison of the results and the future land use map of Glynn County indicates that the alternative land-use pattern should be taken into consideration for climate hazard adaptation. The results of this study will be useful in not only visualizing but also understanding future land-use trends in Glynn County.

INDEX WORDS: land use, LUCIS model, climate hazard, Geographical Information Systems (GIS)

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ZHAN SHI

B.A., Changchun Normal University, 2010

M.S., Jilin University, 2013

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ZHAN SHI

Major Professor: Rosanna G. Rivero

Committee: Jack Crowley

Alison Smith

Paul D. Zwick

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
December 2015

DEDICATION

This thesis is dedicated to my parents, for their endless love, support and presence in my life. It is also dedicated to the cause of hazard resilience and sustainable land development for coastal areas world-wide.

ACKNOWLEGEMENTS

I truly appreciate the participation of my committee members: Rosanna Rivero, Jack Crowley, Alison Smith and Paul Zwick. I would like to give thanks to Rosanna Rivero, who helped me with studying the LUCIS model and inspired me to reimaging my ideas in this thesis. I am grateful to Jack Crowley, who gave me important support and encouragement during my study. I would like to thank Alison Smith for her guidance in helping me navigate the GIS software. Special thanks go to Paul Zwick, who is the author of *Smart Land-Use Analysis*, for introducing the LUCIS model to the public and joining my committee with enthusiasm.

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CHAPTER 1

INTRODUCTION

As living in Florida becomes more expensive and crowded, larger numbers of retirees and second home purchasers are seeking out the Georgia coast (Glynn County, 2007). From 1990 to 2013, the economy of Georgia increased as a result of the rapid development of land along Coastal Georgia (Gunther, 2014). As in other coastal regions, sea level rise and hurricanes bring a pressing issue within Coastal Georgia. This newly developing coast's low elevation makes it extremely vulnerable to the consequences of sea level rise as predicted by NOAA and the Environmental Protection Agency, and causes detrimental flooding due to storm surges from hurricanes and tropical storms (University of Georgia, 2014). Facing current climate change, flooding risk is a tough issue for those residents who dream of migrating to coastal areas. Both the natural resources of coastal areas and the property of coastal residents are vulnerable to climate hazard. It is imperative to develop a solution to deal with this challenging situation. To help with maintaining the sustainability of land use in the Georgia coastal area, this study proposes planning for future land use by modeling with Geographic Information Systems (GIS) and considering hazard mitigation.

Study Area—Glynn County

The study area, Glynn County (Figure 1.1), is being exposed to the pressures of population growth. Glynn County is located in the southeast of Costal Georgia, the county seat of which is the city of Brunswick. The Interstate 95 corridor runs north to south of the city, towards the western boundary of the city of Brunswick. The five islands, Jekyll Island, St. Simons Island, Sea Island, Little St. Simons Island, and Blythe Island, are known as the Golden Isles and are surrounded by vast marshes. "Much of the County's land lies in environmentally constrained land such as wetlands, floodplains, and poorly drained soils. As a result, development patterns must largely conform to environmental constraints" (Glynn County, 2007, p. 37). Figures 1.2 and 1.3 describe the land cover condition for Glynn County in 2011. Existing urban land and conservation land (according to the current conservation land data) are, respectively, 9.11 percent and 8.96 percent of the area.

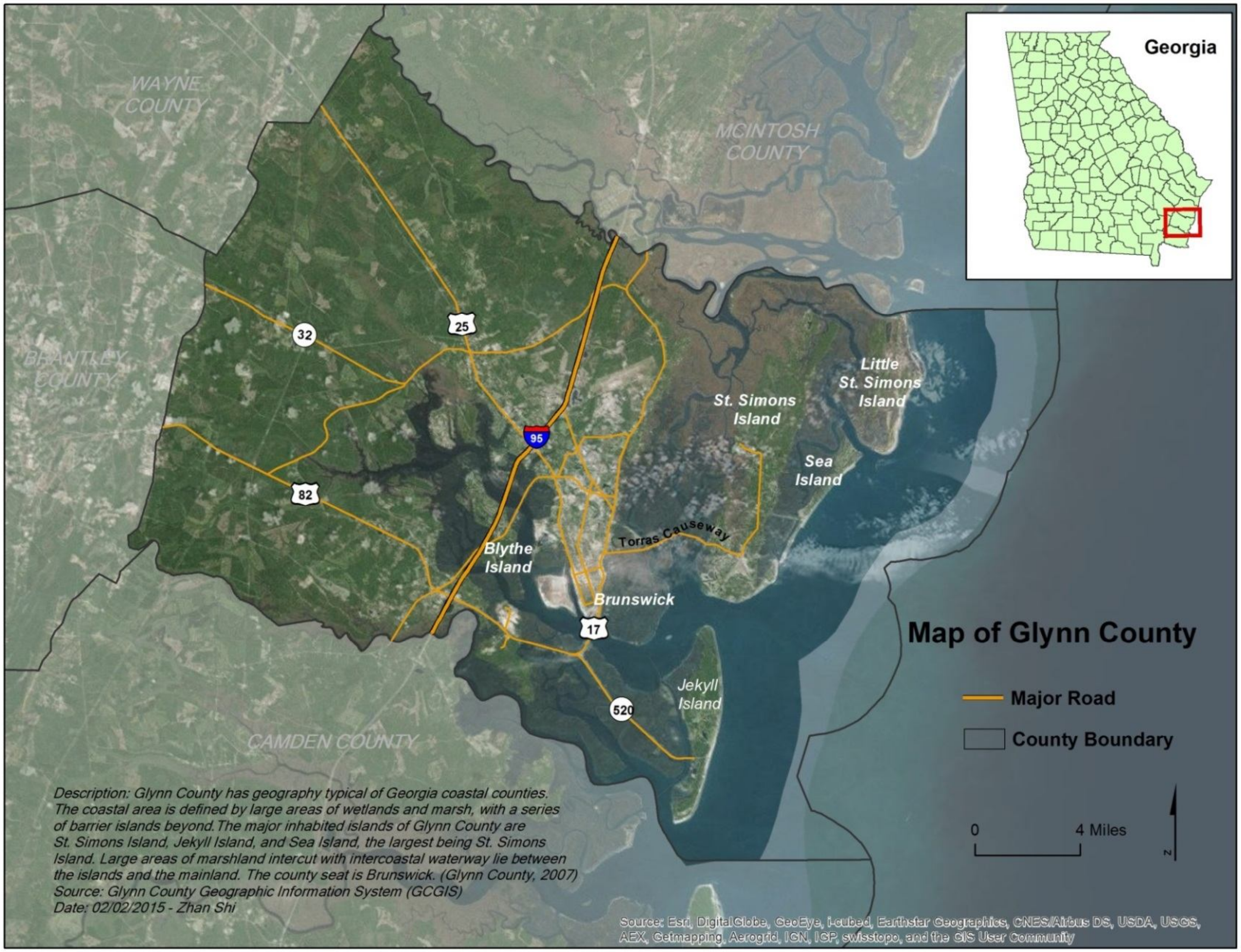


Figure 1.1: Map of Glynn County (Environmental Systems Research Institute & Glynn County GIS).

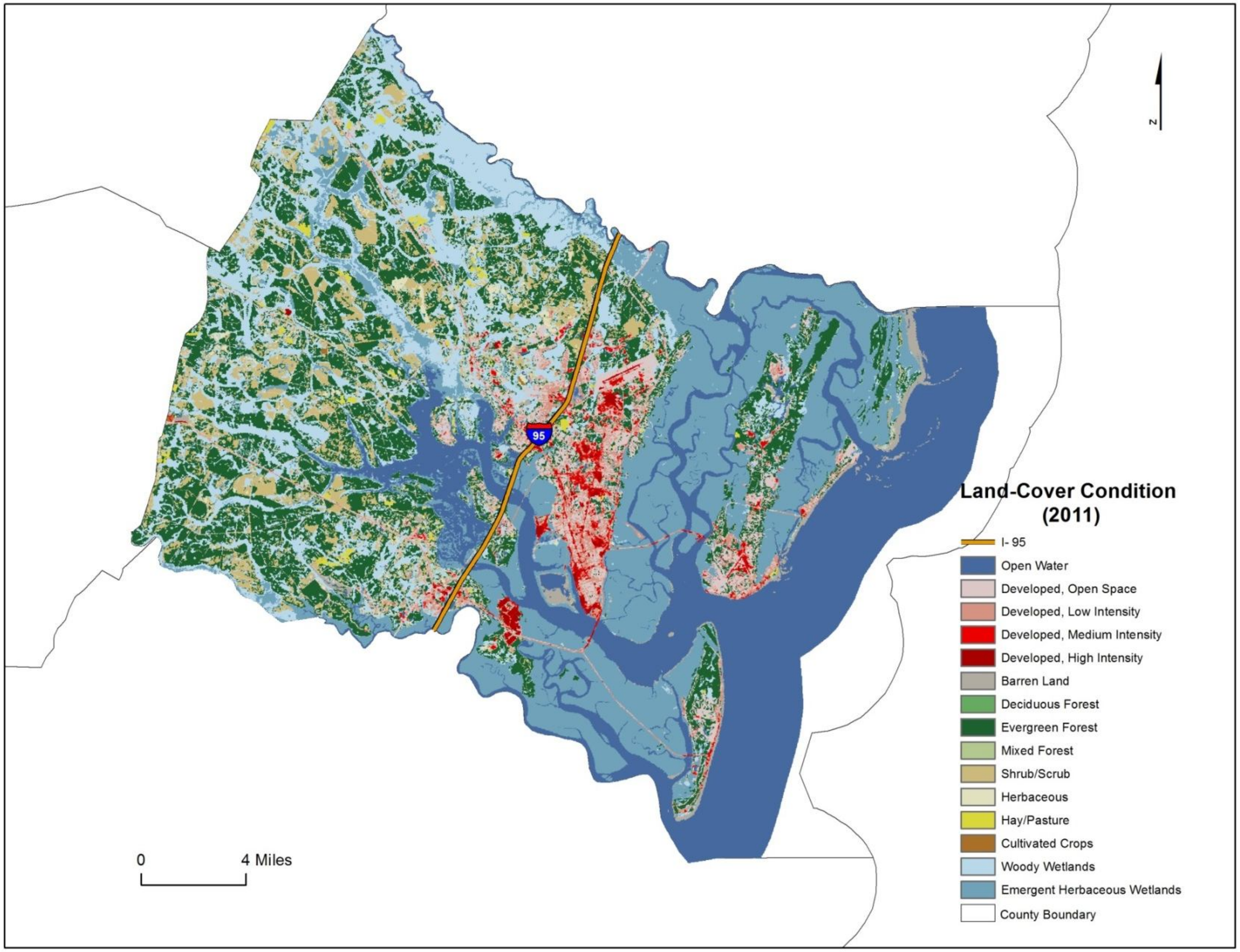


Figure 1.2: Glynn County land cover in 2011 (2011 National Land-Cover Database).

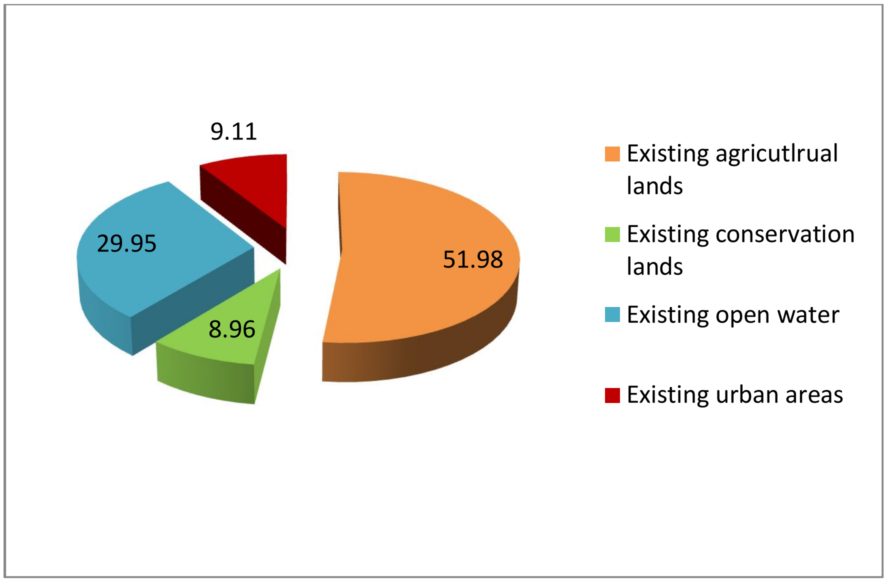
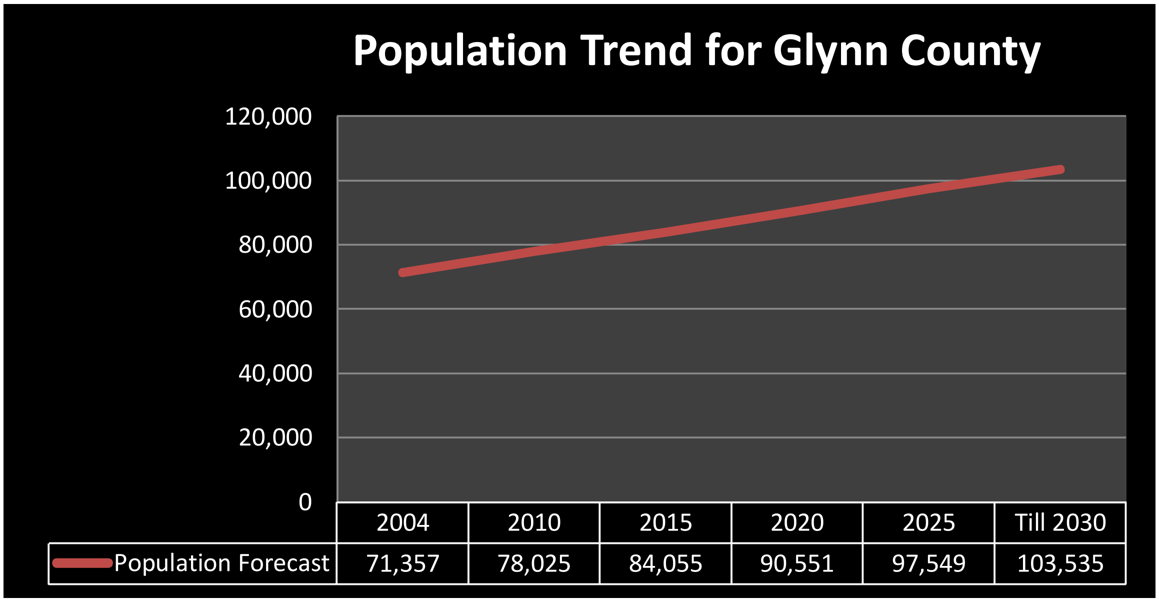


Figure 1.3: Percent of land cover in 2011.

Glynn County's growth will be significant over the next few decades. In 2004, the population was estimated to be 71,357 and forecasted to grow at 1.5% annually. The projected population growth in Glynn County may come from three sources: increasing number of retirees and second home residents; low rate of unemployment and a high rate of employment growth; and natural population increase (Glynn County, 2007). Based on this trend, by 2030, the population is predicted to reach 103,535 people (Figure 1.4). With the urban area expansion, on the one hand, county services and infrastructure have to be improved to serve this demographic change; on the other hand, it is critical to investigate the spatial reality of incremental land-use change.

Figure 1.4: Population Trend for Glynn County from 2004 to 2030 (Glynn County, 2007).



"Glynn County is susceptible to flooding from three sources: 1) from heavy amounts of local rainfall, usually caused by tropical storms, 2) storm surge from a tropical storm or hurricane, and 3) rainfall occurring upstream along the Altamaha during storm events" (Glynn County, 2007, p. 42). According to *The Hazard and Resilience Plan* for the coast of Georgia, flooding, hurricanes, storm surges, and sea level rise are very likely and considered the most hazardous events for this county (University of Georgia, 2014). Existing resources and property in Glynn County are extremely vulnerable to climate hazard, which poses a threat to the health and welfare of citizens. Table 1.1 presents part of the preliminary issues and opportunities as identified through the initial review of Glynn County and input obtained from the steering committee and stakeholder interviews conducted by the county (Glynn County, 2007). As illustrated in the summary, population growth, land-use conflict, and increasing flood risk are major issues that will influence the future development potential of Glynn County in the next 20 years. In the face of this continual rise in demand for land development, urban infrastructure upgrade, and natural resource protection, future land-use proposal should be designed and used as a reference during any planning process in order to maintain a sustainable living environment. Based on the public input and guidance from the Comprehensive Plan-Community Assessment conducted by Glynn County, specific goals, objectives and proposals should be developed in this study to ensure that a realistic strategy is available to update a future comprehensive plan or land-use plan of Glynn County for the coming years.

Table 1.1: Summary of the preliminary issues and opportunities in Glynn County (Glynn County, 2007, p. v).

Category	Preliminary Issues and Opportunities Identification
Land Use/ Community Facilities/Economic Development	Increased development presents potential land use conflicts between rail corridors, environmentally sensitive areas, and residential land uses.
	Strip commercial development increasing throughout the county.
	Increased drainage and flooding problems throughout the county.
	Limited plans for open space or parks on the western part of the county. Need for additional open space acquisition planning.
	Need to ensure adequate community facilities of all types to meet population growth on western part of the county.
	Decreasing level of public access to natural resources, especially boating and fishing.
	Protect state's investment in Port facilities and rail and truck access by limiting land use conflicts.
Natural Resources	Unique ecosystems on barrier islands need to be protected, and public access needs to be preserved on beaches and other natural areas of significance.
	Coastal environment is a major component to the quality of life and the economy in the county.

CHAPTER 2

LITERATURE REVIEW & METHODOLOGY

GIS Suitability Analysis and Applications

In the last 40 years, there has been great progress in the use of Geographic Information System (GIS) for spatial land-use analysis. “An important feature of a GIS is the ability to generate new information by integrating the existing diverse datasets sharing a compatible spatial referencing system” (Goodchild et al., 1993, p. 8). Technologically, “one of the most powerful applications of GIS for land-use planning is suitability analysis. Broadly defined, land-use suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specify requirements, preferences, or predictors of some activity” (Malczewski, 2004, p. 4). GIS-based land-use suitability analysis has been applied on a wide scale. This includes physical and economic land evaluation (Kalogirou, 2002), geo-environmental evaluation for urban land-use planning (Dai et al., 2001), defining land suitability/habitant for animal and plant species (Pereira & Duckstein, 1993; Store & Kangas, 2001), developing land for agriculture use (Akıncı et al., 2013; Mendas & Delali, 2012), urban land development (Liu et al., 2014), and land-use planning for sea-level rise (Berry & BenDor, 2015). Through suitability analysis, it is possible to identify locations that are most adequate for development or conservation based on the goals defined.

LUCIS Model and Applications

The Land-Use Conflict Identification Strategy (LUCIS) model was developed by Carr and Zwick at the University of Florida in 2007 as a way to expand on the original capability of traditional suitability models, and facilitate decision-making by identifying potential future land-use conflicts. In their book *Smart Land-Use Analysis*, they describe the model (Figure 2.1) as a powerful tool to clearly and accurately represent the probable spatial consequence of the incremental decisions based on the GIS platform. It also reduces the possible negative influence caused by the conflict from long-term land development. As Figure 2.2 illustrates, the LUCIS model is achieved in 5 steps: (1) defining goals and objectives, (2) data inventory and preparation, (3) defining and mapping land-use suitability, (4) integrating community values to determine land-use preference, and (5) identifying potential land-use conflict (Carr & Zwick, 2007).

The LUCIS model has been widely applied in various planning issues. It has been used, for instance, to forecast future land-use change in Lake County, Florida, and its significant effect on long-range transportation demand (Thompson, 2010); in hazard resilience planning to assess the recovery level in post-disaster urban areas (Ward et al., 2010). The LUCIS model has also been applied in determining the location of renewable energy plants to attain sustainable development (Colavito & Patten et al., 2011). Furthermore, LUCIS is also employed as a key tool for many other applications, including strategic conservation planning, real estate investments, infrastructure planning and general market analysis (Burian, 2008). It is critical to reduce and make communities more resilient to natural disasters by applying coordinated analysis of land-use mapping and potential natural hazard analysis (Georgia Department of Community Affairs, 2013). This study employs the LUCIS model to identify areas best suited for future urbanization, conservation and agriculture with a particular interest in considering climate hazard and flood risk. Figure 2.3 shows the conceptual method for applying the LUCIS model in this study. Since LUCIS is a goal-driven strategy model, adding climate hazard mitigation as one of these goals could significantly contribute to a valuable proposal for coastal future land use, which might be extremely helpful in avoiding prospective economic and ecological losses.

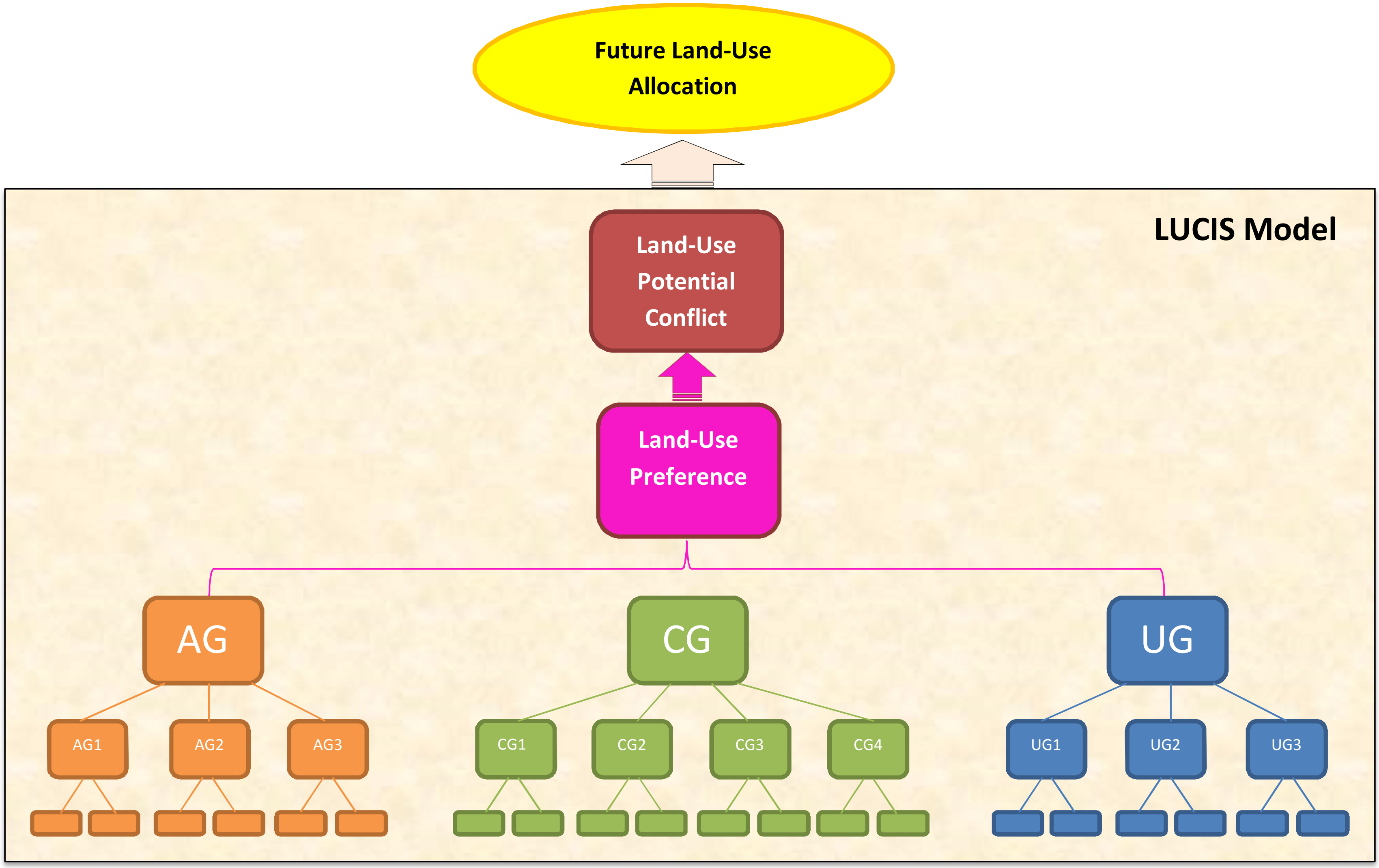


Figure 2.1: Work flow chart for the LUCIS model. AG represents agricultural goal; CG represents conservation goal; and UG represents urban goal.

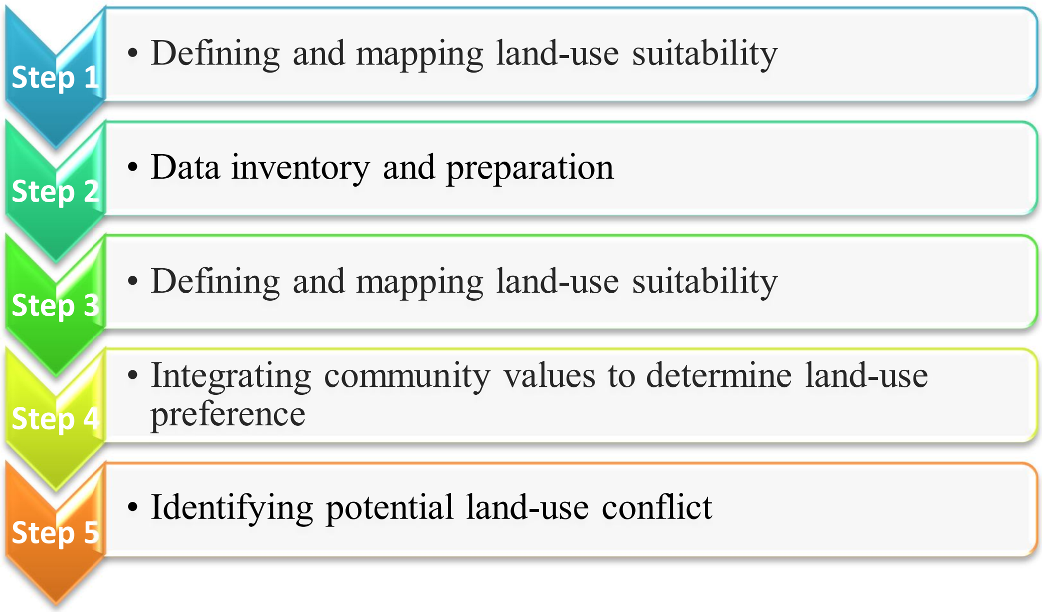


Figure 2.2: Five steps of the LUCIS model.

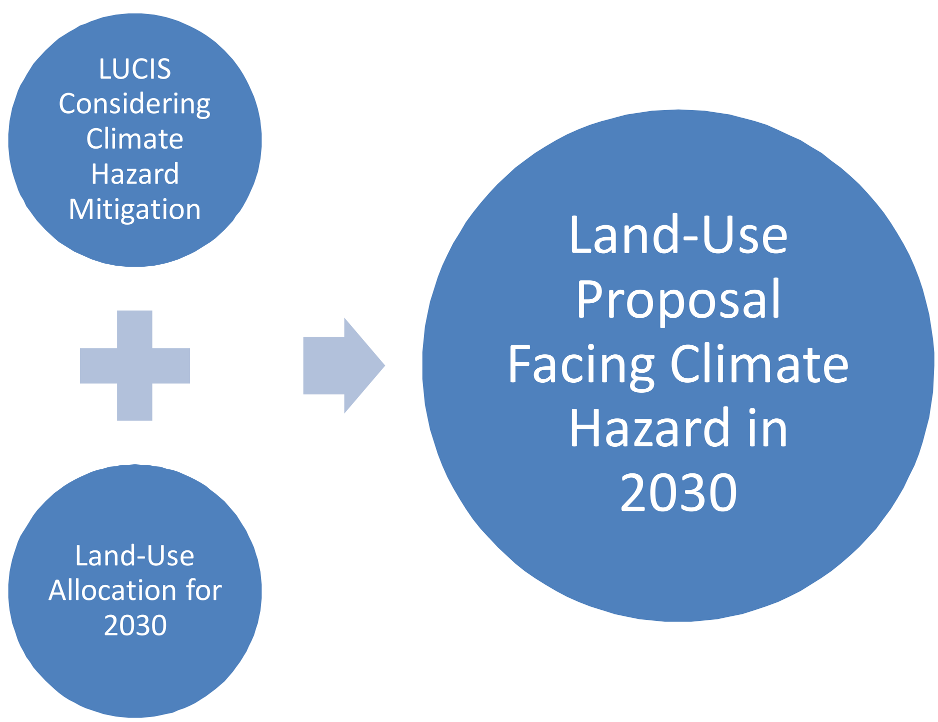


Figure 2.3: Conceptual study method.

Setting Goals and Objectives

Goals and objectives are statements with hierarchical structure to define what is to be accomplished and the supporting objectives. In planning and design, goals and objectives, along with a third or even fourth level of supporting statements, are widely used. Carr and Zwick describe LUCIS as a "goal-driven GIS model that produces a spatial representation of probable patterns of future land use" (Carr & Zwick, 2007, p. 9). The conceptual basis of goals in the LUCIS model is derived from four general land-use types adapted from the work of Eugene P. Odum, who built the theoretical foundation of ecology in the twentieth century. In Odum's compartment model, all areas of the landscape are classified into one of four types: productive areas, protective areas, compromise areas, and urban/industrial areas. "By increasing and decreasing the size and capacity of each compartment through computer simulation, it would be possible to determine objectively the limits that must eventually be imposed on each compartment in order to maintain regional and global balance in the exchange of vital energy and materials" (Odum, 1969, p. 268).

Odum's compartment model is the foundational basis for LUCIS land-use classification. However, LUCIS uses three, rather than four, categories for its entire analysis. In the LUCIS model, "agriculture serves as a direct correlate of Odum's productive category. The combination of protective and compromise landscapes into one conservation category is justifiable because conservation lands, in reality, comprise a combination of productive and protective lands. Urban serves as the equivalent of Odum's urban/industrial category and is presumed to contain privately owned lands and publicly owned lands with a purpose other than conservation" (Carr & Zwick, 2007, p. 11). Despite the fact that the land-use classification derives from the LUCIS model in this study, the definition of each category is more target-specific. Glynn County does not have considerable agricultural lands, but there are significant forestry lands, most of which are believed to be owned by private forestry (Glynn County, 2007). Because of this situation, for agriculture land use in this study, the definition had to be inclined toward commercial and private plantation, rather than traditional cultivation and livestock management. For the purpose of the land conservation goal, since large areas of Glynn County lie within the 100-year floodplain, as determined by the Federal Emergency Management Agency (FEMA) (Glynn County, 2007), this goal in this study takes flood hazard mitigation into consideration rather than only focusing on significant natural resources and ecological habitat. Table 2.1 compares this difference between Odum's compartment model with the LUCIS land classification scheme and also describes the derivative definition in this study. To obtain a complete perspective on the analysis, the three major goals in this study, urban, conservation, and agriculture, are shown in the diagram in Figure 2.4. These three major goals can be further subdivided into multiple objectives and subobjectives to develop a comprehensive analysis.

Feature of This Research

Because modeling with LUCIS demands comprehensive data, and the available GIS data are limited for Glynn County, the main feature of this thesis is based on the following two aspects.

1. Visualizing future land-use scenarios based on the LUCIS model by using available GIS data for Glynn County.
2. Taking climate change and flood risk into consideration when building goals, especially for urban and conservation land-use analysis.

Table 2.1: Comparison of Odum's Compartment model land-use classifications, LUCIS land-use classifications, and their application in this study (Carr & Zwick, 2007).

Odum's compartment model land-use classifications	LUCIS land-use classifications	LUCIS land-use classification that was applied in this study
Productive: where succession is continually retarded by human controls to maintain high levels of productivity	Agriculture: lands that produce food, fuel, and fiber	Agriculture: lands for private and commercial plantation, cultivation and livestock management
Protective: natural areas	Conservation: environmentally significant lands	Conservation: lands with environmental significance and vulnerability to climate hazard and flood risk
Compromise areas: where some combination of the first two stages exists		
Urban /Industrial: biologically non-vital areas	Urban: lands that support relatively intense human activity such as residential, commercial, and industrial uses	Urban: lands that support relatively intense human activity such as residential, commercial, and industrial uses

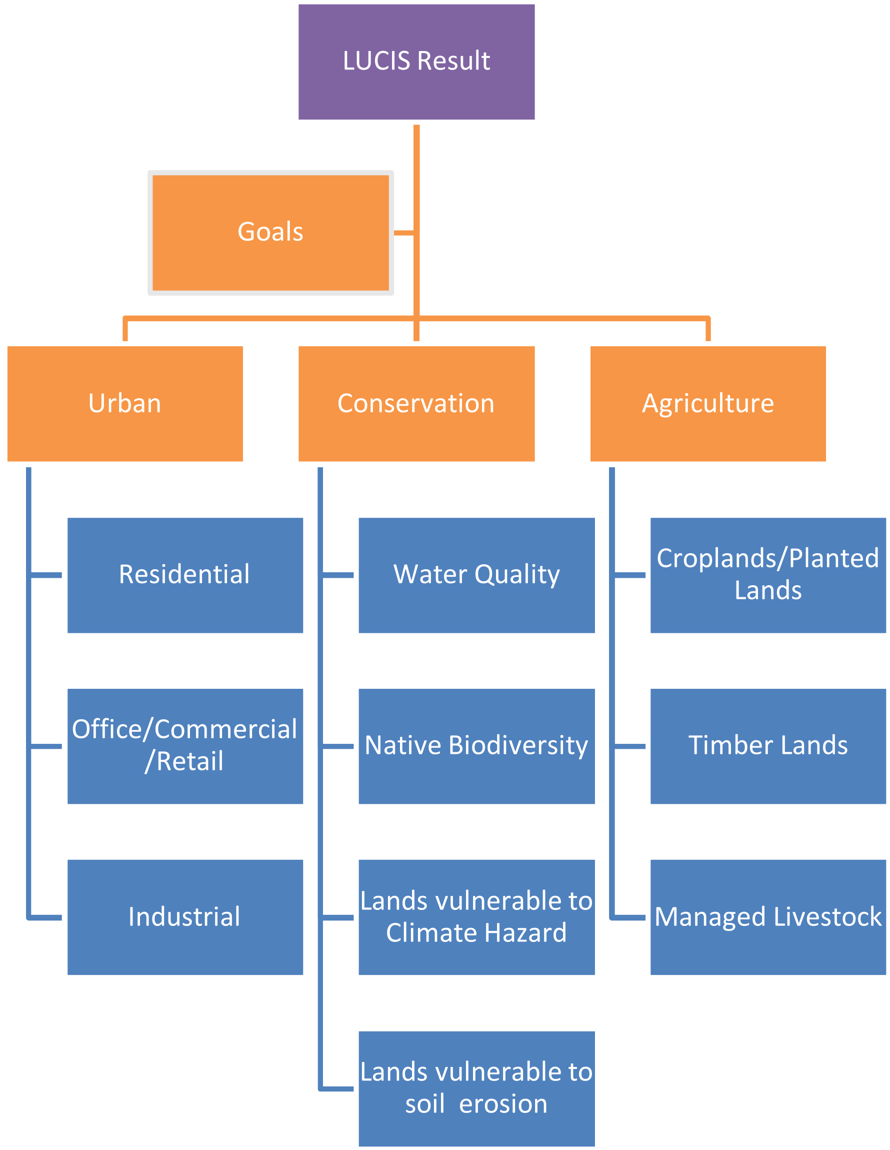


Figure 2.4: Glynn County LUCIS model set of goals and objectives.

CHAPTER 3

ANALYSIS AND RESULT

Defining Goals and Objectives

LUCIS modeling is directed by the goals, objectives and subobjectives, which are often summarized in the statement of intent. Table 3.1 displays the overall statement of intent, the category statements of intent, and all the goals for the three land-use categories selected by LUCIS for the Glynn County case study. Furthermore, under each set of goals is a series of objectives and subobjectives that address the specific factors for each goal. For example, as Table 3.2 demonstrates, subobjective1.2.2 (under the objective 1.2, which is under urban goal 1) questions the model to identify lands proximal to schools. The complexity of the suitability analysis for each objective contributes to the sustainable development in each goal, and that in turn contributes to the whole future land-use scenario.

Table 3.1 and Table 3.2 present goals, objectives and subobjectives in hierarchical order to support each land-use category. The objectives of Conservation Goal 3 are listed in Table 3.3, and they particularly focus on climate hazard mitigation. All of the objectives and subobjectives are defined on the basis of urban and environmental planning principles, Glynn County Comprehensive Plan-Community Assessment, and review of existing literature.

Table 3.1: Summary of land-use categories and goals.

Overall Statement of Intent:	Determine the lands preferred for agriculture, conservation, and urban use in Glynn County, GA. Compare the resulting preferences to derive the most likely locations for future conflict.
Agriculture	
Statement of intent	Identify lands most suitable for agricultural use
Goal 1	Identify lands suitable for croplands/row crops
Goal 2	Identify lands suitable for timber/silviculture
Goal 3	Identify lands suitable for managed livestock
Conservation	
Statement of intent	Identify lands most suitable for permanent protection through the application of conservation strategies
Goal 1	Identify lands suitable for protecting native biodiversity
Goal 2	Identify lands suitable for protecting water quality
Goal 3	Identify lands vulnerable to climate change and flood risk
Goal 4	Identify lands vulnerable to soil erosion
Urban	
Statement of intent	Identify lands most suitable for urban development
Goal 1	Identify lands suitable for residential land use
Goal 2	Identify lands suitable for commercial land use
Goal 3	Identify lands suitable for industrial land use

Table 3.2: Example: Urban Goal 1

Urban Goal 1	**Identify lands suitable for residential land use**
Objective 1.1	Determine lands physically suitable for residential land use
Subobjective1.1.1	*Identify soils suitable for building construction*
Subobjective1.1.2	*Identify elevation suitable for residential land use (for flood mitigation)*
Subobjective1.1.3	*Identify lands free of flood potential (flood-zone)*
Subobjective1.1.4	*Identify land-cover suitable for building land-use*
Objective 1.2	Determine lands economically suitable for residential land use
Subobjective1.2.1	*Identify lands proximal to existing residential development*
Subobjective1.2.2	*Identify lands proximal to schools*
Subobjective1.2.3	*Identify lands proximal to health care facilities*
Subobjective1.2.4	*Identify lands proximal to roads*
Subobjective1.2.5	*Identify lands proximal to airports*
Subobjective1.2.6	*Identify lands proximal to fire station*
Subobjective1.2.7	*Identify lands proximal to police station*
Subobjective1.2.8	*Identify lands proximal to electricity power*
Subobjective1.2.9	*Identify lands proximal to communication facility*
Subobjective1.2.10	*Identify lands proximal to parks, other recreational opportunities, protected conservation lands*
Subobjective1.2.11	*Identify lands proximal to waste water facilities*

Table 3.3: Example: Conservation Goal 3

Conservation Goal 3	**Identify lands vulnerable to climate change and flood risk**
Objective 1	Identify lands proximal to the areas within hurricane surge (CAT 1-5)
Objective 2	Identify lands proximal to the areas within 100-year flood plain
Objective 3	Identify lands proximal to the areas vulnerable to tropical storm
Objective 4	Identify lands proximal to the impervious areas
Objective 5	Identify lands proximal to the waterbodies

Data Inventory and Preparation

1) Identifying potential data

Using Ian McHarg principles, from his book in *Design with Nature,* the GIS data prepared for this analysis was grouped into seven broad categories for further land-use analysis (Table 3.4) (McHarg, 1969). The data inventory is a powerful mean of identifying potential issues and opportunities when addressing land-use questions. For the purposes of this study, a wide range of GIS data, in both raster and vector formats from various sources, were collected. All the data have been stored in a geodatabase and converted to a common projection and coordinate system for consistency. Data were collected from Glynn County GIS, Georgia GIS Data Clearinghouse, and the Federal Emergency Management Agency (FEMA).

Table 3.4: Data inventory.

Category	Data	Source	Application
Geophysical	Statewide Contours (1996)	U.S. Geological Survey	Urban Goal: Objective 1.1 Objective 2.1 Objective 3.1 Conservation Goal: Objective 1.3 Objective 2.1 Objective 2.2 Objective 2.3 Objective3.2 Objective 3.5 Objective 4.1 Objective 4.2 Agriculture Goal: Objective 1.2 Objective 1.3 Objective 1.4 Objective 2.1 Objective 2.3 Objective 3.2 Objective 3.3
	Slope (1997)		
	Groundwater Recharge Area		
	Lakes & Ponds (2000)	Georgia Department of Transportation	
	Streams & Rivers(2000)		
	SSURGO Soils (2004)	U.S. Department of Agriculture, Natural Resources Conservation Service	

Ecological/Conservation	Vegetation(2008)	Georgia Department of Natural Resources	Conservation Goal: Objective 1.1 Objective 1.2 Agriculture Goal: Objective 2.2
	DNR Managed Lands(2015)		
	Land Trusts and Other Private Lands(2013)		
	National Park Service Lands(2009)		
	Natural Resource Conservation Service Lands(2013)		
	NARSAL GA. conservation lands(2012)	University of Georgia Natural Resources Spatial Analysis Laboratory	
Hazard	Hurricane Surge(2011)	Glynn County	Conservation Goal: Objective 3.1 Objective 3.2 Objective 3.3
	Tropical Flood	Federal Emergency Management Agency (FEMA)	
	Flood Zone		
Infrastructure	County Parks Poly	Glynn County	Urban Goal: Objective 1.2 Objective 2.2 Objective 3.2
	School Points		
	Roads & Highways (2013)	Georgia Department of Transportation & Information Technology Outreach Services - University of Georgia	
	Airports	FEMA's Emergency Management Institute	
	Hospitals		
	Ports		
	Waste Water Facilities		
	Communication Facilities		
	Fire Stations		
	Police Stations		
	Electricity Powers		

2) Map projections and cell size

Map projection consistency has been ensured by setting map projection in the Environments Dialog and the Data Frame Properties. The Output Coordinate System is "NAD 1983 State Plane Georgia East FIPS 1001 Feet" which is a common projection used by state agencies in Georgia.

Raster cell resolution was set to 50 feet, in order to better depict parcel size for residential, commercial and industrial areas.

3) Processing of datasets and documentation

Revision of the source data is needed before they can be applied in certain analyses. For example, the existing residential data is necessary for the analysis of Urban Goal 1: identifying lands suitable for residential land use. Such data have not been created by any agency for Glynn County, so the existing residential points were derived from the attribute of property type in "911 physical address" data using the Select by Attributes tool in ArcGIS. Likewise, data of commercial and industrial areas were extracted by "911 physical address" data as well. The study area raster was obtained from the land-cover data by erasing water bodies, and then setting the result as a mask in the Geoprocessing Environments Dialog.

Defining and Mapping Land-Use Suitability

The result of any suitability analysis for each land-use category is applied to determine the optimum location for a specific interest by following the land-use goals. There are two types of suitability values: single utility assignment (SUA) and multiple utility assignments (MUA). In SUA, a single layer or objective has been assigned by value and the output measures the suitability of a single objective or subobjective. Figure 3.1 shows the example of using urban subobjective 1.2.2 to measure the lands proximal to schools. Certain weights were assigned using the Weighted Overlay tool for each single utility assessment (SUA) according to the stakeholders, expert suggestions, and reliable literature and documents. The weights should add up to 100 for each objective or subobjective. A multiple utility assessments (MUA) functions as combining rasters derived from multiple SUAs. A MUA indicates the lands with the highest or the lowest suitability by using the SUAs as input. Figure 3.2 shows the MUA of urban objective 1.2. The color scheme for suitability changes from dark green to dark red, which reflects the suitability from high to low for lands physically suitable for residential use.

Objective 1.2 serves as an example of how to obtain suitability results. First, a Euclidean Distance layer was created for the urban infrastructure facilities, such as hospitals, schools, and major roads. Then, a Zonal Statistic Table tool was used to determine the range of distance (mean distance and standard deviation) of existing residential areas from these urban infrastructure facilities. The suitability values ranged from 1 to 9 were assigned by using the Reclassify tool, with 1 representing lowest suitability and 9 representing highest suitability. Cells with values of 0 to the mean were assigned a new value of 9 (high suitability), since they were closer than the average existing land use to certain urban infrastructure facilities. The remaining cells were assigned values from 8 to 2 in quarter-standard-deviation increments, and the remaining cells were assigned 1 as a value.

As Figure 3.2 presents, the MUA of urban objective 1.2 was combined with the suitability SUAs previously described using the Weighted Overlay tool. For the 11 subobjectives under objective 1.2, 10 was assigned to subobjective 1.2.1, and the others were given equal weight, which was 9. The procedure is similar to obtaining the result of goal MUAs except for the value of weights.

Figure 3.3, represents, the final MUAs respectively for the three agriculture goals, four conservation goals, and three urban goals.

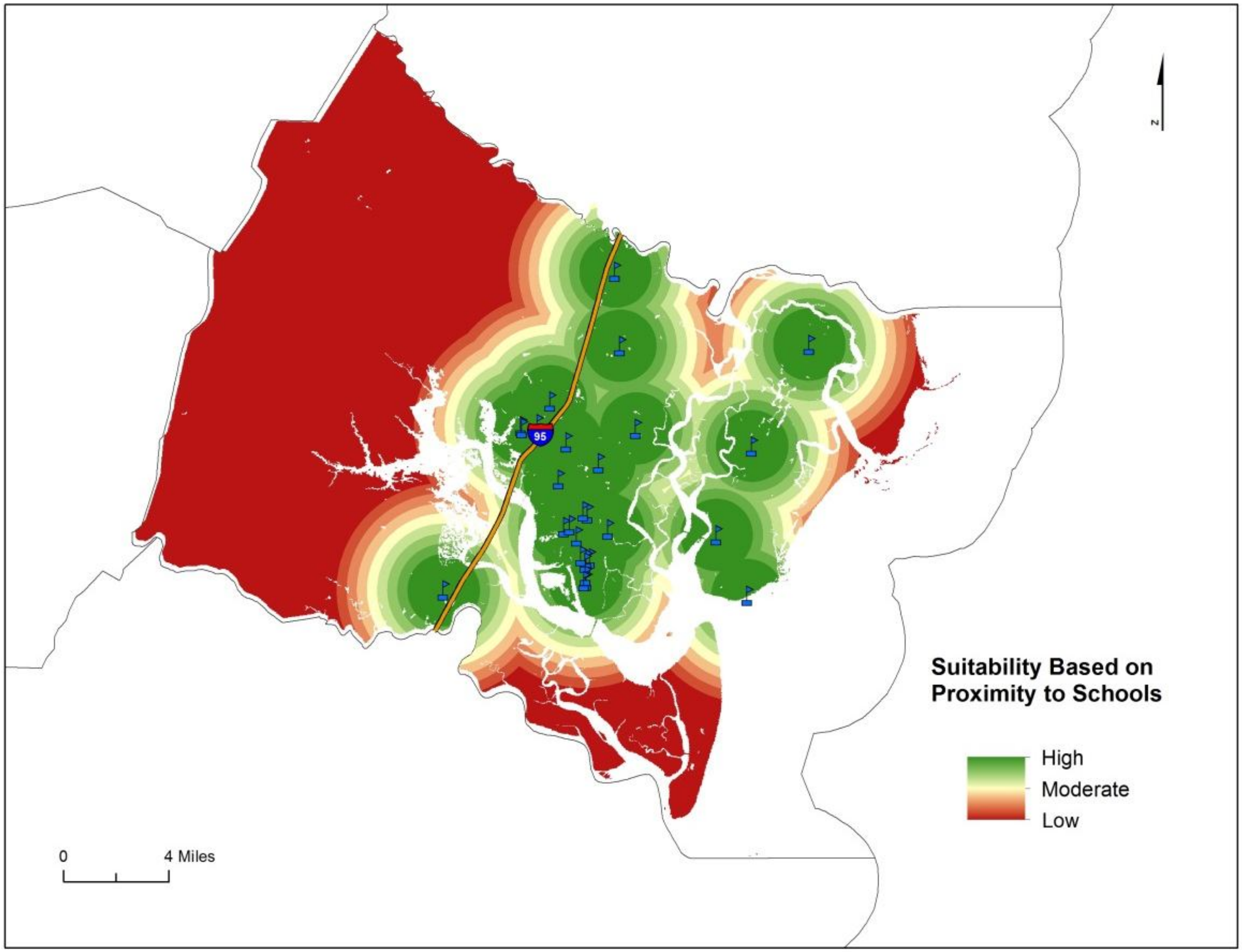


Figure 3.1: Result of the SUA for the urban subobjective 1.2.2.

The areas more proximal to schools are considered highly suitable.

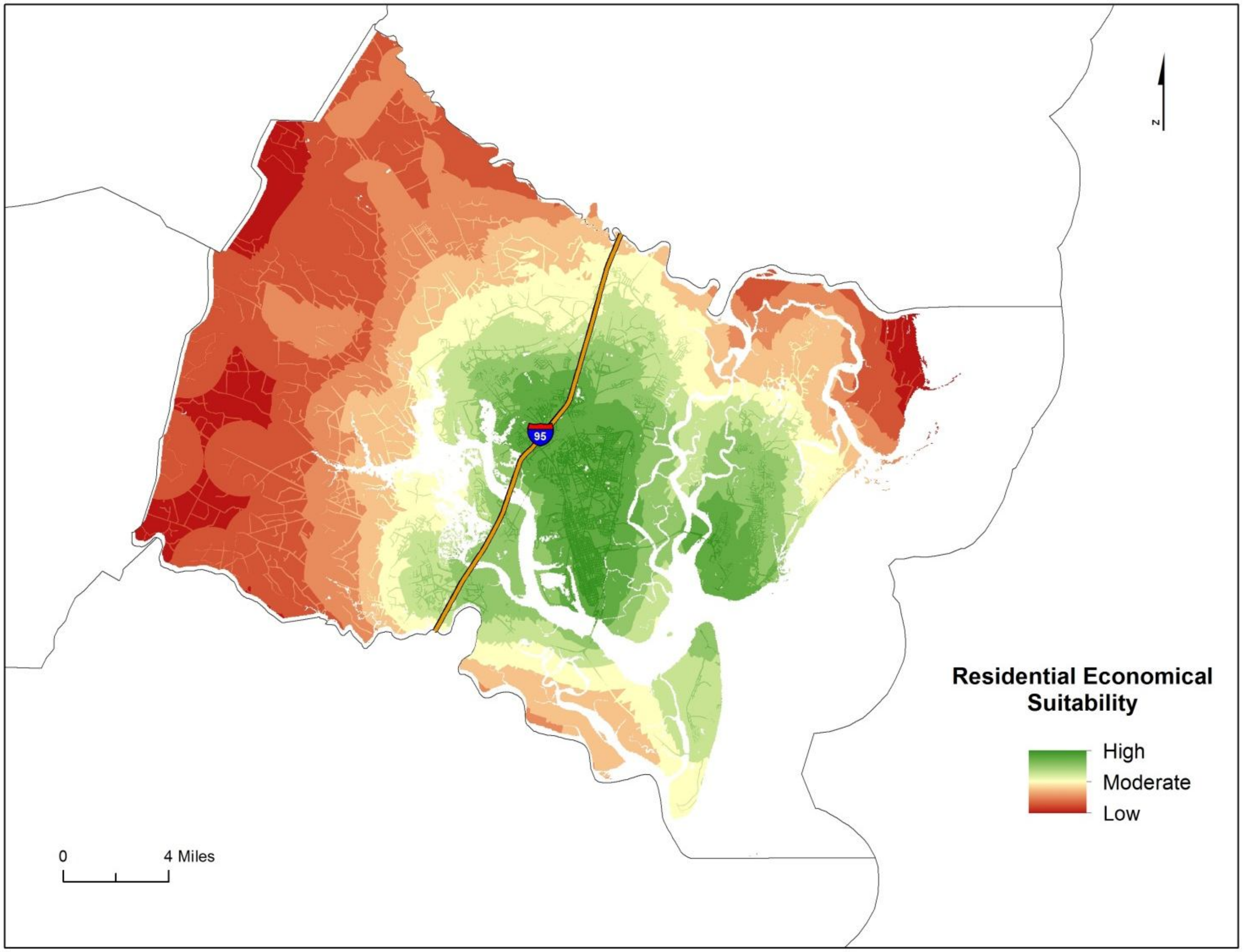


Figure 3.2: Result of the MUA for the urban objective 1.2.

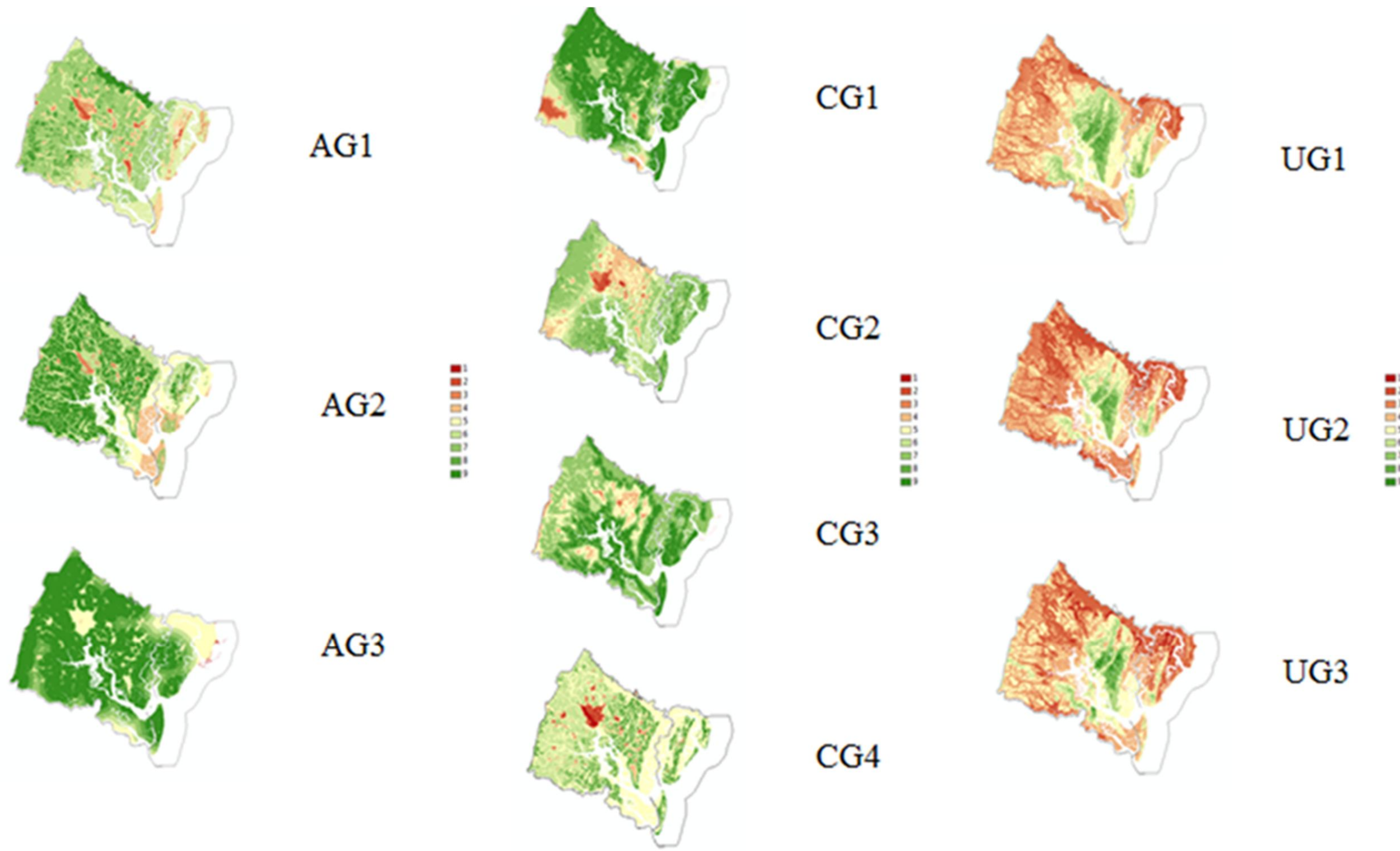


Figure 3.3: Land-use suitability for each goal.

Integrating Community Values to Determine Land-Use Preference

Transforming land-use suitability to land-use preference is to question which of the contributing suitability criteria is most important. The preference for each land-use category should be identified based on the suitability result of each final MUA from the prior analysis. Suitability layers for all the goals are combined together and weighted to generate the overall land-use preference layer for each land-use category. The weighted values are percentages in GIS and should be determined according to land-use purpose. In the original LUCIS case study presented by Carr and Zwick, the authors utilized the Expert Choice software to determine community values and preferences. Given that this study did not apply this method, a review of these results from the original LUCIS method applied in Florida, existing documents for Glynn County, such as the Community Assessment from the Comprehensive Plan of Glynn County, and author's best judgment and knowledge of the area, were used to determine these weights. As Table 3.5 describes, for agriculture goals, considering that the main agriculture type of Glynn County is commercial timber followed by crops and livestock, we can set the weights respectively as the follows: croplands/row crops (16%), timber/silviculture (46%), and managed livestock (38%). For conservation goals, which are unlike what is described in the book, the weights have been set according to preservation priorities in this study: native biodiversity (40%), water quality (30%), climate change and flood risk (20%), and soil erosion (10%). For urban goals, we can combine commercial, retail and office as one category since the available data in Glynn County has already incorporated all the categories. Therefore, there are just three urban goals for this study, and the weights are respectively Residential (62%), Commercial (33%), and Industrial (5%). The result of applying the preference weights is shown is Figure 3.4.

Table 3.5: Preference weights for each goal.

Suitability	**Preference Weights (%)**
Agriculture	
Goal 1: Croplands/row crops	16
Goal 2: Timber/silviculture	46
Goal 3: Managed livestock	38
TOTAL	100
Conservation	
Goal 1: Native biodiversity	40
Goal 2: Water quality	30
Goal 3: Climate change and flood risk	20
Goal 4: Soil erosion	10
TOTAL	100
Urban	
Goal 1: Residential	62
Goal 2: Commercial	33
Goal 3: Industrial	5
TOTAL	100

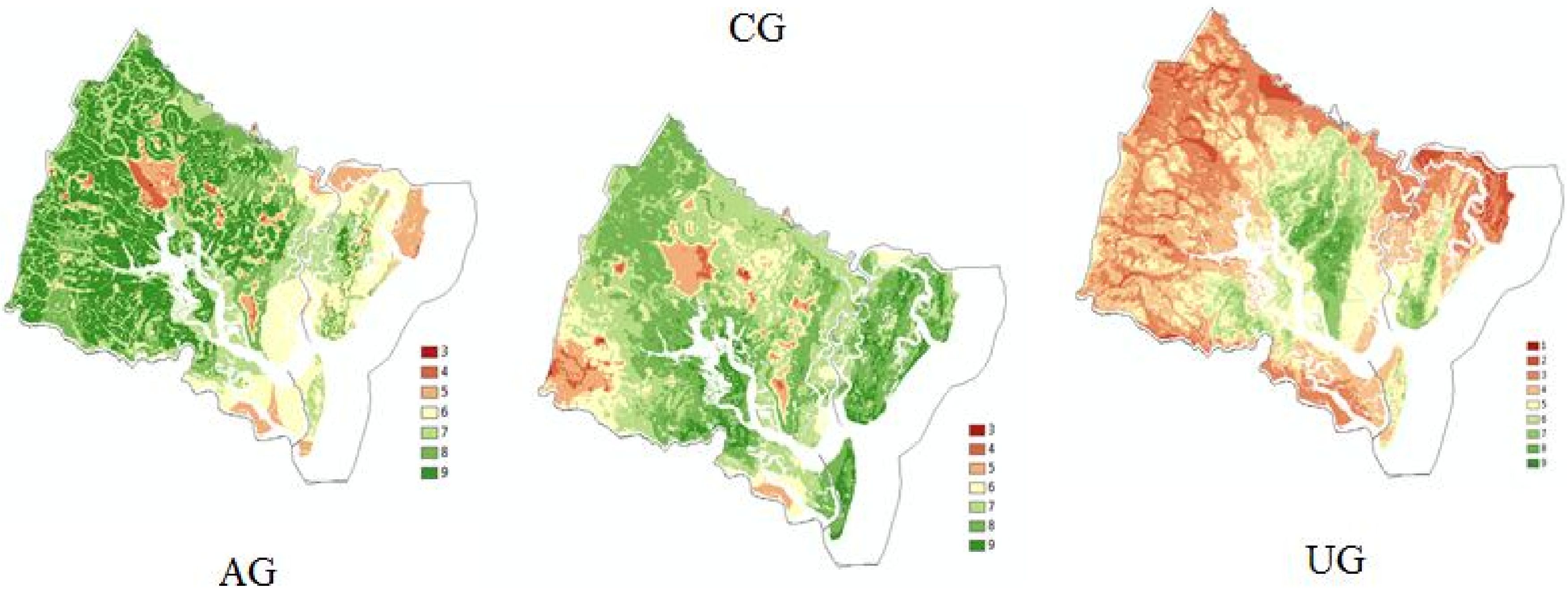


Figure 3.4: Preference for each land-use category.

Identifying Potential Land-Use Conflict

This is the final step of LUCIS model—to create a conflict surface for the three land uses. The conflict surface is very useful in identifying and suggesting the lands where future use is most likely to be disputed. For example, the conflict surface suggests to an urban developer that high preference urban areas that are in conflict could be considered as high priority for future development. Likewise, a conservation institution, which desires to protect more valuable wetland or other ecological habitats, might regard the areas with high conservation preference in conflict as priority.

In this step, the preference values are collapsed into three classes: high, medium and low. In this way, land-use preference and the conflict areas between land-use categories could be easily identified and compared. Quantile is selected for the collapsed method in this situation. This Quantile method is useful to highlight changes in the middle values of the distribution. According to Law and Collins, "With quantiles, all classes have the same number of features. This method is appropriate when data is linearly distributed. It can create a balanced-looking map because no classes have too many, too few, or no values" (Law & Collins, 2013, P. 253).

After obtaining the collapsed preference rasters, the next step is to reclassify the conflict rasters. Figure 3.5 shows the LUCIS conflict space diagram, which looks like a cube. "The combination of 1-1-1 occurs at one corner of the cube, which represents a high degree of conflict but equally low preference among the three land-use classes. The high conflict and high preference combination of 3-3-3 occurs at the diagonally opposite corner. The combination of 2-2-2 sits between these two. The rest of the possible combinations are logically dispersed throughout the remainder of the cube" (Carr & Zwick, 2007, p. 147). According to the conflict space diagram, we can reclassify the collapsed preference raster of agriculture to: low=100, moderate=200, and high=300. The conservation collapsed preference raster is reclassified into three different categories: low=10, moderate=20, and high=30. The urban collapsed preference raster is reclassified into another three categories: low =1, moderate =2, and high =3. The three reclassified collapsed preference rasters are added together by Map Algebra tool to generate 27 combinations between 1-1-1 and 3-3-3 like Figure 3.5 presents.

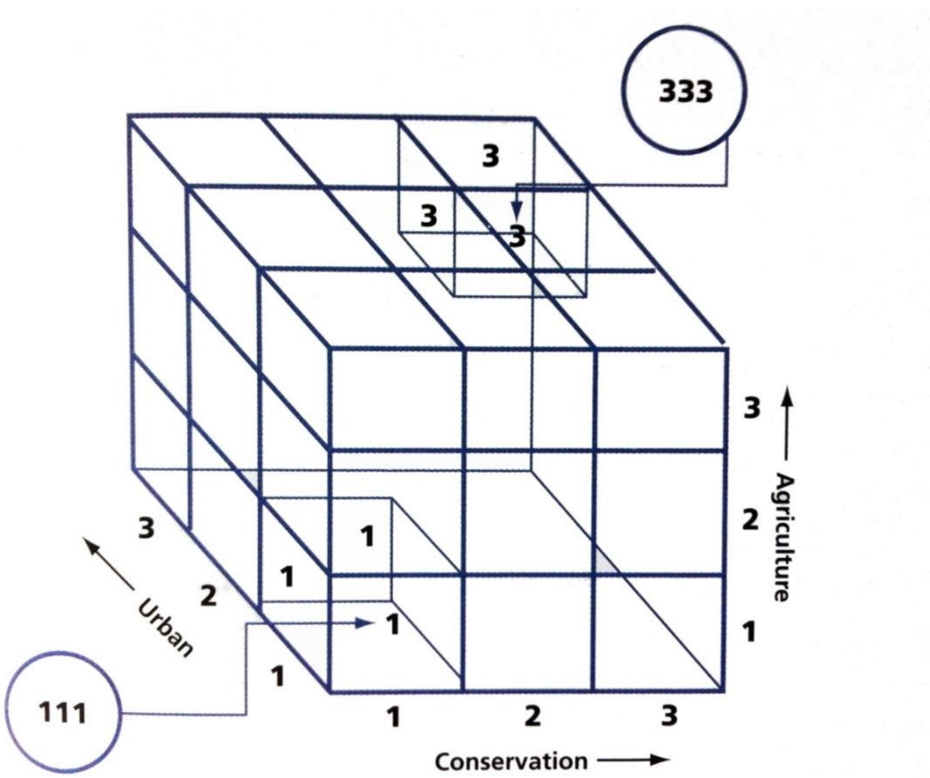


Figure 3.5: The conflict space diagram (Carr & Zwick, 2007, p. 147).

The distribution of cell value and their counts in the land-use conflict raster is shown in Figure 3.6, with the conflict values shown in orange and the value of no conflict shown in gray. The conflict raster surface is shown in Figure 3.7. According to Figure 3.7, the number of 1-2-1 is highest, which means moderate conservation preference and low agriculture and urban preference. This implies that if conservation preference had not dominated in these cells, there would be a significantly larger number of cells of 1-1-1, which is a high potential conflict. The number of combination of 3-2-1 is in second place, which indicates that agriculture preference is also a greater portion among all the preference categories. Major conflict is primarily the combination of 1-1-1, which is low preference among all of the three land-use categories. The majority of moderate conflict is the combination of 1-2-2, which means moderate conservation preference conflicts with moderate urban preference. In high preference, moderate conflict combination of 3-2-3 plays as the majority, which means high conflict exists between agriculture and urban categories. There is a smaller number of cells in major conflict occurs in high preference, which is the combination of 3-3-3.

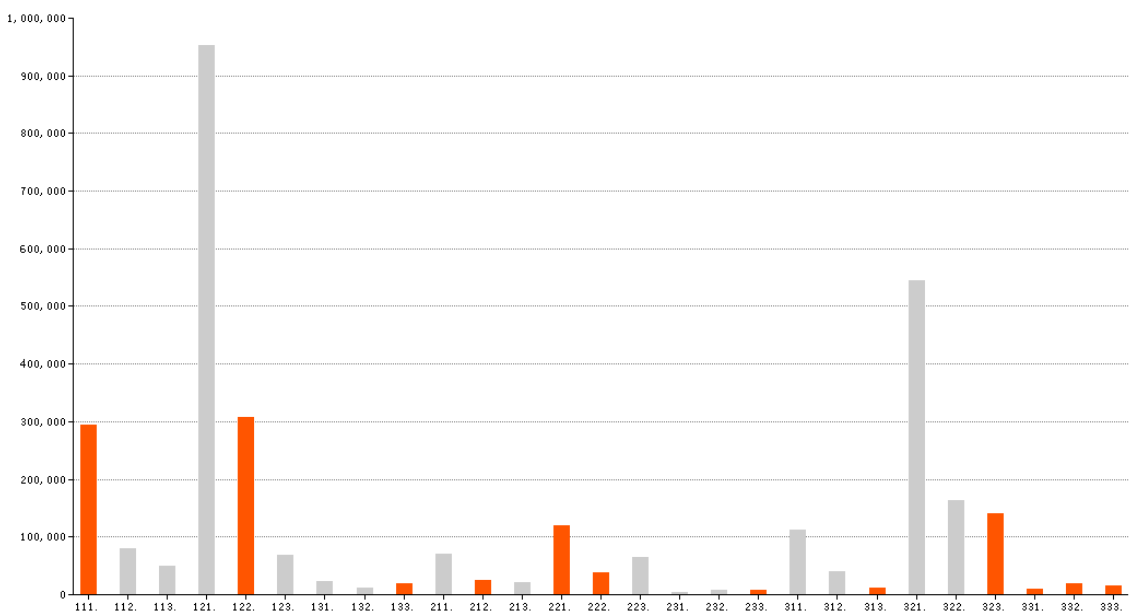


Figure 3.6: A histogram showing the distribution of cell value and their counts in the land-use conflict raster.

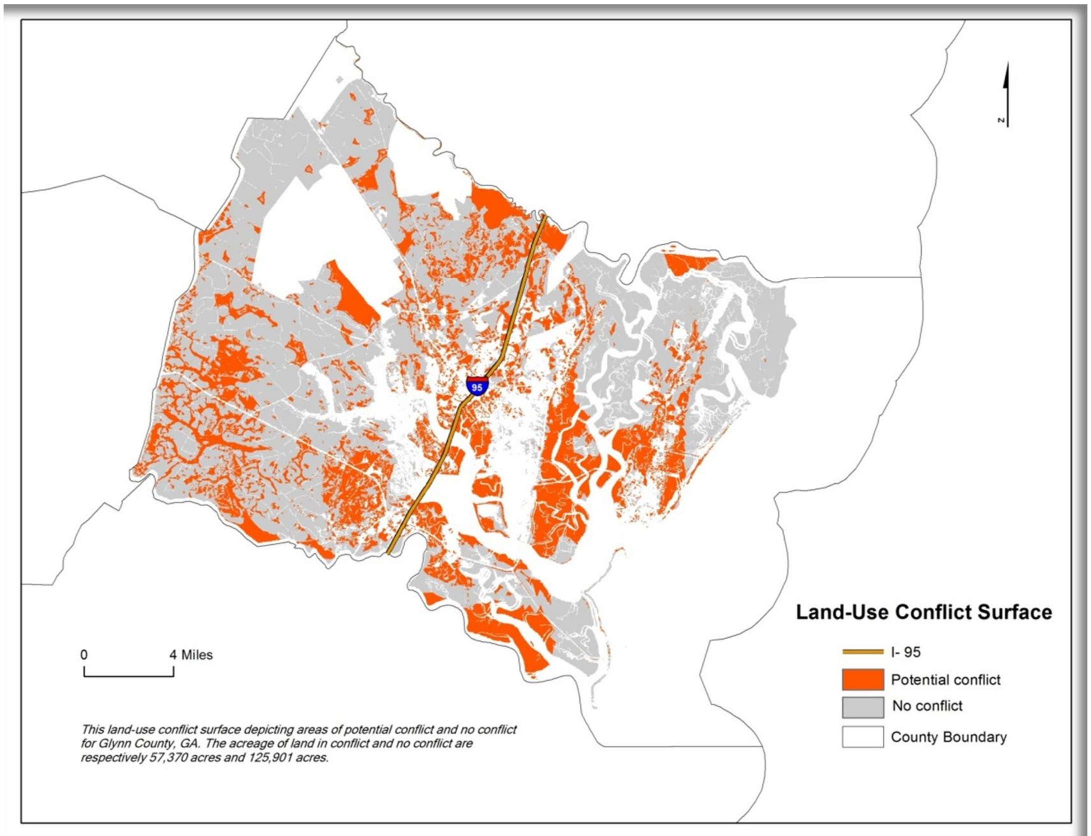


Figure 3.7: Land-use conflict surface.

A more detailed description of the character and spatial distribution of the areas of potential land-use conflict is shown in Figure 3.8, which includes a major conflict (conflict between all three) and three moderate conflict categories (potential conflicts between agriculture and conservation, agriculture and urban, and conservation and urban). Areas of no conflict are also presented in the map, where one land-use category has greater preference than either of the other two. Table 3.6 summarizes the potential land-use conflict in Glynn County described by acre and percentage. The majority of the conflict between urban and agriculture occurs along the Interstate 95 corridor, while prime agricultural land lies in the western part of Glynn County. There are 19,015 acres of conservation-urban conflict in total, the most of which can be found in the central part of the southeast, where Brunswick and St. Simons Islands are expanding southwestward proximal to wetland dominant areas. The areas of agriculture-conservation conflict locate primarily on the western side of the Interstate 95 corridor, where the majority of the existing agriculture land is located.

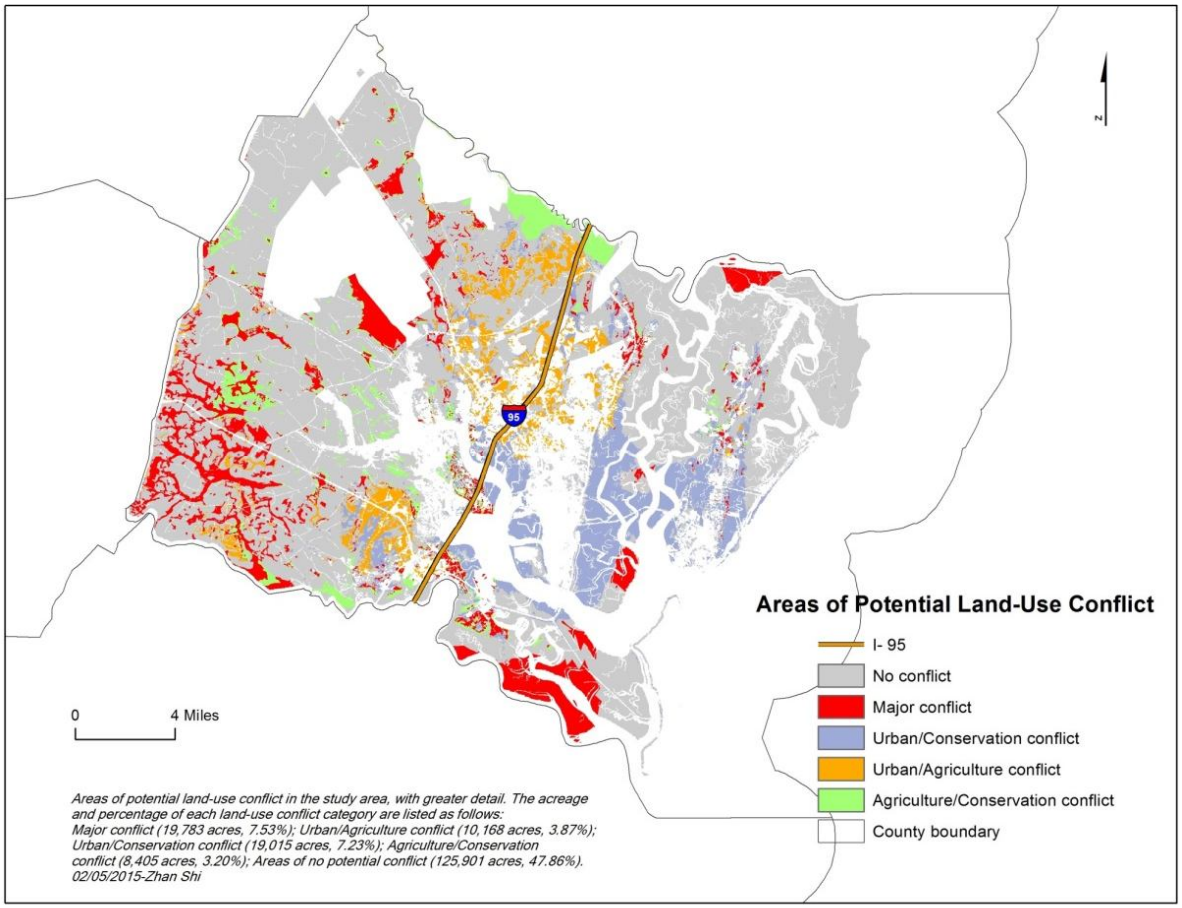


Figure 3.8: Areas of potential land-use conflict in detail.

Table 3.6: Areas of potential land-use conflict, described by acre and percentage of total study area.

Category	Area in acres	Percent of the study area
Agriculture/Conservation conflict	8,405	2.38
Urban/Agriculture conflict	10,167	2.88
Urban/Conservation conflict	19,015	5.39

Major conflict (conflict among all three land-use categories)	19,783	5.61
Areas of no potential conflict	125,900	35.71
Existing urban areas	32,129	9.11
Existing conservation areas	31,606	8.96
Areas of open water	105,600	29.95
TOTALS	**352,605**	**100.00**

Figure 3.9 maps the areas of agriculture preference, conservation preference, urban preference, major conflict, and moderate conflict. Table 3.7 summarizes the statistics of the results represented in Figure 3.9. Conservation preference is found to be the greatest acreage (56,848 acres) and percentage (16.12%) of Glynn County, and the acreage and percentage of agriculture preference are almost equal to that of conservation preference, which are 52,953 acres and 15.02 percent. The description above indicates that these areas are significantly more suitable for conservation and agriculture use than urban use based on the objectives in the suitability analysis. Among these categories, the acreage and percentage of urban preference are much less than that of the others, which are 16,099 acres and 4.57 percent.

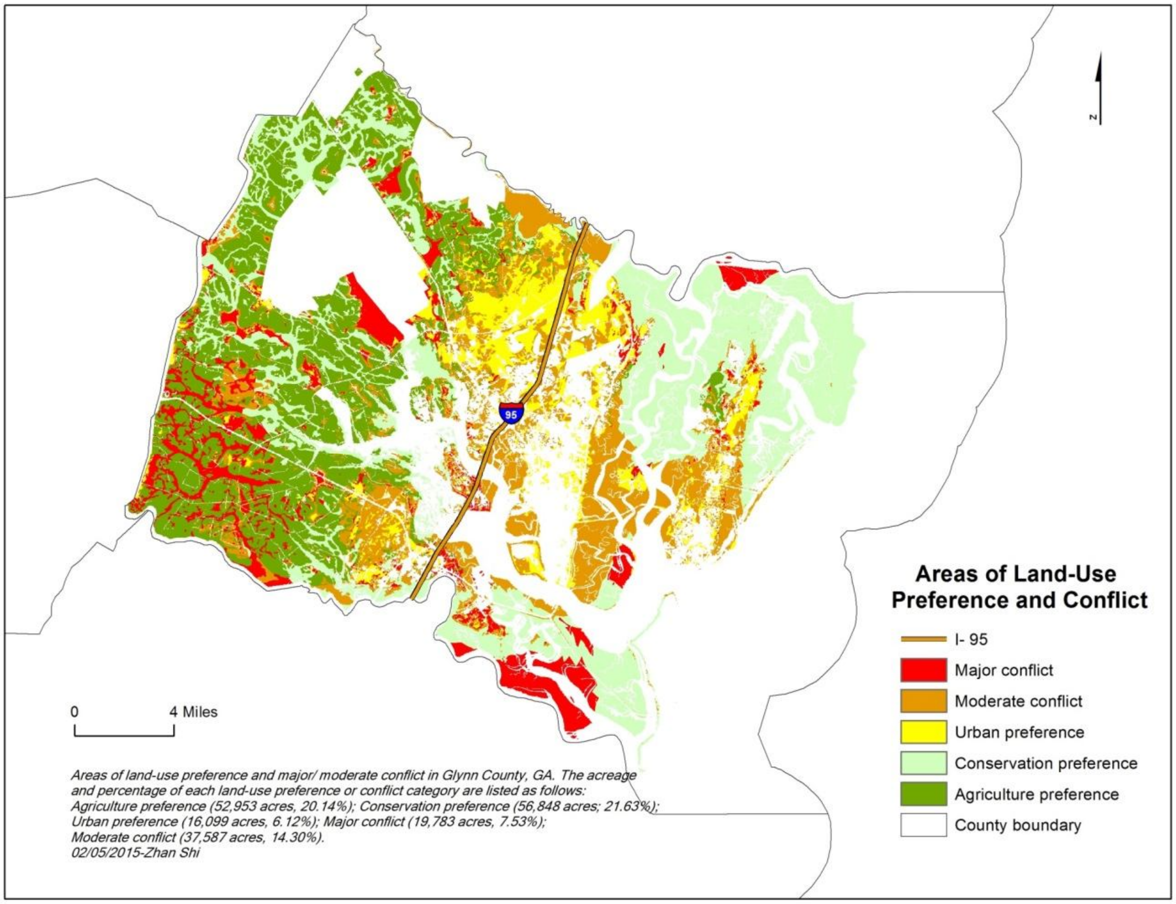


Figure 3.9: Areas of land-use preference and conflict with greater detail.

Table 3.7: Areas of land-use preference and conflict in the study area, described in acres and percentage of total study area.

Land-Use Preference and Conflict		
Category	**Area in acres**	**Percent of area**
Agriculture preference	52,953	15.02
Conservation preference	56,848	16.12
Urban preference	16,099	4.57
Major conflict (conflict among all three land-use categories)	19,783	5.61
Moderate conflict (conflict among two land-use categories)	37,587	10.66
Existing urban areas	32,129	9.11
Existing conservation areas	31,606	8.96
Areas of open water	105,600	29.95
TOTALS	**352,605**	**100.00**

Future Land-Use Allocation

After identifying potential future land-use conflict by LUCIS model, the next step is to use the conflict raster to visualize future land-use allocation scenarios to fulfill the proposed population growth until 2030. By utilizing the conflict raster for future determination, decisions need to be made about which space should be avoided in the future development and which space should be developed following certain land-use categories. A baseline future land-use allocation has been chosen to be applied in Glynn County. Baseline allocation is a method to allocate land based on status quo land-use policies and the current gross urban density (Carr & Zwick, 2007). Four inputs are required in this process, including the projected population, gross urban density, the total number of urban acres required to support the projected population, and the LUCIS conflict raster.

The fundamental regional land-use equation which has been described by Carr and Zwick is listed as below：

Projected increased population/gross urban density
= acres of land needed to support human settlement

In 2004, Glynn County's population was 71,357 people estimated by the Census Bureau. Following the growth rate of 1.5% annually for the next 25 years, until 2030, the projected population will be 103,535 people, which represents an increase in population of 32,178 people from the year of 2004 to 2030.

The latest and the only available land-cover/land-use data for Glynn County is the one from 2011, through which the urban land acreage can be calculated. The regional gross density for the study area is calculated by dividing the projected regional population in 2011 (79,195 people, calculated with the growth rate described in the Glynn County Comprehensive Plan-Community

Assessment) by the total acreage of urban land in 2011, and which is 2.5 people/acre. Based on the calculation above, it is easy to conclude that, an additional 12,871 acres urban land are required by 2030 to support the projected increased population, which is indicated as follows:

32,178 projected increased people/2.5 people per acre =12,871 additional urban acres (rounded up)

To allocate the projected increased population to the preferred place for future urban use, six steps are required to accomplish this goal, which are described in Figure 3.10.

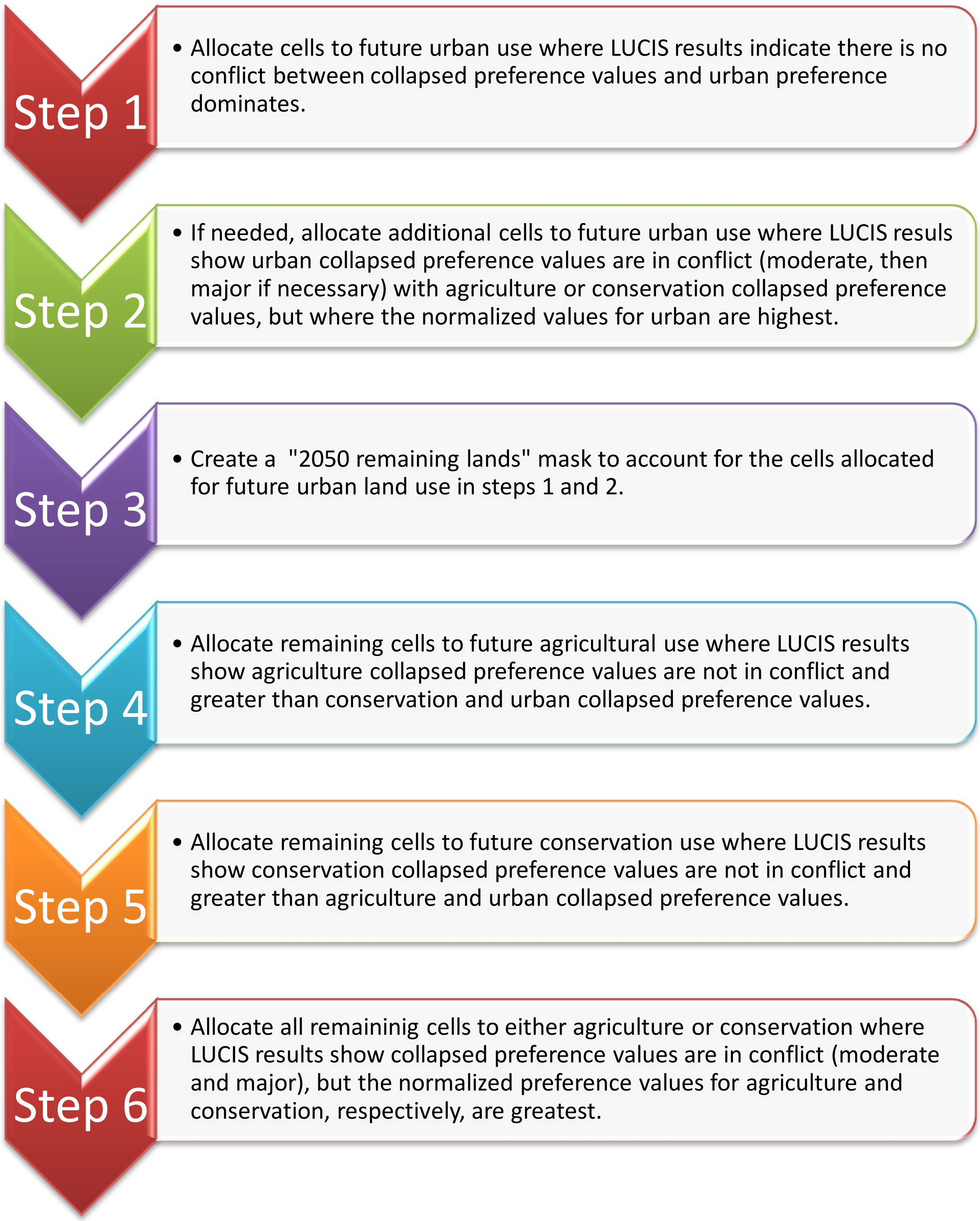


Figure 3.10: Six steps for future land allocation (Carr & Zwick, 2007, p. 167).

For the second step, since the land acreage in the step 1, which is 16,099 acres, has already sufficed for the future required urban land, which is 12,871 acres, there are an additional 3,228 acres existent for future urban land remaining in Step 1. The total 16,099 acres urban land in Step 1 has to be divided into two parts in Step 2: (1) urban lands of more preference, and (2) urban lands of less preference.

Figure 3.11 shows the map of the future land-use scenario I which was generated by the baseline analysis described above. As Table 3.8 describes, compared with the land-use condition in 2011, the acreage of total conservation lands, including existing and newly allocated lands, is more than 34 percent of Glynn County, which is more than 3 times of the amount already in that category. Including open water, the conservation area takes up to 64 percent of the whole area, which would be a large portion of land just for conservation purpose in Glynn County. For urban land use, 4.56 percent of total land in Glynn County for newly allocated urban preference is enough to sustain future proposed increased population. In these urban lands, about 11,608 acres are more preferred for urban land use and should be developed in priority. About 4,492 acres which are less preferred for urban development could be reserved as future urban land use after 2030.

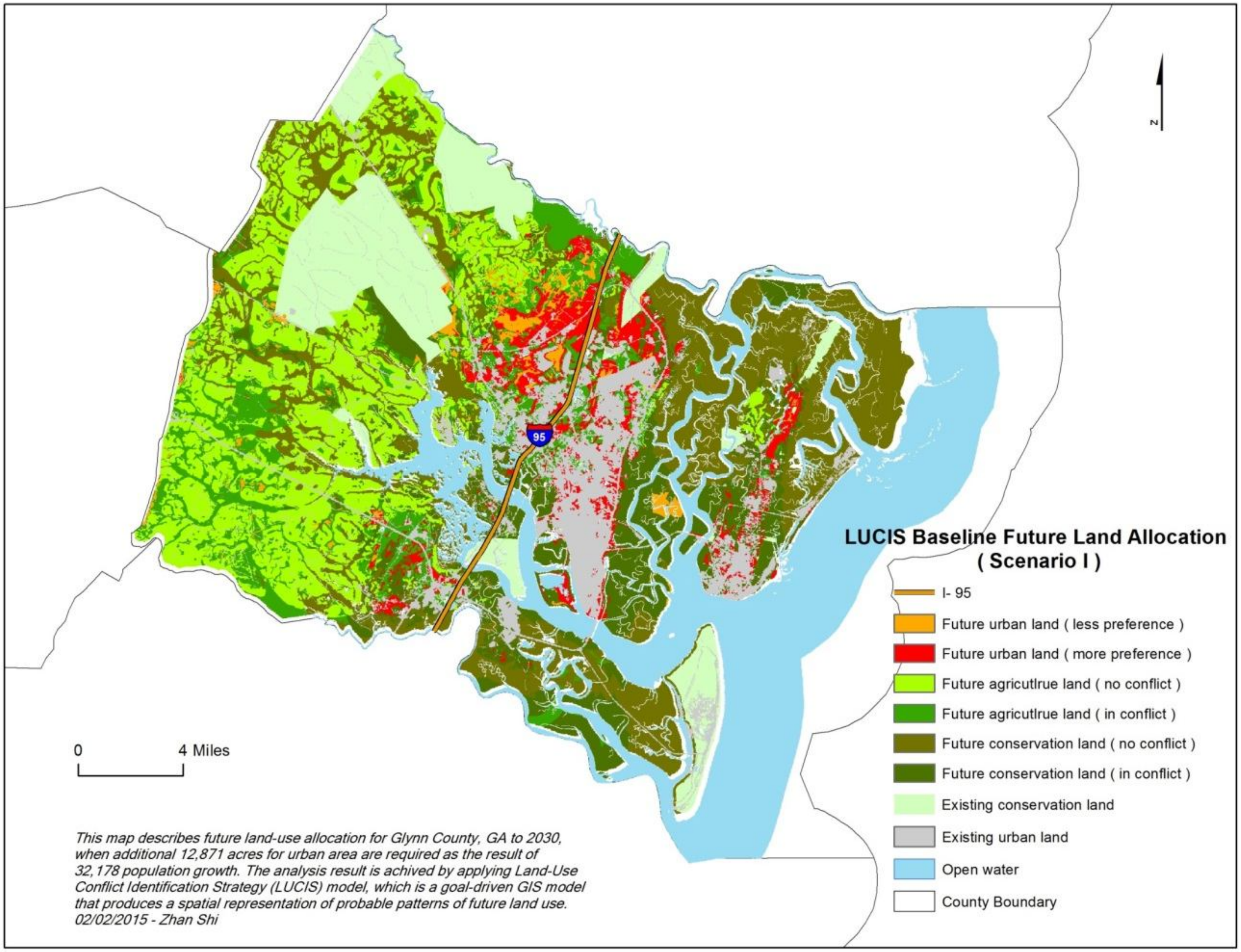


Figure 3.11: LUCIS baseline land allocation for 2030 (Scenario I).

Table 3.8: Tabulation of future land-use allocation for 2030 (Scenario I) according to baseline analysis principles.

Land-Use Allocation (2030 I)	Acres	Percent of Area
Agriculture allocation		
Area of no conflict	52,953	15.02
Area of in conflict	25,837	7.33
Agriculture subtotals	78,790	22.35
Conservation allocation		
Areas of no conflict	56,848	16.12
Areas of in conflict	31,532	8.94
Existing conservation lands	31,606	8.96
Existing open water	105,600	29.95
Conservation subtotals	225,586	63.98
Urban allocation		
Areas of more preference	11,608	3.29
Areas of less preference	4,492	1.27
Existing urban areas	32,129	9.11
Urban subtotals	48,229	13.68
TOTAL	**352,605**	**100.00**

The *Coastal Marshlands Protection Act*, which was passed by the Georgia General Assembly in 1970 to prohibit any conversion of marshland without a permit (Kundell, 1988). But it is still necessary to identify priority areas for conservation, and priority areas for other land use future allocation. A more realistic baseline allocation scenario is to reduce the amount of new conservation land. Figure 3.12 shows the second scenario for future land-use allocation in Glynn County. In this scenario, the amount of lands in newly allocated conservation is reduced by only using the cells highly preferred for conservation and transferring the cells with some degree of conflict (with low and moderate preference for agriculture and urban use) with other land-use categories to agricultural category. As Table 3.9 describes, in scenario II, total conservation land decreases from 34.02 to 25.08 percent, and agricultural use increases from 22.35 to 31.29 percent, which designates the conservation areas only for the land with significant purpose.

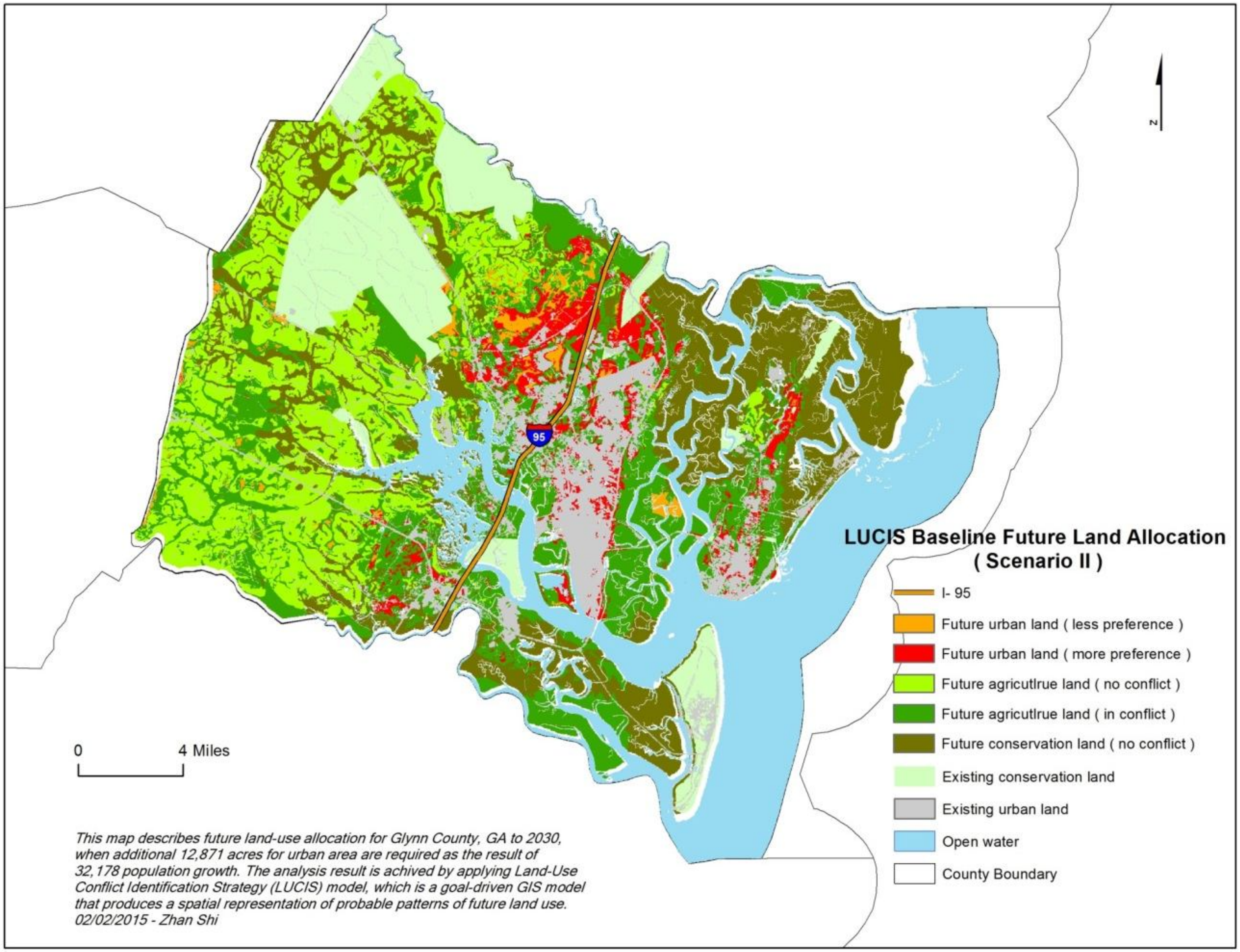


Figure 3.12: LUCIS Baseline Future Land Allocation for 2030 (Scenario II).

Table 3.9: Tabulation of future land-use allocation for 2030 (Scenario II) according to baseline analysis principles.

Land-Use Allocation (2030 II)	Acres	Percent of Area
Agriculture allocation		
Area of no conflict	52,953	15.02
Area of in conflict	57,369	16.27
Agriculture subtotals	110,322	31.29
Conservation allocation		
Areas of no conflict	56,848	16.12
Existing conservation lands	31,606	8.96
Existing open water	105,600	29.95
Conservation subtotals	194,054	55.03
Urban allocation		
Areas of more preference	11,608	3.29
Areas of less preference	4,492	1.27
Existing urban areas	32,129	9.11
Urban subtotals	48,229	13.68
TOTAL	**352,605**	**100.00**

CHAPTER 4

CONCLUSION

In this section, the results of the baseline future land allocation scenarios are reviewed for Glynn County. The comparison of the two future land-use allocation scenarios and the land-use condition in the year of 2011 leads to a better understanding of future land-use change. For scenario I (Figure 4.1, Table 4.1), almost half of the agricultural lands in 2011 are converted to urban and conservation areas, reducing the amount of agricultural lands from 51.98 percent to 22.35 percent. For scenario II (Figure 4.2, Table 4.2), more than 20 percent of agricultural lands are converted to urban and conservation land use, reducing these areas from 51.98 percent to 31.29 percent. In the first scenario, the newly allocated conservation areas increase to 25.06 percent, which is much larger than the existing conservation lands. Even in the second scenario, the newly allocated conservation areas increase to 16.12 percent. These outcomes suggest that given climate change and flood risk, the significance of these lands should be enhanced in future land-use proposals for Glynn County. The newly allocated urban land is 4.57 percent in both scenarios, which might suffice for the proposed population growth until 2030 or even longer. Additionally, since the urban goal has already assisted in avoiding flooding risk, based on existing urban growth density, infill, in existing urban areas, and expansion, or a combination of both are desirable in future land-use development. That means, if there is an increase in gross urban density, infill could be considered in order to accommodate the projected population. A combination of both infill and expansion is an alternative that can be applied in future land-use scenarios.

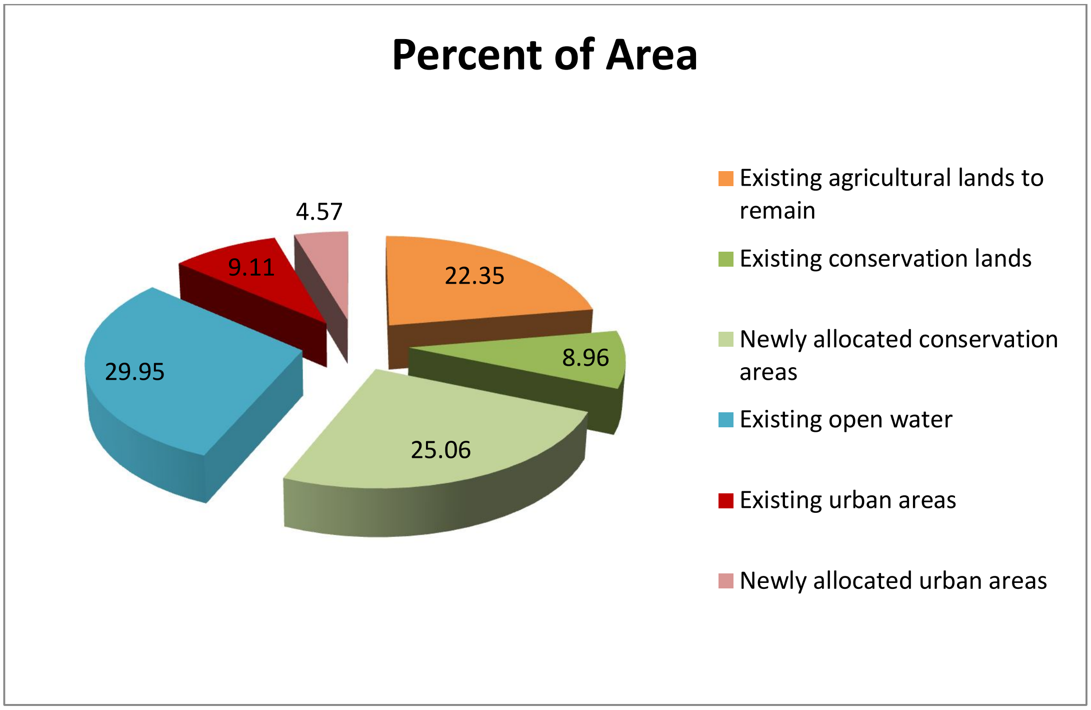


Figure 4.1: Percent of land-use area in 2030 (Scenario I).

Table 4.1: Projected land-use allocation for 2030 (Scenario I).

Land-Use Allocation for 2030 I	Acres	Percent of Area
Existing agricultural lands to remain	78,790	22.35
Existing conservation lands	31,606	8.96
Newly allocated conservation areas	88,380	25.06
Existing open water	105,600	29.95
Existing urban areas	32,129	9.11
Newly allocated urban areas	16,100	4.57
TOTAL	**352,605**	**100.00**

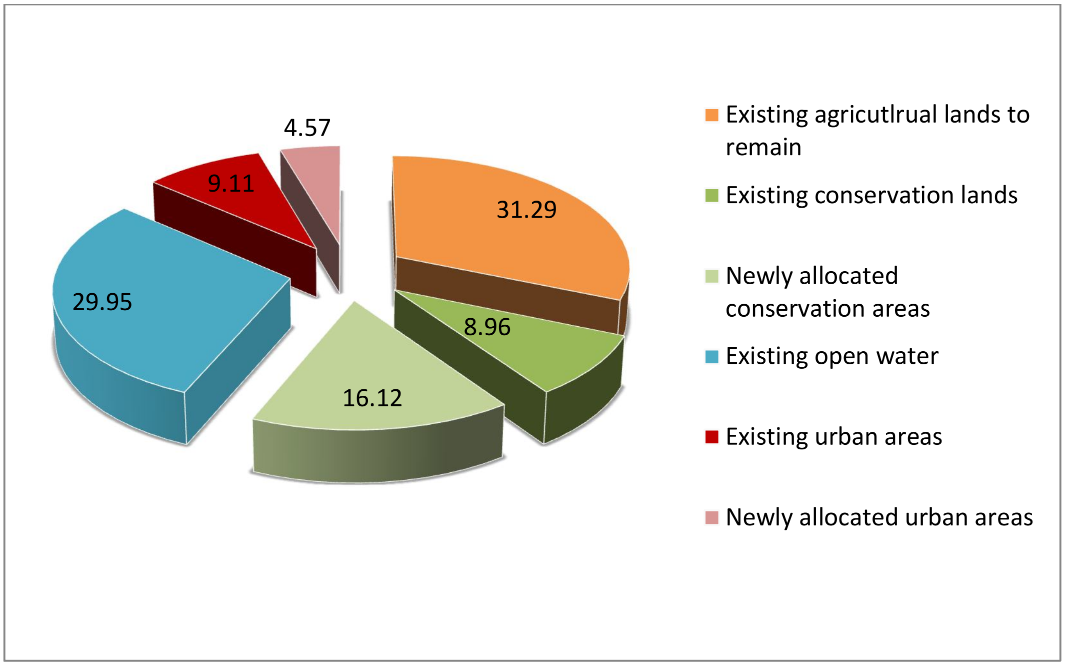


Figure 4.2: Percent of land-use area in 2030 (Scenario II).

Table 4.2: Projected land-use allocation for 2030 (Scenario II).

Land-Use Allocation for 2030 II	**Acres**	**Percent of Area**
Existing agricutlrual lands to remain	110,322	31.29
Existing conservation lands	31,606	8.96
Newly allocated conservation areas	56,848	16.12
Existing open water	105,600	29.95
Existing urban areas	32,129	9.11
Newly allocated urban areas	16,100	4.57
TOTAL	**352,605**	**100.00**

The two scenarios were compared to the Future Land-Use Map (Figure 4.3), which was adopted by the Community Department of Glynn County in 2009, to provide alternatives when determining future land-use. Since the projected location of land use in each category is highly overlapped, there is a great similarity between both of the results was regard to future land-use

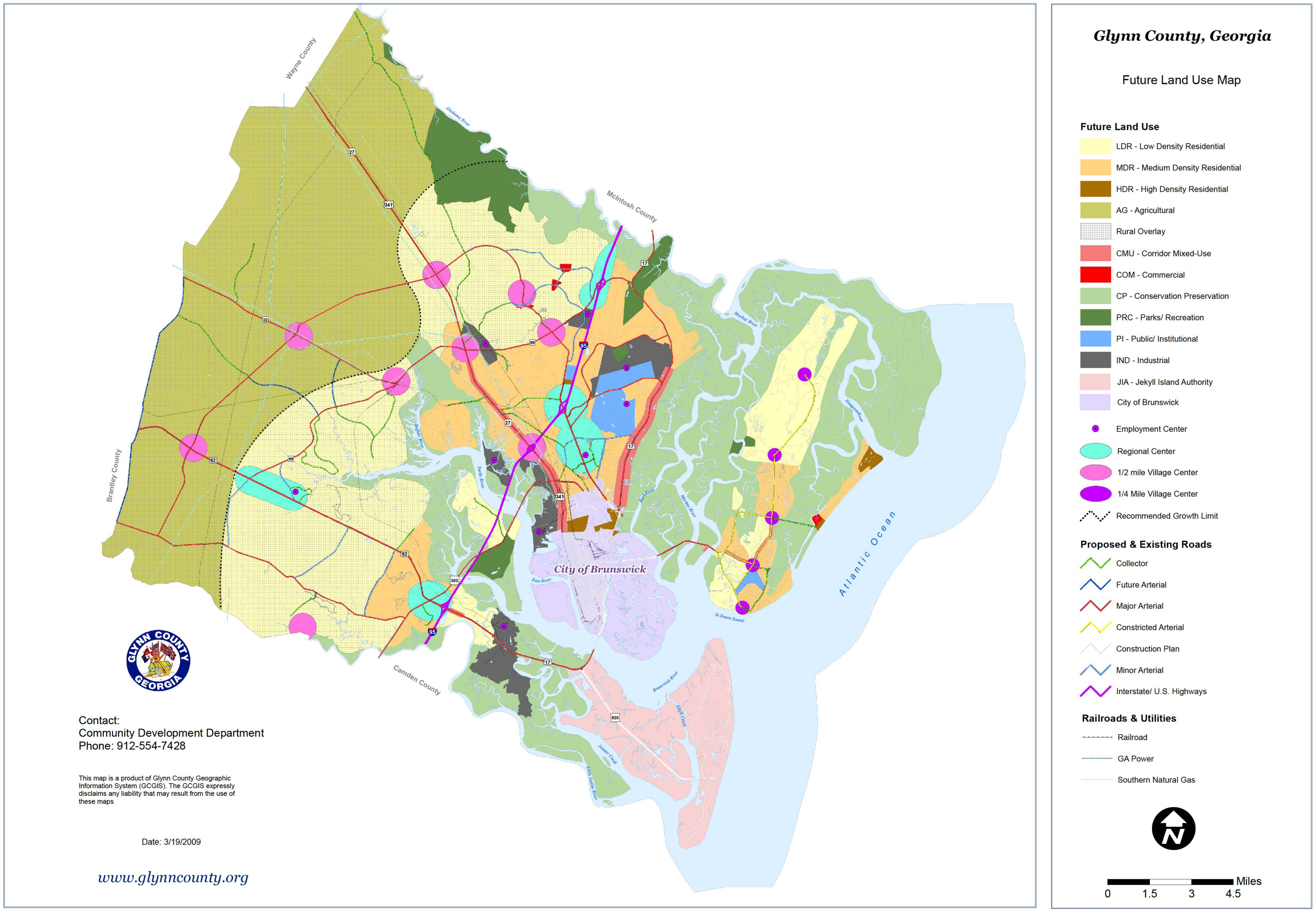
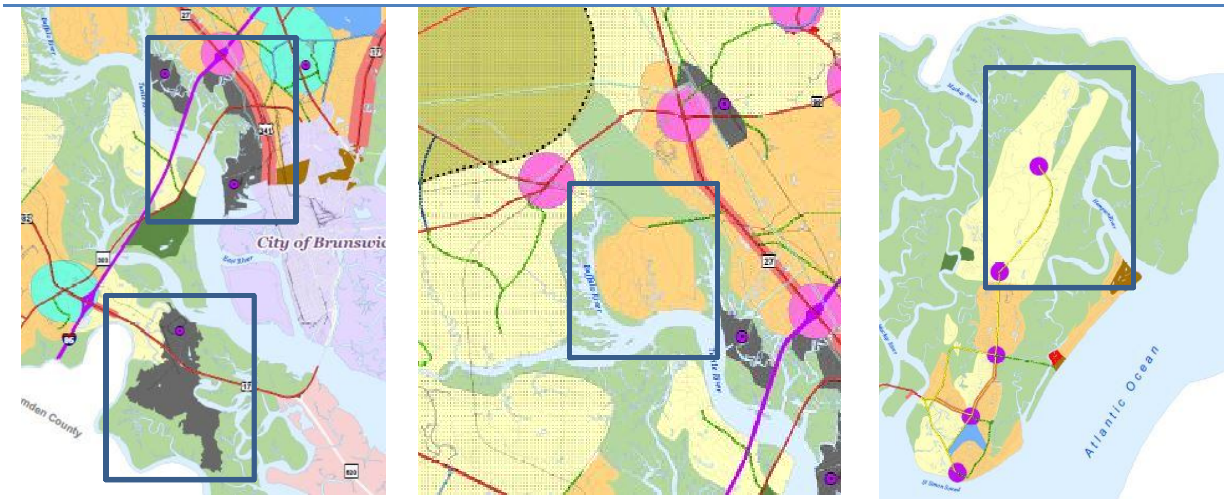


Figure 4.3: Future land use map of Glynn County (GCGIS, 2009)

decisions. An obvious difference identified in the maps could be summarized as the result of the conflict between development and conservation. Figure 4.4 shows the areas that are assigned for conservation or agricultural use by the LUCIS model, however, are planned for industrial and residential use in the Future Land-Use Map.



Industrial	Medium Density Residential	Low Density Residential

Figure 4.4: Differences identified in the Future Land-Use Map.

What is special in the two scenarios is that they, on the one hand, further extract conservation areas from agriculture land use; on the other hand, to indicate future land-use priorities, such as more preference areas with high development priority and fewer preference areas with lower development priority. Furthermore, it is of great value to compare the results of this study and the Future Land-Use Map when discussing future land use in detail. For example, according to the map, the county reserves more low-residential areas between agriculture and urban land, which may include agricultural-residential or other residential types. Conservation easement by a land trust or government entity could be considered based on the conservation lands demonstrated in both scenarios within these areas of low-residential.

Visualizing future land-use scenarios is important, especially for the coastal areas facing climate change and flood risk. This study contributes to not only to visualizing but also understanding future land-use trends in Glynn County. On the basis of this study, future work can be done to expand this model process to other coastal areas national-wide or even world-wide. Moreover, alternative future land-use scenarios are still important and need to be generated when any changes occur in land-use policy and growth urban density.

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APPENDIX: Glynn County Future Land-Use Strategies Assessment
Suitability Assessment- Model Objectives

Overall Statement of Intent: Determine the lands preferred for agriculture, conservation, and urban use in Glynn County, GA. Compare the resulting preferences to derive the most likely locations for future conflict.	
Urban Goal	**Identify lands suitable for urban land use**
Urban Goal 1	**Identify lands suitable for residential land use**
Objective 1.1 **UG1O11**	**Determine lands physically suitable for residential land use**
Subobjective1.1.1 ***UG1O11SO111***	*Identify soils suitable for building construction*
Subobjective1.1.2 ***UG1O11SO112***	*Identify elevation suitable for residential land use(for flooding consideration)*
Subobjective1.1.3 ***UG1O11SO113***	*Identify lands free of flood potential*
Subobjective1.1.4 ***UG1O11SO114***	*Identify land-cover suitable for building land-use*
Objective 1.2 **UG1O12**	**Determine lands economically suitable for residential land use**
Subobjective1.2.1 ***UG1O12SO121***	*Identify lands proximal to existing residential development*
Subobjective1.2.2 ***UG1O12SO122***	*Identify lands proximal to schools*
Subobjective1.2.3 ***UG1O12SO123***	*Identify lands proximal to health care facilities*
Subobjective1.2.4 ***UG1O12SO124***	*Identify lands proximal to roads*
Subobjective1.2.5 ***UG1O12SO125***	*Identify lands proximal to airports*
Subobjective1.2.6	*Identify lands proximal to fire station*

UG1O12SO126	
Subobjective1.2.7 UG1O12SO127	*Identify lands proximal to police station*
Subobjective1.2.8 UG1O12SO128	*Identify lands proximal to electricity power*
Subobjective1.2.9 UG1O12SO129	*Identify lands proximal to communication facility*
Subobjective1.2.10 UG1O12SO1210	*Identify lands proximal to parks, other recreational opportunities, protected conservation lands*
Subobjective1.2.11 UG1O12SO1211	*Identify lands proximal to waste water facilities*
Urban Goal 2	**Identify lands suitable for office/commercial/retail land use**
Objective 2.1 UG2O21	**Determine lands physically suitable for office/commercial/retail land use**
Subobjective2.1.1 UG2O21SO211	*Identify soils suitable for building construction*
Subobjective2.1.2 UG2O21SO212	*Identify elevation suitable for residential land use(for flooding consideration)*
Subobjective2.1.3 UG2O21SO213	*Identify lands free of flood potential*
Subobjective2.1.4 UG2O21SO214	*Identify land-cover suitable for building land-use*
Objective 2.2 UG2O22	**Determine lands economically suitable for office/commercial/retail land use**
Subobjective 2.2.1 UG2O22SO221	*Identify lands proximal to existing residential development*
Subobjective 2.2.2 UG2O22SO222	*Identify lands proximal to hospitals*
Subobjective 2.2.3 UG2O22SO223	*Identify lands proximal to major roads*
Subobjective 2.2.4	*Identify lands proximal to airports*

UG2O22SO224	
Subobjective 2.2.5 ***UG2O22SO225***	*Identify lands proximal to fire station*
Subobjective 2.2.6 ***UG2O22SO226***	*Identify lands proximal to police station*
Subobjective 2.2.7 ***UG2O22SO227***	*Identify lands proximal to electricity power*
Subobjective 2.2.8 ***UG2O22SO228***	*Identify lands proximal to communication facility*
Subobjective 2.2.9 ***UG2O22SO229***	*Identify lands proximal to parks, other recreational opportunities*
Subobjective 2.2.10 ***UG2O22SO2210***	*Identify lands proximal to waste water facilities*
	Urban Goal 3 Identify lands suitable for industrial land use
Objective 3.1 **UG3O31**	**Determine lands physically suitable for Industrial land use**
Subobjective 3.1.1 ***UG3O31SO311***	*Identify soils suitable for building construction*
Subobjective 3.1.2 ***UG3O31SO312***	*Identify elevation suitable for residential land use(for flooding consideration)*
Subobjective 3.1.3 ***UG3O31SO313***	*Identify lands free of flood potential*
Subobjective 3.1.4 ***UG3O31SO314***	*Identify land-cover suitable for building land-use*
Objective 3.2 **UG3O32**	**Determine lands economically suitable for Industrial land use**
Subobjective 3.2.1 ***UG3O32SO321***	*Identify lands far from existing residential development*
Subobjective 3.2.2 ***UG3O32SO322***	*Identify lands proximal to major roads*
Subobjective 3.2.3	*Identify lands proximal to ports*

UG3O32SO323	
Subobjective 3.2.4 UG3O32SO324	*Identify lands proximal to airports*
Subobjective 3.2.5 UG3O32SO325	*Identify lands proximal to rail road*
Subobjective 3.2.6 UG3O32SO326	*Identify lands proximal to fire station*
Subobjective 3.2.7 UG3O32SO327	*Identify lands proximal to electricity power*
Subobjective 3.2.8 UG3O32SO328	*Identify lands proximal to communication facility*
Subobjective 3.2.9 UG3O32SO329	*Identify lands proximal to waste water facilities*

Conservation Goal	**Identify lands suitable for land conservation**
Conservation Goal 1	**Identify lands suitable for protecting native biodiversity(377)**
Objective 1.1 CG1O1	Identify lands proximal to the habitat of rare species
Objective 1.2 CG1O2	Identify proximal to existing conservation areas/easement/open space
Objective 1.3 CG1O3	Identify lands proximal to waterbodies
Conservation Goal 2	**Identify lands suitable for protecting water quality (203)**
Objective 2.1 CG2O1	Identify lands proximal to waterbodies
Objective 2.2 CG2O2	Identify lands proximal to groundwater aquifer
Objective 2.3 CG2O3	Identify lands with the soil type with strong ability of filter
Conservation Goal 3	**Identify lands vulnerable to climate change and flood risk**

Objective 3.1 CG3O1	Identify lands proximal to the areas within hurricane surge within (CAT 1:high, CAT2-3:medium, CAT4-5:low)
Objective 3.2 CG3O2	Identify lands proximal to the areas within 100-year flood plain
Objective 3.3 CG3O3	Identify lands proximal to the areas vulnerable to tropical storm
Objective 3.4 CG3O4	Identify lands proximal to the impervious areas(less vegetation and infiltration)
Objective 3.5 CG3O5	Identify lands proximal to the waterbodies (<75:high,75-200:medium,>200:low)
Conservation Goal 4	**Determine lands vulnerable to soil erosion**
Objective 4.1 CG4O1	Identify lands proximal to waterbodies(<35:high,35-150:medium,>150:low)
Objective 4.2 CG4O2	Identify lands with the soil type of sand

Agriculture Goal	**Identify lands suitable for agriculture development**
Agriculture Goal 1	**Identify lands suitable for agriculture development**
Objective 1.1 AG1O1	Identify lands proximal to existing crop/cultivation land
Objective 1.2 AG1O2	Identify lands with loamy soil and silky clay loamy that are suitable for crop growth (low erosion risk)
Objective 1.3 AG1O3	Identify lands proximal to waterbodies
Agriculture Goal 2	**Identify lands suitable for timber/silviculture**
Objective 2.1 AG2O1	Identify lands proximal to waterbodies
Objective 2.2 AG2O2	Identify lands proximal to existing pine plantation

Objective 2.3 **AG2O3**	Identify lands proximal to the soil type preferred by Pine Plantation
	Agriculture Goal 3 Identify lands suitable for managed livestock
Objective 3.1 **AG3O1**	Identify lands proximal to hay/Pasture
Objective 3.2 **AG3O2**	Identify lands proximal to waterbodies (within 800 ft)