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IDENTIFYING POTENTIAL SEDIMENTATION SOURCES THROUGH A REMOTE SENSING AND GIS ANALYSIS OF LANDUSE/ LANDCOVER FOR THE WEEKS BAY WATERSHED, BALDWIN COUNTY, ALABAMA

By

John Harrison Cartwright

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in the Department of Geosciences

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IDENTIFYING POTENTIAL SEDIMENTATION SOURCES THROUGH A REMOTE SENSING AND GIS ANALYSIS OF LANDUSE/ LANDCOVER FOR THE WEEKS BAY WATERSHED, BALDWIN COUNTY, ALABAMA

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The Weeks Bay watershed in Baldwin County, Alabama has experienced rapid changes in landuse/ landcover (LULC) from 1990 to 2000. These changes have resulted in increased upland erosion and higher concentrations of suspended sediment within the watershed. For this research project a spatial model was developed to identify potential sources of sediment relevant to LULC and slope. Landsat satellite imagery was classified to assess LULC within the Weeks Bay watershed. The classification includes forested vegetation, herbaceous vegetation (seasonal and persistent), mixed/ transitional vegetation, urban/ built-up areas, sparse/ residual vegetation and water, with an overall accuracy of 78%. Change detections of the classified images yielded substantial increases in urban areas (92.5%). These data were coupled with slope data in a geographic information system and a raster analysis provided a qualitative evaluation of potential sediment sources within the Weeks Bay watershed based on the change in LULC and slopes of the landscape.

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CHAPTER I

INTRODUCTION

Overview

In 1972 the United States Congress passed the Coastal Zone Management Act (CZMA). Through the CZMA, and subsequent amendments, Congress officially stated that resources within the coastal zone are of national importance and these resources should be protected. A coastal resource of national significance is any coastal wetland, beach, dune, barrier island, reef, estuary, or fish and wildlife habitat determined to be of substantial biological or storm protective value (CZMA, 1972). The CZMA also establishes that the coastal zone is not only the areas immediately adjacent to the shore lands, the coastal zone is to include all tidelands and uplands to the extent necessary to control the shore lands.

In section 315 of the CZMA the National Estuarine Research Reserve System (NERRS) was established. The NERRS allows for the designation of healthy estuarine ecosystems of typically different regions of the U.S. to be managed for long-term research and estuarine education. The general framework of the NERRS allows for the sharing of management approaches, research findings, and estuarine education with other coastal programs. The establishment of the NERRS by the CZMA helps to address the current and potential problems related to the degradation of coastal resources due to increased and competitive demands for these resources of national significance. Under section 315 of the CZMA there are presently twenty-five National Estuarine Research Reserves located in the United States and Puerto Rico. Of these twenty-five NERRS sites, four are located in the Gulf of Mexico region in the states of Florida, Alabama, and Mississippi (Figure 1). In order to help address and increase the understanding of some of the problems associated with estuarine ecosystems the National Oceanographic and Atmospheric Administration (NOAA) provides research resources for estuarine research projects through the NERR's system. Research areas of interest include nonpoint source pollution (NPS), socioeconomic development, ecosystem biodiversity, estuarine resource sustainability, estuarine restoration projects, and impacts of invasive species on estuarine ecosystems (NOAA, 1998).

Research efforts at the Weeks Bay NERR have concentrated on the collection and generation of baseline data. One of the critical issues of interest of the Weeks Bay NERR is the change in landuse/land-cover (LULC) of the Weeks Bay watershed, especially in terms of urban, residential, and commercial development. LULC patterns can alter watershed dynamics in terms of the amount of runoff and upland erosion, with the later being directly related to estuarine or bay sedimentation (Halcomb, 1995). Changes in LULC patterns are also responsible for nonpoint source pollutants, which may be introduced as bacteria, nutrients, toxic substances, and sediment (Beck, 1995).

Geographic Information Systems (GIS) have proven to be a very accurate and efficient in producing models for monitoring LULC change and sedimentation patterns (Fedra, 1993). A GIS model that incorporates LULC and the potential sedimentation

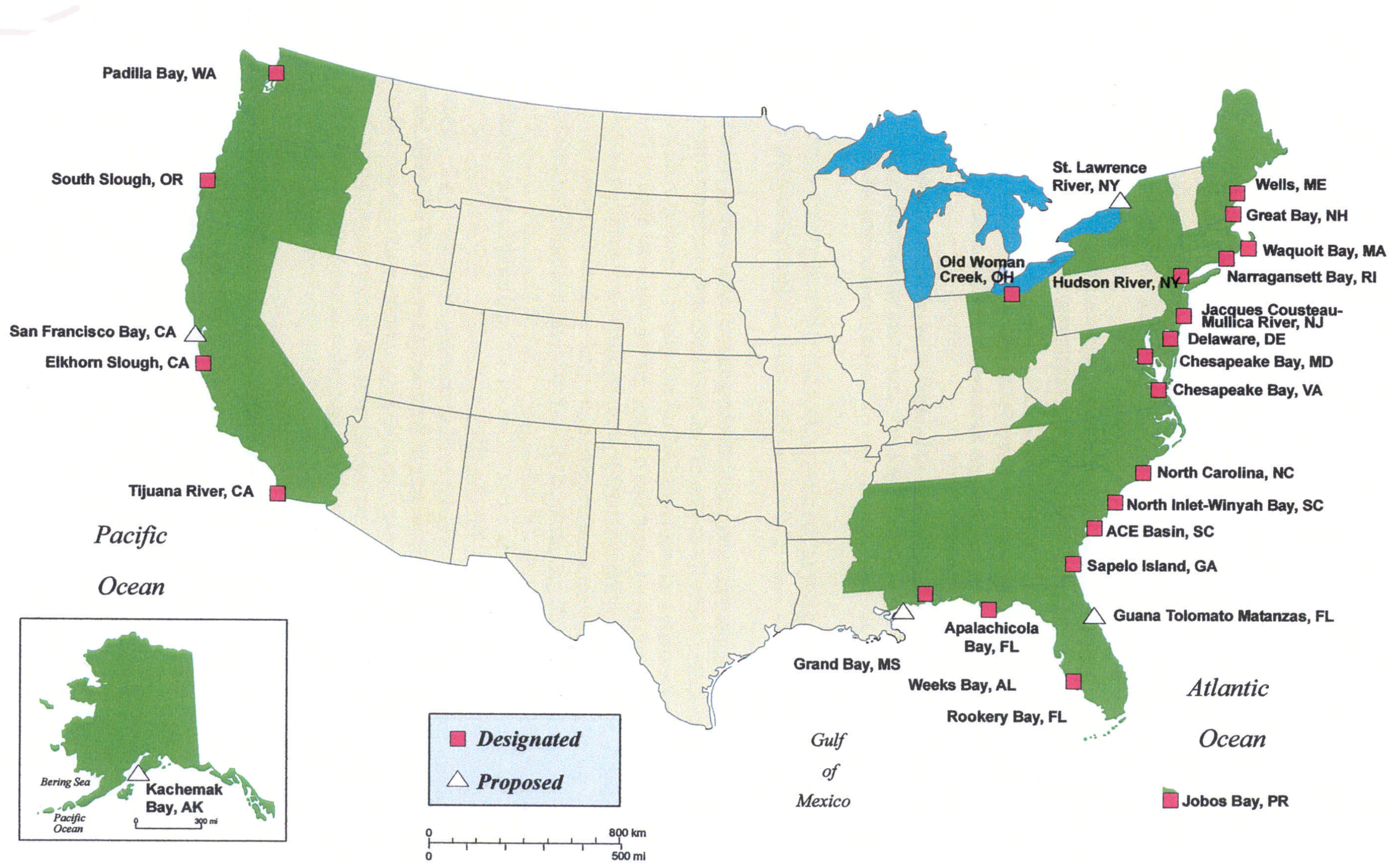


Figure 1: Designated and proposed National Estuarine Research Reserve sites (NOAA 1998).

associated with it would prove to be very useful in such a rapidly changing area such as Weeks Bay. This type of model would provide a spatial perspective to the Weeks Bay area, focusing on the socio-economic development in this area and the potential sources for sedimentation in terms of NPS pollution.

Objective of Study

The primary focus of this study is to use GIS to determine changes in LULC for the Weeks Bay watershed for 1990 to 2000. The LULC data will then be coupled with slope data in a rule-based model to help indicate potential areas of increased erosion due to changes in the landscape. Production of this type of model will develop a spatial database for the Weeks Bay Watershed Management area, which is a stated need for this area (Miller-way, Dardeau, and Crozier, 1996). Some of the specific questions to be answered by this project are as follows:

1. How has the LULC changed overall in the Weeks Bay watershed?
2. Where has the greatest amount of LULC change occurred in the watershed?
3. How much have urban areas expanded within the watershed?
4. Where is the greatest potential for erosion based on these changes to the landscape?
5. What is the overall threat of erosion in terms of bay sedimentation for the Weeks Bay estuary?

CHAPTER II

BACKGROUND

The Weeks Bay National Estuarine Research Reserve

In February of 1986 Weeks Bay was designated as the sixteenth National Estuarine Sanctuary and in April of that same year the name was changed to the Weeks Bay National Estuarine Research Reserve (WBNERR). The Weeks Bay NERR is located to the east of Mobile Bay in south Baldwin County Alabama about 50 kilometers southeast of the city of Mobile, Alabama (Figure 2). The Weeks Bay NERR presently manages more than 525 hectares of buffer land made of five tracts of state owned land and about 1900 hectares of core land that is state owned submerged lands (water bottom) (NOAA, 1998). The submerged land includes Weeks Bay proper, portions of the Fish and Magnolia rivers, and a portion of Bon Secour Bay.

In addition to the core and buffer tracts the reserve also helps to monitor the drainage basin or watershed associated with Weeks Bay. The Weeks Bay watershed encompasses about 51,000 hectares; this includes the watersheds of both the Fish and Magnolia Rivers (Miller-Way, et al., 1996). The Weeks Bay watershed includes portions of the towns Fairhope, Foley, Loxley, Robertsdale, and Summerdale, which are located in Baldwin County Alabama (Figure 3). The population in the 1990 of these towns range from slightly more than 12,000 (Fairhope, AL) to as little as 1600 (Loxley). The

Figure 2: Location of the Weeks Bay watershed and Baldwin County, Alabama.

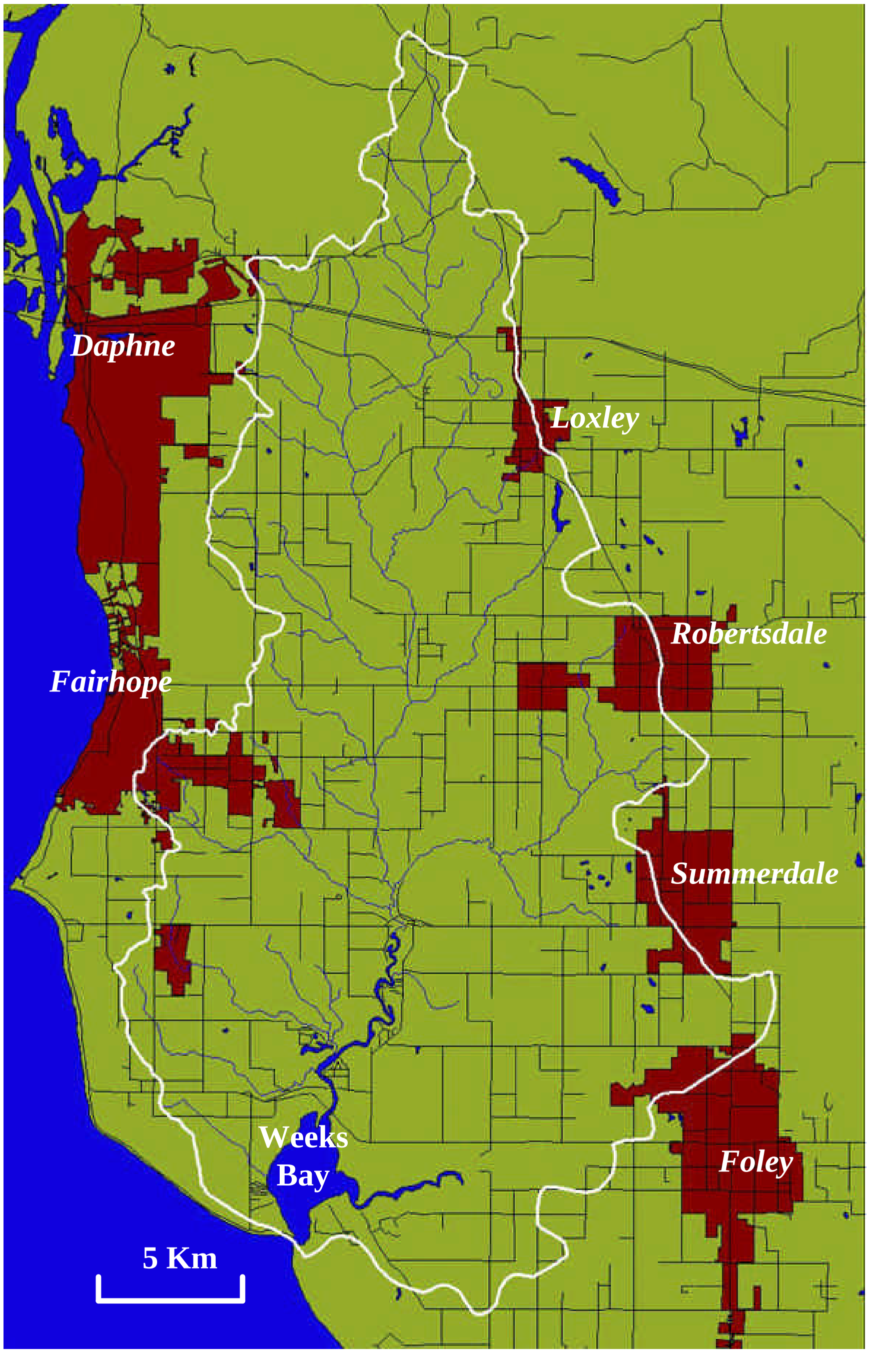


Figure 3: The Weeks Bay watershed and surrounding area in southern Baldwin County, Alabama.

watershed has been primarily characterized as a rural area but it is experiencing a considerable increase in urban related development, including residential and commercial. This may in part be due to the area being within a commutable distance from Mobile, AL and Pensacola, FL, the region's two major metropolitan areas.

Physical and Environmental Setting

Weeks Bay is considered to be the local base level (terminate flow point) for the Weeks Bay watershed, the bay itself is a small, shallow, microtidal, tributary estuary. The bay is described as a tributary estuary since it is part of the much larger estuarine system of Mobile Bay, however it is classified as a coastal plain estuary because it is formed by the drowning of a river valley. Weeks Bay has approximately 7.5 square kilometers of open shallow water with an average depth of 1.4 meters. Tidal range in the Weeks Bay estuary varies from 0.3 to 0.5 meters. As stated earlier the watershed of Weeks Bay encompasses about 51,000 hectares with an estimated 270,000 metric tons of soil eroding from the surface of the watershed annually. The majority of the erosion is spawned by agricultural practices within the watershed, with approximately 15% of the eroded soil reaching the streams associated with watershed and half of that is being deposited in Weeks Bay (NOAA, 1998).

Weeks Bay freshwater inflows come from the Fish and the Magnolia rivers and the inflow of saltwater from the Gulf of Mexico through Mobile Bay. The mean combined discharge of the Fish and Magnolia rivers is approximately 9 cubic meters per second with the Fish River contributing nearly 75% of this discharge. The Fish and

Magnolia rivers range in depth from 2 to 14 meters with the deeper areas being confined to scours at the mouths of the rivers (Schroeder, Wiseman, and Dinnel, 1990). The Weeks Bay watershed is very flashy in terms of response to local rainfall events as the water within the bay can be replaced in two or three days from freshets and in about three days from tidal exchange with Mobile Bay (Schroeder, et al, 1990).

The Weeks Bay watershed is located in the humid subtropical climate region, which dominates the states adjacent to the Gulf of Mexico. This provides for typically warm summers and relatively mild winters with occasional cold waves. The winter storms, summer thunderstorms, and tropical systems help to yield an annual precipitation accumulation of approximately 165 centimeters (Miller-Way, et al., 1996). This annual rainfall total makes this region second in annual rainfall in the continental United States, with the Pacific Northwest being the only region with more annual rainfall.

The Weeks Bay watershed is located within the Middle Coastal Plain Province and the Flatlands Coastal Plain Province of the Gulf Coastal Plain physiographic province. The northern parts of the watershed are contained to the Middle Coastal Plain, with the northern portion being in the Southern Loam Hills and the southern portion in the Citronelle Plains (Chermock, Boone, and Lipp, 1974). The area immediately adjacent to Weeks Bay is within the Coastal Flatwoods Region of the Flatlands Coastal Plain Province. The geology of the watershed is predominately quartz rich sands inter-bedded with silts and clays. Formations within the watershed include the Citronelle from the Pliocene, undifferentiated Miocene Series, and Holocene alluvium.

Previous Investigations

Selley 1988, defines sedimentation as the process of deposition of a solid material from a state of suspension or solution in a fluid (usually air or water). Sedimentation occurs when ground cover is removed allowing increased rates of erosion through physical forces acting upon the ground surface and removing loose weathered material (Carver, 1998). Sediment accumulation in lakes, rivers, and streams decreases their capacity for particle storage and creates water quality problems. The primary water quality problem associated with sediment is its designation in transport of pollutants in sediment. Sedimentation is the largest volumetric pollutant source to surface waters in the United States (Basnyat, Teeter, Flynn, and Lockaby, 1999).

The degree of sedimentation in a body of water can be directly related to the type of landuse within the surrounding area and specific sedimentation patterns can be associated with a specific landuse (Schloss and Rubin, 1992). Research to date in the Southeast United States has focused primarily on problems associated with sedimentation or erosion due to agricultural practices in rural areas. However, a trend of accelerated development in rural areas has been observed in the United States over the past two decades (Fuguitt and Voss, 1979). Residential, urban, and commercial areas are now being identified as the number one source of pollutants transported by sediment. Both agricultural practices and urban development have been proven to be significant sources of sedimentation, with major contributions of NPS pollutants (Basnyat, et al., 1999).

The amount of estuarine sedimentation can be regulated by three simple factors: (1) the type and area of ground cover, (2) the amount of precipitation, and (3) the surface lithology (Dyer, 1986). The first factor can be directly related to the specific type of landuse activities occurring within the estuary's watershed and the second factor is controlled by the climate of an area. The climatic controls most often considered along the Gulf Coast are associated primarily with occurrence and intensity of tropical storms, since they are capable of producing large amounts of precipitation in a very short period of time (Fisher, 1998). The third factor relates specifically to the local geology and it's ability to be eroded, transported and deposited (Dyer, 1986).

Historical trends of landuse follow a pattern of development trends, dating back to the 1800's (Figure 4) During the mid 1800's there was a boom in the forestry industry across much of the United States (Rooney and Smith, 1999). The result of these practices left a barren landscape void of vegetation, most often without efforts of replanting to help to stimulate the rejuvenation of vegetation. The barren land was then incorporated into agricultural practices, which aided in vegetation cover being reestablished. The present trend in the United States involves the conversion of preexisting agricultural lands to urban areas. It is important to note that in some cases deforested land may be converted into an urban area without going through the agricultural phase.

The Weeks Bay watershed of Baldwin County, Alabama is not an exception to the accelerated development in rural areas. Baldwin County was the second fastest growing county in the State of Alabama throughout the 1990's (SARPC, 1993). The area associated with the Weeks Bay watershed has been classified in the past as primarily rural, with a dominance of agricultural land-use practices. The cities within the watershed

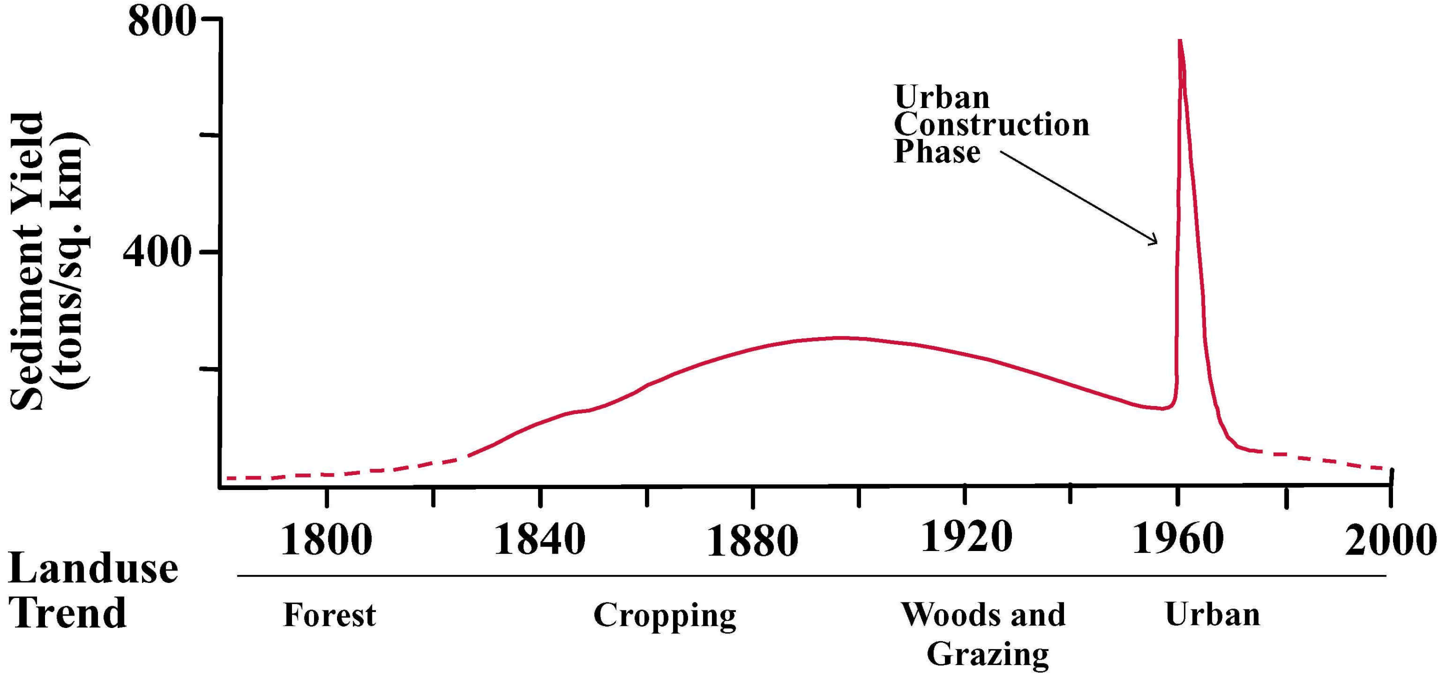


Figure 4: Historical trends of sediment yield and land used for the United States (Wolman in Keller,1996).

are growing rapidly in terms of population and development, due in part to the area's proximity of Alabama's popular recreational beaches. Commercial developments in the area are expected to follow these demographic trends as the area's tourism industry continues to rapidly grow (NOAA, 1998).

The South Alabama Regional Planning Commission (SARPC) has given projections of landuse and population through the year 2010 (Table 1). The projections show an increase of almost 40% in developed landuse in the Weeks Bay watershed and a similar increase in population for Baldwin County (SARPC, 1993). The projected growth patterns give rise to problems associated with the integrity of the Weeks Bay watershed as related to sedimentation. Weeks Bay can encounter negative impacts due to the sediment produced by upland erosion within the watershed by residential, urban, and commercial development (Basnyat, et al., 1999).

Impacts of estuarine sedimentation have been extensively researched throughout the United States for past three decades. Areas studied extend from the Pacific coast to the Atlantic coast, including areas of the Gulf coast and Puerto Rico up to the shores of the Great Lakes. In general most of the present day research focuses on estuarine sedimentation as it relates to changes of landuse and the impacts of tropical storms, the later being confined to the Atlantic-Gulf coastal plain. Landuse increases estuarine sedimentation by the removal of ground cover, which stimulates erosion. The impact of tropical storms is related directly to the increased precipitation produced by these events.

Rooney and Smith (1999) estimate that sedimentation rates of coastal waters has doubled since prehistoric times. This increase in sedimentation has been primarily due to

Table 1: 1990 landuse and 2010 landuse predictions for Baldwin County, Alabama (SAPRC 1993).

	Acres		**Change**	
Classification	**1990**	**2010**	**Number**	**Percent**
Residential	12,285	16,250	3,965	+32.28
Commercial	1,802	2,708	906	+50.28
Industrial	907	1,586	679	+74.86
Public / Semi-public	31,036	42,742	11,706	+37.72
Subtotal Developed	**46,030**	**63,286**	**17,256**	**+37.49**
Resource Production and Extraction	721,463	718,546	-2,917	-0.40
Vacant	68,345	54,006	-14,339	-20.98
Wetlands	174,082	174,082	0	0
Water	46,462	46,462	0	0
Subtotal Undeveloped	**1,010,352**	**993,096**	**-17,256**	**-1.71**
Total Area	**1,056,382**	**1,056,382**		

anthropogenic activities such as crop farming, livestock grazing, logging, and urbanization . These alterations of landuse have dramatically increased nearshore sediment loading, which are affecting coastal marine environments (Rooney and Smith, 1999). It has been reported that greater than 95 % of the riverine sediment delivered to the Atlantic coast is trapped in estuaries and coastal wetlands (Meade, 1982).

The effects of landuse on upland erosion, sediment transport, and reservoir deposition were analyzed in Lago Loiza basin in Puerto Rico. This was a comprehensive investigation looking at several decades (1953 – 1993) of data for landuse, climate, soil erosion rates, and basin geometry. The Lago Loiza basin lost 47% of its storage capacity since impoundment in 1953 due to increases in sedimentation (Gellis, Webb, Wolfe, and McIntyre, 1999). Land use change results of the study showed early decreases in cropland with increases in pasture with later increases in forested land and urban development. Sediment yield and concentrations were calculated for four landuses, cropland, pasture, forest, and disturbed land. The current data was then compared to sediment yield data from historical landuses within the basin. Present results varied in the amount of sediment produced with the historical measurements, but all results followed the same trend. Trends showed that disturbed or construction land had the highest erosion rates, with cropland second, and pasture and forest having minimal erosion rates.

A study of Tomales Bay, California provided data which link estuarine sedimentation to changes in landuse. The results from this study were compiled using GIS techniques and preexisting digital bathymetric models of Tomales Bay. The GIS model suggests that mass accumulations of sediment in the bay quadrupled. However, the data are insufficient in determination of the timing and magnitude of high sedimentation events. Variations in sedimentation from the watershed to the estuary were found to be in response to variations in runoff (Rooney and Smith, 1999).

Significant changes to other watersheds have been analyzed with the use of GIS models. GIS has been used to calculate sediment yields within the Old Woman Creek watershed of Erie and Huron counties, Ohio (Evans and Seamon, 1997). The estuary associated with the Old Woman Creek watershed is unique, in that it lacks the defining feature of an estuary (mixing of fresh and saline water). The GIS model employed was based on the Universal Soil Loss Equation, which is controlled by the combinations of soil types, slopes, vegetation, and landuse (Evans and Seamon, 1997). The model proved to be very accurate in the comparison of soil loss and sediment yield data for the watershed, estimating that 21-25% of the soil is delivered to the estuary and the remaining 75-79% is found in intrabasinal storage (Evans and Seamon, 1997). The indication of specific sediment sources could not be determined with this model, however an erosion problem area was identified in the southeast portion of the watershed. The determination of this area was indicated by large amounts of stream sediment loading from sediment routing models. The problematic region combines highly erodible soils with moderate relief and agricultural landuse practices (Evans and Seamon, 1997). It is anticipated that better management of these agricultural regimes could have beneficial effects on sediment accumulations within the watershed and associated estuary.

Water quality can be affected greatly by changes in landuse, whether it is fresh surface water in the upper regions of a watershed or in the brackish water near the local base level, often an estuary. The level of water quality can correspond to specific types of landuse practices, due to the by products produced by the ongoing activities. Landuse activities affect water quality by altering sediment, chemical loads, and watershed hydrology (Basnyat, Teeter, Flynn, & Lockaby, 1999). Water quality may increase or decrease with respect to the type of pollutants and the amount of sediment produced by a specific landuse. Agricultural and urban landuses are the most detrimental to watershed quality with respect to total sediment and nitrates (non-point source [NPS] pollutants) (Basnyat, et al., 1999). The project involved in the determination of these problems was completed for the Fish River watershed, Baldwin County, Alabama. A landuse / landcover (LULC) classification was developed with the use of Systeme Probatoire d’Observation de la Terre (SPOT) satellite imagery and high-resolution aerial photography (Basnyat, et al., 1999). Streams within the watershed were then sampled and problematic areas were identified with the use of GIS. Urban areas have been identified as the number one contributor of nitrates and active agricultural areas were identified as the second. Implementation of streamside buffer zones have shown dramatic increases in water quality by filtering out nitrates (carried in the sediment) prior to interception with the stream (Basnyat, et al., 1999).

The determination of the exact source of sediment in a watershed is often very difficult. Most often the temporal resolution of high altitude aerial photography may not allow for recognition of specific landuse events that impact estuarine sedimentation

(Basnyat, et al, 1999). In this instance fly-byes of areas of known interest may produce photograph records of sedimentation events at relatively low cost (Carver, 1998). Aerial photographic data was collected in the Dog River watershed of Mobile County Alabama. Sediment buildups were observed as well as sediment plumes in the suspended load of river and it's tributaries. The sediment buildups and plumes could then be traced back to the source of the sediment (Carver, 1998). The majority of the source regions were urban areas, which were under development. Other photographs from the study captured sediment plumes in response to intense precipitation associated with tropical storms.

Historical estuarine sedimentation has been presented as proxy indicators of cyclically recurring Category 4 and 5 hurricanes (Liu and Fearn, 1993). This activity gives detailed aspects of the mid-to-late Holocene coastal evolution, 3.2 thousand years before present. The sedimentation scar left by these storm events is represented by sand laminae, enclosed in the characteristic estuarine clay and mud deposits (Otvos,1999). The sand laminae can then be dated by the use of microfossils and maze pollens to determine the relative time of the hurricane activity and possibility the introduction of human agricultural activities (Liu and Fearn, 1993).

Many of the Gulf coastal lakes have been sampled by sediment coring in order to observe the historical sedimentation of ancient estuaries (Otvos, 1999). Sampling sites studied range from the shoreline of Louisiana to northwest Florida. The majority of the radiocarbon dates from disseminated organic material suggest a recurrence interval of 600 years for Category 4 and 5 hurricanes (Liu and Fearn, 1993). Otvos (1999) reviewed Liu and Fearn's radiocarbon dates with his own subsurface data to provide a better explanation of the coastal history for Alabama. Present storm deposits are also being studied along the gulf coast of the United States. Liu and Fearn recorded a nine centimeter sand laminae in a core from the southern shore of Shelby Lake, Alabama (Otvos, 1999). The nine centimeter sand laminae was deposited by a Category 3 hurricane in 1979 (Hurricane Fredric).

The University of South Alabama is presently conducting research of bottom sediment characteristic in the Weeks Bay, Alabama. The Weeks Bay research involves sediment sample grabbing in order to produce bathymetric maps of the bay (Fisher, 1998). During the bottom sampling and grain size analysis a thin sand laminae or bed was observed. The sand laminae ranges from 1 to 5 centimeters in thickness and it is thought that the sand laminae was produced by the passing of Hurricane Danny in 1997. The sand laminae contrast greatly from the typical bottom sediment of Weeks Bay, which is mostly silt and clay. The preservation potential of the sand laminae is uncertain at this time. Bioturbation of sand has been observed in relatively thin areas (less than 2 centimeters thick), but remains undisturbed in areas of greater thickness (Fisher, 1998). Future research by the individuals at the University of South Alabama will involve the extraction of sediment cores to analyze past sediment deposition events of Weeks Bay.

This background of GIS/ LULC/ sedimentation studies points out how these techniques can enhance resource management. This study applies these concepts to the specific problem of the potential for accelerated sedimentation in Weeks Bay because of increasing urban landuse and the relation to increased erosion potential.

CHAPTER III

DATA AND METHODS

Introduction

Software used in this project includes products from Erdas Geographic Imaging Systems and Environmental Research Systems Institute (ESRI). All of the software products used have similar operations that allow for the manipulation and analysis of geographic data, whether it be raster (image) or vector data types. GIS capabilities allow the user to identify and query complex databases based on specific attributes or data values by spatial constraints. Vector GIS analysis often involve procedures isolating data by its spatial relation to other data layers. Raster analysis are often more powerful and allow the user to analyze the data with individual data cells with specific values representing features. The geographic data used in this project consisted of mostly raster or image data layers with vector data layers used for overlay operations of the raster data analysis.

Data

Specific data needs for this project include satellite imagery for the LULC classification, surface elevation data for slope generation, and vector data overlays for the Weeks Bay watershed and the surrounding area. The acquisition of data began through an examination of the local archives at the Weeks Bay NERR. The reserve had a crude GIS database for the area. Most of the data in this database had been obtained from local, state, and federal organizations with the majority of the data consisting of vector data layers representing various features in the watershed area. In house data from county surveys, past research, and state surveys were identified and compared to determine the layers that would be useful in this project.

The acquisition of image data for the LULC classification began by first accessing the needs for this data layer. One clear need is that the data must be formatted for future research interest. The satellite image data selected for this project were collected by two individual Landsat satellites. The image data layer used in the 1990 LULC classification was captured by the Landsat 5 Thematic Mapper (TM) and the data for the 2000 LULC classification was captured by the Landsat 7 Enhanced Thematic Mapper (ETM+). Both of these platforms have very similar characteristics with the primary differences being the addition of a higher resolution panchromatic band onboard the Landsat 7 platform and easier consumer data acquisition of more recent Landsat 7 data. The Landsat satellite image data were obtained from the United States Geological Survey (USGS) through the EROS Data Center in Sioux Falls, South Dakota.

The final data layer to be acquired is that of surface elevation. Surface elevation can be expressed as digital elevation contour lines or as a digital elevation model (DEM). Other sources of surface elevation data can be obtained from local field surveys. To help lessen some of the data-preprocessing task the elevation data form selected for this project was a DEM. These data are represented as a raster or gridded elevation surface. If digital elevation contour lines or elevation survey points were to be used it would require a surface to be generated, which might be scrutinized by the surface interpolation technique. The USGS DEM's were obtained through the GIS Data Depot. The GIS Data Depot is the federal outlet for all no charge geospatial data sources. DEM's at a scale of 1:24,000 were collected for all of the USGS quadrangles in the Weeks Bay Watershed area.

Vector Data

Vector data layers consist of features represented by points, lines, polylines, and polygons, with various data attributes about each feature. Vector data is most often preferred for the final map composition due to their very aesthetic appearance and accurate representation of map features. Vector data layers were obtained from the GIS database at the Weeks Bay NERR in formats compatible with ESRI GIS software. All of the layers were either an ESRI ARC/INFO coverage or ESRI ArcView GIS shapefile. The different file formats were not an issue since both formats are supported by either of ESRI's GIS software packages with simple commands to convert files between a coverage and a shapefile.

Vector Data Layers

Vector data layers collected for the Weeks Bay NERR include layers representing hydrology, geology, transportation, city boundaries, and watershed boundaries. Other data layers in database include the NERR's core and buffer lands as described by

Protected Areas Geographic Information System (PAGIS), as well as standard data layers (typical map features) for Baldwin and Mobile County. However, these data layers were not incorporated into the research or analysis portion of this project and were instead used for base map generation of areas beyond the watershed boundary. The decision to exclude these data was made due to the undefined sources of this data and lack of good metadata or documentation.

The vector data layers included in the analysis were generated by the Geological Survey of Alabama (GSA), the research activities of Auburn University and personnel of the Baldwin County department of GIS. The data layers from GSA and Auburn University include hydrology, geology, transportation, city boundaries, and watershed boundaries. All of these data layers had a map projection of Universal Transverse Mercator, Zone 16, with map units of meters based on the North American Datum of 1927 (NAD 27). The Baldwin County GIS layers included an updated transportation layer as well as point data layers representing building locations and other features in the southern part of Baldwin county Alabama. All of the Baldwin County GIS data layers were in the Alabama State Plane projection based on the North American Datum of 1983 (NAD 83) with map units of feet. The data layer used from Baldwin County GIS was that of transportation centerlines, which had much more detail than those from GSA and Auburn.

Satellite Image Data

Four Landsat satellite image scenes were acquired from the EROS Data Center for use in the LULC generation of the Weeks Bay Watershed. The satellite image scenes acquired include data for the dates of 22 August 1990, 14 February 1991, 15 February 2000, and 08 July 2002, which should allow for LULC comparison over a 10 year time span. Two scenes were acquired for each year in the summer and winter seasons. The seasonal variations of the satellite imagery collection dates would help discriminate between leaf-on and leaf-off vegetative conditions. The objective was to collect image data from each time span with correlating dates for similar representation of features within the imagery. The 1990 imagery dates for the historical analysis of LULC had to be offset due to the lack of an image with acceptable quality from leaf-off conditions. An image from February of 1991 was substituted for the 1990 winter data.

Satellite Image Data Layers

The satellite images were purchased from EROS Data Center at cost of $600.00 per scene for the Landsat 7 ETM+ data and $425.00 per scene for the Landsat 5 TM data. The images were ordered at a level 1G systematic correction in a GEOTIFF format. The level 1G systematic correction produces images that are radiometrically and geometrically correct to a map based reference system. The GEOTIFF format was selected based on import options available for the Erdas Imagine geographic imaging software. All images had been resampled by cubic convolution during the systematic correction. This resampling method was suggested by personnel at the EROS Data

Center. Each image was collected from the path 21 row 39 of the satellite orbit and contained all of the study area, as well as the majority of the Alabama and Mississippi gulf coast (Figure 5).

An advanced multispectral scanner (MSS) aboard each of the satellites collected the Landsat imagery used for this project, referred to as TM and ETM data, as it much improved from the MSS sensor aboard Landsat satellites 1 - 3. The MSS sensors collected data in bands representing the blue, green, and red portions of the visible spectrum and in the near infrared, short wave and thermal infrared portions of the electromagnetic spectrum. The spatial resolution of the data captured was equal to 28.5 meters in visible, near infrared, and short wave infrared bands. The thermal infrared band on the Landsat 5 TM sensor has a ground resolution of 120 meters and on Landsat 7 ETM+ it is equal to 60 meters. In addition to the bands listed above Landsat 7 also captures data in a panchromatic band with a ground resolution of 15 meters. Each of the satellites has a temporal resolution of 16 days consisting of 233 orbits and has a sun-synchronous orbit at an altitude 705 kilometers. Table 2 gives a complete description of characteristics for the MSS sensors of Landsat 5 TM and Landsat 7 ETM+.

Landsat 7 is the only satellite actively collecting data from the Landsat satellite series at present. Plans are under development for the launch of a new Landsat satellite, Landsat 8. However Landsat 8 is to be very similar to Landsat 7, which will allow for future data that can be compared to the previous Landsat satellite systems with similar accuracies and results.

Figure 5: Landsat 7 ETM+ scene from 15 February 2000, collected from path 21 row 39. Displayed in with bands 4, 5, and 2 with an overlay of state boundaries.

Table 2: Summary and comparison of Landsat 5 and Landsat 7 satellite image characteristics.

	Landsat 5 (TM)	**Landsat 7 (ETM+)**
Launch Date	**March 1, 1984**	**April 15, 1999**
Number of Bands	**Seven**	**Eight**
Spectral Range	**0.45 – 12.5 µm**	**0.45 – 12.5 µm**
Spatial Resolution	**30/120 meters**	**15/30/60 meters**
Temporal Resolution	**16 Days**	**16 Days**
Altitude	**705 Km**	**705 Km**
Image Size	**185 x 172 Km**	**183 x 170 Km**
Cost per Scene	**$425.00**	**$600.00**

Surface Elevation Data

Digital elevation data were obtained from the GIS Data Depot in the form of USGS 1:24,000 DEM's. A total of nine quadrangles were required to represent the area associated with the Weeks Bay Watershed. The quadrangles associated with the watershed include the following: Stapleton, Daphne, Silverhill, Robertsdale, Point Clear, Magnolia Springs, Foley, Bon Secour Bay, and Gulf Shores. The DEM's were obtained in a Spatial Data Transfer Standard (SDTS) format. This format was created to prevent the loss of any data through the transfer process to various computer platforms. This data format was processed by first extracting the .dem file from the SDTS format and then importing the .dem into an ARC grid format, which is the standard raster data type for ESRI GIS software.

Surface Elevation Data Layers

USGS DEM's represent surface elevations of the Earth's bare surface with a ground resolution or grid spacing of 30 meters and are based on the National Elevation Data Set (NED). The elevation data is derived from the interpolation of Digital Line Graph (DLG) hypsographic and hydrographic, digital separates of topographic map data. This type of interpolation produces level-2 DEM accuracy, which has a root mean square error (RMSE) less than one half the contour interval. All 1:24,000 DEM's are horizontally referenced to the UTM coordinate system with units of meters. For the Weeks Bay watershed study area the coordinate system is UTM zone is 16, based on NAD 27. The DEM's are vertically referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) with elevation units in meters or feet depending on location. Elevation units of the DEM's for the Weeks Bay watershed varied and required conversion to a single elevation unit, with meters being the chosen unit of measure.

Methods

Data Preprocessing

Once all of the data had been acquired they needed to be processed in order to have identical spatial domains. This processing included selecting a map projection and datum and transformation of all data layers to the same projection. In addition to being in the same map projection coordinate system the data layers also had to be georeferenced or georectified to one another. The georectification is a crucial step since a geospatial analysis of features to each other would impact the final output of this project.

The map reference system selected for this project was UTM zone 16 based on the NAD 27 datum. The selection of this map reference system was two fold, with the first and most important factor being that this is reference system used by the Weeks Bay NERR and this allow for products from this project to be incorporated into the GIS database with little or no processing by the NERR staff. The second factor in selection of this reference system is that it would require less preprocessing of data layers since the large majority of data acquired was already in the UTM map reference system.

Vector Data

The preprocessing was minimal for the vector data layers of this project with the primary preprocessing being data layer comparisons to ensure each would overlay accurately. All of the data layers, with exception of transportation, had the same map projection and overlaid accurately. An ARC coverage of transportation from the Baldwin County Department of GIS was selected over the transportation data layers from GSA and Auburn University due its higher detail and representation of transportation in the Weeks Bay watershed area. The transportation data layer was in an Alabama State Plane coordinate system based on the NAD 83 datum with units of feet. All processing of the vector data layers was performed with ESRI’s ARC/INFO GIS software. This provides a much more powerful and efficient method in terms of vector data processing and analysis as compared to ESRI's ArcView GIS software package.

The transportation data layer was divided into five separate tiles or areas, which completely covered the Weeks Bay watershed. All of the individual data tiles were in the Alabama State Plane coordinate system. The first step was to append the five tiles together into one ARC coverage, this was accomplished by using the ARCINFO command:

```
OUT_COVER =  APPEND (IN_COVER 1, IN_COVER 2, ETC…)
```

This functioned produced one continuous ARC coverage of transportation in the Weeks Bay watershed area. The single coverage was then reprojected from the State Plane coordinate system to UTM with the PROJECT command in ARCINFO. The input and output parameters for the reprojection are as follows:

INPUT	OUTPUT
PROJECTION = STATE PLANE	PROJECTION = UTM
UNITS = FEET	UNITS = METERS
DATUM = NAD 83	DATUM = NAD 27
SPHEROID = GRS 1980	SPHEROID = CLARKE 1866

This data layer would be used in the georeferencing of the image data layers and it was crucial that it was accurate in spatial representation. The transportation coverage was then compared to the other UTM data layers of the watershed for overlay purposes and met post-processing expectations.

Image Data

Four individual Landsat satellite image scenes were acquired for the Weeks Bay watershed study area, two for a historical analysis and two for near present conditions. Each GEOTIFF image, consisted of seven separate files for the TM data and eight separate files for ETM data. Each file represents an individual data band for each image collected by the sensor. Multiple preprocessing steps were completed to produce a georectified multi-band image subset of the Weeks Bay watershed. Erdas Imagine geographic imaging software was used for the preprocessing of all image data used in this project. This software simplified some of the complex processes that were performed since it has built-in modules for processing multi-band images.

Image Import and Band Merging

Each individual image band is imported and merged together to produce a multi-band image used for analysis. Only data bands 1 – 5, and band 7were imported and used in the analysis. These bands represent the visible (1 –3), near infrared (4), and mid infrared (5, 7) potions of the electromagnetic spectrum. The first step was to import the individual tiff band files to an Imagine format (.img file). This was done by using the import utility and produced six files for each image. Next the appropriate bands had to merged or fused together into a single image. This task was completed with a utility in Imagine known as a layer stack. Careful consideration has to be made while doing this to keep the proper band order within the merged image.

Image Reprojection and Rectification

The newly merged multi-band images now needed to be projected and referenced to the UTM coordinate system based on the NAD 27 datum. This was accomplished with the projection utility module within Imagine for each of the four images. This module allows the input of an image with a defined projection system to be reprojected to another projection system. After the images were reprojected to UTM NAD 27 there were still discrepancies with the overlay of the other data layers used in this project. This is to be expected as the processing by the EROS Data Center only corrects the image geometrically and does not rectify them to ground control points (GCP’s) on the Earth’s surface.

Once the images were reprojected they were rectified to known GCP’s of the Weeks Bay watershed area. Prior to the rectification images were subset to an area that completely contained the entire watershed. Using the small image subset required a less rigorous transformation during the rectification process. Each image was compared to the transportation vector data layer to observe how closely the vector data layers would overlay. The image that had the tightest fit to the transportation layer was chosen to begin the rectification process. The image from 15 February 2000 was rectified to the vector transportation layer with 15 GCP’s. The GCP’s were based on the intersections of roads distinguishable in both the image and vector data layers. Once the 15 February 2000 image was rectified the remaining three images were rectified to the 15 February 2000 image with same GCP’s (Figure 6). A RMSE was calculated for each of the rectified images to give a measure of accuracy in terms of the rectification process with the following formula:

$$T = \sqrt{\frac{1}{n}\sum_{i}^{n} XR_i^2 + YR_i^2}$$

Where: T = *Total Root Mean Square Error*
n = *Number of GCP's*
i = *GCP Number*
XR_i = *X Residual for* GCP_i
YR_i = *Y Residual for* GCP_i

Image Spatial Subset

All four images once rectified were subset or cropped to an area of interest (AOI) that represented only the area within the boundaries of the Weeks Bay watershed. This provided for a smaller analysis area and allowed for the definition of LULC classes only contained within the watershed. This task was completed by setting a polygonal vector data layer, representing the watershed boundary, to an AOI in Imagine. Once the AOI was generated it was used to subset each of images to the watershed. In addition to creating smaller more defined analysis images, this also produced smaller file sizes, which helped in terms of data storage issues and analysis processing time.

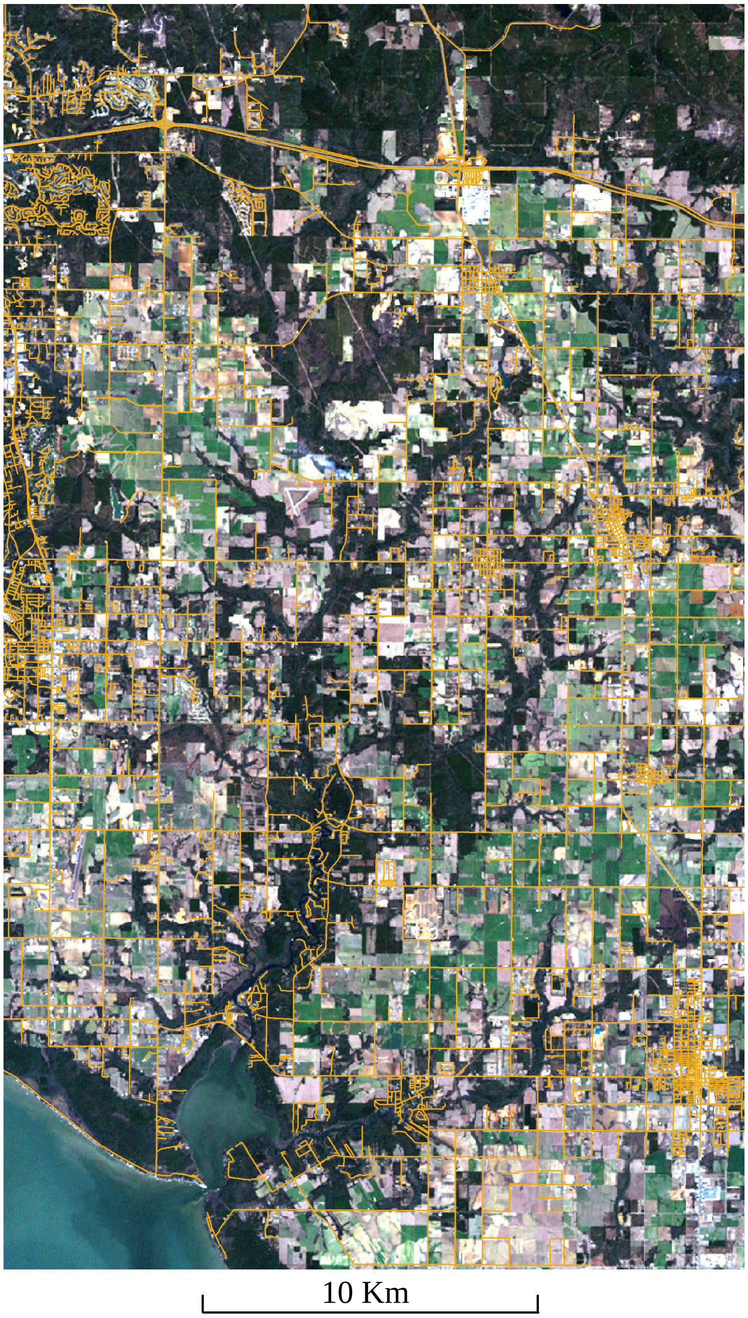


Figure 6: Vector transportation coverage overlaid on Landsat satellite imagery for evaluation of image projection and rectification.

Elevation Data

The DEM's acquired were in the SDTS format and had to be imported to a format accepted by the software used to complete this project. The preferred format is an ARCINFO grid, which is accepted by both Erdas and ESRI software. The DEM's were received already projected in UTM NAD 27 and met expectations in terms of overlay or registration with the other data layers, thus no reprojection or referencing had to be performed. The data extracted from the SDTS is in the form of a .dem file and not an ARC grid, thus two file conversions were made to make the data usable.

Elevation Data Import and Conversion

Several methods are available for converting SDTS data to ARC grid data. There are modules built into ESRI's ARCINFO and extensions for ArcView that perform this task. In addition to modules within this software there are also stand alone programs that can extract the .dem file from the SDTS, which can than be directly imported to ESRI software packages. The attempt here was to save time and confusion by eliminating multiple steps and files with two-phase conversion methods. The preferred method of import was a module within ARCINFO's Arc Tool Box that used an interface allowing for direct import from SDTS to ARC grid, with intermediate files (.dem) being stored in a temporary directory and discarded upon completion. This method, while very computer and time intensive, completed the task and helped to eliminate confusion with multiple intermediate files.

As a side note, there were only nine files that need converting for this project and based on the author's experience any one of the other methods listed above would be more time efficient. If a large number of files were to be converted it is the author's recommendation to run a batch file if the Arc Tool Box module is to be used that would run the processes at a time of low computer usage.

Elevation Data Merge

Each of the nine elevations grids were merged to each other in order to produce one data layer, very similar to the transportation vector data layer. Prior to merging all of the grids had to have the same elevation units. Again, meters was selected for the elevation unit for specific data generation needs. The grids with cell values representing elevation in feet were converted by multiplying the cell values by a conversion factor of 0.3048. The task of merging the grids was performed by using ARCINFO commands available at the GRID prompt, the raster based data processing and analysis feature within ARCINFO. The MERGE command was used for this task and is very similar to the APPEND command used earlier, the command is as follows:

```
OUT_GRID = MERGE (GRID_1, GRID_2, ETC…)
```

This operation produced one grid consisting of the nine grids with elevation units in meters. The resulting grid did have spatial gaps formed by missing information between adjacent quadrangle grids.

To produce a seamless merged grid the grid was then processed with the FOCALMEAN command at the grid prompt. The FOCALMEAN command calculates values for empty data cells by sampling 3X3 rectangle of the surrounding cells to determine the mean. The command for FOCALMEAN is as follows:

```
MEAN_GRID = FOCALMEAN (MERGED_GRID, RECTANGLE, 3, 3, DATA)
```

The new grid produced now has data in the cells that were empty before, however it also recalculates the values of all the cells. Therefore, this grid was not used due to the modifications of the original cell values and is merged back to the original grid to fill in the empty cells.

Elevation Data Subset

The surface elevation data was subset in similar method to that of the satellite imagery. The reasons for the elevation data subset were identical to those for the imagery subset. The preferred method for this subset was to use an extension available with ArcView that allows the user to subset or clip a grid data set to a polygonal boundary. The method is very similar to that of Erdas Imagine subset module, but does not require any file conversion. The subset elevation grid was produced by using the same polygonal boundary for the watershed as an area of interest for the merged elevation grid. All data values outside of the boundary are set to a value of no data, which is numerically equal to –9333 by default.

Data Classification

Prior to any final analysis the image and elevation data must be simplified by classification. The classification process involved categorizing the data of each layer based on the values of the associated image or grid cells. The image classification produced a LULC based on spectral similarities of the features within the image scenes for the 1990 and the 2000 time periods. The elevation classification involved first calculating the slope of the surfaces and then reclassifying the slopes in terms of relative steepness. The change of the LULC and the slope classes were then used to determine erosion potential based on the LULC and topography in the data analysis.

Image Classification

The four preprocessed Landsat satellite images were classified with an unsupervised classification with input data from bands 1, 2, and 5. This band combination was selected due to its representation of urban development, which was the stated concern of the Weeks Bay NERR for the LULC classification. An unsupervised classification is an automated process in which the computer software organizes the data into separate spectral classes or groupings inherent in the data. The alternative to an unsupervised classification is a supervised classification, which is a classification process where the user trains the data by selecting areas of known values and uses the known information to separate the data into spectral classes. This type of classification was considered, but was thought to be inferior to the unsupervised classification due to the use of medium resolution imagery causing significant pixel mixing or confusion.

Prior to classifying the images, a classification scheme had to be defined to identify specific LULC classes within the watershed. Officials of the Weeks Bay NERR had expressed concern about increases in urban development within the watershed, pointing the overall goal of this project toward the importance of determining potential sources of sedimentation, since urban construction practice has the highest sediment yield potential. With erosion potential therefore being the primary analysis, a LULC classification scheme was developed that focused on relative vegetation density and seasonal alterations. The classification scheme used was modified form of The Nature Conservancy (TNC) Vegetation Classification Standard. The TNC classification focuses on vegetation and uses a system approach with classes and subclasses. For a complete description of each classification type refer to Appendix A.

The classification scheme utilized in the project incorporated six classes for each of the four Landsat images. The LULC classes included forested vegetation, herbaceous vegetation, transitional/ mixed vegetation, sparse/ residual vegetation, urban/ built-up land, and water. The final classified images for 1990 and 2000 have an additional class, seasonal/ intermittent herbaceous vegetation, which was the product of seasonal comparisons of the leaf-off and leaf-on images for each year. Descriptions of features contained within each of the LULC classes are given in table 3. The classification scheme was driven by the need to represent erosion potential based on changes in LULC and these descriptions allowed for that distinction.

Table 3: LULC classification scheme and description of classes.

LULC Class	Description
Water	All water bodies including freshwater lakes, rivers, and streams, as well as marine water environments.
Forested Vegetation	All forest vegetation types including evergreen, deciduous, and wetland forest vegetation types.
Herbaceous Vegetation	All grass like vegetation including pastures, row crops, recreational, and residential grasses.
Seasonal Herbaceous Vegetation	Intermittent grass like vegetation, most often representative of seasonal variations in agricultural lands. Derived non-spectrally
Transitional or Mixed Vegetation	Vegetative areas combined of herbaceous and forested vegetation. Often includes scrub or shrub lands.
Urban or Built-Up	Includes all residential, commercial, and industrial development.
Sparse or Residual Vegetation	Barren or sparsely vegetated areas most often representative of bare earth or soil.

The unsupervised classification utilized 100 classes that were categorized by the ISODATA or Iterative Self-Organizing Data Analysis technique. The ISODATA technique is a modified version of K-Means clustering to group image pixels based on similarities. The ISODATA technique evaluates spectral differences in each band and assigns the data to distinct classes. The categorization of the data is controlled by a maximum number of iterations and a convergence threshold. The maximum number of iterations limits the number of times that the data may be reclustered with the ISODATA technique. The convergence threshold halts the data clustering if a specified percentage of the data classed does not change with categorization iteration. The 100 classes for the imagery used in this project were set to a maximum of 12 iterations with a convergence threshold of 95%.

The 100 classes, produce by the ISODATA technique, were visually and spectrally analyzed. Once the classes were assigned the proper class label they were then recoded into the six initial classes of the classification scheme. The classified images of each time span were compared to each other with a thematic image change model within Erdas's Image Analysis extension for ArcView. This resulted in a new composite LULC image for 1990 and 2000 consisting of 36 classes. The 36 classes were then recoded to the final seven LULC classes based on representing seasonal vegetative variations.

Elevation Classification

The generation of a layer representing erosion potential based on topography required two phases. The first phase was generating a representation of slope within the

Weeks Bay watershed. The second phase was reclassifying the slopes based on the relative steepness. The correct calculation of slopes requires that elevation and map units be the same, in this case meters. The slopes can then be computed in degrees or percent grade using modules within the software. All of the softwareused in this project could perform this operation, however ESRI's ArcView with the Spatial Analyst extension was chosen for this process as it had a more user-friendly interface. For reclassification reasons the slopes were generated for the Weeks Bay watershed in degrees.

The classification of the slopes within the watershed required a standard for the slope classes. The first attempt of standardization was to classify the slopes based on a global standard. This proved to be ineffective due to the lack of relief within the Weeks Bay watershed because of its location in the coastal plain. Therefore slopes were classified based on the relative slopes within the Weeks Bay watershed. The average slope was calculated for the watershed and class breaks were placed for slopes within one standard deviation below the mean and within one, two, three, and more than three standard deviations above the mean.

Data Analysis

The analysis of the data was performed in two phases. First, analysis of LULC change in terms of area estimates was undertaken and second, an erosion potential model based on LULC change and degree of slope was developed. The analysis consisted of model development that is representative of the change in LULC and how it spatially relates to topographic features within the watershed, as well as simple table comparisons of the amount of change in terms of area.

LULC Change Analysis

Prior to any comparison of LULC change from 1990 to 2000 the accuracy was accessed for the classified image from 2000. The accuracy assessment was completed by taking ground survey points and comparing them with classified pixels within the image. A total of 100 ground survey points were randomly generated with Erdas Imagine. The points were confined to a 90 meter buffer along the transportation vector coverage to help improve accessibility (Figure 7). The class values for the points were determined by using a focal majority of the surrounding eight cells to remove uncertainties due to pixel mixing if areas were not homogenous. The survey points were navigated using a Garmin Etrex Vista handheld global positioning system (GPS). The GPS had Wide Area Augmentation System (WAAS) ability, which produces accuracy within 2 – 5 meters. Accuracy was not accessed for the classified 1990 image as historical data for this period could not be found.

The classification accuracy was then defined with an error matrix by tallying assessment sites with classified image pixels. The accuracy is given by overall accuracy calculated by dividing the total number of correctly classified assessment sites by the total number of assessment sites. An omission error or producer’s accuracy was also calculated, this measures the probability of a reference site being correctly classified. Omission error is calculated by dividing the total number of correct assessment sites for a

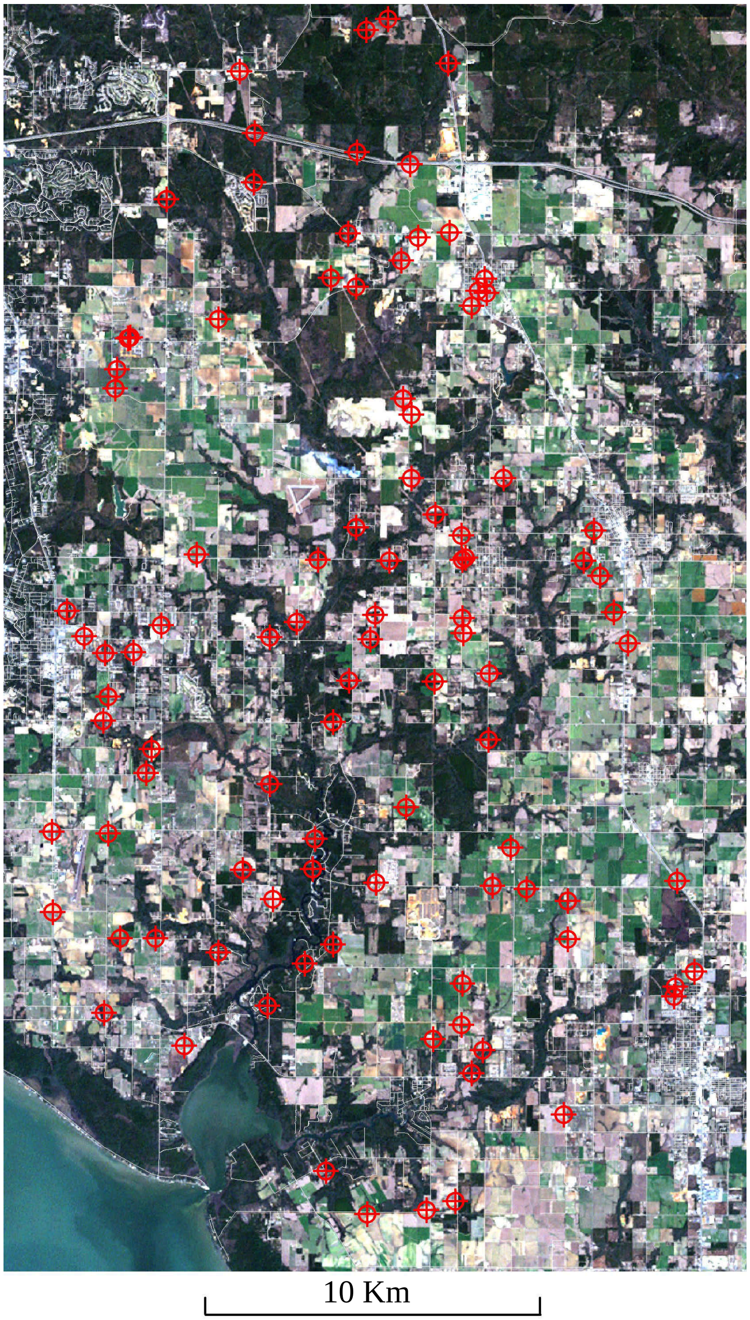


Figure 7: Ground sampling points for the 2000 LULC accuracy assessment.

class by the total number of reference sites for that class. The final measure is the commission error or users accuracy. The commission error is the probability that a map pixel actually represents that pixel on the ground. Commission error is calculated by dividing the number of correct accuracy sites for a class by the number of accuracy sites classified in that class.

Once the accuracy was calculated for the LULC classification a change analysis was performed. The change analysis consisted of calculating the total number of cells or pixels in each class and determining the amount of change in terms of number and percent change over the 10 year time span. The valued amount of change was charted and then used to spatially identify areas of increased LULC change in terms of erosion potential.

Erosion Potential Analysis

The potential for erosion was analyzed by looking at impacts from the LULC change and steepness of slope. The first phase consisted of determining the erosion potential based on the degree of slope. The slope erosion potential was the same as the slope classification, with slope class 1 having the greatest potential for erosion and slope class 5 having the least potential for erosion. The erosion potential based on LULC change was more complicated and required a spatial change analysis of LULC classes from 1990 to 2000.

A thematic image change model was used to assess the amount of change between 1990 and 2000 for erosion potential. The seven defined LULC classes were analyzed and used to define erosion potential based on historical trends of LULC change and sedimentation yield. The model produced 49 LULC erosion potential classes, which were recoded to five classes based on a set logical rules that looked at change in the type of landcover (Appendix B). The LULC classes were defined to match the slope erosion potential, with class 1 having the greatest potential and class 5 having the least erosion potential. Once this data model layer was complete it was exported to an ARC grid format for analysis with slope erosion potential data model.

The final analysis phase or model utilized applications of map algebra to combine the LULC and slope erosion models. The ArcView Spatial Analyst extension allows for these type of grid manipulations and used for this analysis. The map calculations were simple and did not give more weight to either of the erosion models. The grid cell values of each model were summed and divided by 2 to produce five new cell classes in terms of total erosion potential based on the following expression.

(SLOPE_POTENTIAL + LULC_POTENTIAL)/2 = EROS_POTETIAL

Intermediate values would be round into the greater potential class, for example of value of 1.5 would be placed in class 1 instead of class 2. The resulting class scheme matched those of the previous erosion potential models, with class 1 having the greatest potential and class 5 having the least erosion potential.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The results include data observations and tabulations for the data preprocessing, data classification, and data analysis portions of this project. Due to the spatial nature of this project most of the results are graphical representations of map data with numerical summations of analysis cell counts with numerical comparisons of changes between analyses.

Results

Data Preprocessing

The results of the data preprocessing were predominately intermediate data products, which were used for data classification and analysis. One of the more important results of the data preprocessing was the reprojection and rectification of all the data layers due to the spatial nature of this project. Accurate results of the data preprocessing were essential for the remaining processes and analysis.

Vector Data

The results of the vector preprocessing were minimal, due to the limited preprocessing that was required of vector data layers. The primary process involved was reprojecting the transportation coverage from Alabama State Plane coordinate system to UTM zone 16 coordinate system. The result was satisfactory when overlaid with the other vector data layers of the Weeks Bay Watershed. This allowed for an accurate geospatial analysis with tight registration between data layers.

Image Data

As described earlier various steps were involved in the preprocessing of the Landsat satellite image data layers. The results of preprocessing produced image data that was closely registered for change analysis for an area limited to the extent of the Weeks Bay watershed boundary.

Image Import and Band Merging

The individual bands from all four Landsat images were imported to the specified format for continued processing. The band merger produced four individual Landsat image scenes with 6 spectral bands representative of the blue, green, and red portions of the visible spectrum as well as one near infrared band and two mid infrared bands. This resulted in satellite image data with numerous viewing and classification possibilities.

Image Reprojection and Rectification

The reprojection of the Landsat satellite images yielded data based on the same coordinate system and datum as the other layers within the GIS database under development. This provided the necessary correction for the data to be registered to the transportation coverage for correct spatial overlay without excessive pixel warping. The final projection information for all Landsat satellite images was UTM zone 16 based on the NAD 27 datum.

The registration of the 15 February 2000 image to the transportation vector coverage, and subsequent registration of the remaining three satellite image scenes to the previously registered satellite image, yielded an RMSE of less than one pixel (30 meters) for all images. The total RMSE of all the images are as follows:

08 July 2000 = 13.98 meters (0.466 pixels)
15 February 2000 = 12.84 meters (0.428 pixels)
14 February 1991 = 17.67 meters (0.589 pixels)
22 August 1990 = 15.39 meters (0.513 pixels)

These results were verified by visual inspection of image features that were apparent in all of the images. Each of the images was swiped over the other images with tools in Erdas Imagine to check the alignment of features constant to all the images.

Image Spatial Subset

The subset image data yielded four satellite images that represented only the area within the Weeks Bay watershed (Figure 8). Comparisons between subset images were made to check for exactness in the extent of coverage. All of the images represented the same area, as determined by visual inspection. This is as expected, due to the close registration produced by the rectification process with sub pixel RMSE for all of the images. The resulting images were then used for the LULC classification process.

Figure 8: Subset Landsat satellite image for the Weeks Bay Watershed.

Surface Elevation Data

The preprocessing of the surface elevation data or DEM's was also minimal, but crucial to the success of the final data analysis of this project. The most demanding task of the preprocessing was the import and data conversion of the acquired DEM's to a usable format. All of the DEM's acquired were in the desired map projection and coordinate system, UTM zone 16 NAD 27, which eliminated any need to reproject the data. The results of the merged DEM's was unusable due to the data gaps of adjoining quads, since the Weeks Bay watershed was made up of nine quadrangles there were numerous data gaps. The FOCALMEAN operation removed these gaps and when this output was merged with the original DEM the result was a seamless DEM with minimal extrapolation of data values (Figure 9). The subset or clipping performed on the DEM resulted in elevation data for the area confined to the Weeks Bay watershed boundary, matching that of the imagery to used for the LULC analysis.

Data Classification

The slope and LULC, classification results were important in terms of the final data analysis due their use in model development. Any inaccuracies in classification results would need to be recognized and accounted for prior to data model analysis. The classification results were represented by a series of image maps with inherent trends of data categorization analyzed for logical accuracy.

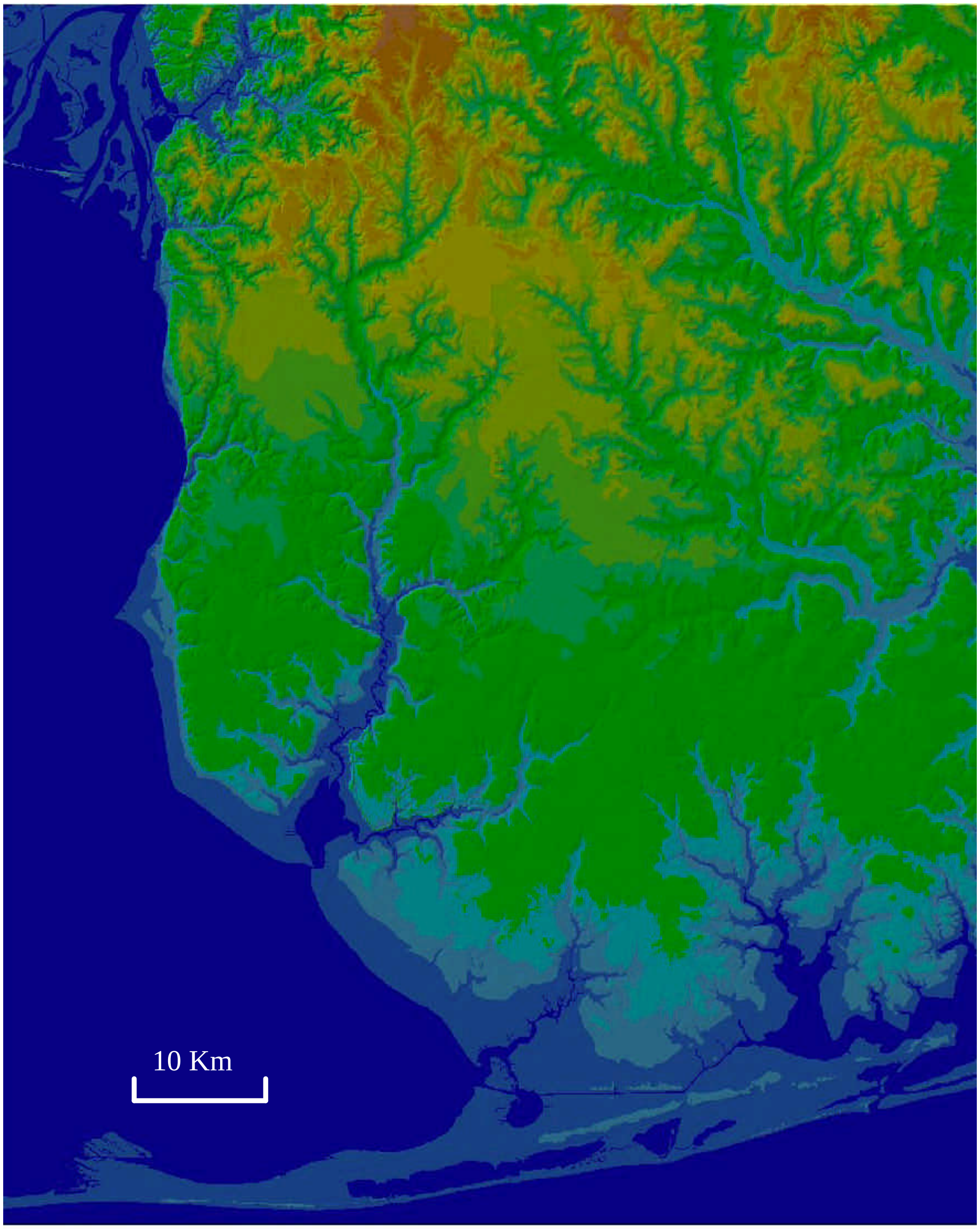


Figure 9: Seamless USGS DEM of the Weeks Bay watershed area used for slope calculation and classification.

Image Classification

The unsupervised classification of the imagery simplified the spectral data within each of the images during leaf-off and leaf-on conditions. Classifications were performed on each of the images based on 100 classes categorized by the ISODATA technique. The 100 classes were then recoded or simplified to six classes consisting of forested vegetation, herbaceous vegetation, transitional or mixed vegetation, sparse or residual vegetation, urban and built up areas, and water based on common spectral similarities. The results from the first level of classification were not used due the lack of representation of seasonal variations in the vegetative features. This lack of seasonal representation was most problematic in an over abundance of sparse or residual vegetation classes, which contradicted observations made in the field.

The classified images were further scrutinized by comparing the leaf-off and leaf-on classifications. The rule based model used for this analysis resulted in 36 new classes that were then recoded to seven classes, with the additional class being a seasonal or intermittent herbaceous vegetation class (Figure 10). This reclassification or recode resulted in data that was more representative of field observations and eliminated the over abundance of sparse or residual vegetation classes.

Slope Classification

The slopes were generated for the elevation surface within the Weeks Bay watershed. Slopes were calculated in degrees, which were derived from the inverse tangent of the slope percent or the rise / run. Consideration had to be given to the

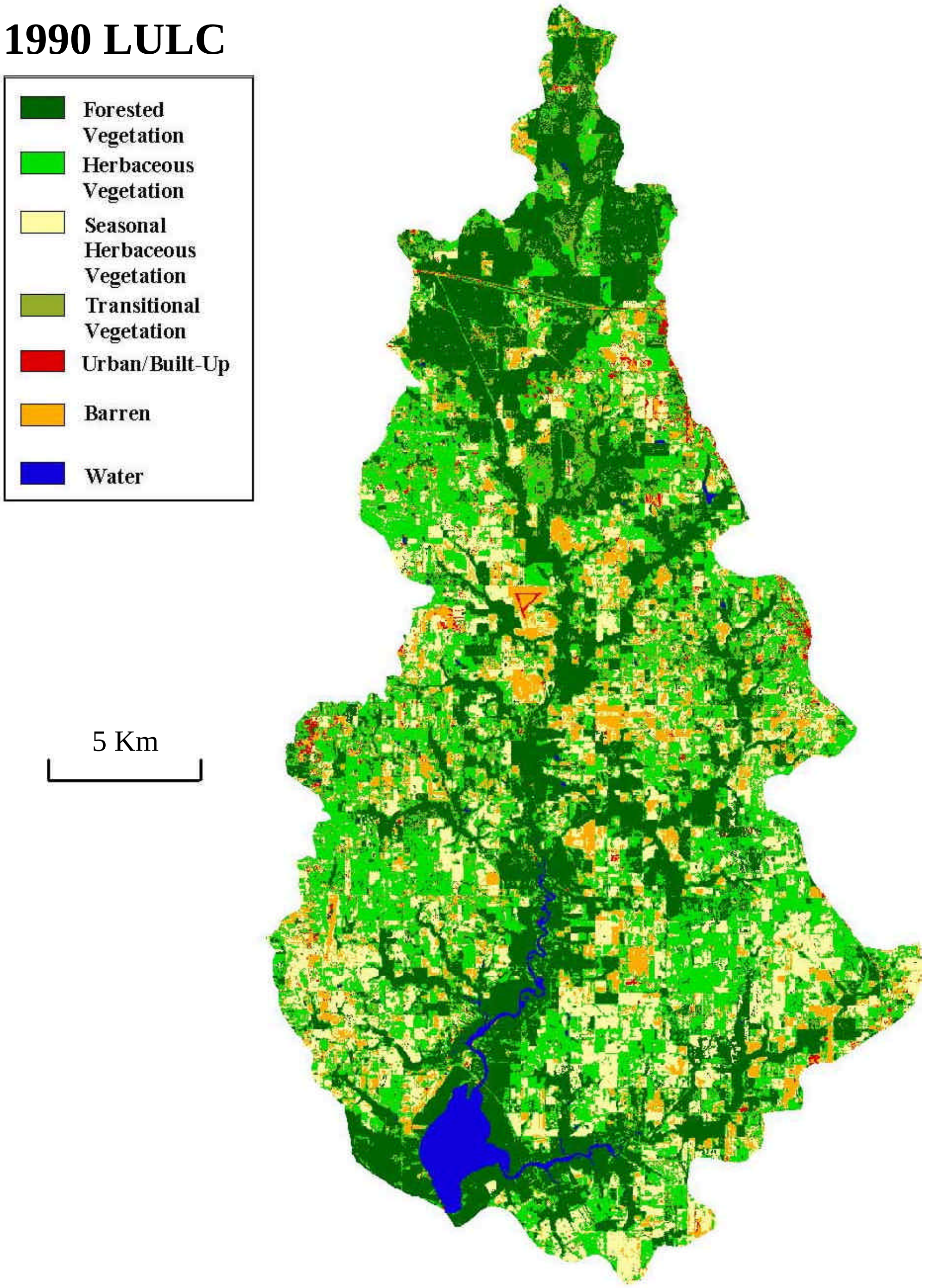


Figure 10a: LULC classification for the Weeks Bay watershed for 1990.

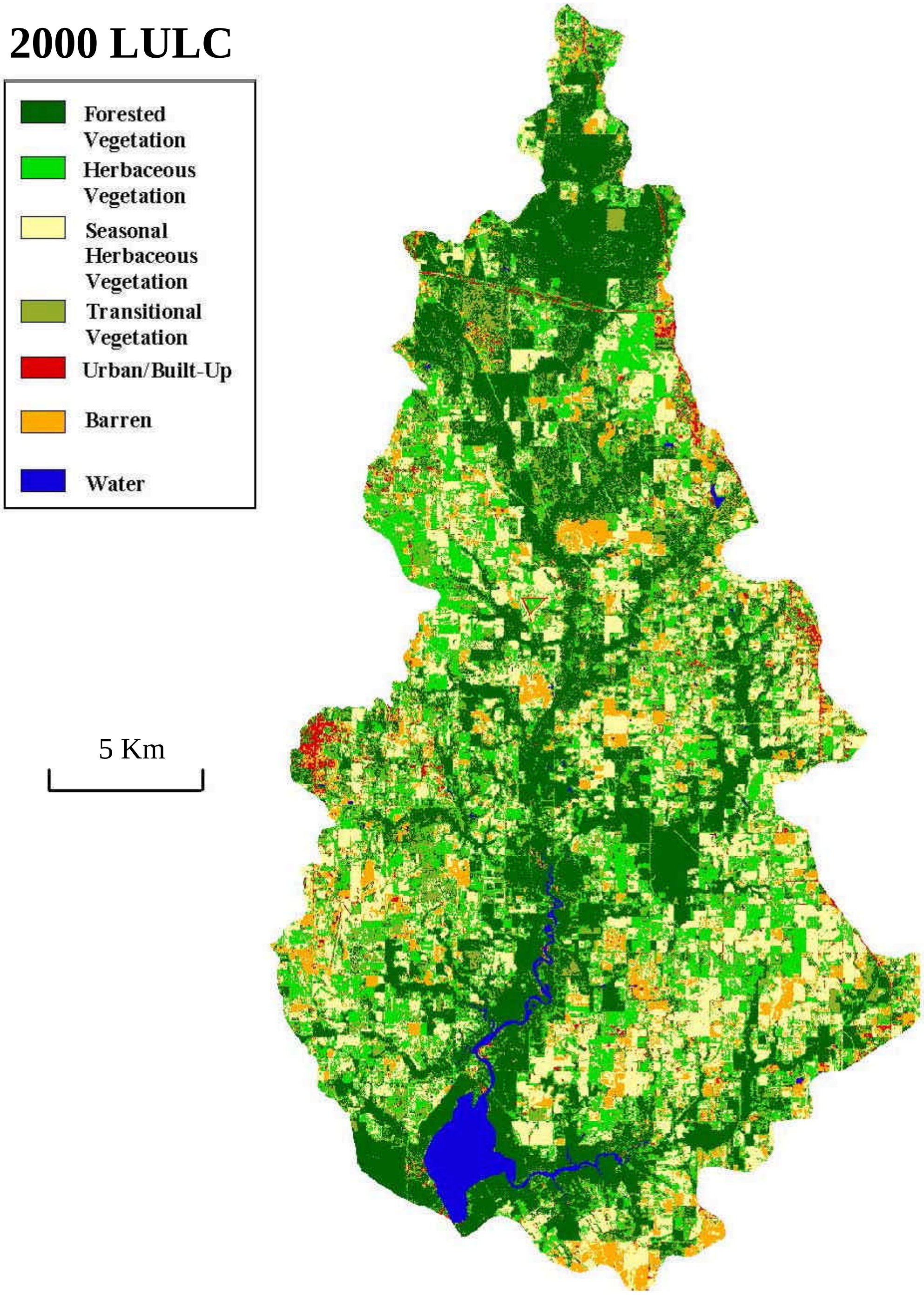


Figure 10b: LULC classification for the Weeks Bay watershed for 2000.

elevation units of the surface data, or z factor, which must be the same as map units for slopes to be calculated accurately. The slopes were then sorted into five classes based on variations from the average slope.

The five slope classes were based on standard deviations from the average slope, which was equal to 1.2 degrees. The steepest slopes were assigned to class 1 and the remaining classes decreased in slope as the slope class value increased. Table 4 gives the slope degree ranges for all of the slope classes.

Table 4: Class value summary for the five slope classes used for erosion potential.

Slope Class	Standard Deviation	Slope Range (Degrees)
Class 1	**> 3**	**5.0 – 13**
Class 2	**2 – 3**	**3.7 – 5.0**
Class 3	**1 – 2**	**2.5 – 3.7**
Class 4	**0 – 1**	**1.2 – 2.5**
Class 5	**-1 – 0**	**0 – 1.2**

Data Analysis

The results of the data analysis yielded a quantitative change of LULC with in the Weeks Bay watershed from 1990 – 2000. The second portion of the results shows potential sources for estuarine sedimentation based on upland erosion within the Weeks

Bay watershed. The sources of sedimentation were based on amount of slope, LULC changes, and a combination of the two factors. The potential sedimentation results are qualitative and give no representation of actual sediment yields within the watershed.

LULC Change Analysis

The ground survey based accuracy assessment yielded a satisfactory result in terms of overall accuracy for the 2000 LULC classification. The overall accuracy for the classification was 78%, which is acceptable based on the limitations of the data used. In addition to the overall accuracy the producer's and user's accuracy was also calculated. The producer's accuracy or omission error ranged from 100% for the forested vegetation class to a 48% for the mixed or transitional vegetation class. This gives an indication of a class being correctly classified with no spatial context in terms what is actually observed on the ground. The user's accuracy or commission error represents the likelihood of a map pixel representing that pixel on the ground. The user's accuracy ranged from 100% for the urban class to 67% for the herbaceous vegetation class and the sparse or residual vegetation class. Kappa coefficients were also calculated for each of the classes indicating the error of the classification process as compared to a random classification. The classes defined by this classification process eliminated at least 60% of the errors that a random classification would generate, with the urban classification eliminating 100% of the errors. The water class was omitted from the accuracy assessment sites due to the primary water feature being Weeks Bay and accessibility constraints; it was also thought that the addition of water might bias the accuracy assessment results. Overall the accuracy results were very acceptable based on the satellite data used. Similar types of classification projects have produced overall accuracies from 65% to 80%. Refer to table 5 for a complete compilation of the accuracy results for the composite classification for 2000.

The comparison of the 1990 and 2000 composite LULC classifications showed drastic changes in applied land practices within the watershed (Figure 11). The most prevalent change was the increase in urban or built-up land by more than 92%, more than twice the predicted value for 2010 by the SARPC. The majority of these increased were observed along the fringes or outskirts of existing towns, primarily Daphne and Fairhope. Decreases were seen in all other classes except for the transitional or mixed vegetation class and the seasonal herbaceous vegetation classes. Each of these classes had increases, which indicates an overall change in the amount of vegetative cover or density on the landscape. The change in the seasonal herbaceous vegetation is due to variations within the two herbaceous vegetation classes. Herbaceous vegetation decreased by 27.5% and seasonal herbaceous vegetation increased by 17.6%, the overall change in these classes when combined is a decrease of slightly more than 9%. Changes in forested vegetation were minimal with only a decrease of 4.9% with most of the noticeable changes occurring in the northern part of the watershed. The majority of the forested vegetation within the watershed is associated with riparian forest along the hydrologic features of the watershed. The overall LULC changes are in line with what was expected and coincided with observations made in the field. Table 6 shows the tabular results from the LULC change analysis in terms of cell counts, area, and percent and amount of change.

	Reference Total	Classified Total	Number Correct	Producer's Accuracy	User's Accuracy	Kappa Coefficient
Forested Vegetation	**15**	**19**	**15**	**100%**	**78.95%**	**.75**
Herbaceous Vegetation	**20**	**27**	**18**	**90%**	**66.67%**	**.58**
Seasonal Herbaceous Vegetation	**23**	**26**	**21**	**91.3%**	**80.77%**	**.75**
Transitional / Mixed Vegetation	**25**	**13**	**12**	**48%**	**92.31%**	**.90**
Urban / Built-Up	**9**	**6**	**6**	**66.67%**	**100%**	**1.00**
Sparse / Residual Vegetation	**8**	**9**	**6**	**75%**	**66.67%**	**.63**

Overall Accuracy = 78.0%

Table 5: Accuracy assessment for the 2000 LULC classification.

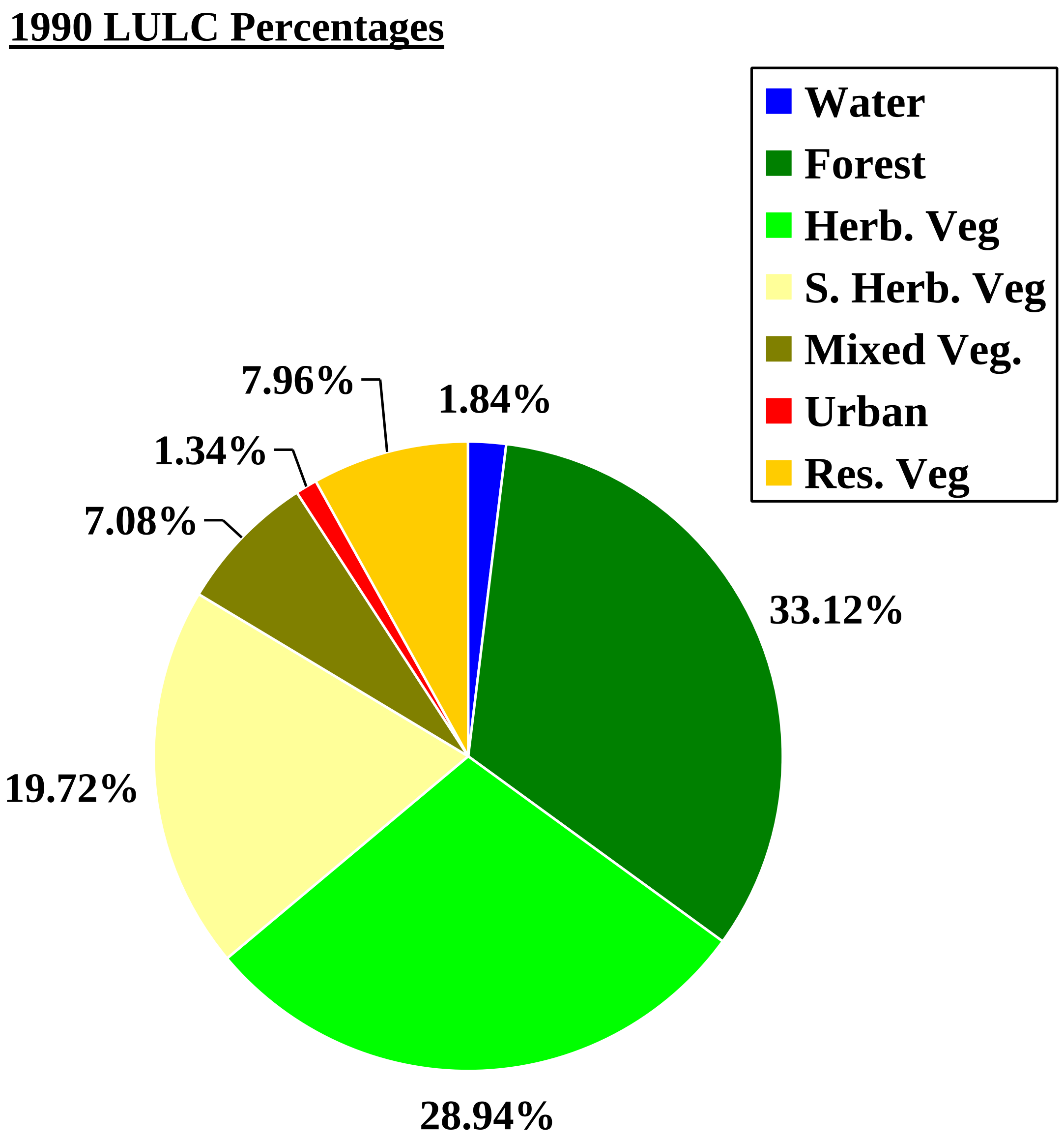


Figure 11a: LULC percentages for the Weeks Bay Watershed 1990.

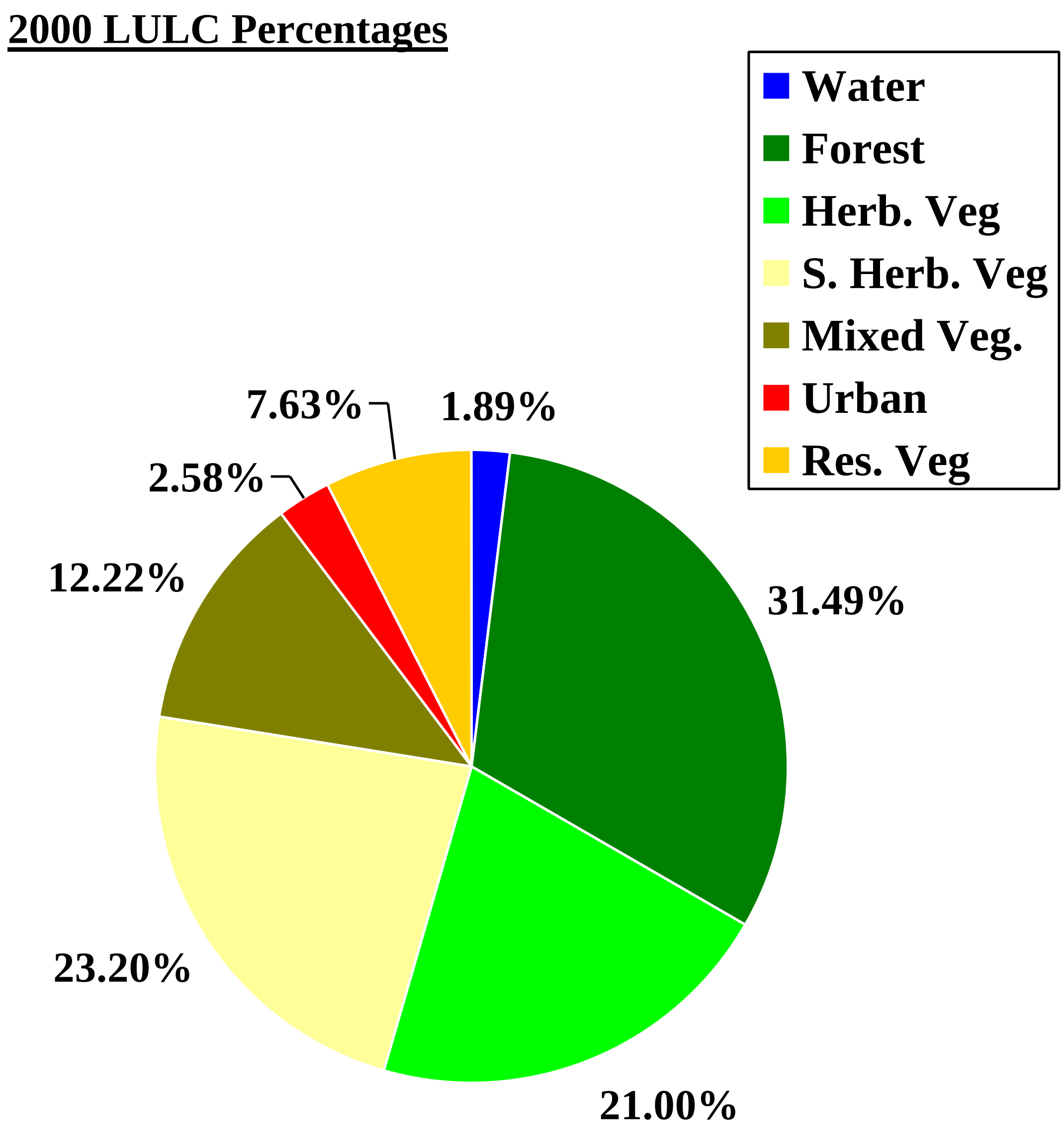


Figure 11b: LULC percentages for the Weeks Bay Watershed 2000.

Table 6: Summary of 1990 and 2000 LULC and the amount of change.

	1990			**2000**			
	Percent of Watershed	**Acres**	**Hectares**	**Percent of Watershed**	**Acres**	**Hectares**	**Percent Change**
Water	1.84%	2302	932	1.89%	2365	957	2.74%
Forested Vegetation	33.12%	41,468	16,781	31.49%	39,431	15,957	-4.91%
Herbaceous Vegetation	28.94%	36,235	14,664	21.00%	26,292	10,640	-27.44%
Seasonal Herbaceous Vegetation	19.72%	24,696	9994	23.20%	29,043	11,753	17.60%
Transitional / Mixed Vegetation	7.08%	8864	3587	12.22%	15,296	6190	72.56%
Urban / Built-Up	1.34%	1677	679	2.58%	3228	1306	92.47%
Sparse / Residual Vegetation	7.96%	9969	4034	7.63%	9557	3868	-4.13%

Erosion Potential Analysis

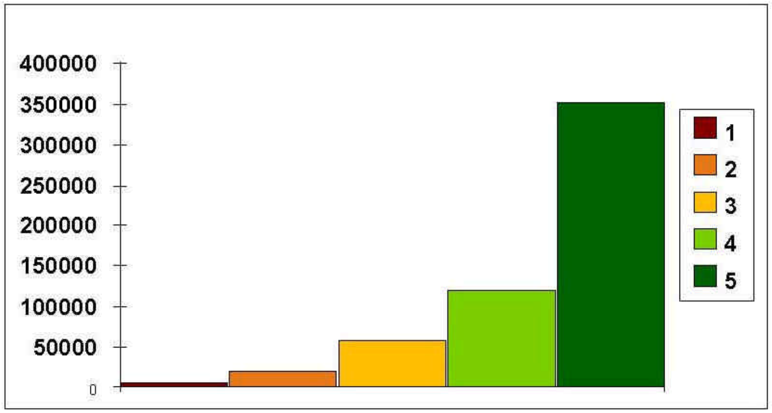
The erosion potential for the Weeks Bay watershed was developed from two primary factors, the change in LULC from 1990 – 2000 and the steepness of slope. These two factors were then combined in order to better determine the overall impact of LULC change and associated slope in terms of erosion potential.

The erosion potential based solely on slope utilized the previously classified slope data derived from surface elevation data. The five slope classes were recoded in terms of erosion potential with class 1 having the greatest and class 5 having the least or most gentle slopes. Over 60% of the slopes were in class 5, this class represents relief having very gentle slopes. Class 1 slopes made up 1.4% of the study area and were isolated along the drainage network of the watershed (Figure 12).

The erosion potential based on the change in LULC was created with a rule based thematic change model resulting in 49 classes that were recoded to five classes matching those of the slope erosion potential.. The model rules consisted of statements that recoded LULC classes based on the type of change that occurred, for example: if LULC 1990 class was forested vegetation and LULC 2000 class was urban then LULC erosion potential class equals class 1. This series of rules created an erosion model for LULC change with approximately 60% of analysis cells in class 5 and 2.35% of cells in class 1 (Figure 13). The majority of all class 1 cells were associated with areas of increased urban development along the fringes of the towns of Fairhope and Daphne. The rules used in the model were based on the concept of historical sedimentation and landuse

Erosion Potential Classes based on Slope

Class 1 = Greatest Potential
Class 5 = Least Potential



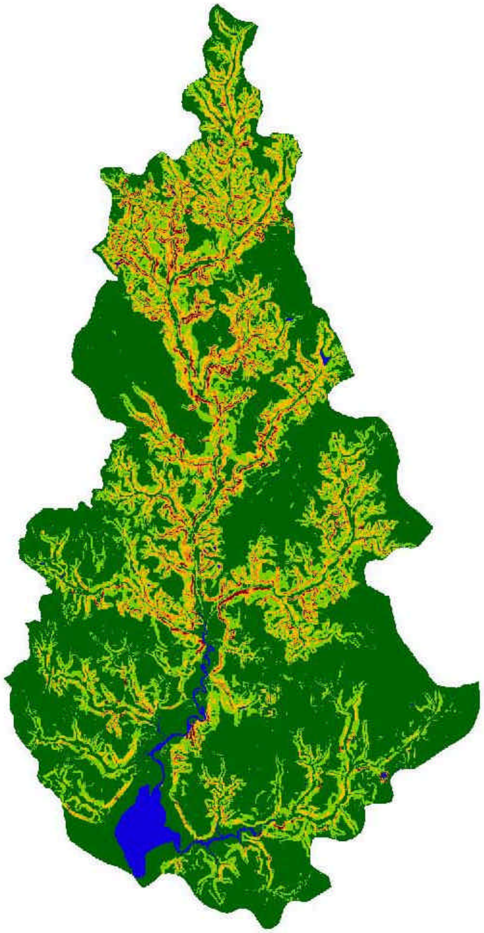


Figure 12: Erosion potential classes due to slopes within the Weeks Bay watershed.

Erosion Potential Classes based on LULC Change

Class 1 = Greatest Potential
Class 5 = Least Potential

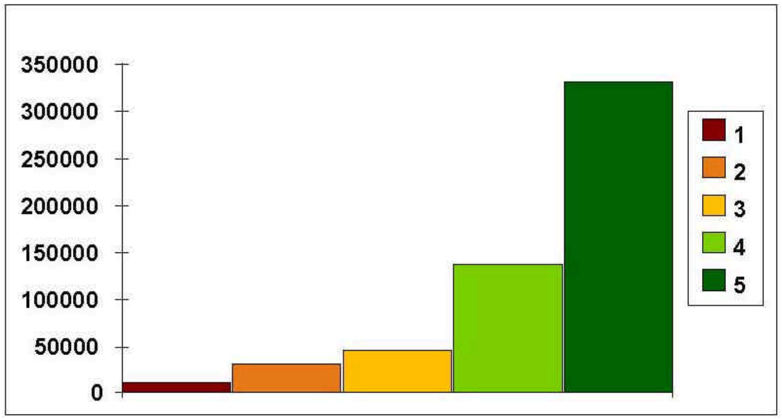


Figure 13: Erosion potential classes due to LULC changes within the Weeks Bay watershed.

trends, with precedent giving to changes that altered the amount and type of vegetation cover on the landscape.

The overall erosion potential was calculated by giving slope and LULC erosion potentials equal weight in terms of impact on the landscape. The analysis almost entirely deleted class 1 in terms of overall erosion potential with only 496 analysis cells (0.09%) being grouped in class 1 (Figure 14). Substantial increases were recorded in class 4 and class 3, with class 4 consisting of approximately 50% of the cells analyzed, more than double (100% increase) of the previous two analysis. Increases in class 3 were not as large with an average increase of about 80% when compared to the to the previous analyses (Table 8)

Erosion Potential Classes based on Slope and LULC Change

Class 1 = Greatest Potential
Class 5 = Least Potential

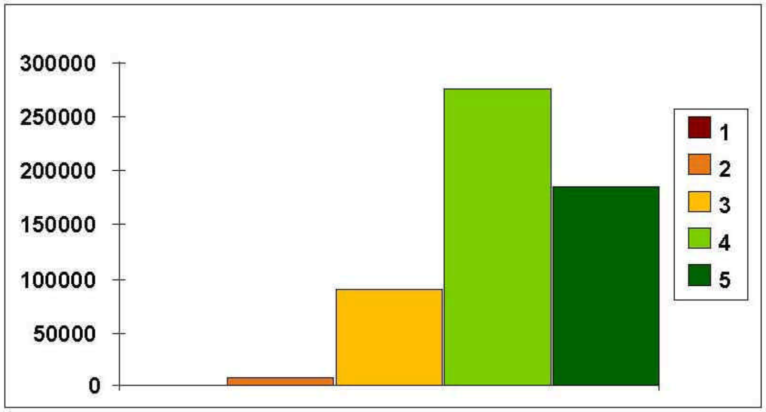


Figure 14: Erosion potential classes due to slopes and LULC changes within the Weeks Bay watershed.

Table 8: Summary of erosion potential classes, with 30 meter cell counts and percentage of watershed for each erosion potential analysis.

	Slope Erosion Potential		**LULC Erosion Potential**		**Combined Erosion Potential**	
	Percent of Watershed	**Cell Count**	**Percent of Watershed**	**Cell Count**	**Percent of Watershed**	**Cell Count**
Class 1	**1.42%**	**7958**	**2.28%**	**12,581**	**0.09%**	**496**
Class 2	**3.69%**	**20,733**	**5.83%**	**32,849**	**1.52%**	**8558**
Class 3	**10.57%**	**59,358**	**8.08%**	**45,514**	**16.10%**	**90,375**
Class 4	**21.70%**	**121,852**	**24.68%**	**138,934**	**49.16%**	**275,963**
Class 5	**62.61%**	**351,530**	**59.12%**	**332,868**	**33.13%**	**185,949**

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop a LULC change for the Weeks Bay watershed over the past decade. The classification scheme used was modified from TNC vegetation systems and Anderson's Level 1landuse classification. The change in the LULC was then used to estimate potential sources of erosion or sediment and coupled with erosion potential derived from land surface elevation data.

The methodology used for this project was based on the analysis of Landsat satellite imagery for leaf-off and leaf- on periods of 1990 and 2000. The individual image scenes were classified based on spectral characteristics and then modeled with a rule based thematic change model to determine what was the most likely ground class observed through out the year. The change in LULC was then modeled once more to estimate erosion potential in a similar manner. This data was spatially analyzed with classified slope classes to estimate erosion potential based on the combined factors with basic map algebra.

The accuracy of the LULC was determined by field sampling of random ground control points and comparing these points to the classified image pixels. The overall accuracy was 78%, which is acceptable when compared to other LULC classifications of similar data. The main concern, in terms of LULC, was increased urban development and the classification methodology was built around that need. This was apparent in the accuracy assessment with the urban class having notably high accuracies in terms of classification procedure.

The changes in LULC over the past decade are representative of speculative landuse trends made for the Weeks Bay watershed. There has been a substantial increase in urban development, associated primarily with existing towns in the area. The changes in forested vegetation have been minimal due to the lack of upland forest with the primary forest being associated with riparian streamside buffers. The LULC classification generated for the Weeks Bay watershed shows an area dominated by agriculture landuse practices with increasing urban development and mainly riparian forest.

The erosion potential analysis indicated that the combination of surface slopes and changes in LULC had much more impact on the erosion potential than either of the factors alone, with large increases in the number of analysis cells for erosion potential classes 3 and 4. The erosion potential model gives no indication of the total sediment yield or erosion rates for the watershed. The final output did give insight to possible problematic areas in terms of sediment sources as it relates to nonpoint source pollution. The final products of this research were a series of image maps with LULC change estimates and possible sources of sediment measured by relative erosion potential with in the Weeks Bay watershed.

The recommendations proposed for the analytical techniques of the project include:

- Due to intensive computational processing use batch file commands for data preprocessing and processing at times of low computer usage.

- Use a multi-phase LULC classification process for all classes to be classified, with specific band combinations that would best represent or define a class.
- Use vector overlays to further subset the data into smaller classification sampling areas, which would eliminate spectral confusion between classes, perhaps to the subwatershed level.
- Addition of an accurate soils data layer to erosion potential model for a soil erodability factor.

Several conclusions were reached from the completion of this project. They are as follows:

1. The overall changes in LULC in the Weeks Bay watershed are indicating a trend of increasing urban development in a rural dominated area.
2. The most significant changes within the watershed are urban areas increasing by 92.5% and the lack of change in forested vegetation (-4.9%) indicating the preservation of streamside buffers.
3. The majority of urban increases are associated with the expansion of existing urban areas within the watershed.
4. The greatest threat of erosion is associated with the areas of increased urban development and the steep slopes associated with the drainage features of the watershed.

5. The overall threat of erosion in terms of bay sedimentation in Weeks Bay is minimal with the most problematic areas being regions of increased urban development since slope within the watershed are not very steep.

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APPENDIX A

THE NATURE CONSERVANCY VEGETATION STANDARD

Terrestrial Vegetation System Classes and Subclasses

Class	Subclass
Forest Trees over 5m with interlocking crowns with >60% cover.	Evergreen Forest Deciduous Mixed evergreen-deciduous forest
Woodland Trees over 5m with non-touching crowns with 25-60% cover.	Evergreen woodland Deciduous woodland Mixed evergreen-deciduous woodland
Sparse woodland Trees over 5m with widely spaced crowns with 10-25% cover.	Evergreen sparse woodland Deciduous sparse woodland Mixed evergreen-deciduous woodland
Shrubland Trees or shrubs 0.5-5m tall with >25% cover.	Evergreen shrubland Deciduous shrubland Mixed evergreen-deciduous shrubland
Sparse shrubland Trees or shrubs 0.5-5m tall with 10-25% cover.	Evergreen sparse shrubland Deciduous sparse shrubland Evergreen-deciduous sparse shrubland
Dwarf shrubland Shrubs <0.5m tall with >25% cover.	Evergreen dwarf shrubland Deciduous dwarf shrubland Evergreen-deciduous dwarf shrubland

Sparse dwarf shrubland Shrubs <0.5m tall with 10-25% cover.	Evergreen sparse dwarf shrubland Deciduous sparse dwarf shrubland Evergreen-deciduous sparse dwarf shrubland
Herbaceous Graminoids and/ or forbs with >10% cover with >10% woody cover.	Tall grasslands Medium tall grasslands Short grasslands Tall forb vegetation Low forb vegetation Hydromorphic rooted vegetation
Sparsely vegetated/non-vascular Vascular vegetation cover is no more than 10%.	Sparsely vegetated consolidated rocks Sparsely vegetated gravel, cobble rocks Sparsely vegetated screes and talus True deserts Low forb vegetation Sparsely vegetated mud flats and eroding slopes

APPENDIX B

EROSION POTENTIAL MODEL RULES

Thematic change rules used to assess erosion potential based on the change in LULC from 1990 to 2000. Class 1 = greatest potential, Class 5 = least potential

If was Water in 1990 and is Urban/built-up in 2000 then erosion potential = Class 1

If was Forested Vegetation in 1990 and is Urban/built-up in 2000 then erosion potential = Class 1

If was Herbaceous Vegetation in 1990 and is Urban/built-up in 2000 then erosion potential = Class 1

If was Seasonal Herbaceous Vegetation in 1990 and is Urban/built-up in 2000 then erosion potential = Class 1

If was Transitional/Mixed Vegetation in 1990 and is Urban/built-up in 2000 then erosion potential = Class 1

If was Sparse/Residual Vegetation in 1990 and is Urban/built-up in 2000 then erosion potential = Class 1

If was Water in 1990 and is Sparse/Residual Vegetation in 2000 then erosion potential = Class 2

If was Forested Vegetation in 1990 and is Sparse/Residual Vegetation in 2000 then erosion potential = Class 2

If was Herbaceous Vegetation in 1990 and is Sparse/Residual Vegetation in 2000 then erosion potential = Class 2

If was Seasonal Herbaceous Vegetation in 1990 and is Sparse/Residual Vegetation in 2000 then erosion potential = Class 2

If was Mixed/Mixed Vegetation in 1990 and is Sparse/Residual Vegetation in 2000 then erosion potential = Class 2

If was Herbaceous Vegetation in 1990 and is Water in 2000 then erosion potential = Class 2

If was Seasonal Herbaceous Vegetation in 1990 and is Water in 2000 then erosion potential = Class 2

If was Mixed/Mixed Vegetation in 1990 and is Water in 2000 then erosion potential = Class 2

If was Seasonal Herbaceous Vegetation in 1990 and is Seasonal Herbaceous Vegetation in 2000 then erosion potential = Class 3

If was Herbaceous Vegetation in 1990 and is Seasonal Herbaceous Vegetation in 2000 then erosion potential = Class 3

If was Mixed/Mixed Vegetation in 1990 and is Seasonal Herbaceous Vegetation in 2000 then erosion potential = Class 3

If was Seasonal Herbaceous Vegetation in 1990 and is Herbaceous Vegetation in 2000 then erosion potential = Class 3

If was Sparse/Residual Vegetation in 1990 and is Sparse/Residual Vegetation in 2000 then erosion potential = Class 3

If was Forested Vegetation in 1990 and is Water in 2000 then erosion potential = Class 4

If was Forested Vegetation in 1990 and is Herbaceous Vegetation in 2000 then erosion potential = Class 4

If was Forested Vegetation in 1990 and is Seasonal Herbaceous Vegetation in 2000 then erosion potential = Class 4

If was Forested Vegetation in 1990 and is Mixed/Mixed Vegetation in 2000 then erosion potential = Class 4

If was Mixed/Mixed Vegetation in 1990 and is Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Seasonal Herbaceous Vegetation in 1990 and is Forested Vegetation in 2000 then erosion potential = Class 5

If was Water in 1990 and is Seasonal Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Herbaceous Vegetation in 1990 and is Mixed/Mixed Vegetation in 2000 then erosion potential = Class 5

If was Herbaceous Vegetation in 1990 and is Forested Vegetation in 2000 then erosion potential = Class 5

If was Mixed/Mixed Vegetation in 1990 and is Mixed/Mixed Vegetation in 2000 then erosion potential = Class 5

If was Herbaceous Vegetation in 1990 and is Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Water in 1990 and is Forested Vegetation in 2000 then erosion potential = Class 5

If was Water in 1990 and is Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Water in 1990 and is Mixed/Mixed Vegetation in 2000 then erosion potential = Class 5

If was Water in 1990 and is Water in 2000 then erosion potential = Class 5

If was Forested Vegetation in 1990 and is Forested Vegetation in 2000 then erosion potential = Class 5

If was Seasonal Herbaceous Vegetation in 1990 and is Mixed/Mixed Vegetation in 2000 then erosion potential = Class 5

If was Mixed/Mixed Vegetation in 1990 and is Forested Vegetation in 2000 then erosion potential = Class 5

If was Urban/built-up in 1990 and is Water in 2000 then erosion potential = Class 5

If was Urban/built-up in 1990 and is Forested Vegetation in 2000 then erosion potential = Class 5

If was Urban/built-up in 1990 and is Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Urban/built-up in 1990 and is Seasonal Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Urban/built-up in 1990 and is Transitional/Mixed Vegetation in 2000 then erosion potential = Class 5

If was Urban/built-up in 1990 and is Urban/built-up in 2000 then erosion potential = Class 5

If was Urban/built-up in 1990 and is Sparse/Residual Vegetation in 2000 then erosion potential = Class 5

If was Sparse/Residual Vegetation in 1990 and is Water in 2000 then erosion potential = Class 5

If was Sparse/Residual Vegetation in 1990 and is Forested Vegetation in 2000 then erosion potential = Class 5

If was Sparse/Residual Vegetation in 1990 and is Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Sparse/Residual Vegetation in 1990 and is Seasonal Herbaceous Vegetation in 2000 then erosion potential = Class 5

If was Sparse/Residual Vegetation in 1990 and is Transitional/Mixed Vegetation in 2000 then erosion potential = Class 5