SPATIO-TEMPORAL ANALYSIS OF TEXAS SHORELINE CHANGES USING GIS TECHNIQUE

A Thesis

by

CESAR AUGUSTO ARIAS MORAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Geography

SPATIO-TEMPORAL ANALYSIS OF TEXAS SHORELINE CHANGES

USING GIS TECHNIQUE

A Thesis

by

CESAR AUGUSTO ARIAS MORAN

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Approved as to style and content by:

Hongxing Liu (Chair of Committee)	William Bryant (Member)
Robert Dull (Member)	Douglas J. Sherman (Member)

Douglas J. Sherman
(Head of Department)

December 2003

Major Subject: Geography

ABSTRACT

Spatio-Temporal Analysis of Texas Shoreline Changes

Using GIS Technique. (December 2003)

César Augusto Arias Morán, B.S., Escuela Superior Naval, Ecuador

Chair of Advisory Committee: Dr. Hongxing Liu

One of the most important aspects of coastal management and planning programs that needs to be investigated is shoreline dynamics. Long-term coastal analysis uses historical data to identify the sectors along the coast where the shoreline position has changed. Among the information that can be obtained from these studies are the general trend of coasts, either advancing or retreating. The erosion or accretion rates at each location can be used to forecast future shoreline positions.

The current techniques used to study shoreline evolution are generally based on transects perpendicular to a baseline at selected points. But these techniques proved to be less efficient along more complex shorelines, and need to be refined. A new and more reliable method, the topologically constrained transect method (TCTM), was developed for this study and tested using data available for three sectors of the Texas Gulf Coast. Output data generated from TCTM also allowed performing shoreline evolution analysis and forecasting based on historical positions.

Using topological constrained transects, this study provides a new method to estimate total areas of accretion or erosion at each segment of the coastline. Reliable estimates of future gains or losses of land along the coast will be extremely useful for planning and management decisions, especially those related to infrastructure and environmental impacts, and in the development of coastal models. Especially important is the potential to quickly identify areas of significant change, which eliminates the need for preliminary random sample surveying, and concentrate higher-resolution analyses in the most significant places.

The results obtained in this research using the new methodology show that the Texas coast generally experiences erosion, with anthropogenic factors responsible for accretion. Accretion areas are located near coastal infrastructure, especially jetties that block the along shore sediment transport. The maximum erosion rate obtained in the study area is 5.48 m/year. This value helps make us aware of the powerful dynamic of the sector.

DEDICATION

This thesis is dedicated to my parents, Cesar and Aida, who have taught me the importance of knowledge to achieve success, and how to establish objectives in my life that are both ambitious and attainable.

I also dedicate this research to my wife, Solange, and especially to my kids, Cesar and Victoria. I am pretty sure that, if some day they make these words their own, I will have accomplished another objective – to motivate them to scientific knowledge. I hope one of their first steps will be reading – and bettering – their father's previous work.

ACKNOWLEDGMENTS

My first thanks must go to the Oceanographic Institute of the Ecuadorian Navy, which supported my studies at Texas A&M University, and especially to Commander Fernando Zurita. He was the mastermind behind the agreement between the Ecuadorian Navy and Texas A&M University which made possible that four officers follow his steps, and pursue graduate education at one of the leading universities in the U.S.A.

I also want to thank Dr. Hongxing Liu who introduced me to the fascinating fields of GIS and remote sensing; his patient guidance and constant encouragement were instrumental to the achievement of this project.

Last, but not least, I thank the other members of my committee; Dr. Douglas Sherman, Dr. William Bryant and Dr. Robert Dull for their time and advice, and the department of Geography at Texas A & M University for their knowledgeable staff and up-to-date laboratories.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

Coastal zones are generally synonymous with high populations across the globe. In the United States, coastal areas amount to approximately 17% of the total land area, but accommodate over 50% of the population (CZM, 2003). Mirroring the national trend, the Texas Gulf Coast is characterized by rapid urbanization and increasing recreational use.

As urbanized areas expand along the Texas coast, so increases the vulnerability of the population of Texas to natural phenomena. Coastal areas have been periodically subjected to hurricanes and floods, but regular coastal erosion is also a major factor. Over the past century the Gulf Coast has experienced the greatest rate of coastal erosion in the United States, retreating up to 5.48 meters per year. The Texas coastline has not, however, retreated uniformly. Many areas have experienced sustained erosion, while some beaches have actually experienced net accretion (Gibeau et al. 2000).

Morton (1979), a leading researcher in the field, stated that mapping shoreline changes and predicting future shoreline positions have to be worldwide scientific and coastal management objectives. Accurate measures of historic shoreline position and prediction of future locations are essential to

---

This thesis follows the style of the *Journal of Coastal Research.*

coastal planning and management. While in some areas changes in shoreline position are small, in other areas high erosion rates may threat existing infrastructure.

Traditional approaches to the study of shoreline dynamics are based on temporal scales, either addressing long-term or short-term coastal changes. Long-term changes occur over periods such as decades or centuries, while short-term changes refer to movements occurring from over a season to a few years. Studies of long-term variations are better suited for large-scale coastal planning and management, since decision makers goal is to identify major trends over larger areas. Historical data are used to identify the segments along the coast where the shoreline has changed. Among the information that can be obtained from these studies are the general trend of coastal advance or retreat over time, and the erosion or accretion rates, which can be used to forecast future shoreline positions.

In Texas, state legislation requires the forecast of shoreline set backs for periods of 30 and 60 years in order to identify areas for preservation, location of infrastructure, and areas where construction should not be authorized (Crowell et al., 1999). Over the years, a large amount of historical data such as topographical maps, aerial photographs, and satellite images have been collected by federal and local agencies and are used in research and modeling. These data can easily be combined and processed in a GIS environment.

The Bureau of Economic Geology of the University of Texas has extracted extensive digital historical shoreline data (Gibeau et al. 2000.) The Bureau also created the Shoreline Shape and Projection Program (SSAPP), a software package designed to calculate erosion rates and forecast shoreline position at each point of the coast. But many programs require shoreline data to be exported from ArcView in order to be analyzed, step that can be avoided if all operations are performed by ArcView's tools.

At present, the best example of the additional capabilities of ArcView to perform coastal analysis is provided by the Digital Shoreline Analysis System (DSAS), which is a free ArcView extension available from the USGS (Thieler et al. 2003.) In this program, the shoreline change rate analysis is based on the perpendicular transects method, which is reliable over regularly-shaped coastlines, but problematic over complex shoreline sections.

The first objective of this thesis is to develop an improved methodology that could measure shoreline displacement more accurately and decrease processing time for automated shoreline assessment. This new methodology, the topologically constrained transect method (TCTM,) solves some of the problems found in the existing methods by using a new and more flexible shoreline segmentation process in order to improve transect orientation and shoreline change rate analyses. Additionally it provides an alternative forecasting method to estimate shoreline positions that can also be used in complex coastal environments. TCTM was tested for the Texas Gulf Coast using the historic shoreline data from the Texas Bureau of Economic Geology.

The long-term evolution of the Texas Gulf coast has been the object of many studies, but neither area change values due to shoreline position change, nor the shape properties of the coast have been adequately covered in any of them.

1.1 Research Background

The existing literature in coastal dynamics deals primarily with three major themes: 1) geomorphology of coastal environments; 2) techniques for data acquisition (shoreline mapping); and 3) methodology for shoreline position change and prediction.

Most articles on the first theme deal primarily with coastal behavior, and applied coastal studies. Publications that are representative of this type include Shalowitz (1964), Hudson and Mossa (1997), Sherman and Gares (2000), and Andrews et al. (2002). Shalowitz (1964) discussed the definition of the U.S. maritime boundaries and advanced important concepts related to coastal studies. Sherman (2000) stressed the importance of coastal studies, and provided a classification of coasts with five major classes: resistant coasts; coarse clastic coasts; sandy beaches; inlet and marshes; and coastal dunes. Basic principles for using GIS techniques for modeling coastal sediment behavior were presented by Andrews et al., 2002, who emphasized the importance of understanding sand flows in a coastal environment. Horn (1997) presented a comprehensive discussion of major changes in the techniques used for coastal research through the past twenty years.

A detailed analysis of the Texas Gulf Coast was found in Morton and White, 1995, where he also classified the types of coast found in its upper (eastern) section. He also explained erosion processes based on the geological differences of shoreline components, and stressed the real importance of relating shoreline types and their erosion rates.

The second theme of publications deals with the techniques available for shoreline mapping. Since there are no widely accepted standards to map shoreline position changes, significant controversies between authors have been frequent (Pajak and Leatherman, 2002).

An important article was due to Thieler and Danforth (1994), who provided a conceptual and analytical framework for an improved method of extracting geographic data from maps and aerial photographs. In this article, he presented a new approach to shoreline mapping based on the high water line. Moore (2000) provided a comprehensive discussion of sources of error in shoreline mapping, and analyzed in detail the effectiveness of aerial photography. Image space distortions, object space displacements, and the real importance of accurate ground control points were taken into account.

The third theme deals with shoreline prediction based on the analysis of long- or short-term shoreline changes. Short-term studies have been focused on how to predict seasonal variations or the effects of episodic and violent events such as storms, floods and hurricanes. Violent events can lead to more substantial changes in the coast than the cumulative effect of long-term variations due to the higher amounts of energy that can be liberated by variables such as high-velocity winds, flood discharges, and large waves, and storm surge.

The importance of forecasting shoreline positions for a more effective coastal management was also discussed by Douglas and Crowell (2000.) He evaluated the methods currently available for long-term shoreline analysis, stressing the shortcomings of using linear regression methods to study a complex problem like shoreline prediction. Fenster et al. (1993) developed an efficient non-linear method to conduct long-term shoreline position prediction based on time series analysis. Unfortunately these authors could not take full advantage of the capabilities provided by functions embedded in new GIS software such as ArcGIS.

1.2 Significance of Shoreline Studies

Shoreline position changes can significantly affect human activities (Frihy and Lotfy, 1994.) Some of the most obvious causes of coastal change are the sinking of low lands due to subsidence, the silting and closure of ports, or the losses of land due to coastal currents. Human societies can create negative impacts of their own, such as the installation of heavy equipment and permanent infrastructure (such as roads and ports) along unstable coastlines, the extraction of underground resources in areas with propensity to subsidence, and the development of industries and residences in environmentally-sensitive areas.

The economic impact of coastal erosion processes across the United States is very significant. The Federal Emergency Management Agency estimates that the aggregated costs related to erosion amounted to $530 million/per year for homeowners in the coast (FEMA, 2000). The National Flood Insurance Program has been paying an average of $80 million per year for erosion-related damage.

For many years, the main objective of research dealing with the reduction of economic losses caused by erosion on coastal zones was to decide which solution would be the most appropriate (Morelock, 1978). In the past there was a dominant approach of trying to stabilize coastlines by installing defense structures, in order to minimize changes, with mixed success (Fanos et al., 1995.) A fundamental economic problem resulted from the continuous effort of federal and local government of building expensive but also massive, immovable structures on highly dynamic environments to counteract the effects of erosion (Bush et al., 1996). Many of these structures proved less and less efficient over time, and more work was required to compensate for decreasing efficiency, and often to protect the structures themselves. Over time, the frequent damage or destruction of infrastructure, and the continuous drain of resources to consolidate endangered defenses both gave strength to the idea that coastal processes cannot be domesticated and must be better understood.

Local and Federal agencies from different parts of the country have created geo-databases, where digital historical shoreline data sets can be stored and retrieved to facilitate an easy and quick access. These digital data sets allowed researchers to create coastal behavior models with the intention of identifying erosion hazard areas, which are defined along the coast using thresholds based on the Average Annual Erosion Rate (AAER). The average annual erosion rate has been the main element to predict shoreline setback positions in hazard maps, usually considering periods of 30 and 60 years into the future (Douglas et al, 1998.) The identification of these areas is extremely important to restrict (or even bar) dangerous uses and minimize economic losses.

The study of historical shoreline data can be useful to identify the predominant coastal processes operating in specific coastal locations using change rates as an indicator of shoreline dynamics. The real importance of such studies is to avoid decisions based on insufficient knowledge, wrong assessments or arbitrary decisions, leading to losses in resources and infrastructure that could have been prevented.

Coastal behavior must be understood in order to avoid the mistakes of the past and ensure that the best uses will be selected for each place. Every step toward a better understanding of the dynamics of the Texas coastal systems and forecasting its changes with the purpose of assisting in future developments will be one more step in the right direction.

1.3 Problem Statement

Long-term studies of shoreline evolution involve the comparative study of the positions of key points in the shoreline over several periods of time, and often involve the prediction of their future positions. Many coastal management programs have been assuming that long-term shoreline change proceeds at a steady pace, and consequently use average change rates. Although more recent empirical analyses show that shoreline evolution is a more complex process and rarely follows a steady pattern (Zheng and Dean, 1997), the most reliable forecasting models are still based on the calculation of annual change rates.

Several statistical methods are available to estimate annual erosion rates and forecast shoreline positions such as end-point (EP), linear regression, time series analysis, and geostatistics. But, the lack of a standard method for shoreline displacement analysis among coastal scientists has resulted in the publication of a variety of data utilizing non-comparable measurement techniques and rate-of-change calculations that can be a problem comparing coastal changes from regional to national scales (Thieler and Danforth, 1994). In other words, different methods may lead to significantly different results.

In Texas, the state Bureau of Economic Geology has been using historical cartography and aerial photography to develop data sets for different years, and to estimate annual average erosion rates based on these data sets. Morton (1975) also developed a comparable methodology and measured erosion rates along selected segments of the Texas coastline.

In spite of the continuous improvements in shoreline mapping techniques, transects remain the basis of shoreline displacement analysis, and over recent years few attempts to improve this technique can be found in the literature (Duffy and Dickson, 1995). These authors used a raster-based technique to calculate the shortest Euclidian distance between two historical shorelines in order to measure the displacement.

The transect method proved to be of limited value in indented coasts and must be refined in order to produce more reliable and precise results. When the shoreline is very irregular, transects may cross each other in confusing patterns; in this case, the common practice is to use an artificial baseline that does not reflect coastal traits (Fig. 1). Another important deficiency of the perpendicular transect method may occur when some transects intersect the same shoreline in more than one occasion (Fig. 2). An improved and more flexible method is necessary to deal with transect definition in a complex coastal environment.

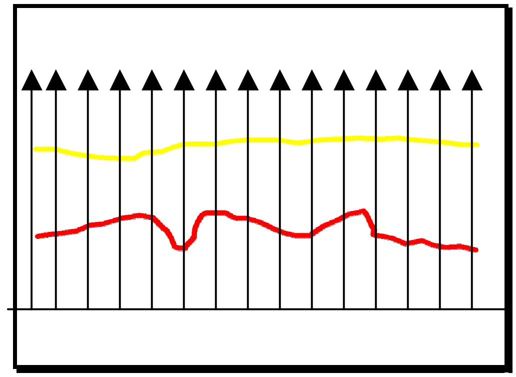


Fig. 1 Perpendicular transect limitation

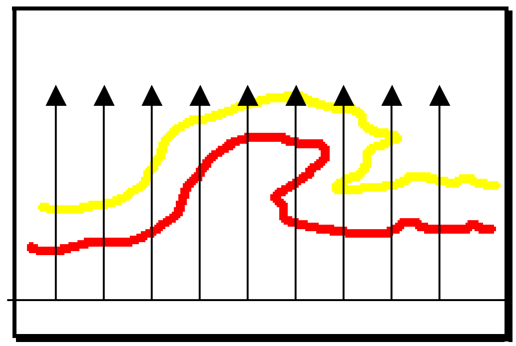


Fig. 2 Perpendicular transect limitations

The lack of an easy method to estimate coastal area changes due to erosion or accretion has been limiting the use of historical shoreline data in other fields. Many models dealing with environmental and ecological problems (Wathern, 1990) or real estate assessments (Parson and Powell, 2001) often need to estimate net economic gains or losses due to shoreline dynamics. The availability of such values for coastal change would be of foremost importance for policy-makers that have to deal with alternative land uses, and for governments that have to decide on the need to place infrastructure or the implementation of measures to counter negative effects of sedimentation or erosion.

1.4 Research Objective

In this thesis there are two intertwined objectives. The first objective relates to the development of an effective method for the measurement of shoreline displacement, and implements it as a software tool. The second objective deals with the application of a new method to the analysis of historical variation on the Texas Gulf shoreline. Specific tasks of this research are:

1) to develop a new method for quantifying shoreline changes based on topologically constrained transects; this method, by relating each transect with both the baseline and neighboring transects, increases the accuracy and reliability of shoreline position forecasting;

2) to implement an ArcGIS-compatible tool that automatically creates sets of transects among shorelines segments, identifies points of intersection, gets the erosion rates, and forecasts the new shoreline position based on the topologically constrained transect method proposed in this research; and

3) to apply the new method and the software tool to selected portions of the Texas Gulf Coast in order to analyze the coastal dynamics and spatio-temporal changes in coastal morphology for the period between 1856 and 2000.

1.5 Major Characteristics of the Texas coast

The Texas coast is considered a passive margin, having the characteristic elements of an old geomorphologic structure. Major traits include the low gradient plains, a wide continental shelf with low slope, stable tectonics, fine and abundant sedimentation, and composite landforms of deltas and extensive barriers islands that cover more than the 80 percent of its length.

The relative location of a coastal system also influences its geomorphologic processes. The dominant movements in the atmosphere and the ocean determine the intensity of currents, waves, tidal regime, and coastal and offshore ecology (Short, 1999). Due to its geographic position in the middle latitudes and in the northern side of the Gulf of Mexico, the Texas coast is directly influenced by tropical cyclones. The coastal system is not subjected to high tides, and has a typical tide range of less than 2m, and moderate to high waves.

Using the geomorphologic, climatologic, hydrologic and ecologic characteristics, the Texas coast can be divided into three main sectors: upper, middle and lower coast (Fig. 3).

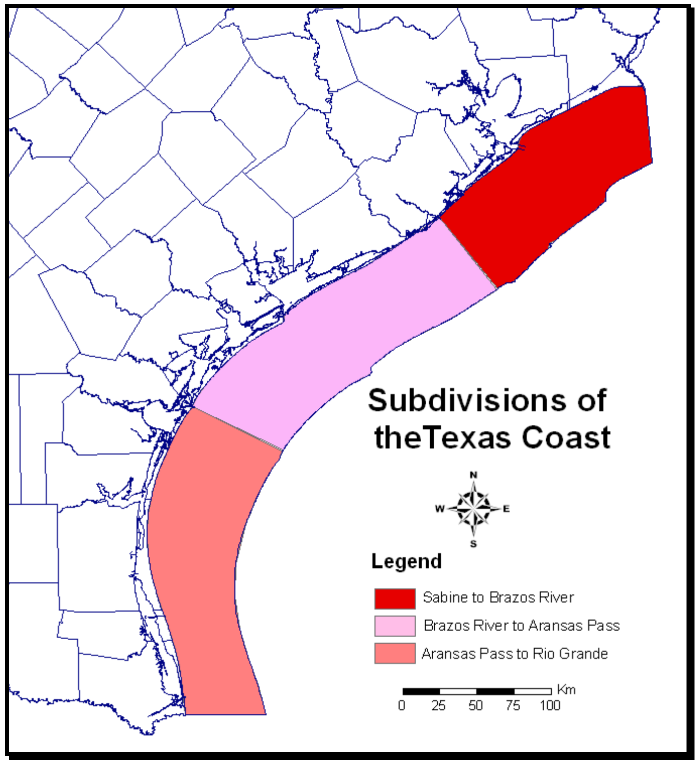


Fig. 3. Subdivisions of the Texas Coast

The upper coast of Texas extends from Sabine Pass, in the border with Louisiana, west to the Brazos River mouth. This sector is characterized by marshes, coastal prairie, and barrier islands (Morton, 1995). The erosion rate in this area shows higher erosion levels than the middle and lower sectors. This could be related on the higher frequency of hurricanes and tropical storms in the area.

The middle coast of Texas extends from the Brazos river mouth to Pass Aransas, in the southwestern end of Matagorda Island. This sector is a micro tidal, wave-dominant type of coast, according to the Hayes (1979) classification.

One major feature to be taken into account in this area is the existence of a dredged entrance channel and a protective jetty at Pass Cavallo, between the Matagorda peninsula and Matagorda Island that were created in 1966 and that changed the shoreline dynamic of the sector (Gibeau et al, 2000).

The lower coast of Texas extends from Aransas Pass to South Padre Island and the mouth of the Rio Grande, and is characterized by long and narrow barrier islands. It has been affected by human intervention. Especially, the opening of Aransas Pass in 1911 created an interruption on the long-term eastward sediment flow along Mustang Island (Gibeau et al, 2001).

A segment with the greater number of historical shorelines is selected from each of the three main sectors of the Texas coast. Those included segments are: 1) from Sabine Pass to the Brazos river mouth, representing the whole upper coast of Texas; 2) the ocean front of Matagorda peninsula westward to Pass Cavallo, in the middle coast of Texas; and 3) from Aransas Pass to the northern end of Padre Island, including the whole Mustang Island, in the lower coast of Texas (Fig. 4).

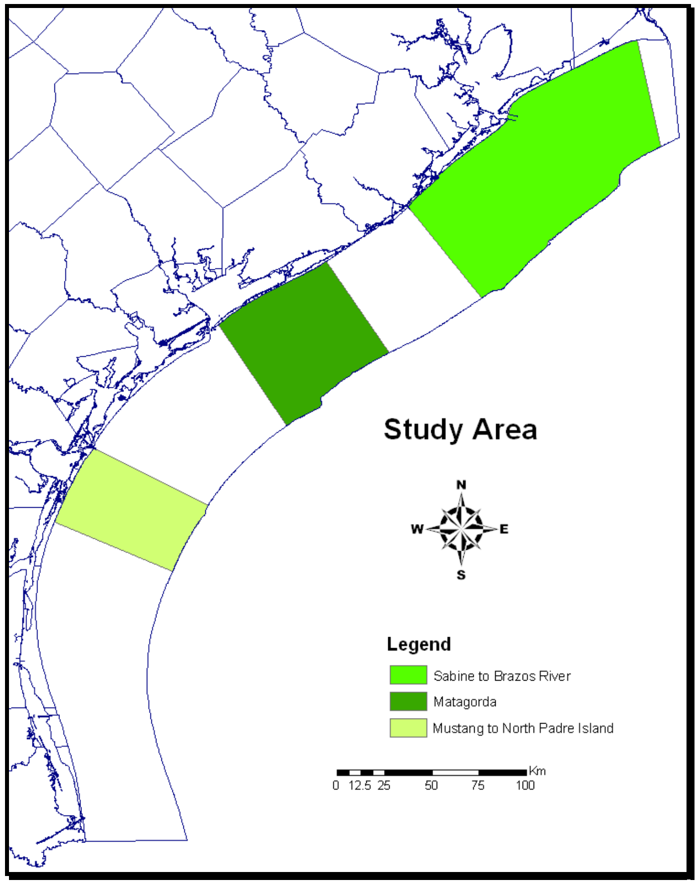


Fig. 4 Study Area

Each of these three sections contain areas of major human intervention, especially channels dredged to give access to inland ports, as well as areas that remain non-urbanized.

1.6 Data Sources

The historical data used in this research was obtained from the Texas Bureau of Economic Geology (Gibeau et al. 2000). The Bureau of Economic Geology compiled shoreline positions for most parts of the Texas Gulf coast for several years, from 1856 to 2000. Since historical surveys were not carried out all over the state coast, the dates for data sets do not completely coincide for the three selected areas.

The data sets were produced by the Texas Shoreline Change Project, and were directly obtained from the Texas Bureau of Economic Geology web page (Gibeau et al. 2000). The data sets available include historical shorelines, forecasted shorelines, and a basic geological classification of shoreline types. They are provided in ArcView shapefile format Table 1.

Table 1. Data sets used in this research

Sector	**Historical Data year**
Sabine to Brazos River	1856-1936-1956-1974-1982-1996-2000
Matagorda Peninsula	1937-1956-1965-1974-2000
Mustang Island to North Padre Island	1856-1937-1956-1965-1974-1991-2000

The oldest shorelines positions were derived from 19th century topographic sheets (T-sheets) of the National Ocean Service (NOS). The other more detail sets were obtained from aerial photographic coverage and LIDAR surveys.

The shoreline data sets used in this study provide sufficient information to calculate the primary direction of change, and the rate of either accretion or erosion at every point, from the time of a data set to the next. But since data sets are separated by relatively long lapses of time, it is not possible to establish which episodes happened in between, nor their duration. Especially important would be to identify the beginning of shifts in drift direction or the time of trend reversals, and to measure the duration of each period of accretion or erosion, in order to discuss their eventual causes.

This fact makes it impossible to determine either the time frame related to each erosion or accretion episode, or the threshold time related to each change of direction. In some places, storms could be responsible for triggering changes in the shoreline net drift direction, since they cause large pulses of material to flow in directions that are independent of the regular drift direction (CETN, 1992).

All shoreline positions from the Texas Bureau of Economic Geology are in the UTM coordinate system. The whole length of Texas coast stretches through two different UTM zones (14th and 15th), which required the use of two different coordinate systems in ArcView. To conduct the shoreline change analysis, all shoreline data sets need to be presented in the same coordinate system. To measure the area changes in this research, Texas Centric Mapping System/Albers Equal Area Mapping System was selected. This allows the representation of the State of Texas, without the limitations of mapping the state into the 3 different UTM zones it covers, and provides precise measurement of the areal size of land loss or gain.

CHAPTER II

THEORETICAL FRAMEWORK

In coastal research literature, the terms "coastline" and "shoreline" are generally held as synonymous (Shalowitz, 1964). But some researchers considered that it was necessary to establish the difference between them (Kniffen and Hillard, 1988). Lam and Qiu (1992) consider that shoreline represents the dynamic boundary between land and water, a continuous and often indented line that includes numerous small bays and prominent points, and the coastline refers to the outer, more stable and more general shape of the shore.

The only situation where these terms have a clearly different meaning is in international law. This difference is encountered in the demarcation of international boundaries, where the coastline is defined by simplified, often straight lines between conspicuous points. This method avoids complex lines that would make it difficult to establish territorial waters and project the economic exclusive zones. Both of them are buffer zones from the simplified shape of the coastline. In this thesis the terms “shoreline” and “coastline” are used interchangeably as synonyms.

2.1 Definition of Shoreline

A shoreline map represents a snapshot of the boundary between ocean and land at a specific time, since coastal areas are dynamic in nature with changes occurring over many time scales (Moore, 2000). Shoreline position is a dynamic feature, and it can be established using different definitions and criteria (Fig. 5).

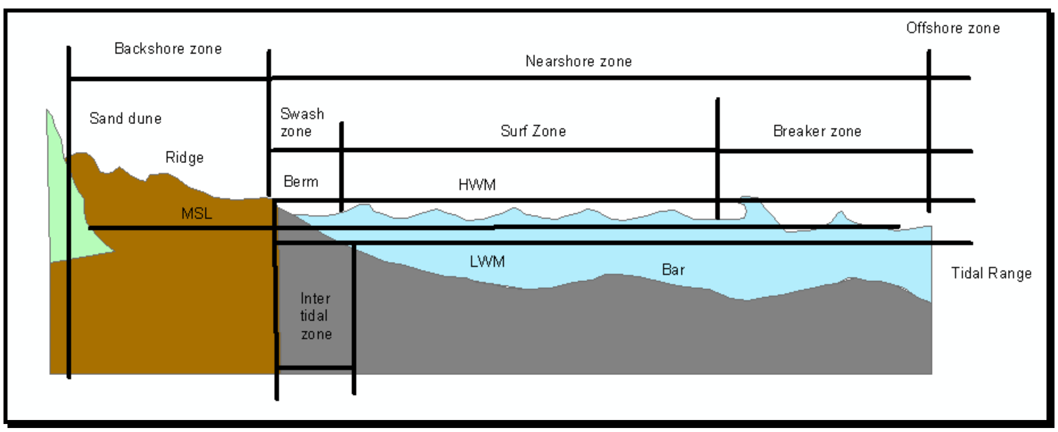


Fig. 5 Shoreline Indicators adapted from Hamson, 1988

Taking regular position measurements at multiple points along the coast would be both very time-intensive and expensive. Consequently, the definition of shoreline should allow for a fast (and less expensive) method of data collection such as aerial photography and remote sensing.

The most logical shoreline indicator is based on tide position, especially the average position of the shore between the high and the low tide or at the peak of the high tide. But measuring tide-related positions has a number of disadvantages, namely the need of using precise values that have to be taken at the same moment in all the points along the coastline. In real conditions, it is practically impossible to plan a flight over the coastline that collects data for all the points of the study area at exactly the right tide-related moment. Further complications follow factors that temporarily affect shore positioning, such as the variation of tide amplitudes linked to the lunar cycle, or local winds and waves at the moment of data collection.

The use of indirect and more stable indicators related to morphology or vegetation has proved to be reliable and more suitable for multiple-point data collection. It is necessary to define some prominent shoreline feature that is easily identifiable and indicates the positioning of the water on a regular basis.

Some of the practical indicators are berm crests, scarp edges, vegetation lines, dune toes, bluff toes, or the wet marking left on the sand by the last high tide (Pajack and Leatherman, 2002). All of them can be directly identified in aerial photographs (Fig. 6).

In this study the shoreline data sets were obtained from the BEG, which were extracted based on different criteria. Since rough data were collected over a long period of time, new became available. In older maps the shoreline was extracted from the low water level (LWL), which was represented due to navigational needs. From 1937 to 1991 the main criteria to establish the shoreline position was the mark left on the sand by the highest tide, which could directly be identified in aerial photographs. The last data set was obtained from high-resolution topographic models created by remote sensing (the LIDAR method, which will be discussed further).

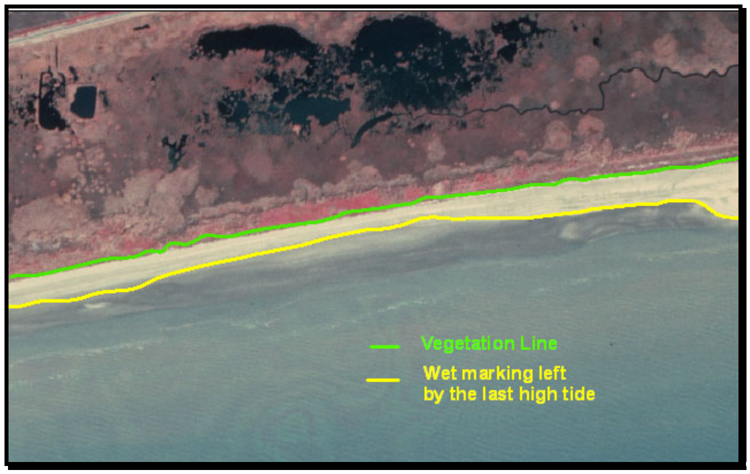


Fig. 6 Possible shoreline indicators

Even though dealing with data collected using very different methods, especially in terms of accuracy of position and resolution, The Texas Bureau of Economic Geology tried to compensate for method deficiencies on a case to case basis, in order to produce historical shoreline data that could be comparable. Since the BEG data sets provide the best and most reliable and comprehensive information about shoreline position in the Texas coast (and the only source where historical information was rectified and made comparable), it was decided to make full use of them in this study.

2.2 Factors that Influence Shoreline Position Change

The transport of material along the coast is linked to natural forces such as waves, tidal movements, long- and cross-shore currents, and wind. Anders and Byrnes (1991) discussed five of the primary factors that may change shoreline position: 1) wave and current processes, 2) sea level change, 3) sediment supply, 4) coastal geology and morphology, and 5) human intervention.

Wind-generated waves are one of the most important energy transfer agents along the Texas coastline and its inland bays. These waves release their energy by hitting the coast, and generating cross-shore and along shore erosion. Coastal areas subjected to regular wave action tend to reach stability after some period of time, with a mean wave height action, unless external factors interfere to create a new unbalance. The Texas coast is characterized by a high frequency of hurricanes and tropical storms, events characterized by much higher levels of energy release. The raised wave heights produces a new cycle, which affects the shoreline stability, and reshapes the shoreline (Leont'yev, 1996).

Another main cause of erosion along the Texas coast is anthropogenic action. An increasing number of scientists support the hypothesis that all infrastructure construction on coastal environments triggers erosion effects (Hall and Pilkey, 1991). They argue that the coastal environments always move towards stability, and manmade structures such as jetties, groins, harbors, and dams produce major changes in the sediment transportation cycle. Such changes create a new physical environment that once more looks for stability, producing unpredicted shoreline position changes. Dam construction is one of the verified manmade structures that may affect coastal erosion, since damming produces inland sediment impound, and ultimately reduces the sediment flow into the coastal areas (Petts, 1984; Hudson and Mossa, 1997).

Each of the elements that contribute to shoreline change does not operate regularly, at constant rates. Its strength changes through time, sometimes in combination with other elements, sometimes in ways that are contrary to the action of other elements. Over time, the combined effect of several factors of variable strength may result in more complex patterns in the rates of change, and sometimes it may even lead to abrupt shifts in drift direction or the reversal in the sediment movement process from deposition to erosion, or vice-versa.

2.3 Shoreline Data Acquisition Techniques

Various data acquisition techniques have been developed to map the position and shape of shoreline over time (Thieler and Danforth, 1994). They include ground surveys, aerial photography, satellite imagery, mobile GPS, and airborne LIDAR.

Ground surveys maximize the contact between the researcher and the coast. They are the most reliable technique for studying small processes in small areas. But this technique requires long periods of time, can only collect a limited number of sampling positions, and generally they provide a coarse spatial resolution.

Remote sensing technique allows for observation and measurement of coastline without direct contact. The most widely used is aerial photographs taken from airplanes at relatively low speed and steady altitude. Aerial photographs can provide two or three-dimensional measurements, and have the advantage of covering much larger areas than ground survey method.

Aerial photographs should be considered as historical records, since they represent objects at a given location at a precise time. But they also have some disadvantages, since they can only be taken on daylight and through clear skies (which makes them weather dependent), cannot properly represent objects in motion, and they require rectification to compensate for image distortions (Ritchie et al, 1988). Infrared aerial photography technology is able to capture images beyond the reach of the human eye. It is useful for coastline mapping.

Over the last two decades there has been an increasing use of satellite imagery. Landsat and Spot and one-meter resolution Ikonos satellite images can be used to generate relatively accurate Coastal Terrain Models (CTM) (Li 1998). By using radar images, data can be collected from high altitude and any time of day or night, and atmospheric conditions are no longer a deterrent. The use of space-borne synthetic aperture radar (SAR) data on coastline mapping and monitoring has been well reported (Lee and Jurkevich, 1990; Mason and Davenport, 1996; Schwäbisch et al., 1997). Extraction of shorelines from radar images is facilitated by a larger contrast in backscatter signals received from the water and the land.

Both aerial photos and satellite imagery need to go through geocoding and orthorectification before shoreline feature extraction. This is necessary to introduce geographic coordinates using ground control points and compensate for image geometric distortions due to various reasons.

The development of the Global Positioning System (GPS), especially differential GPS, provided new avenue for data collections. By driving along the shoreline the geographical coordinates of shoreline position can be automatically recorded by GPS receiver. Mobile GPS technology can map areas with high precision, although it is time consuming and costly.

Airborne light detection and ranging (LIDAR) is an aircraft-based method that can generate a high-accuracy Coastal Terrain Model. Costal Terrain Model can be intersected with predicted water surface levels in order to obtain shoreline positions at any specific time. This method is the most reliable to obtain the prediction of high-water (HWL) and low-water levels (LWL) that enclose the shoreline position.

Shoreline data acquisition is one of the most labor-intensive undertakings in coastal studies. Traditionally it was performed manually, digitizing shoreline from topographic maps, or interpreting and tracing shoreline from aerial photographs. Recent technological developments allowed its automation by using digital image processing methods.

When data is under raster format, software tools can be used to automatically extract the shoreline (Lee and Jurkevich 1990, Shon and Jezek 1999). Most of the tools that can extract the shoreline from aerial photographs or satellite images can identify the thin wet sand zone from its own spectral signature, which is different from land and water. But the same tools are ineffective over large areas because the elements that define shoreline have different spectral signatures. An example of this technique can be obtained from the US Army Corps of Engineering (Hoeke et al. 2001).

An automated method for shoreline extraction from raster images was developed by Liu and Jezek (2003), who implemented a new technique based on the Canny edge detector algorithm. This method proved to be a reliable tool to extract shoreline along extensive coasts.

Currently, the high temporal resolution and increasing spatial resolution of remote sensing systems are available for detecting and monitoring shoreline movements (White and El Asmar, 1999). Although remote sensing can easily delineate the shoreline in some places, wet tidal areas still represent a problem, and conventional field-based surveying remains as the most reliable approach to determine shoreline position change over short time scales (Ryu et al. 2002).

2.4 GIS-based Analysis of Shoreline Dynamics

The study of shoreline dynamics has been based on the analysis of sets of individual transects drawn perpendicularly to a baseline. This has been the dominant technique in the field.

There is no clear consensus about the origin of the perpendicular transect method. Its assumptions are simple: at every point, the shoreline progresses or recedes along a major direction, which is perpendicular to the main orientation of the coastline.

The popularity of the transect method is due to its simplicity. Computers allowed the progressive automation of most of the tasks and a considerable reduction of the processing time. Attempts to automate transect extraction operations can be traced back to Dolan et al. (1978), who used manual measurements, along a baseline and punched the data into computer cards to computerize the calculations. Taking full advantage of progresses in computing, Clow and Leatherman (1984) developed a new technique for the definition of baselines and transects, which substantially increased automated components.

Currently, the most user-friendly and powerful tool available is the digital shoreline analysis system (DSAS), created by Thieler and Danforth (1994). This program was originally developed using loosely couple programming technique, while current versions use the ArcView Avenue Macro language, which converted the tool into an extension of ArcView 3.3. Within an ArcView environment, DSAS can benefit from the other GIS capabilities of ArcView, such as importing shapefiles, coverages and grids, editing, and changing projections. The latest version of DSAS can be downloaded freely from the USGS web page (Thieler et al. 2003).

GIS systems provide new or improved capabilities to study shoreline dynamics. The GIS vector format can handle accurate geographic positions that allow for detecting a very small displacement of spatial features. More recent software specifically developed for coastal analysis gained increased flexibility by using the vector-based concept of polyline, which can be treated as objects, instead of ASCII or binary files that only contain pairs of coordinates.

GIS programs such as DSAS or the Shoreline Shape and Projection Program (SSAPP) of the University of Texas treat shorelines as being constituted by sets of polylines. Each polyline is an ordered collection of paths that can be connected or disjointed (Cadkin, 2002). The paths contain a collection of segments defined by pairs of points (from- and to-points) that must contain x, y values; optional values attributes height, and other properties can also be assigned to each point or line segment.

Newer versions of ArcView of the 8.x generation further improve GIS capabilities for coastal analysis. Having Visual Basic for Applications (VBA) embedded in the system allows for the quick creation of customized applications that can handle a shoreline as an object with its own properties, methods, and events (or actions in the system).

The full use of Object Oriented programming technique and GIS embedded functions in this research allows analyzing shoreline displacement in an easy way without the limitations found in traditional methodologies. The use of polygon overlay and vector analysis is the key element for modeling shoreline displacement.

2.5 GIS-based Data Model for Shoreline Representation

The best option to represent shoreline data in an ArcView environment is provided by the dynamic segmentation data model. The model is built upon the arcs of a line coverage, and allows for the use of real-world coordinates with linear measures.

Dynamic segmentation involves three types of elements: routes, sections and events. A section is a set of related arcs in the line coverage, and provides measures to a route system. A route, which is also a linear feature made up by sections, has a unique identifier and measurement system on the *m* value of attributes, and is treated as a sub-class in line coverages. Events are attribute data such as occurrences and local conditions that are related to the route system by measures of their location. The process of developing a model requires the creation of routes, their measurement, and building event tables.

Bartlett et al. (1997) proposed a dynamic segmentation approach to the coast to facilitate the creation of sensitivity maps. The key variables for their dynamic segmented linear model fell under three major types: environmental data (shoreline types, shore structure, sediments), socio-economic and cultural data (population, scientific interest), and mathematical weight values.

The model created by Bartlett et al. (1997) not only improved shoreline representations in GIS, but also became the foundation for a coastal zone geographic information system (CZGIS). One of the major advantages of this type of GIS is its ability to store shorelines as unique features (polylines) using a route model.

Coastal management agencies have adopted the dynamically segmented model with the purpose of applying classification schemes along the coast using tables. This proved to be a faster method for classification processes, since there is no longer the need of storing the same feature twice, and avoids editing processes that require splitting the shoreline in classified segments. The model also became popular with coastal decision-makers and scientists aiming to better understand the coast, as a framework for storing vital information that can be easily retrieved, mapped and analyzed.

More recently, Morton and Peterson (2003) proposed a schematic model to perform coastal classification. The model is based on a comprehensive list of coastal types based on morphological characteristics that can be easily traced in aerial photographs.

The presence of a given characteristic along a sector of the coast can be treated in a GIS environment as an arc and visually represented through color-based codes. Morton and Peterson also presented an atlas to illustrate the application of their method (Fig. 7).

The advantage of the Morton and Peterson method is that allows for multiple classification of the same segment of the coast when several characteristics are present.

Fig.7 Ideal shoreline classification scheme. Coastal classification atlas by Morton and Peterson 2003

Once all the linear features are identified and coded, segments and routes can then be established according to combinations of criteria defined by the user. Two segments with the same characteristics are expected to have the same behavior.

The concept of dynamic segmentation can also be applied to studies of shoreline displacement. The model provides a reliable tool that identifies segments that have the same net drift direction in order to analyze their temporal-displacement. Flexible combinations of multiple criteria and accurate measurements that can be used at any scale are the real advantages of working with shoreline segments, since assumptions of net drift direction based on large regional scale indicators may give false information if applied on local project scale (CETN, 1992).

The Fig. 8 shows the methodology that supports this research. The new methodology deepens on polygon and linear analysis.

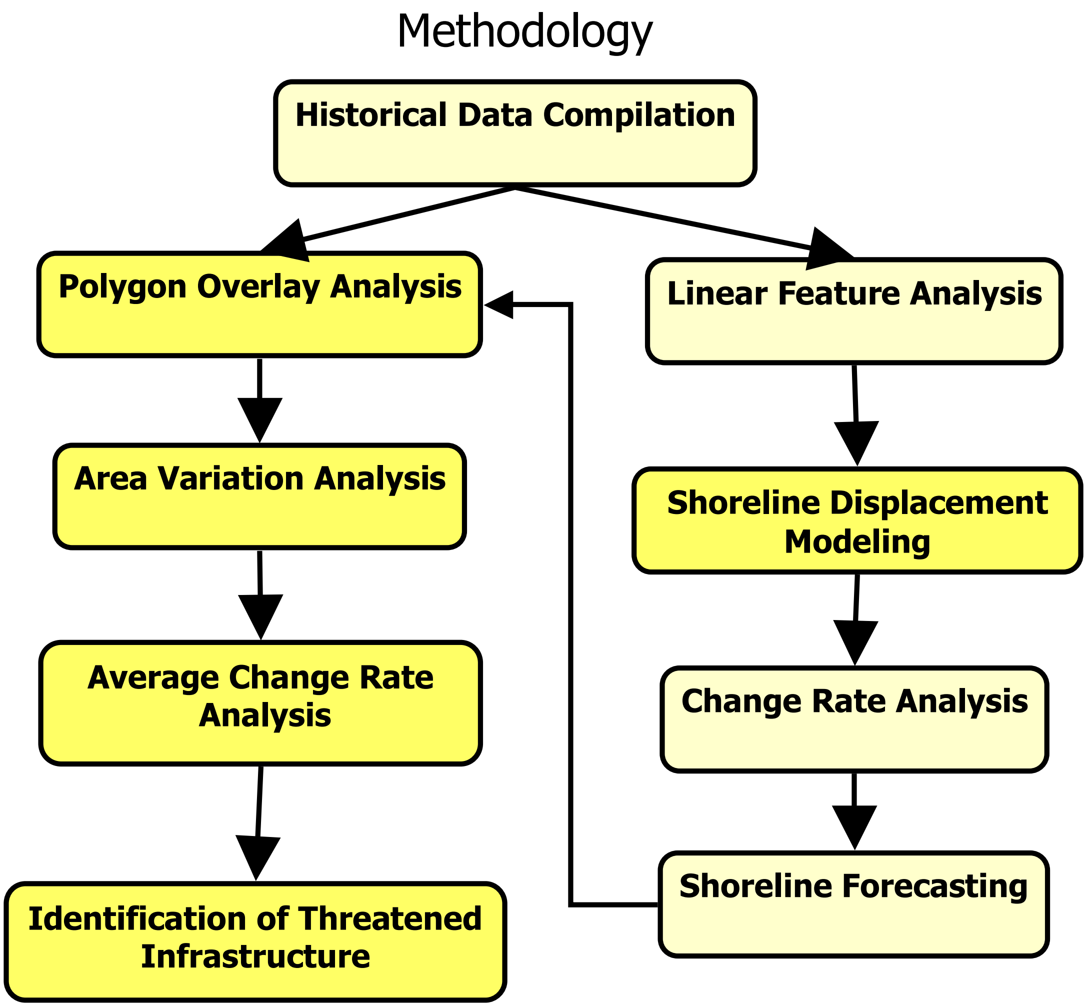


Fig 8. Methodology flow chart

CHAPTER III

COASTAL AREA VARIATION

GIS provides tools to calculate area variations along shorelines. GIS-based polygon overlay analysis was used to analyze land loss and accretion, using some of the simplest GIS operations. Under the method proposed under this section most of the tasks have been automated to save data entry, repetition of instructions, and processing time.

The shapefiles imported from the Texas Bureau of Economic Geology were converted into a personal geodatabase in order to save storage space and processing time in several operations, and minimize risks of file damage. Geodatabases store tables and layers having common attributes under the same file, while shapefiles or coverages require several independent files for each layer, with an obvious duplication of information.

3.1 Data Model for Coastal Area Variation Analysis

Linear objects are not well suited to the study of aereal variations in a GIS environment for topological reasons. Land surfaces require the use of polygons, the basic GIS object used to represent an area. A polygon consists of a closed chain of arcs.

Land mass and ocean mass can be represented by two separate polygons. The shoreline is the common boundary (arc) between land polygon and ocean polygon.

The historical shorelines obtained from the Texas Bureau of Economic Geology are linear features. A polygon implies a closed chain of linear features (arcs). The Texas Bureau of Economic Geology shorelines are interrupted when they meet the mouth of a river or a coastal inlet, as well as where there are digitizing gaps. In these situations, the linear shoreline is edited to fill shoreline gaps, lines are added by extending upstream until it meets the last historical shoreline (the one that is farther from the sea, no matter its age). The extended shoreline segment follows the same line that connects the two portions of the last historical shoreline.

It is important that all the gaps are closed in each historical shoreline; otherwise errors will be introduced in further area computations (Fig. 9).

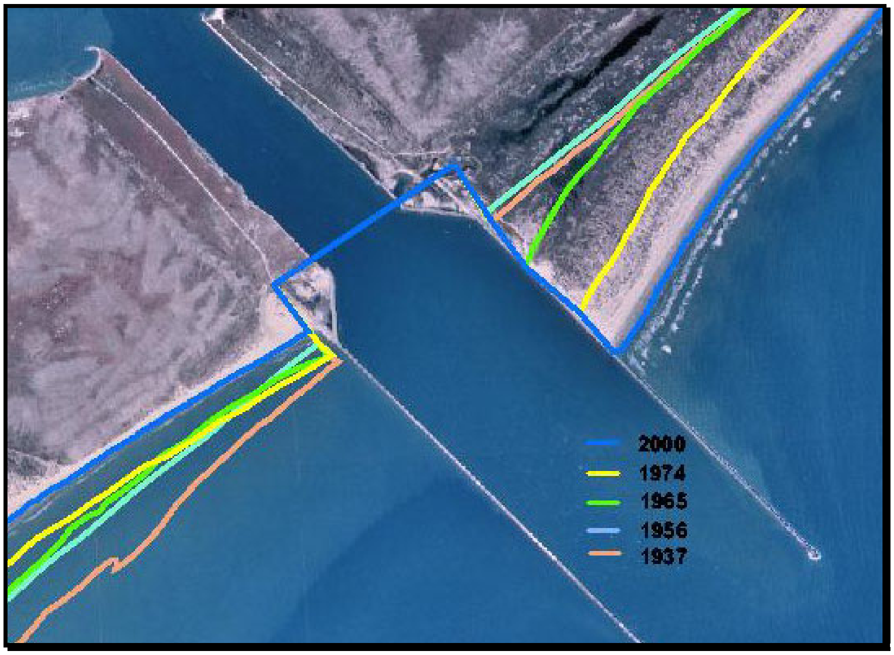


Fig. 9 Closing gaps

Finally, each historical shoreline is topologically coded and stored as a different layer in order to execute GIS vector polygon overlay operations.

Closing the gaps in the BEG historical shorelines and coding each historical data set as a separate layer are the data pre-processing operations necessary to start calculating area changes along the coastline.

3.2 Area Change Analysis

The method that was developed in this study to measure areas of erosion or accretion on the shoreline is based on the intersection of lines and polygons and polygon-to-polygon overlays. This method was selected primarily because the intersection and overlay functions are inserted in any basic GIS system, as well as the operations for polygon area computation.

The overlay operation is feasible, simple, and quick to perform. Once a portion of the coast is selected for analysis, it is necessary to verify that each historical shoreline layer is coded as a polyline and all the gaps along the linear shoreline were closed.

In the first step of the method, a rectangular polygon enclosing all the study area is drawn using new polylines as its sides. For the remaining steps of the process it will act like a boundary polygon in every layer, framing the area where all the subsequent operations will be performed.

In the second step, each of the historical shorelines is successively intersected with the rectangular boundary polygon. In each operation the linear shoreline cuts the rectangle into two enclosed portions – one related to land surface, the other to water surface. After intersection, each of the portions has to be topologically coded as a polygon. A field "Polygon_Code" is added in the corresponding polygon attribute table. In the new field the value 1 is assigned to the new polygon that represents land, and the value 0 to the polygon that represents water.

The third step can be performed after all the historical shorelines were processed and coded as land and water polygons. From the available historical layers it is possible to perform comparative analysis of pairs of shoreline layers.

The two selected layers are intersected in order to produce a set of polygons of different characteristics. The operation is illustrated by the contents of Table 2, where Polygon_Code A represents the older of the two historical shoreline layers, and Polygon_Code B the newer of the two. Those intersected polygons whose Polygon_Code did not change from one layer to the other could be disregarded. When a land-based polygon gives place to a water-based polygon, water advanced over land, and therefore there was a loss of land due to erosion; conversely, when a water-based polygon gives place to a land-based polygon, there was an accretion of land.

Table 2 Boolean interpretation table

Polygon_Code_A	***Polygon_Code_B***	
1 (land)	1 (land)	1 Land (no change)
1 (land)	0 (water)	1-0 Erosion
0 (water)	1 (land)	0-1 Accretion
0 (water)	0 (water)	0-0 Water (no change)

The output of this process is a new polygon layer. From the analysis of its polygon attribute table it is possible to identify the areas of erosion, accretion or non-change, and proceed to their measurement using ArcMap spatial queries and functions (Fig. 10).

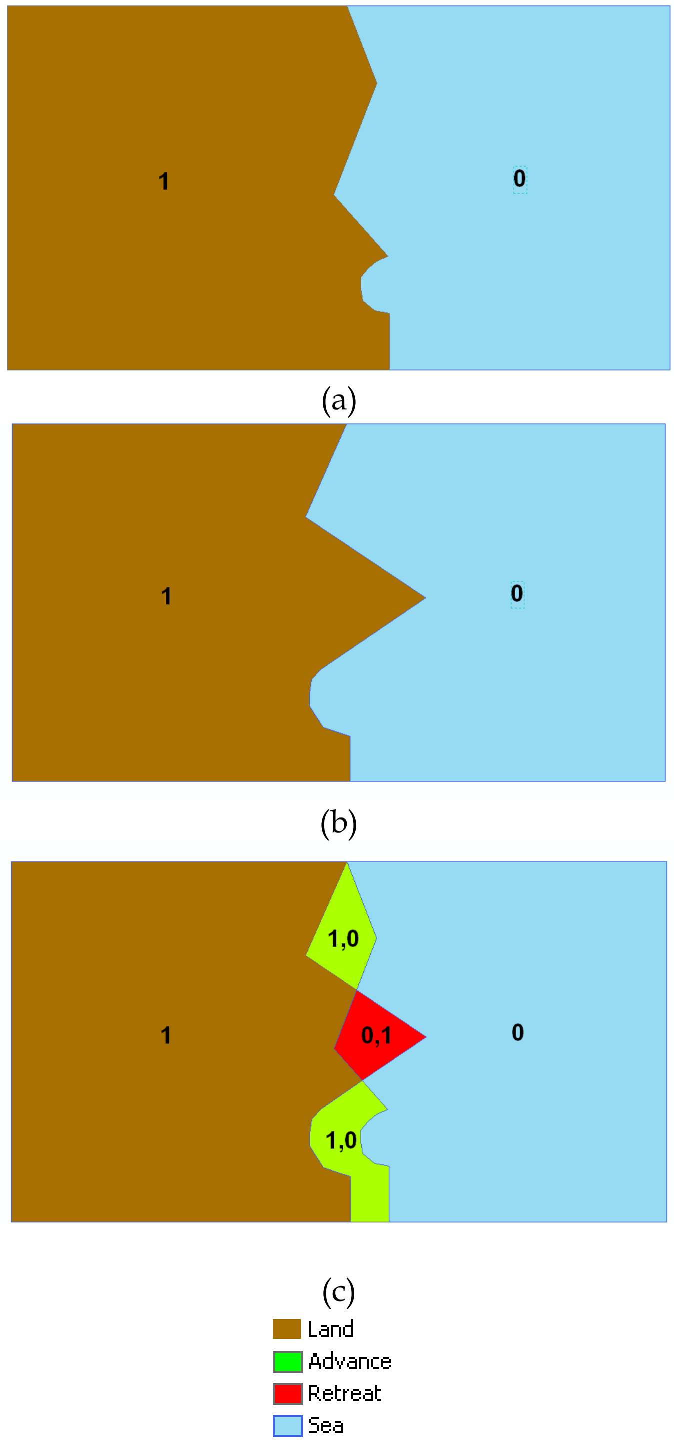


Fig. 10 Polygon overlay analysis. Two polygon layers (a and b) are intersected, and the result (c) can be interpreted using the Table 1.

A VBA macro program for ArcGIS 8.x is developed to automate the coastal area variation analysis. This program creates the intersection layer, interprets the results, obtains the total area affected, and generates symbology for an easy visual interpretation. Its code is listed in the Appendix A.

3.3 Area Variation Analysis

Three sectors were chosen based on historical shorelines extracted by the Texas Bureau of Economic Geology for each area. Even though periods between measurements varied significantly, it is possible to identify the periods of more significant land gains or losses, as well as some general trends over time. The results obtained are presented for each area at a time, based on their relative location from east to west.

3.3.1 Sabine Pass to Brazos River

The longest coastal sector analyzed extends eastward from the Brazos River mouth to the border between Texas and Louisiana. For this area there were six data sets available (1856, 1936, 1956, 1974, 1982, and 2000), and five intermediary periods were analyzed.

There is not a consistent pattern, as periods of significant erosion (especially 1856-1936 and 1956-1974) were immediately followed by more stable periods (Fig. 11). During relatively stable periods, the advance or retreat areas were small, and their values similar. In the periods showing an imbalance between areas of erosion and accretion, eroded areas were always greater than accretion areas, both in relative and absolute terms. Overall, and especially after 1936, it is possible to observe a general trend towards smaller aggregated effects (accretion or erosion) over time.

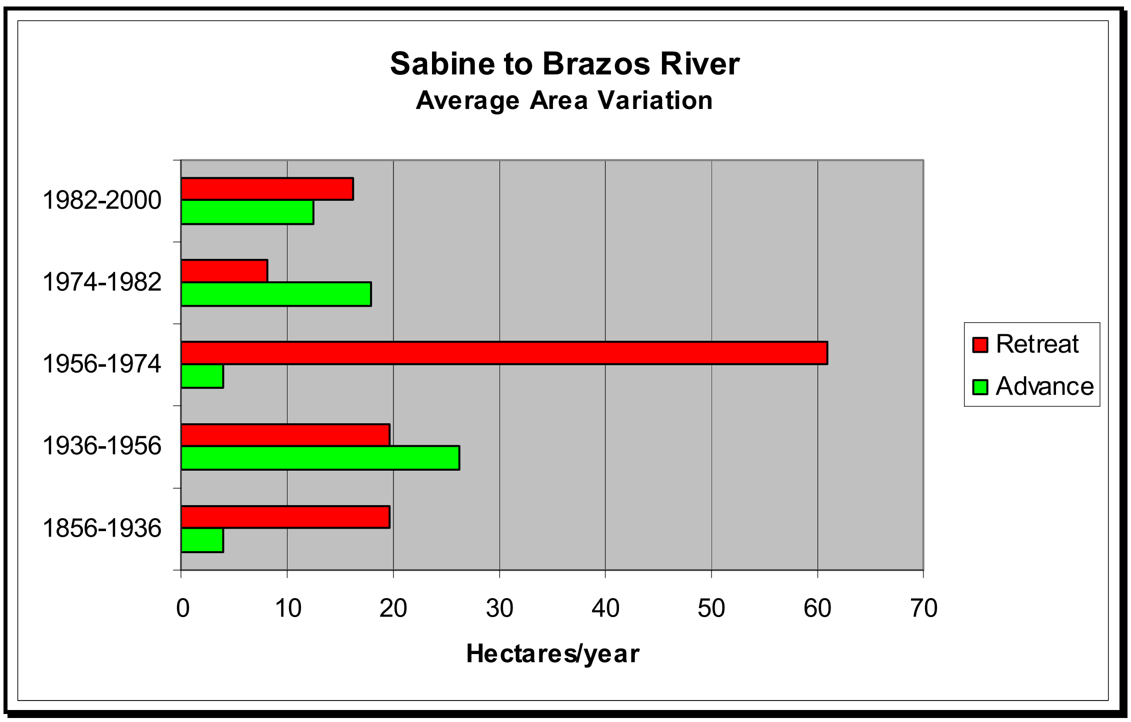


Fig. 11 Sabine to Brazos River average area variation

It is possible that the extremely high values for eroded areas were linked with a few major storms that occurred before the surveys. This may be the case for the 1974 shoreline, which shows a relatively high area being eroded, whose survey was relatively close to hurricane Edith (September 3-18, 1971) and tropical storm Delia (September 1-6, 1973), two cyclonic events that hit this segment of the coast with catastrophic effects.

A similar hypothesis can not be raised for the high value of the eroded areas for the period 1856-1936 and the September 8, 1900 Galveston Great Storm. Both the time difference between storm and survey is quite long, and it is not possible to separate the storm effects from those of the protective infrastructure that was implanted afterwards on the coast.

During the study period the effects of human activities were relevant. The portion of this sector showing the highest accretion area (totaling a net gain of 3.048 square kilometers over the whole period) corresponds to the Bolivar Flats, on the ocean side of the tip of Bolivar peninsula. This area is directly affected by the protective structures built at the entrance of Galveston Bay, which guarantee deep-water access to the ports of Galveston and Houston. From aerial photographs, it is observed that sediments carried westward are blocked and tend to accumulate behind the protective barriers (Fig. 12).

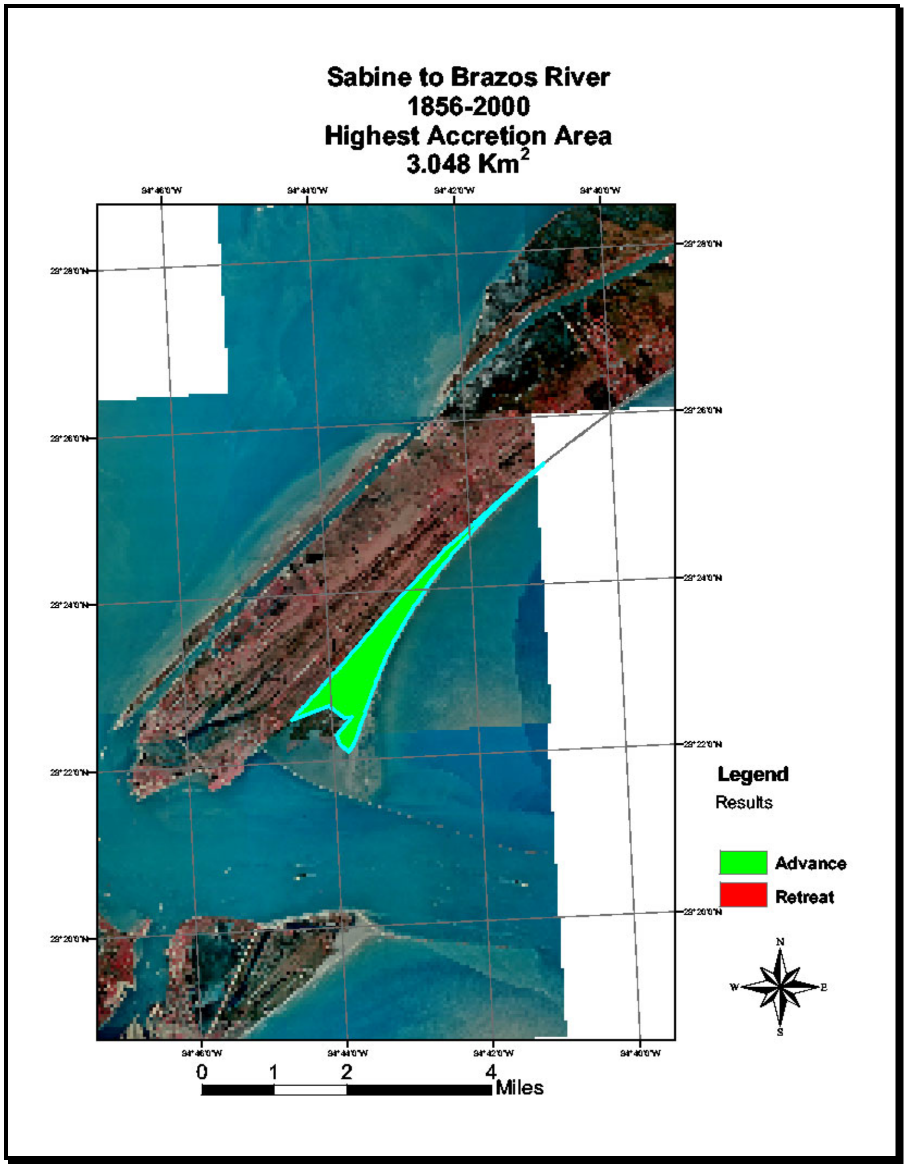


Fig. 12 Sabine to Brazos highest accretion area

The largest area of this sector affected by erosion processes is located along the coastal sections of Chambers and Jefferson counties, immediately to the east of Bolivar peninsula (Fig. 13). This area extends in longitude from approximately 94°05′ W, close to Sea Rim marshes, just South West of Port

Arthur, to 94°30’W, near the town of Caplen, on the isthmus of Bolivar Peninsula. During the study period, the total area losses along this tract of about 50 kilometers of shoreline amounted to 12.01 square kilometer.

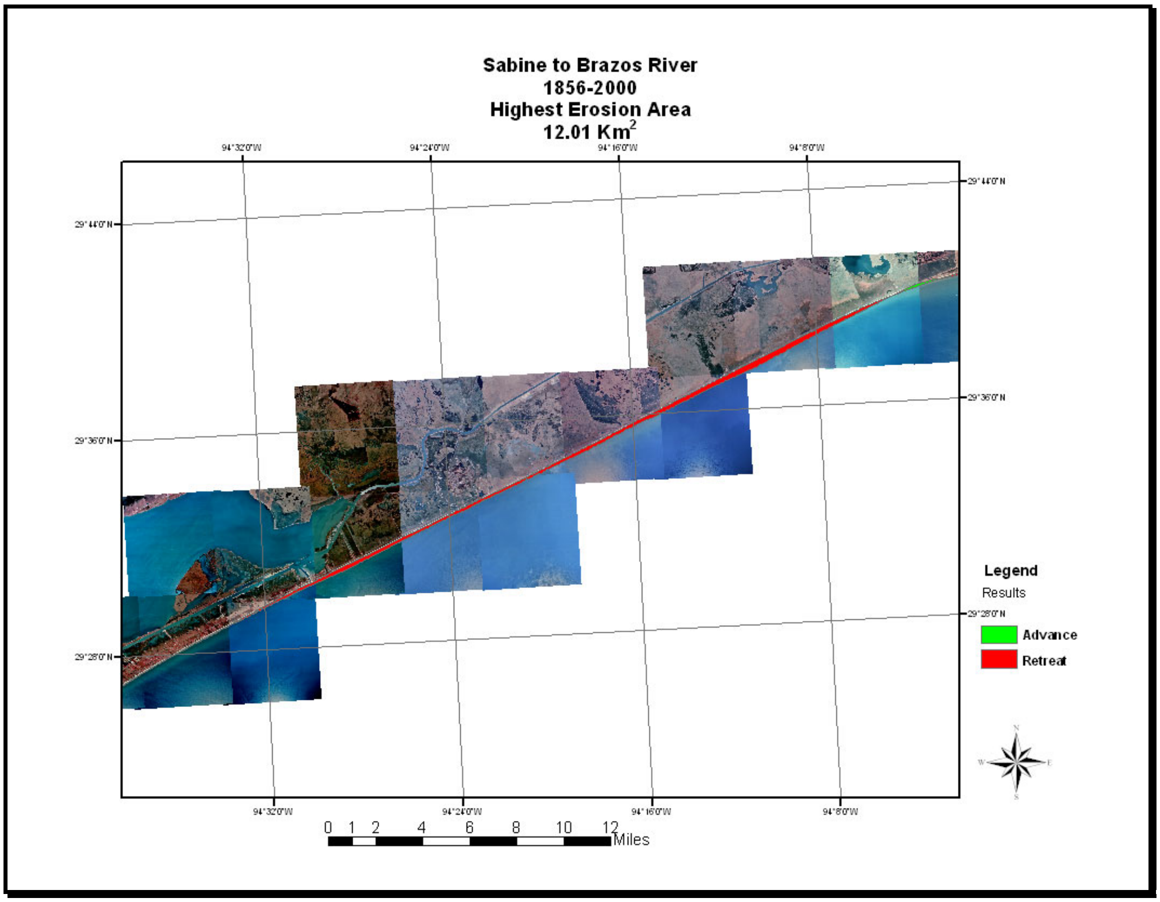


Fig. 13 Sabine to Brazos highest erosion area

The construction of major port-related and shore-protecting infrastructure may have had in the coastal erosion processes in the area.

3.3.2 Brazos River to Pass Cavallo

The coastal section between the Brazos River mouth and Pass Cavallo corresponds to the Gulf of Mexico coast of the Matagorda peninsula. For this area there were five data sets available (1937, 1956, 1965, 1974, and 2000), and four intermediary periods were analyzed (Fig. 14).

It is evident that in this sector erosive processes are dominant. For each shoreline extracted, the total area loss to erosion is larger than the area gained to accretion.

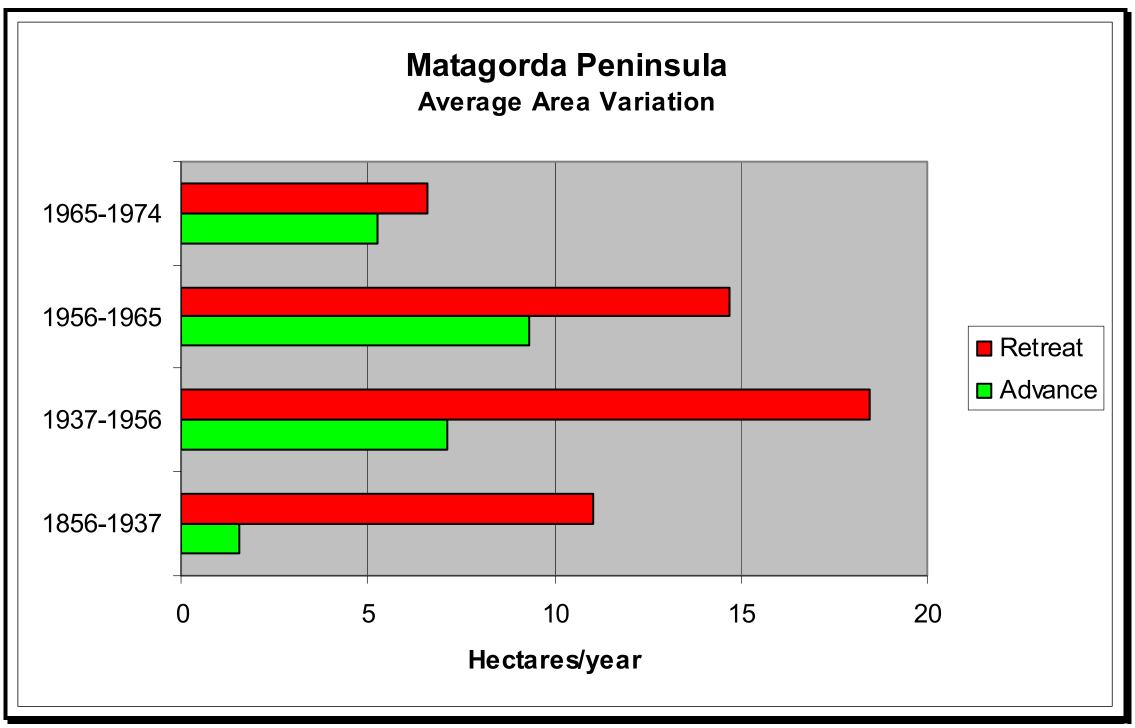


Fig. 14 Matagorda Peninsula average area variation

A small trend in the ratio between eroded and accreted area, which is decreasing over time is discernible. For early periods, eroded areas were comparatively much larger than accreted areas, while the gap between the two figures seems to be close trough over time.

This relative increase in the importance of shoreline accretion may be linked directly to human intervention. During the study period, the largest advancing area (a net gain of approximately 1 square kilometer) is occurred in the eastern Matagorda jetty (Fig. 15), which was built to protect the navigation channel accessing Matagorda Bay. This channel, close to the western tip of Matagorda peninsula, gives access to Port Lavaca and the Intracoastal Waterway. From aerial photographs it stands out that net gains in area are at a maximum behind the jetty, and then progressively decrease away from it.

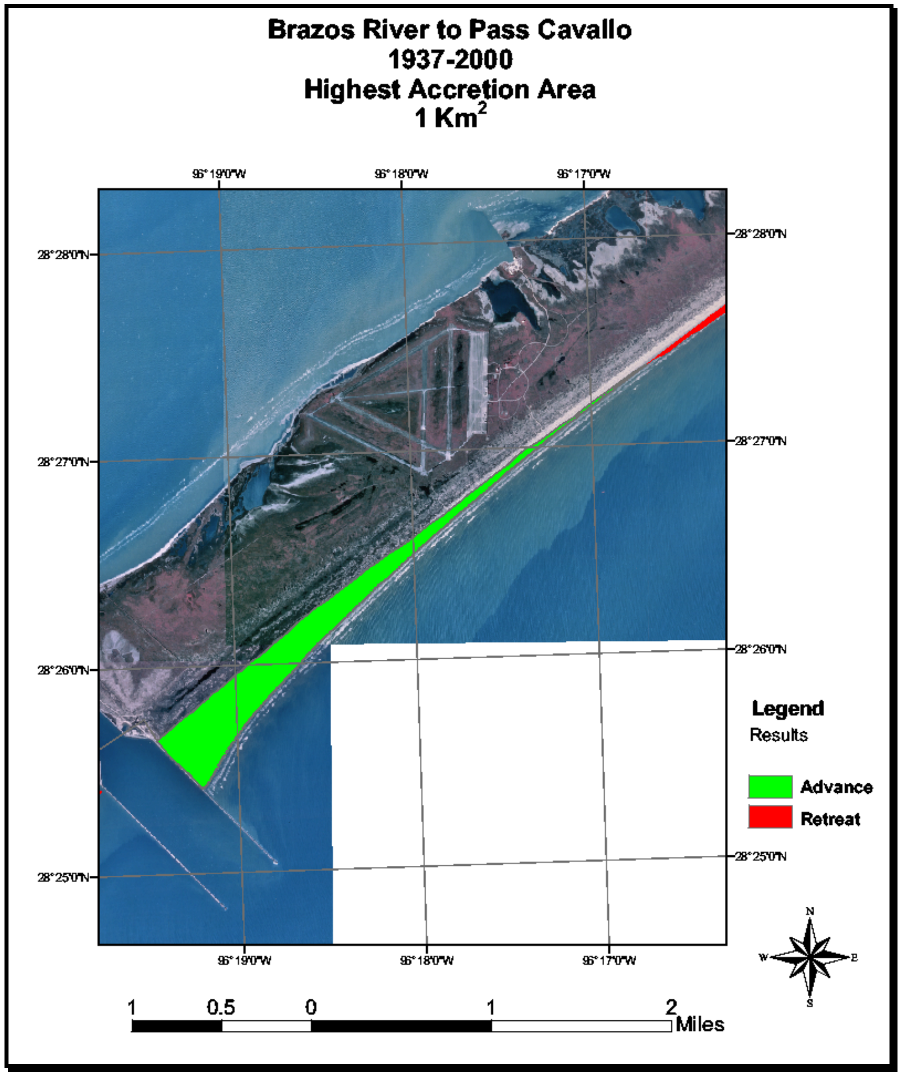


Fig. 15 Matagorda Peninsula highest accretion area

During the whole study period, the portion of this sector that suffered the highest aggregate losses corresponds to the middle portion of the Matagorda peninsula (Fig. 16), from approximately 98° W to 98° 14' W of longitude. In this long tract of about 25 km there is a dominance of erosion along the whole length of the shoreline.

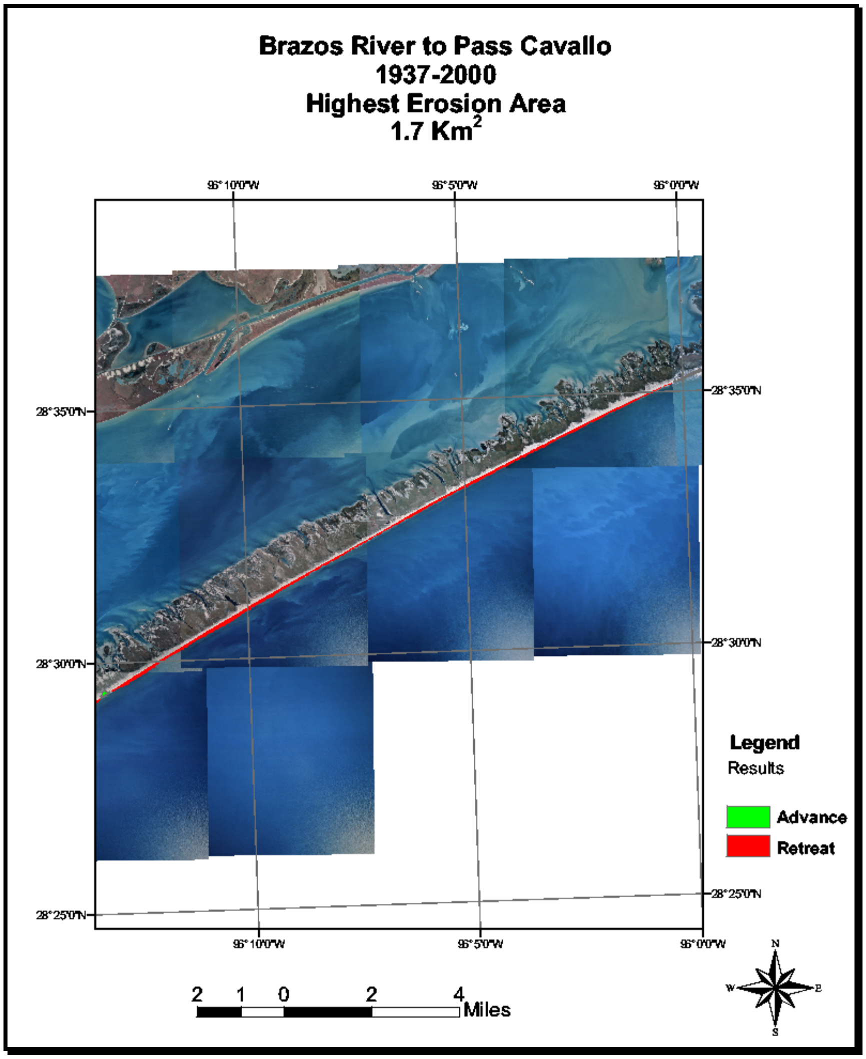


Fig. 16 Matagorda Peninsula highest erosion area

In this sector and the Sabine to Brazos, the largest aggregated area losses along the shoreline were located just eastward from the area of maximum land accretion. This vicinity of an area of significant erosion to the east and an area of significant accretion to the west may be a first indication of predominant movement of sediments from east to west along the middle and upper coast of Texas.

3.3.3 Aransas Pass to Padre Island

The third coastal section analyzed, from the Aransas Pass to the northern tip of Padre Island, corresponds to the oceanic front of Mustang Island, a barrier island that obstructs Corpus Christi Bay. For this area there were six data sets available (1856, 1937, 1956, 1965, 1974, and 2000), and five intermediary periods were analyzed (Fig. 17).

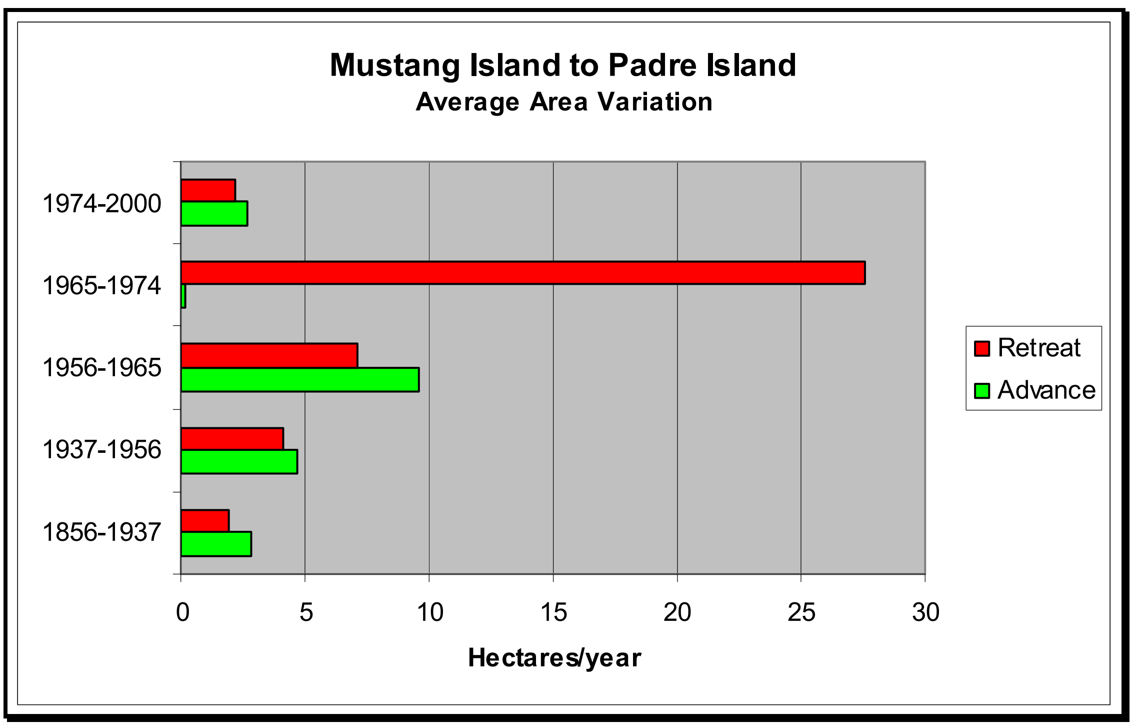


Fig. 17 Mustang Island average area variation

For the majority of the study period it is possible to observe a slight predominance of gains by accretion over losses by erosion. The only exception is the period 1965-1974, when there virtually no accretion and a significant area loss for the whole section. A possible explanation may be related to the effects of hurricane Celia, one of the most destructive ever recorded in history in Texas, that hit the coast on August 3, 1970.

In this tract of the coast the most significant accretion was located at Port Aransas, in the northern tip of Mustang Island (Fig. 18). At this location there was a net increase of 1.38 square kilometers between the southern jetty of Aransas Pass and Mustang Beach, over a tract with approximately 5 kilometers long.

The proximity between the protective jetty and the area of maximum land accretion, as well as the progressive decrease in shoreline advance as the distance increases from the infrastructure is again observed.

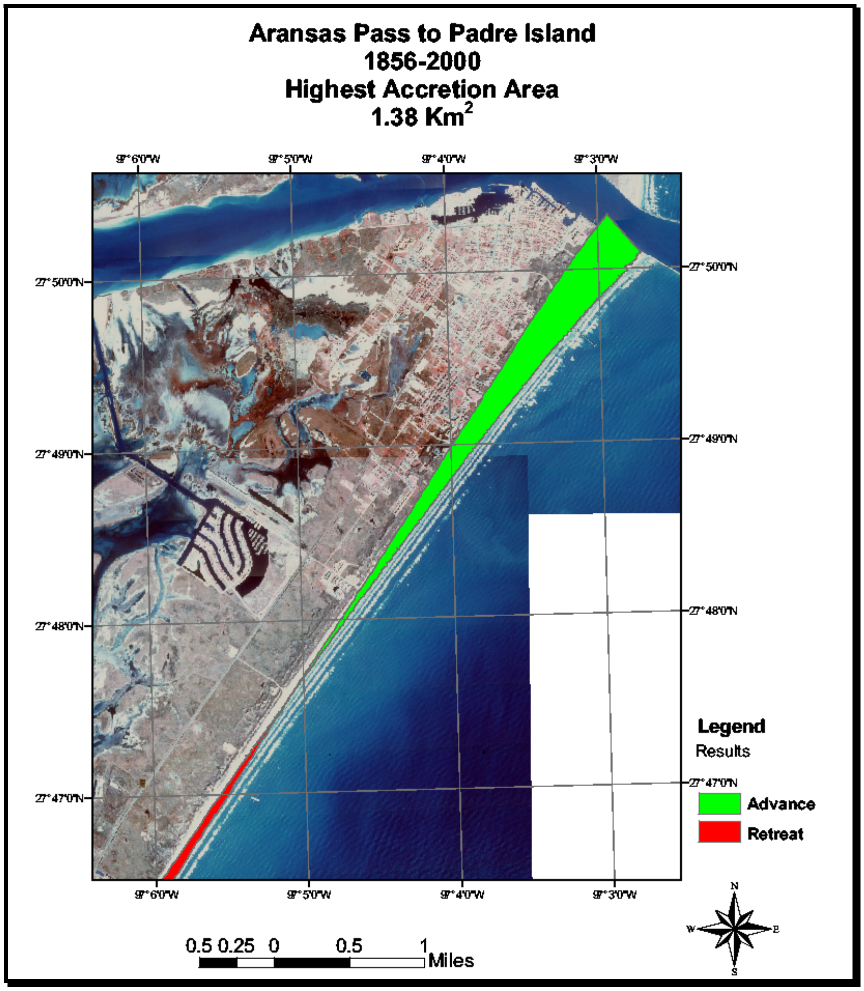


Fig. 18 Padre Island highest accretion area

For this sector of the coast, the tract with the maximum aggregated area losses corresponds to a portion of Padre Island (Fig. 19). It extends, approximately, from Padre Balli Park, southeast from Corpus Christi, southwards to a tract of open shore in Kleberg County, close to the beginning of the Padre Island National Seashore. The northern portion of this area is close to a small canal opened in the barrier island, giving access to an urbanized area on the bay side of the island. The net losses in this tract of the coast amounted to 1.36 square kilometers.

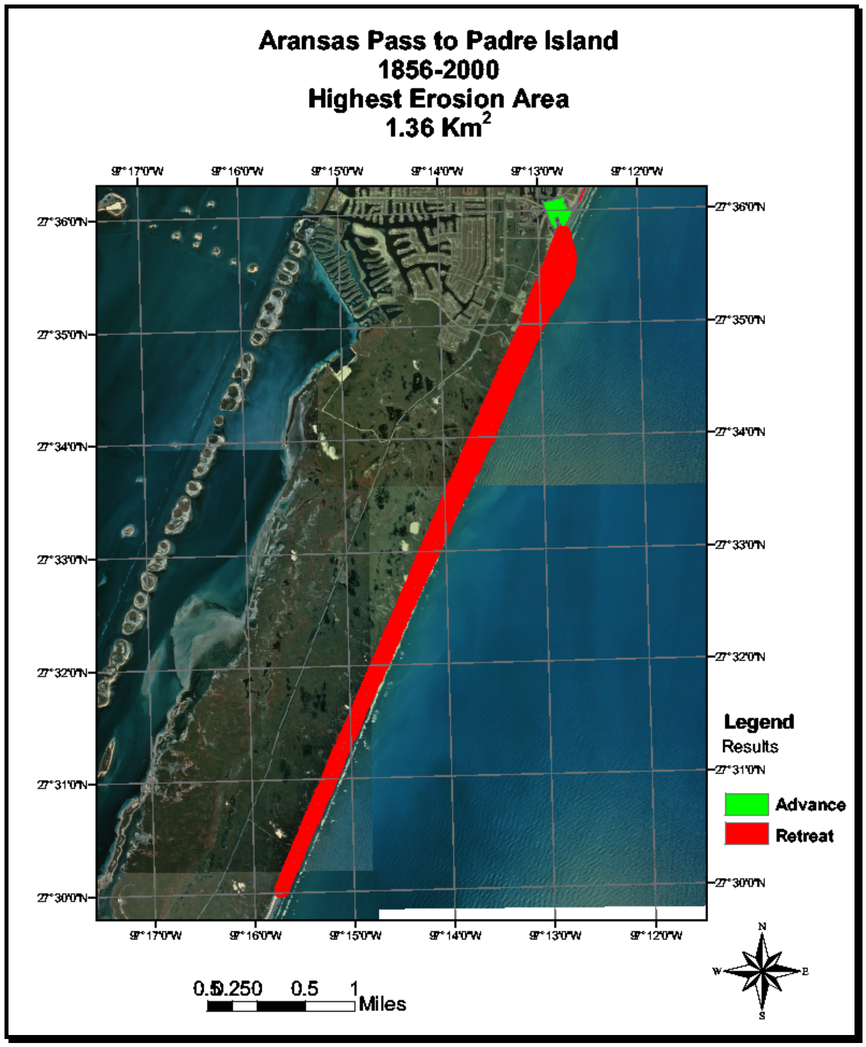


Fig. 19 Padre Island highest erosion area

In this sector of the coast the net land gains or losses are not as large as those in the other sectors. But as in the previous cases, it was verified that the shoreline tract that experienced the maximum area accretion was in the immediate vicinity of a jetty protecting a navigation channel.

The study of shoreline displacement using historic shorelines in a GIS environment using polygon features allowed the identification of the tracts of coast where the most noteworthy changes were happening, and where direct field measurements would more likely be necessary. It also provided some preliminary evidence that there is some direct link between the human intervention and significant land increases in the neighboring areas sheltered by the protective structures of navigation canals.

The coastal areal variation analysis supports the hypothesis that if protective jetties were retaining sediments, and therefore blocking their movement along the coast, they were interfering directly with natural processes along the Texas coast.

By identifying the sources of the sediments deposited close to jetties, it would be possible to verify if human infrastructure may increase sedimentation in some areas by increasing erosion in others.

3.4 Coastal Area Variations for Forecasting

The area gains or losses between two historical shorelines are the key factor to estimate the economical impacts of coastal changes at any given place. In coastal management, the knowledge of the area affected as a consequence of shoreline position change is mandatory. The total economic value losses are direct related with real estate that had defined the cost of each square meter in the nation.

The variation area between the latest and the predicted shoreline obtaining a polygon that can be overlap with an aerial photography, satellite image or land parcel data. It can be realized by ArcMap's transparency visualization technique, setting the transparency of polygon layer to 60 percent in the "EFFECT" tool bar. This procedure allows identifying easily the infrastructure and areas under threatening in the future due to shoreline dynamics.

CHAPTER IV

SHORELINE DYNAMICS

The topological constrained transect method (TCTM) developed in this study requires that all the historical data sets are represented in a common coordinate system.

The TCTM operates directly with the historical shorelines in ArcMap, the visualizing module for ArcGIS (ArcView or ArcInfo).

This method also avoids the problems created by using the raster-based shortest path proposed by Duffy and Dickson (1995), which does not take into account that one point must not be connected to several points, since it would break the univocal relationship that must exist between historical shorelines; a second disadvantage of their method follows the use of raster technology that requires much larger amount of storage space than vector.

4.1 Definition of Critical Points and Dynamic Segments

Critical points are prominent points of the shoreline, and they correspond to major directional changes, geological changes and major infrastructure that can be visually located in the shoreline maps. Every nodal point should be used as a critical point in the TCTM, since they mark the point boundary between areas dominated by erosion and areas of accretion. But in most cases, nodal points are insufficient and additional critical points have to be defined (Fig. 20).

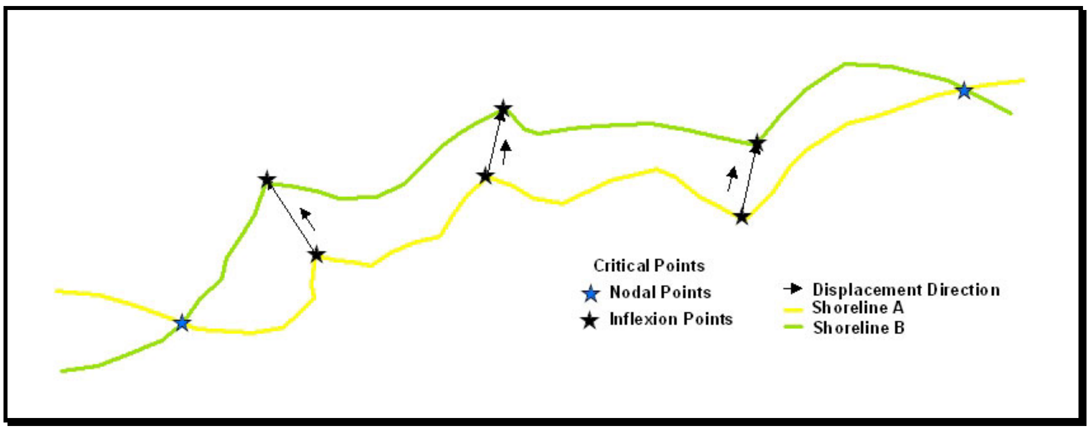


Fig. 20 Critical points

Two methods can be used for critical point selection: 1) through analyzing shoreline geometric properties (i.e. inflection points, fractal dimension); 2) through visual inspection (identification of coastal infrastructure locations using aerial photography).

A labeling tool is designed to interactively mark and label points along a shoreline (Appendix B). At each labeled point the tool draws a line (a labeled transect) perpendicular to the shore. The tool automatically creates a table where all the labeled transects are displayed, along with their relative location (Fig. 21).

Attributes of trans 1856

OBJECTID*	SHAPE*	SHAPE_Length	position
2295	Polyline	199.999961	0
2296	Polyline	200.000010	100.051
2297	Polyline	199.999971	200.103
2298	Polyline	199.999966	300.154
2299	Polyline	200.000145	400.206
2300	Polyline	200.000042	500.257
2301	Polyline	199.999990	600.308
2302	Polyline	200.000049	700.360

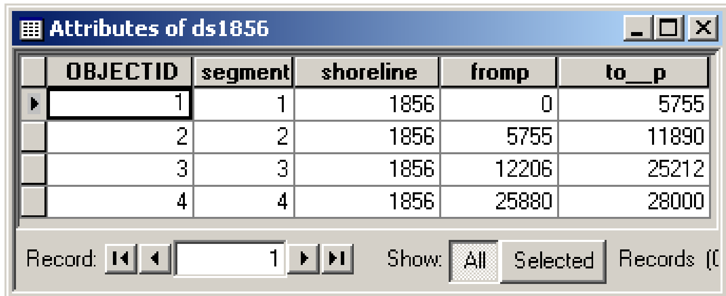
Record: 1 Show: All Selected Records (0 out of 619 Selected.)

Fig.21 Perpendicular transects attribute table

Places where two consecutive labeled transects converge or diverge abruptly are potential candidates for critical points.

New critical points are selected by the operator, based on the relative position of the labeled transects, directional changes of the shoreline, and the position of other historical shorelines. The selection must ensure that no arbitrary choices are made, and only those points that represent clear ruptures are finally selected.

Two consecutive critical points define segments of the shoreline that will be extracted through a dynamic segmentation process. Critical points and segments will be defined by entering the values of distance to the origin of both the from-point and to-point of each segment in the "fromp" and "to_p" columns of a DBF table (Fig. 22). The tool also requires the identification of the historical shoreline and the number of each segment.



OBJECTID	segment	shoreline	fromp	to__p
1	1	1856	0	5755
2	2	1856	5755	11890
3	3	1856	12206	25212
4	4	1856	25880	28000

Fig. 22 Dynamic segmentation table

Three basic conditions are required for the success of the subsequent steps. First, all the historical shorelines must have the same number of critical points, in order to ensure the same number of dynamic segment. Second, once a critical point is selected, the corresponding critical points in other historical shorelines must be selected; the best way to ensure this condition is to perform the selection process in all the shorelines simultaneously. Third, segments defined by equivalent pairs of critical points in different historical shorelines must have the same identification numbers in all the DBF tables.

Each historical shoreline will be automatically converted into a route model by using the ArcMap "create route" tool and selecting its geometric length option. Once the system has a DBF table and a route model is available, it will be possible to start the dynamic segmentation process of the shoreline.

The segmentation process based on ArcMap editing tools (especially the split polyline tool) is extremely time- and storage space-intensive because it requires the creation of many new polylines. To overcome these problems the dynamic segmentation of the shoreline was chosen. A good source to understand the basis of dynamic segmentation is Cadkin (2002).

The use of the coastal geomorphic classification proposed by Morton and Peterson (2003) and previously discussed in section 2.5 has the potential to be used as the base for the future automation of dynamic segmentation over large coastal areas.

4.2 Transect Building with the Topological Constrained Transect Method

After complete the dynamic segmentation of the shoreline, its displacement can be analyzed with the TCTM (Fig. 23). The source code are available in Appendix C.

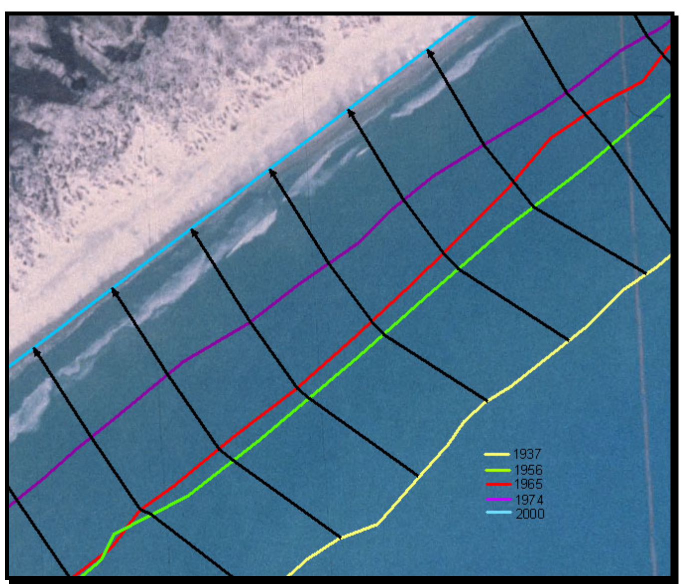


Fig. 23 Topological constrained transects

The TCTM operates with a basic object, transect. Each transect is a polyline with a from-point, an end-point and several intermediate vertices. The from-point corresponds to the starting point of the transect, in the older historical shoreline considered, while the to-point is the final point where the transect reaches the most recent historical shoreline. When the transect reaches an intermediate shoreline, a vertex is defined.

Once the software is initiated, a pop-up window appears, requiring the identification of the segments should be analyzed (based on the segment identification numbers in the DBF tables). The operator has the option of choosing from the whole shoreline to several, or even a single segment, and the number of transects that will be traced within the selection.

Once the segments for analysis are selected, TCTM automatically starts to link equivalent critical points in all the historical shorelines by transects, and at the same time interpolate new transects in order to achieve the specified number of transects. The corresponding points in different shorelines are estimated proportionally from shoreline to shoreline, and not by perpendicular lines. This process will ensure that the number of interpolated points will remain the same over corresponding segments, and all these points in the same segment will be equally spaced.

The new transects created through this method are not unidirectional. Each transect is composed of several links, and each link has a length and direction of its own. The number of links per transect is directly dependent on the number of historical shorelines.

4.3 Shoreline Displacement Analysis

The TCTM is designed to track the historic movement of each vertex on the shoreline along each transect. The result is a composite vector, showing the successive positions occupied by a specific point over time (Fig. 24).

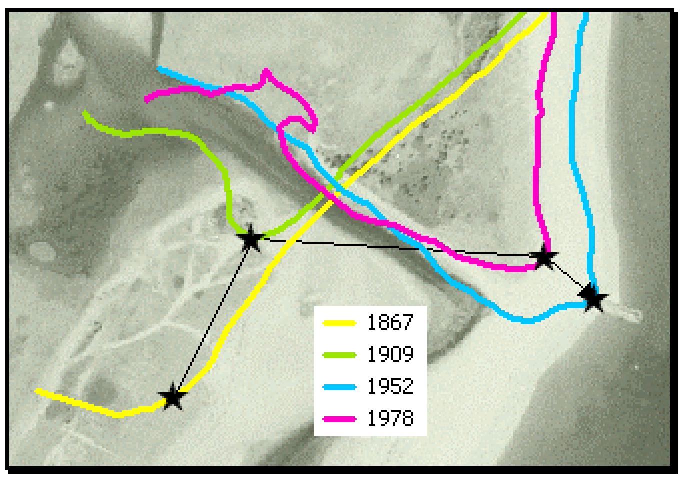


Fig. 24 Critical point displacement (data set obtained from the DSAS tutorial)

One of the major advantages of TCTM over conventional methods is its ability to add a more realistic motion. Conventional perpendicular transect method assumes that shoreline movement proceeds perpendicular to the shore, in the same direction at every point. TCTM shows that directional drift at each point of the coast is not necessarily the same.

If only the first and last historical shorelines were considered, the link between the from-point, intermediate points, and the to-point would correspond to the resultant vector for shoreline displacement at the select position during the whole study period.

One of the best indicators of the reliability of TCTM can be found by performing interpolation between shorelines. The interpolation method assumes a stable change rate trough time between corresponding points of known position.

A interpolation macro program was developed in order to compute intermediate shoreline positions. For a pair of consecutive historical shorelines, the program considers the successive positions of points along transects created by the TCTM. Each transect segment is subdivided uniformly based on its length and the desired number of intermediate positions, producing a sequence of points (Fig. 25). For each intermediate period of time there will be a point in each transect. The macro program links the points of each transect that correspond to the same intermediate period of time and the resulting polyline is the estimated shoreline position.

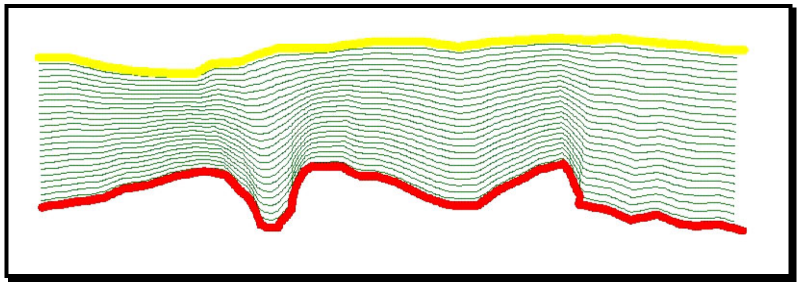


Fig. 25 Shoreline interpolation

If we use the real positions of a critical point in 1990 and 2000 to estimate nine intermediate positions, the method would assume a uniform movement, with the same displacement year after year. Using this method, the displacement between two known shorelines would correspond to the formula

$$P_m = P_o + r.\Delta t$$

where Δt is the average annual displacement, and *r* the number of years. But in reality the value of Δt is not a constant, and it can not be evaluated without the use of ancillary data.

Even though natural processes do not proceed at a steady rate in the real world, interpolation gives us the quite reliable estimates, especially when the interpolation is performed for small period of time. Over a long period, the error will increase, as it is not possible to ensure advance and retreat shifts had happened.

The critical point-based approach taken by TCTM produces a much more reliable estimate for shoreline positions between two measurements.

4.4 Computation of Advance and Retreat Rate

Two methods were used in this study to estimate the average rate of advance or retreat of the shoreline based on the information produced by the TCTM. The first, the resulting vector method, is a simplified method based only on the initial and final shorelines positions. The second, the linear regression method, includes intermediate historical positions (vertices) and uses linear regression to determine an annual displacement rate based on geographical coordinates.

In the resulting vector, the method looks for the vector linking the from- and the to-point of each transect generated by the TCTM. The length of the resultant vector is divided by the time elapsed between the first and the last historical shoreline. With this simple operation it is possible to obtain an annual average erosion rate. This process could be considered as a new and improved variation of the end-point method (EPM) for extracting average rates, since it adds displacement direction at the point level.

The linear regression method takes into consideration the changing spatial locations of each point over time. For each TCTM transect, the coordinates (x, y) of a vertex consist of a sequence. Each displacement between adjacent years could be considered as a vector, resulting from the combination of a horizontal displacement (x, or longitudinal) and a vertical displacement (y, or latitudinal). The horizontal displacement and vertical displacement can be treated as the linear function of time:

$$x = a_1 + b_1 . t$$
$$y = a_2 + b_2 . t$$

A linear regression method is used to estimate two slopes, one for each coordinate direction. The two slopes will define the cartesian components of the annual average erosion or accretion rate.

The formulas used for calculating are following:

$$b_1 = \frac{n\sum_{i=1}^{n}(x_i * t_i) - (\sum_{i=1}^{n} x_i) * (\sum_{i=1}^{n} t_i)}{n\sum_{i=1}^{n} t_i^{\ 2} - (\sum_{i=1}^{n} t_i)^2}$$

$$b_2 = \frac{n\sum_{i=1}^{n}(y_i * t_i) - (\sum_{i=1}^{n} y_i) * (\sum_{i=1}^{n} t_i)}{n\sum_{i=1}^{n} t_i^{\ 2} - (\sum_{i=1}^{n} t_i)^2}$$

$$AAER = \sqrt{b_1^{\ 2} + b_2^{\ 2}}$$

where t_i is the shoreline year for each historical shoreline, and x, y the coordinates of each vertex of the transect.

Both methods can be used to quantify the general shoreline movement trend, and identify areas subject to higher erosion rates. Results obtained from the linear regression use all information available while end point only takes into account the oldest and latest shoreline.

In order to determine rates of erosion and accretion along the study areas selected both the End Point and Linear Regression methods were used. The result obtained show that in less complex systems such as the Texas coast dominated by barrier islands both methods produce similar results showing the same overall trend. The Fig. 26 shows the main accretion area is located in the southern part of jetty of the Corpus Christie ship channel opposite to Matagorda (Fig. 27) and Galveston (Fig. 28) jetty where the sediment deposit is located in the northern sector. The erosion rates values obtained in the study area demonstrate that the general trend is erosion, and the jetties break the sediment flow creating accretion areas.

The erosion rates in Galveston and Matagorda are similar due to both sectors are subject to ocean currents, while Mustang Island sector the along current has less intensity.

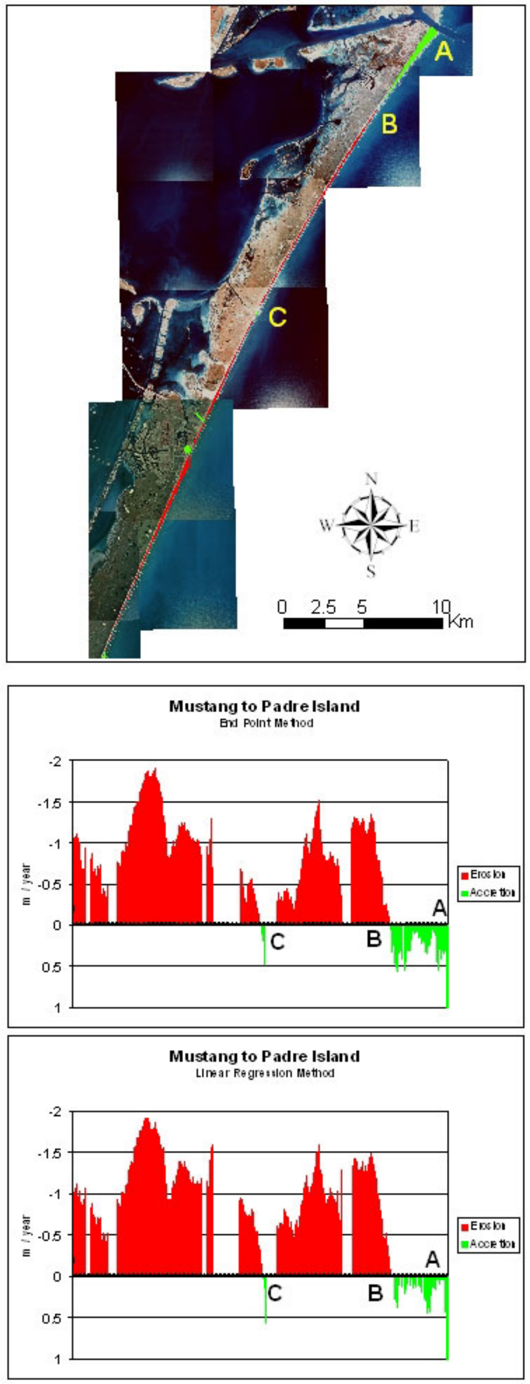


Fig. 26 Padre Island erosion rates

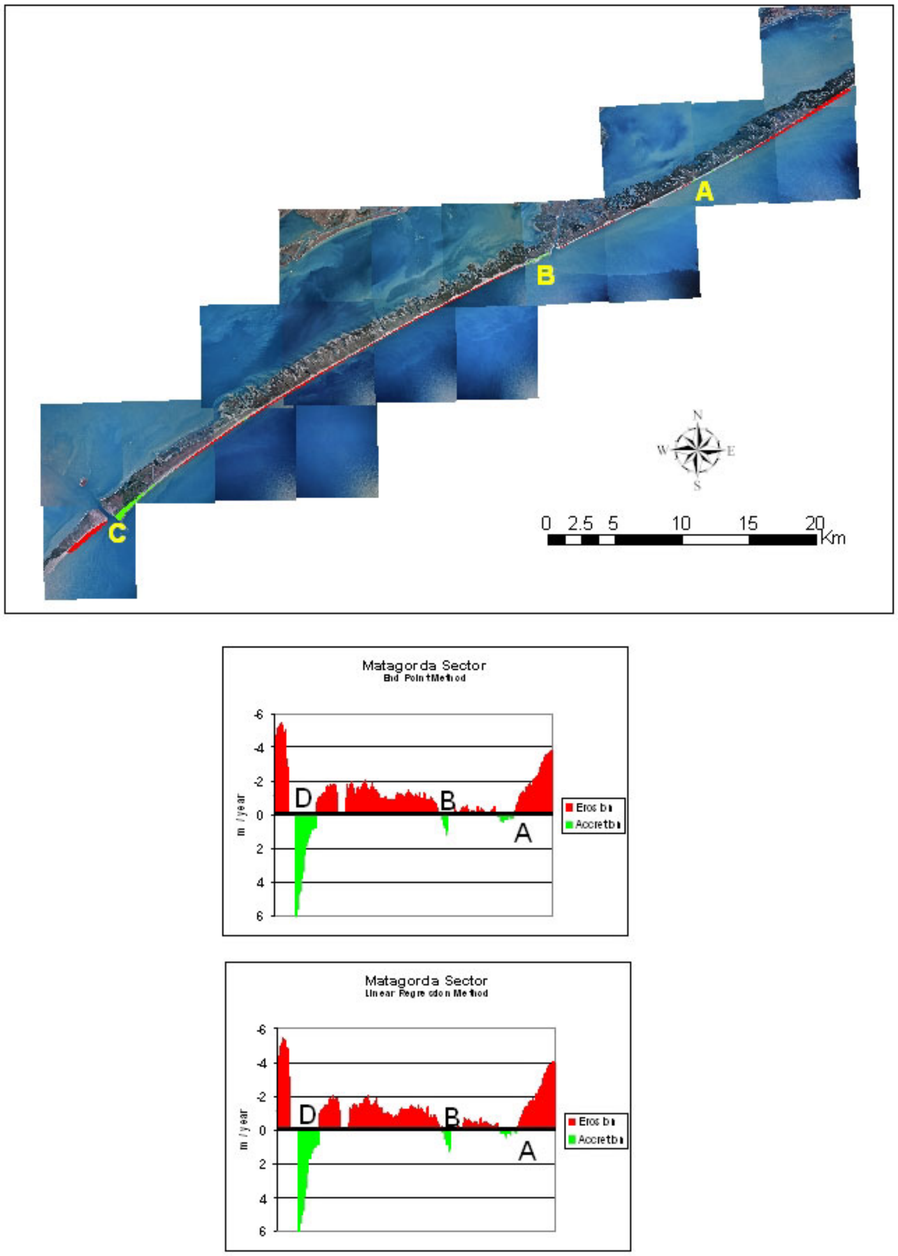


Fig. 27 Matagorda Peninsula erosion rates

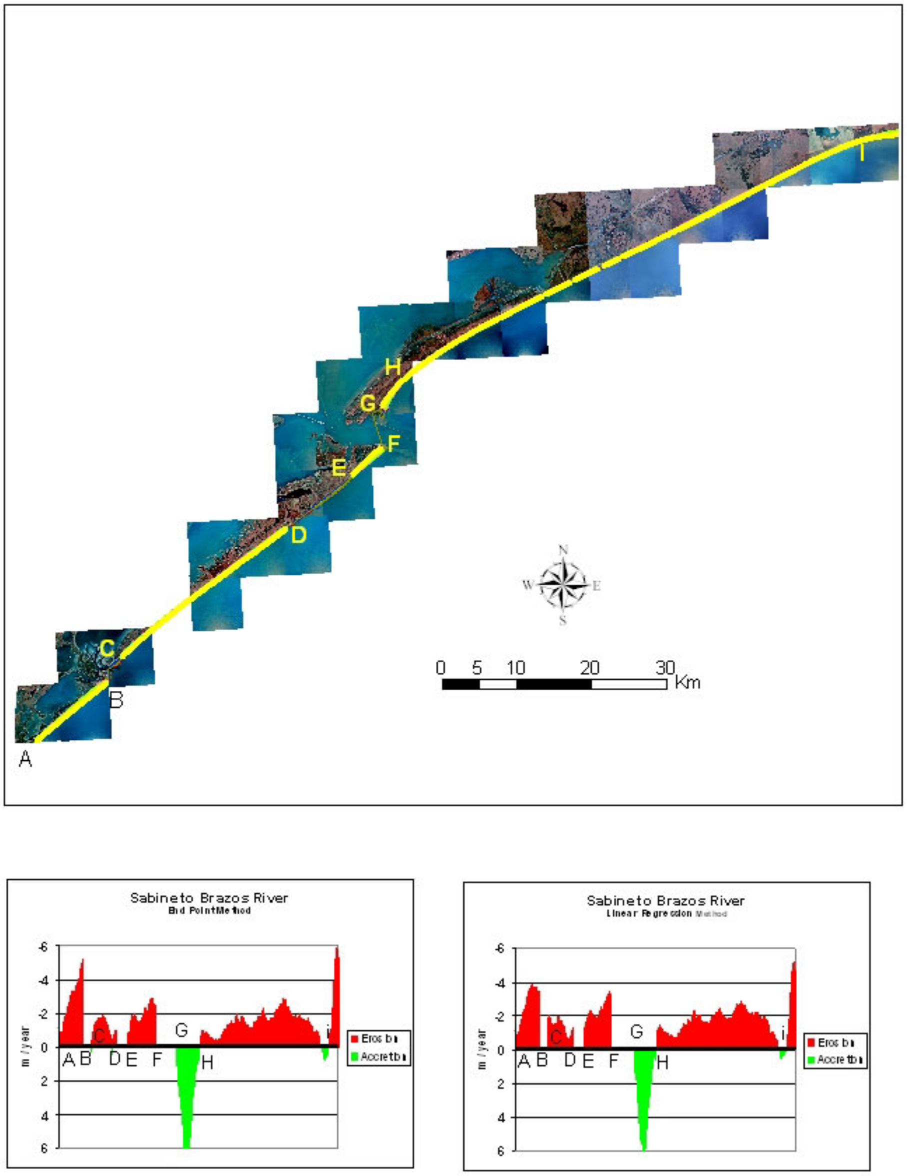


Fig. 28 Sabine to Brazos River erosion rates

CHAPTER V

SHORELINE POSITION PREDICTION

The analysis of historical shoreline displacement is the understanding of the past, in order to associate it with the present, and make forecasts about future shoreline positions.

Most of the governmental agencies in the United States predict shoreline position for next 30 to 60 years. The majority of the coastal states apply a simple historical AAER, obtained with linear regression or the end point method, to transects perpendicular to a baseline in order to project the future shoreline position (Heinz Center, 2000). For researchers that rely on the EPM, the TCTM proposed in this study offers a better framework to the calculation of annual erosion rates.

The application of historical annual displacement rates obtained by the TCTM to shoreline position forecasting is based on the same basic assumption as in the traditional shoreline forecasting methods – the calculation of historical averages provides the most reliable information, since shoreline dynamic processes tend to persist over long temporal scales.

5.1 Shoreline Prediction

The basic principle of traditional forecasting models for shoreline displacement is to apply each AAER to its corresponding point as many times as the number of years that need to be forecasted. Since the values of the AAER are expressed in units of distance per year, if a researcher pretends to preview the shoreline position 20 years in the future, the only operation to be performed is the multiplication of the AAER at each point by 20.

Using the new TCTM methodology, the result is an independent transect for each critical point. , Each transect is defined by a series of points in historical sequence, and each point defined by a pair of geographic coordinates. The linear displacement of each point over time can be subdivided into two directional components, one latitudinal and one longitudinal. For each transect, TCTM uses the successive values of each directional component to forecast future positions along that directional component through a linear regression method. For each transect two liner regressions are necessary, one for the latitudinal and one for the longitudinal components. The result of each pair of operations will provide the two cardinal components of each forecasted position.

If the linear regression method is applied to the to-points of each transect, the process of forecasting the future shoreline position projected from each point will result from the following procedure:

$$\text{Forecasted } Po\,\text{int}(x_f, y_f)$$

$$x_f = a_1 + b_1 * t$$
$$y_f = a_2 + b_2 * t$$

where

$$a_1 = \overline{x} - b_1 * \overline{t}$$

$$a_2 = \overline{y} - b_2 * \overline{t}$$

and

$$b_1 = \frac{n\sum_{i=1}^{n}(x_i * t_i) - (\sum_{i=1}^{n} x_i) * (\sum_{i=1}^{n} t_i)}{n\sum_{i=1}^{n} t_i^{\,2} - (\sum_{i=1}^{n} t_i)^2}$$

$$b_2 = \frac{n\sum_{i=1}^{n}(y_i * t_i) - (\sum_{i=1}^{n} y_i) * (\sum_{i=1}^{n} t_i)}{n\sum_{i=1}^{n} t_i^{\,2} - (\sum_{i=1}^{n} t_i)^2}$$

5.2 Prediction Accuracy

Linear models have proved relatively reliable for short-term forecasting as long as they rely on sufficient historical data. The longer the period of time covered by historical data sets, the better a forecast. For example, five data sets taken at 20-year intervals are preferable than five data sets taken every two years.

The accuracy of the results is inevitably related to the quality of the data available for prediction. Sets of data from different historical periods must be comparable in order to be combined. But when older and less accurate data are included, it is advisable to smooth more recent data in order to eliminate incompatible details. Data collected by remote sensing techniques and automated procedures have much more detailed information than older data sets.

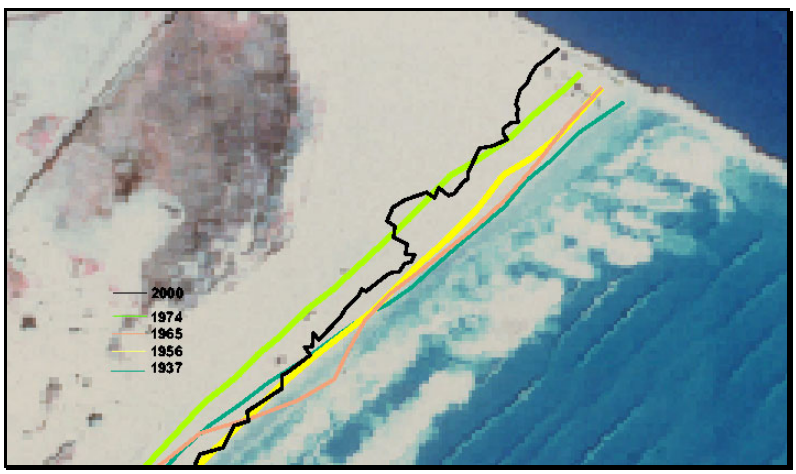


Fig. 29 Automatic shoreline extraction techniques. They produce a high detail shape that results in incompatibility with older data sets on long-term studies using the segmentation process.

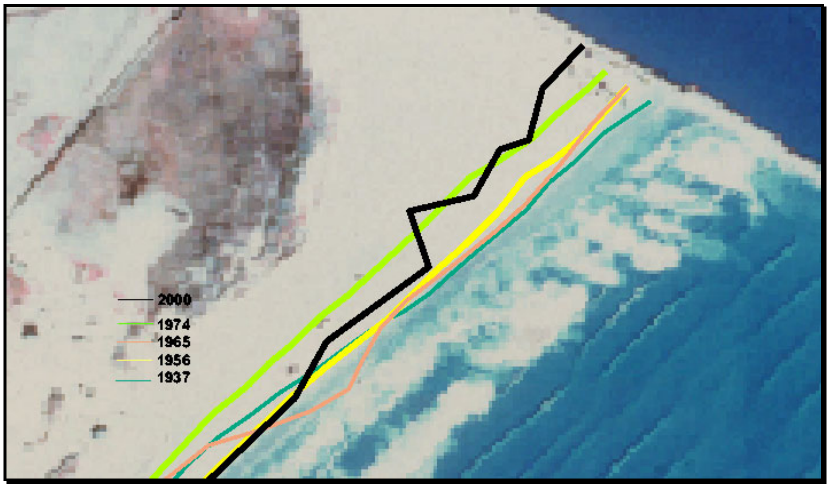


Fig. 30 Line generalization. It is needed in order to analyze the shoreline displacement

.

Fig. 29 and 30 graphically illustrate the need to generalize shorelines that present a level of detail, providing unnecessary detail for long-term prediction.

A third factor affecting data accuracy relates to the selection of historical periods. If the shoreline was affected by a catastrophic event, the use of historical sets taken immediately before the event should be used with caution. They are important explain the historical evolution of the shoreline, but may not represent long-term trend for forecast.

If the dominant processes at each location remain unaltered, the introduction of data sets related to episodic events may distort the AAER and adversely influence the forecast.

5.3 Prediction Results

The effectiveness of the new methodology is evaluated by using cross-validation method. Data sets of previous historical shorelines are used to forecast the 2000 shoreline position, and then shoreline is compared with the actual position. The test was performed for the coastal section between Sabine Pass and the Brazos River mouth, using the available historic shoreline data sets for the period 1856-1990. Figure 31 compares the predicted and actual positions.

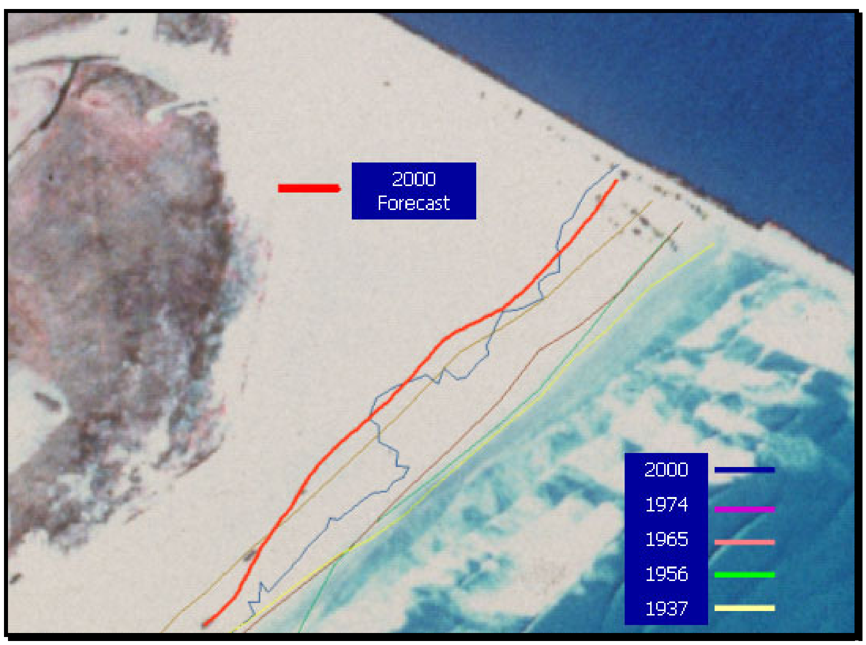


Figure 31 Shoreline forecasting

The overall predictions were very close to reality. Coastal evolution is a highly non-linear, three-dimensional and time-dependant product of morphodynamic processes that occur in response to external hydrodynamic and aerodynamic conditions (VanRijn, 1998).

The new methodology only uses geographic coordinates to forecast a pair (x, y) of future coordinates (latitudinal and longitudinal). But the method does not incorporate the value of z (elevation), which is an important element in the forecasting process. It is not available in the historical data obtained from the Texas Bureau of Economic Geology.

For a perfect mathematical adjustment between forecast and source data the elevation of each shoreline in regard to the reference datum should be incorporated. The forecast should be based on the concept of the ocean as a uniform surface (without taking into account the gravimetric variation obtained by the TOPEX satellite). Historical CTMs (coastal terrain models) can be developed in order to forecast the CTM and the shoreline simultaneously, as long as the shoreline has a constant elevation over the model.

CHAPTER VI

CONCLUSIONS

This study provided new ways of performing long-term coastal analysis in a GIS environment. It also proposes new methods to improve the existing shoreline displacement measurements and forecasting, when based on historical shoreline positions. The use of the new methodology and software tools specifically developed for this analysis increased the accuracy of the measurements.

The Topologically Constrained Transect Method offers a new and more flexible way to analyze coastal systems without the need to define arbitrary reference systems. The method bases its calculations in more than a pair of shoreline positions, and gives the user the freedom to test different hypothesis and use as many historical shorelines as he wishes. TCTM was also developed and tested in order to be applied to more complex coastal systems.

Most of TCTM steps were automated. The use of functions embedded in ArcGIS software was instrumental to automatically compute: 1) the total area affected by coastal advance and retreat; 2) annual average erosion and accretion rates; and 3) shoreline position predictions based in the new method based on geographic coordinates.

The use of polygon features has proved to be an efficient method to calculate the area variation, and to identify critical points along the coast. The linear feature scheme is suitable to analyze shoreline displacement identifying correspond segments between historical shorelines. To avoid time consuming editing process this study has also showed the importance of the shoreline segmentation. The methodology used has proved to be reliable for identifying areas with the same net drift direction along the shoreline. It also allows for better shoreline forecasting, which is of primary importance for coastal management programs, and planning for the protection or implementation of coastal infrastructure.

Another important result of this study was the creation and implementation of a software tool in ArcGIS. Following the theoretical framework proposed in this research, three macro programs were developed in order to efficiently analyze the data in a GIS environment. Additionally, the use of macro language embedded in GIS software helps to focus more on the problem being analyzed, and makes the programming much easier than general computer language like FORTRAN and C.

LITERATURE CITED

Anders F. and M. Byrnes. 1991. Accuracy of shoreline change rates determined from maps and aerial photographs. *Shore and Beach* 59: 17-26

Andrews B., P Gares and J. Colby. 2002. Techniques for GIS modeling of coastal dunes. *Journal of Geomorphology* 48: 289-308.

Bartlett D., R. Devoy, S. McCall, and I. O'Connor. 1997. A dynamically segmented linear data model of the coast. *Marine Geodesy* 20-2-3:137-151

Bush, D., R. Webb, L. Hyman, J. Liboy, and J. Neal. 1995. Living with the Puerto Rico Shore, 214 Geomorphology of Puerto Rico, Duke University Press, Durham, NC.

Bush, M. David, O. Pilkey Jr., and W. Neal. 1996. Living by the Rules of the Sea. 179. Living with the Shore, Duke University Press, Durham, NC.

Byrnes M and M Hiland. 1994. *Shoreline Position and Nearshore bathymetric Change* (chapter3). Technical report prepared for Coastal Engineering Research Center, Vicksburg, Mississippi.

Cadkin J. 2002. Understanding Dynamic Segmentation. ArcUser Magazine October-December 2002: 40-43. ESRI Press, Redlands, California.

CETN, Coastal Engineering Technical Note. 1992. *Using Morphology to Determine Net Littoral Drift Directions in Complex Coastal Systems.* Coastal Geology Unit, Coastal Engineering Research Center, Vicksburg, Mississippi.

Clow, J.B. and S. Leatherman, S.P., 1984. *Metric Mapping: An Automated Technique of Shoreline Mapping, 44th American Congress on Surveying and Mapping*, Falls Church, Virginia, pp. 309-318.

Crowell M., B Douglas B. and S. Leatherman S. 1997. On forecasting future U.S. shoreline positions: A test of Algorithms. *Journal of Coastal Research* 13(4): 1245-1255.

Crowel M., L. Howard and M. Buckley. 1999. Evaluation of coastal erosion hazards study: An overview. *Journal of Coastal Research* 28: 2-9

CZM 2003. U.S. Coastal Zone Management, National Oceanic and Atmospheric Administration (NOAA). http://coastalmanagement.noaa.gov/czm/ accessed June 17, 2003.

Dolan R., B. Hayden and J. Heywood. 1978. A new photogrammetric method for determining shoreline erosion. *Coastal Engineering*, 2: 21-39.

Dolan R., M. Fenster and S. Holme. 1991. Temporal analysis of shoreline recession and accretion. *Journal of Coastal research* 7(3): 723-744.

Dong P. and H. Chen. 1999. A probability method for predicting time-dependent long-term shoreline erosion. *Coastal Engineering* 36: 243-261.

Douglas B., M. Crowell and S. Leatherman. 1998. Considerations for shoreline position prediction. *Journal of Coastal Research* 14(3): 1025-1033.

Douglas B. and M. Crowell. 2000. Long-term shoreline position prediction and error propagation. *Journal of Coastal Research* 16(1): 145-152.

Duffy W. and S. Dickson 1995. *Using grid and graph to quantify and display shoreline change.* White paper, Maine Office of Geographic Information Systems, Augusta, Maine.

Fanos A., A. Khafagy, and R. Dean. 1995. Protective works on the Nile delta coast. *Journal of Coastal Research* 11: 516-528

FEMA. 2000. Evaluation of Erosion Hazards, Summary**.** Federal Emergency Management Agency. http://www.fema.gov/pdf/hazards/hnz_erosn.pdf accessed July 8, 2003

Fenster M., R. Dolan and J. Elder. 1993. A new method for predicting shoreline positions from historical data. *Journal of Coastal Research* 9(1): 147-171

Frihy O. and M. Lotfy. 1994. Mineralogy and textures of beach sands in relation to erosion and accretion along the Rosetta promontory of the Nile delta, Egypt. *Journal of Coastal Research* 10: 588-599

Gibeau J, W. White, T. Hepner, R. Gutierrez, T. Tremblay, R. Smyth and J. Andres…...

2000. *Texas Shoreline Change Project: Gulf of Mexico Shoreline Change from Brazos River to Pass Cavallo.* Texas Bureau of Economic Geology, Austin, Texas.

2001. *Changes in Gulf shoreline position, Mustang, and North Padre Islands, Texas.* Texas Bureau of Economic Geology, Austin, Texas.

GLO, 2001. Texas General Land Office http://www.glo.state.tx.us/coastal/erosion/erosionrates.html Accessed March 14, 2003.

Hall M., and O. Pilkey. 1991. Effects of hard stabilization on dry beach width for New Jersey. *Journal of Coastal Research* 7: 771-785.

Hansom J. 1988. Coasts. New York Cambridge University Press, New York.

Harman J., 2002. Study suggests many factors affect erosion on beaches with seawalls. *Civil Engineering* Vol. 72, Issue 2

Hayes, M. O., 1979. Barrier island morphology as a function of tidal and wave regime. *In:* S. P. Leatherman (Ed), *Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico.* Academic Press, New York, pp. 1–28.

Hoeke R., Zarillo G. and Synder M. 2001. *A GIS tool for extracting shoreline positions from aerial imagery* (Beach tools). US Army Corps of Engineers, Vicksburg, Mississippi. CHETN-IV-37

Horn D. 1997. Beach research in 1990s. *Progress in Physical Geography* 21: 454-470.

Hudson F., and J. Mossa. 1997. Suspended sediment transport effectiveness of large impounded rivers, U.S. Gulf Coast Plain. *Environmental Geology* 32 (4); 263-273.

Kniffen F., and S. Hilliard. 1988. *Lousiana: Its Land and people*. Baton Rouge: Lousiana State University press.

Lam N. and H. Qui. 1992. The fractal nature of the Louisiana coastline. *In* D. G. Janelle, (ed) *Geographical Snap-shots of North America*, New York: Guilford Press.

Lee J. and I. Jurkevich. 1990, Coastline detection and tracing in SAR images. *IEEE Transactions on Geoscience and Remote Sensing* 28: 662-668

Leont'yev I. 1996. Numerical modeling of beach erosion during storm event. *Coastal Engineering* 29: 187-200.

Li R. 1998. Potential of high-resolution satellite imagery for national mapping products. *Photogrammetric Engineering and Remote Sensing* 64(12):1165-1169

Li R., K. Di and R. Ma. 2001. A comparative study of shoreline Mapping techniques. The 4th *International Symposium on Computer mapping and GIS for Coastal Zones Management*, Halifax, Nova Scotia, Canada, June 18-20, 2001.

Liu J-K. 1998 Developing GIS applications in analysis of responses to Lake Erie Shoreline changes. M.S. Thesis, Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University, Columbus, Ohio.

Liu H. and K. Jezek. 2003. Automated extraction of coastline from satellite imagegery by integrating Canny edge detector and locally adaptive thresholding method. *International Journal of Remote Sensing* (in press).

Mason, D.C. and I.J. Davenport. 1996. "Accurate and efficient determination of the shoreline in ERS-1 images. *IEEE Transactions on Geosciences and Remote Sensing* 34-5: 1243-1253.

McMaster R. 1986. A statistical analysis of mathematical measures for linear simplification. *The American Cartographer* 13-2: 103-116

Moore L. 2000. Shoreline mapping techniques. *Journal of Coastal Research* 16(1): 111-124.

Morelock, J., 1978, *Standards for Measuring Shoreline Changes; A Study of the Precision Obtainable, and Needed, in Making Measurements of Changes* (erosion and accretion). Coastal Research and the Geology Dept., Florida State University, Tallahassee, Florida, p. 63-64.

Morton, R. A., 1975. Shoreline Changes Between Sabine Pass and Bolivar Roads - An Analysis of Historical Changes of the Texas Gulf Shoreline. The

University of Texas at Austin, *Bureau of Economic Geology Geological Circular* 75-6: 43 pp.

Morton R. 1979. Temporal and spatial variations in shoreline changes and their implications, Examples from the Texas Gulf Coast. *Journal of Sedimentary Petrology* 49: 1101-1112.

Morton R. and W. White. 1995. *Shoreline types of the upper Texas Coast*, The University of Texas at Austin, Bureau of Texas Natural resources Inventory program, Austin, Texas. Interagency Contract IAC 94-0198, 40 P

Morton R. and R. Peterson, 2003. *West-Central Florida Coastal Classification Maps - Anclote Key to Venice Inlet*. USGS Open File Report 03-227

Pajak M. and S. Leatherman. 2002. The high water line as shoreline indicator. *Journal of Coastal Research* 18(2): 329-337

Parsons G. and M. Powell. 2001. Measuring the cost of the beach. *Coastal Management* 29: 91-103.

Petts, G.E. 1984. *Impounded Rivers: Perspectives for Ecological Management.* Chichester, UK: Wiley.

Ritchie W., M. Wood, R. Wright and D. Tait. 1988. Surveying and Mapping for Field Scientists. Longman, Harlow: New York.

Ryu J-H., J-S. Won and K. Min. 2002. Waterline extraction from Landsat TM data in tidal flat. *Remote Sensing of Environment* 83: 442-456.

Schwäbisch, M., S. Lehner, and N. Winkel. 1997. Coastline extraction using ERS SAR interferometry, In: *Proceedings of the Third ERS Symposium*, Florence, 17-20 March 1997, Vol. I: 1-12.

Shalowitz A. 1964. *Shore and Sea Boundaries*: U.S. Department of Commerce Publication. Washington DC, 10-1, v.2, 729 P

Sherman D. and P. Gares. 2000. The geomorphology of coastal environments. *Geomorphology* 48: 1-6.

Short, AD (ed) 1999. *Handbook of Beach and Shoreface Morphodynamic*. New York : John Wiley.

Skafel M. 1995. Laboratory measurement of nearshore velocities and erosion of cohesitive sediment (till) shorelines. *Coastal Engineering* 24: 343-349.

Sohn H. and K. Jezek. 1999. Mapping ice sheets margins from ERS-1 SAR and Spot imagery. *International Journal of Remote Sensing* 20: 3201-3216

Texas Almanac. 1999. *Texas Almanac Millennium Edition* 2000-2001. Published by The Dallas Morning News. Dallas.

Thieler, E. R., Martin, D., and Ergul, A., 2003. The Digital Shoreline Analysis System, version 2.0: Shoreline change measurement software extension for ArcView. USGS Open-File Report 03-076.

Thieler E.R. and W. Danforth. 1994. Historical shoreline mapping (I): Techniques and reducing positioning errors. *Journal of Coastal Research* 10(3): 549-563.

Thieler E.R. and W. Danforth W. 1994. Historical shoreline mapping (II): Application of the digital shoreline mapping and analysis systems (DSMS/DSAS) to shoreline change mapping in Puerto Rico. *Journal of Coastal Research* 10(3): 600-620.

Van Rijn L., 1998. *Principles of Coastal Morphology,* Aqua Publications, Amsterdam, Netherlands.

Wathern, P. ed. 1990. *Environmental Impact Assessment: Theory and Practice*. Routledge London.

White K., El Asmar H., 1999. Monitoring changing position of coastlines using thematic Mapper imagery, an example from the Nile Delta. *Geomorphology* 29: 93-105

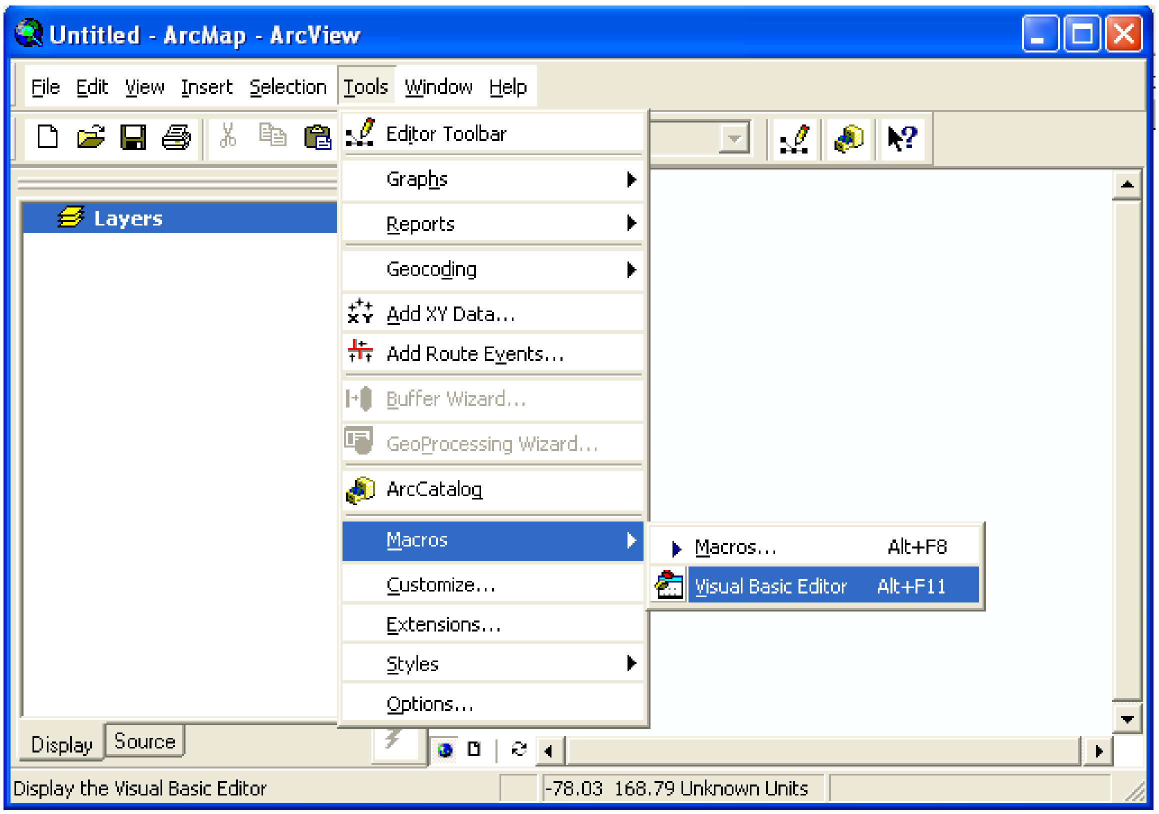
Zheng J. and Dean R., 1997. Numerical models and intercomparisons of beach profile evolution. *Coastal Engineering* 30:169-201

APPENDIX A

Area Variation Analysis Program

The source code was developed using VBA, and it works with ArcGIS 8.x. The steps to implement code in ArcGIS environment is as follow:

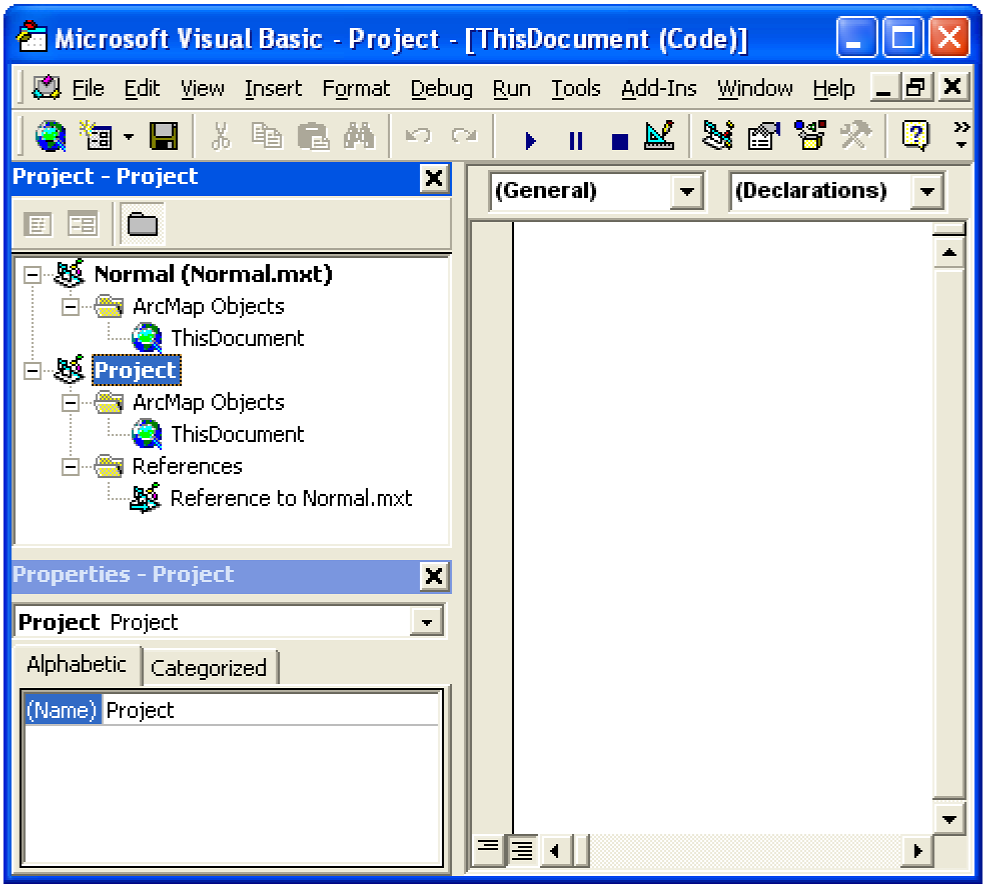
1. Click on Tools->Macros->Visual Basic Editor in the menubar:

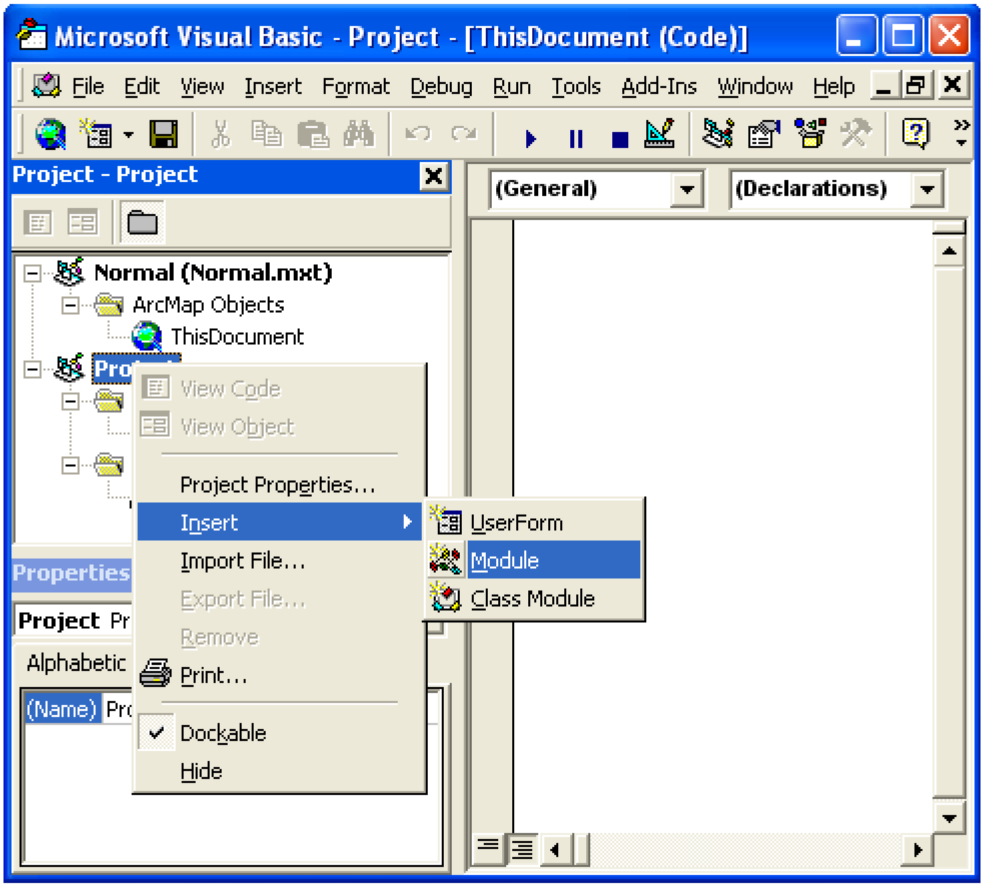


2. The visual basic editor will be displayed.

3. Right Click on the Project to expand it, and then click insert a module.

4. A module is ready to accept the code


Microsoft Visual Basic - Project - [ThisDocument (Code)]
File Edit View Insert Format Debug Run Tools Add-Ins Window Help
Project - Project
Normal (Normal.mxt)
ArcMap Objects
ThisDocument
Project
ArcMap Objects
ThisDocument
References
Reference to Normal.mxt
Properties - Project
Project Project
Alphabetic
Categorized
(Name) Project
(General)
(Declarations)

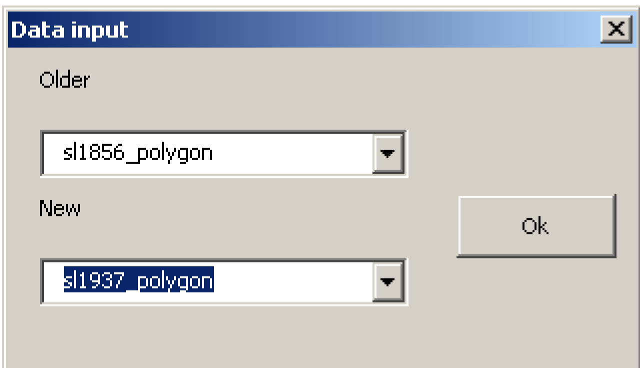


Areal Variation Analysis Program

frmPrincipal Code

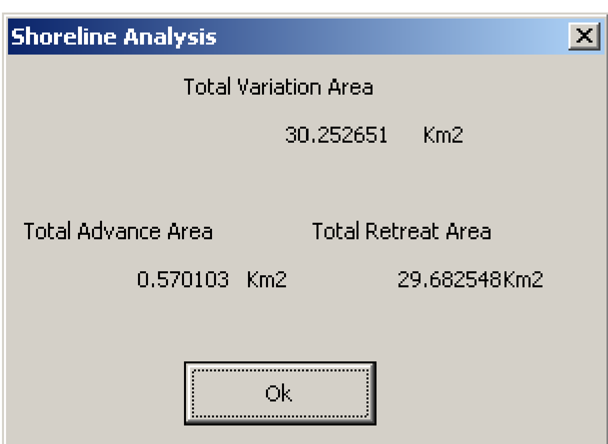
```
Private Sub cmdCancel_Click()
	Unload Me
End Sub

Private Sub cmdOk_Click()
	Unload Me
	frmBegin.Show
End Sub
```



frmBegin Code

```
Private Sub UserForm_Activate()
	Dim intcounter As Integer
	Set pMxDoc = Application.Document
	Set pMap = pMxDoc.FocusMap
	For intcounter = 0 To pMap.LayerCount - 1
		cmbLayer1.AddItem pMxDoc.FocusMap.Layer(intcounter).Name
		cmbLayer2.AddItem pMxDoc.FocusMap.Layer(intcounter).Name
	Next
End Sub
```



frmArea Code

```
Private Sub cmdOk_Click()
            Unload Me
End Sub
```

Module1.bas

```
Public pMap As IMap
Public pMxDoc As IMxDocument
Public pLayer As ILayer
Public pInputFeatLayer As IFeatureLayer
Public pFWS As IFeatureWorkspace
Public strLayer1 As String
Public strLayer2 As String
Public pDatasetName As IDatasetName
Public intArea(2) As Double
Sub intersection()
' Get the input layer and feature class
            Dim intLayer1 As Integer
            Dim intLayer2 As Integer
            Dim intcounter As Integer

              For intcounter = 0 To pMap.LayerCount - 1
                        If pMxDoc.FocusMap.Layer(intcounter).Name = strLayer1 Then intLayer1 = intcounter

                        If pMxDoc.FocusMap.Layer(intcounter).Name = strLayer2 Then intLayer2 = intcounter

            Next

            Set pMxDoc = ThisDocument

            Set pLayer = pMxDoc.FocusMap.Layer(intLayer1)

            Set pInputFeatLayer = pLayer

            ' Use the Itable interface from the Layer (not from the FeatureClass)

            Dim pInputTable As ITable

            Set pInputTable = pLayer

            ' Get the input feature class.

            Dim pInputFeatClass As IFeatureClass
            Set pInputFeatClass = pInputFeatLayer.FeatureClass

            ' Get the overlay layer
            Set pLayer = pMxDoc.FocusMap.Layer(intLayer2)
```

```
        Dim pOverlayTable As ITable
        Set pOverlayTable = pLayer

        ' Error checking
        If pInputTable Is Nothing Then
                MsgBox "Table QI failed"
                Exit Sub
        End If

        If pOverlayTable Is Nothing Then
        MsgBox "Table QI failed"
        Exit Sub
        End If

' Define the output feature class name and shape type (taken from the
‘ properties of the input feature class)
        Dim pFeatClassName As IFeatureClassName
        Set pFeatClassName = New FeatureClassName
        With pFeatClassName
                FeatureType = esriFTSimple
                ShapeFieldName = "Shape"
                ShapeType = pInputFeatClass.ShapeType
        End With

' Set output location and feature class name

        Dim pNewWSName As IWorkspaceName
        Set pNewWSName = New WorkspaceName
        pNewWSName.WorkspaceFactoryProgID = "esriCore.ShapeFileWorkspaceFactory.1"
        pNewWSName.PathName = "h:\temp"

        Set pDatasetName = pFeatClassName
        pDatasetName.Name = "Analysis_" & Mid(strLayer1, 3, 4) & "_" & Mid(strLayer2, 3, 4)

        Set pDatasetName.WorkspaceName = pNewWSName

' Set the tolerance.  Passing 0.0 causes the default tolerance to be used.
' The default tolerance is 1/10,000 of the extent of the data frame's spatial domain
        Dim tol As Double
        tol = 0#

' Perform the intersect
        Dim pBGP As IBasicGeoprocessor
        Set pBGP = New BasicGeoprocessor
        Dim pOutputFeatClass As IFeatureClass
        Set pOutputFeatClass = pBGP.Intersect(pInputTable, False, pOverlayTable, False, tol,
        pFeatClassName)

' Add the output layer to the map
        Dim pOutputFeatLayer As IFeatureLayer
        Set pOutputFeatLayer = New FeatureLayer
        Set pOutputFeatLayer.FeatureClass = pOutputFeatClass
        pOutputFeatLayer.Name = pOutputFeatClass.AliasName
```

```
            pMxDoc.FocusMap.AddLayer pOutputFeatLayer

Module3.color

End Sub
```

Module2.bas

```
Sub intersection()
            Const strFolder As String = "h:\"
            Const strName As String = "Polygon Overlaping" ' Dont include .shp extension
            Const strShapeFieldName As String = "Shape"

' Open the folder to contain the shapefile as a workspace
            Dim pFeatureLayer As IFeatureLayer
            Dim pMxDocument As IMxDocument
            Dim pMap As IMap
            Dim pFWS As IFeatureWorkspace
            Dim pWorkspaceFactory As IWorkspaceFactory

'Create a new ShapefileWorkspaceFactory object and open a shapefile folder
            Set pWorkspaceFactory = New ShapefileWorkspaceFactory
            Set pFWS = pWorkspaceFactory.OpenFromFile(strFolder, 0)

' Set up a simple fields collection
            Dim pFields As IFields
            Dim pFieldsEdit As IFieldsEdit
            Set pFields = New esriCore.Fields
            Set pFieldsEdit = pFields

            Dim pField As IField
            Dim pFieldEdit As IFieldEdit

' Make the shape field
' it will need a geometry definition, with a spatial reference
            Set pField = New esriCore.Field
            Set pFieldEdit = pField
            pFieldEdit.Name = strShapeFieldName
            pFieldEdit.Type = esriFieldTypeGeometry

            Dim pGeomDef As IGeometryDef
            Dim pGeomDefEdit As IGeometryDefEdit
            Set pGeomDef = New GeometryDef
            Set pGeomDefEdit = pGeomDef

            With pGeomDefEdit
                        GeometryType = esriGeometryPolygon
                        Set .SpatialReference = New UnknownCoordinateSystem
            End With
            Set pFieldEdit.GeometryDef = pGeomDef
            pFieldsEdit.AddField pField
```

```
 ' Add another miscellaneous text field
        Set pField = New esriCore.Field
        Set pFieldEdit = pField
        With pFieldEdit
            Length = 30
            Name = "MiscText"
            Type = esriFieldTypeString
        End With
        pFieldsEdit.AddField pField

' Create the shapefile
 ' (some parameters apply to geodatabase options and can be defaulted as Nothing)
        Dim pFeatClass As IFeatureClass
        Set pFeatClass = pFWS.CreateFeatureClass(strName, pFields, Nothing, _
                        Nothing, esriFTSimple, strShapeFieldName, "")

 'Create a new FeatureLayer and assign a shapefile to it
        Set pFeatureLayer = New FeatureLayer
        Set pFeatureLayer.FeatureClass = pFWS.OpenFeatureClass(strName)
        pFeatureLayer.Name = pFeatureLayer.FeatureClass.AliasName
'Add the FeatureLayer to the focus map
        Set pMxDocument = Application.Document
        Set pMap = pMxDocument.FocusMap
        pMap.AddLayer pFeatureLayer

'start edition

        Dim pEditor As IEditor
        Dim pID As New UID
        Dim pDataset As IDataset
        Dim LayerCount As Integer

        Set pMxDoc = Application.Document
        Set pMap = pMxDocument.FocusMap
        pID = "esriCore.Editor"
        Set pEditor = Application.FindExtensionByCLSID(pID)

        If pEditor.EditState = esriStateEditing Then Exit Sub

 'Start editing the workspace of the first featurelayer you find
        For LayerCount = 0 To pMap.LayerCount - 1
            If TypeOf pMap.Layer(LayerCount) Is IFeatureLayer Then
                Set pFeatureLayer = pMap.Layer(LayerCount)
                Set pDataset = pFeatureLayer.FeatureClass
                pEditor.StartEditing pDataset.Workspace
                Exit For
            End If
        Next LayerCount
End Sub
```

Module3.bas

```
Sub color()
```

```
        Dim pGeoFeatureLayer As IGeoFeatureLayer

        Set pMxDoc = ThisDocument
        Set pMap = pMxDoc.FocusMap
        Set pGeoFeatureLayer = pMap.Layer(0)

        Dim pRenderer As IUniqueValueRenderer
        Dim pSymbol As ISymbol

        Set pRenderer = New UniqueValueRenderer

        pRenderer.FieldCount = 2

        pRenderer.Field(0) = "COVER"
        pRenderer.Field(1) = "COVER_1"
        pRenderer.FieldDelimiter = ","

        pRenderer.AddValue "1,1", "Results", GetFillSymbol(RGB(168, 112, 0))
        pRenderer.Label("1,1") = "Land"

        pRenderer.AddValue "0,1", "Results", GetFillSymbol(RGB(0, 255, 0))
        pRenderer.Label("0,1") = "Advance"

        pRenderer.AddValue "1,2", "Results", GetFillSymbol(RGB(255, 0, 0))
        pRenderer.Label("1,0") = "Retreat"

        pRenderer.AddValue "2,2", "Results", GetFillSymbol(RGB(190, 232, 255))
        pRenderer.Label("0,0") = "Sea"

        pRenderer.DefaultSymbol = GetFillSymbol(RGB(0, 255, 255))
        pRenderer.UseDefaultSymbol = True

        Set pGeoFeatureLayer.Renderer = pRenderer
        pMxDoc.ActiveView.PartialRefresh esriViewGeography, Nothing, Nothing
        pMxDoc.CurrentContentsView.Refresh pGeoFeatureLayer
        Module4.seleccion
End Sub

Private Function GetFillSymbol(RGB As Long) As ISymbol
        Dim pFillSymbol As ISimpleFillSymbol
        Dim pLineSymbol As ILineSymbol
        Dim pColor As IColor

        Set pFillSymbol = New SimpleFillSymbol
        pFillSymbol.Style = esriSFSSolid

        Set pLineSymbol = New SimpleLineSymbol
        pLineSymbol.Width = 1
        pFillSymbol.Outline = pLineSymbol

        Set pColor = New RgbColor
        pColor.RGB = RGB
```

```
        pColor.UseWindowsDithering = True
        pFillSymbol.color = pColor

        Set GetFillSymbol = pFillSymbol

End Function
```

Module4.bas

```
Public Sub seleccion()

        Dim pActiveView As IActiveView
        Dim pFeatureLayer As IFeatureLayer
        Dim pFeatureSelection As IFeatureSelection
        Dim pQueryFilter As IQueryFilter

        Set pMxDoc = Application.Document
        Set pMap = pMxDoc.FocusMap
        Set pActiveView = pMap

 'For simplicity sake let's use the first layer in the map
        Dim intLayer As Integer
        Dim intcounter As Integer

        For intcounter = 0 To pMap.LayerCount - 1

                If pMxDoc.FocusMap.Layer(intcounter).Name = pDatasetName.Name Then intLayer =
        intcounter

        Next

        Set pFeatureLayer = pMap.Layer(intLayer)
        Set pFeatureSelection = pFeatureLayer 'QI

'Create the query filter

        Dim intcases As Integer

        For intcases = 0 To 1
                Set pQueryFilter = New QueryFilter

                If intcases = 0 Then pQueryFilter.WhereClause = "COVER = 1 AND COVER_1 = 2"

                If intcases = 1 Then pQueryFilter.WhereClause = "COVER = 2 AND COVER_1 = 1"

 'Invalidate only the selection cache
 'Flag the original selection
                pActiveView.PartialRefresh esriViewGeoSelection, Nothing, Nothing
 'Perform the selection
                pFeatureSelection.Clear
                pFeatureSelection.SelectFeatures pQueryFilter, esriSelectionResultNew, False
 'Flag the new selection
                pActiveView.PartialRefresh esriViewGeoSelection, Nothing, Nothing
```

```
            intArea(intcases) = PolygonArea / 1000000

        Next

' Report the final result to the user
        pFeatureSelection.Clear
        frmArea.Show vbModal

End Sub

Private Function PolygonArea() As Long

' Initialize an Enumeration set (the selected features)
        Dim pSelected As IEnumFeature
        Set pSelected = pMxDoc.FocusMap.FeatureSelection

' Move the pointer in the set to the top
        pSelected.Reset

' Initialize a reference to a geographic entity
        Dim pFeature As IFeature
        Set pFeature = pSelected.Next

' Initialize an area object to store the polygon area
        Dim pArea As IArea

' Initialize a variable to hold the cumulative area
        Dim totalArea As Double

' Loop through all of the selected polygons
        Do While (Not pFeature Is Nothing)
' If it's a polygon, add it's area to the totalArea variable
         If (pFeature.Shape.GeometryType = esriGeometryPolygon) Then
        Set pArea = pFeature.Shape
        totalArea = totalArea + pArea.Area
        End If
' Otherwise, skip to the next feature
        Set pFeature = pSelected.Next
        Loop
        PolygonArea = totalArea

End Function

Private Sub UserForm_Activate()
        lblTotalArea.Caption = CStr(intArea(0) + intArea(1))
        lblTotalAdvance.Caption = CStr(intArea(1))
        lblTotalRetreat.Caption = CStr(intArea(0))
End Sub
```

APPENDIX B

Perpendicular transects to a polyline program

```
Option Explicit
Dim pMxDoc As IMxDocument
Dim pMap As IMap
Dim pActiveView As IActiveView
Dim pFeatureLayer As IFeatureLayer
Dim pFeatureSelection As IFeatureSelection
Dim pQueryFilter As IQueryFilter

Dim pEnumFeat As IEnumFeature
Dim pFeature As IFeature
Dim pSelection As ISelection
Dim pDisplay As IScreenDisplay
Dim pPolyline As IPolyline

Dim pPolyline2 As IPolyline
Dim pMouseCursor As IMouseCursor
Dim pStatusBar As IStatusBar
Dim pProgbar As IStepProgressor

Sub perpendicular_transects()

Dim pField As IField
Set pField = New Field
Dim pFieldEdit As IFieldEdit
Set pFieldEdit = pField
        With pFieldEdit
                Name = "position"
                Type = esriFieldTypeDouble
                Precision = 11
                Length = 12
                Scale = 3
        End With

        Set pMxDoc = Application.Document
        Set pMap = pMxDoc.FocusMap
        Set pActiveView = pMap

        Set pStatusBar = Application.StatusBar
        Set pProgbar = pStatusBar.ProgressBar
        pProgbar.Position = 0

 'For simplicity the program uses the first layer in the map
        If Not TypeOf pMap.Layer(1) Is IFeatureLayer Then Exit Sub
        Set pFeatureLayer = pMap.Layer(1)
        Set pFeatureSelection = pFeatureLayer 'QI

 'Create the query filter
        Set pQueryFilter = New QueryFilter
        pQueryFilter.WhereClause = "Id = 1856"

        pFeatureSelection.SelectFeatures pQueryFilter, esriSelectionResultNew, False
 'Flag the new selection
```

```
Set pSelection = pMap.FeatureSelection
Set pEnumFeat = pSelection

pEnumFeat.Reset

Set pFeature = pEnumFeat.Next

Set pPolyline = pFeature.Shape

Dim pLine As ILine
Dim pQueryLine As ILine

Set pLine = New Line
Set pQueryLine = New Line

Dim plinelayer As IGeoFeatureLayer

Set plinelayer = pMap.Layer(0)

Dim A As Integer

Dim pSegCollection As ISegmentCollection

Set pPolyline2 = New Polyline

Dim total_lenght As Double

total_lenght = pPolyline.Length

Dim round As Integer

round = total_lenght / 100

plinelayer.FeatureClass.AddField pField

pStatusBar.ShowProgressBar "Creating perpendicular transects...", 0, _
round, 1, True

For A = 0 To round

        Dim plclass As IFeatureClass
        Set plclass = plinelayer.FeatureClass
        Dim pyline As IFeature
        Set pyline = plclass.CreateFeature

        pPolyline.QueryNormal 0, A * pPolyline.Length / round, False, _
        200, pLine

        Set pSegCollection = pPolyline2

        pSegCollection.AddSegment pLine

        Set pyline.Shape = pPolyline2
        pyline.Store
```

```
        Dim pFeat As IFeature
        Set pFeat = pyline
        pFeat.Value(plinelayer.FeatureClass.FindField("position")) = _
        A * pPolyline.Length / round

        pFeat.Store

        pPolyline2.SetEmpty
        pStatusBar.StepProgressBar
    Next

    pFeatureSelection.Clear
    pStatusBar.HideProgressBar
    pActiveView.Refresh

End Sub
```

APPENDIX C

Topological constrained transect method program

```
Option Explicit

Dim pMXdoc As IMxDocument
Dim pMap As IMap
Dim pActiveView As IActiveView
Dim pFeatureLayer As IFeatureLayer
Dim pFeatureSelection As IFeatureSelection
Dim pQueryFilter As IQueryFilter

Dim pEnumFeat As IEnumFeature
Dim pFeature As IFeature
Dim pSelection As ISelection
Dim pDisplay As IScreenDisplay
Dim pPolyline As IPolyline
Dim pPoint As IPoint
Dim strQuery As String
Dim dblPercentage As Double

Dim pP1 As IPoint
Dim pP2 As IPoint

'Cursor icon
Dim pMouseCursor As IMouseCursor

 'Progress bar controls
Dim pStatusBar As IStatusBar
Dim I As Long
Dim pProgbar As IStepProgressor

'Proxmity operator

Dim pProxOp As IProximityOperator
'Multipoints
Dim pMultiPointA(5) As IPointCollection
Dim pMultiPointB As IPointCollection
Dim capa As Integer
Dim nTransectos As Double

Public Sub TCTM()

        On Error GoTo Errorhandler

        Dim counter As Integer

        Dim round3 As Integer

        For round3 = 0 To 4
                Set pMultiPointA(round3) = New Multipoint
        Next

        Dim transectos As Integer
```

```
        Dim a As Double
        Dim B As Double

'Iniciar cursor y progress bar

        Set pMouseCursor = New MouseCursor
        Set pStatusBar = Application.StatusBar
        Set pProgbar = pStatusBar.ProgressBar
        pProgbar.Position = 0

        Set pProxOp = New Polyline

  pMouseCursor.SetCursor 2

' el 100 representa el # de transectos que se lo debe setear a una
' variable junto con el siguiente for

        pStatusBar.ShowProgressBar "Transects...", 0, 500, 1, True

        Dim round As Integer
        strQuery = "segment = 23"
        nTransectos = 16
        Dim intShoreline(5) As Integer
        intShoreline(0) = 1937
        intShoreline(1) = 1956
        intShoreline(2) = 1965
        intShoreline(3) = 1974
        intShoreline(4) = 2000

        For round = 0 To 4

                capa = round + 1
                selectShoreline1

 'Get points values from the select Polyline

                Set pSelection = pMap.FeatureSelection
                Set pEnumFeat = pSelection

                pEnumFeat.Reset
                Set pFeature = pEnumFeat.Next
                Set pPolyline = pFeature.Shape
                pFeatureSelection.Clear

                        For transectos = 0 To nTransectos - 1

                                Set pP1 = PtConstructAlong(transectos * pPolyline.Length /
                                nTransectos, pPolyline, esriNoExtension, False)
                                pP1.Z = intShoreline(round)
                                pMultiPointA(round).AddPoint pP1
                                pStatusBar.StepProgressBar

                        Next

                pStatusBar.StepProgressBar
```

```
            Next

            createline

            'refresh the map and hide the progress bar

            pActiveView.Refresh
 'create length and azimuth for each polyline
            length_sub
            azimuth_sub

            pStatusBar.HideProgressBar

Exit Sub


Errorhandler:
  MsgBox Err.Number & "..." & Err.Description
  Exit Sub

End Sub

Function PtConstructAlong(dDist As Double, ByVal pCurve As ICurve, extension As
esriSegmentExtension, aRatio As Boolean) As IPoint

            Dim pCPoint As IConstructPoint
            Set pCPoint = New Point
            pCPoint.ConstructAlong pCurve, extension, dDist, aRatio
            Set PtConstructAlong = pCPoint

End Function

Private Sub selectShoreline1()

            Set pMXdoc = Application.Document
            Set pMap = pMXdoc.FocusMap
            Set pActiveView = pMap

 'For simplicity sake let's use the first layer in the map
            If Not TypeOf pMap.Layer(capa) Is IFeatureLayer Then Exit Sub
            Set pFeatureLayer = pMap.Layer(capa)
            Set pFeatureSelection = pFeatureLayer 'QI


'Create the query filter
            Set pQueryFilter = New QueryFilter
            pQueryFilter.WhereClause = strQuery

'Invalidate only the selection cache
'Flag the original selection
            'pActiveView.PartialRefresh esriViewGeoSelection, Nothing, Nothing
'Perform the selection

            pFeatureSelection.SelectFeatures pQueryFilter, esriSelectionResultNew, False
'Flag the new selection
```

```
End Sub

Private Sub createline()

        Set pMXdoc = ThisDocument
        Set pMap = pMXdoc.FocusMap

        Dim plinelayer As IGeoFeatureLayer
        Set plinelayer = pMap.Layer(0)
        Dim counter As Integer

        For counter = 0 To nTransectos - 1

                Dim round2 As Integer
                Dim plclass As IFeatureClass
                Set plclass = plinelayer.FeatureClass
                Dim pyline As IFeature
                Set pyline = plclass.CreateFeature
                Dim pSegCollection As ISegmentCollection
                Set pPolyline = New Polyline
                Set pSegCollection = pPolyline

                For round2 = 0 To 3
                        Dim pLine As ILine
                        Set pLine = New Line
                        Set pP1 = pMultiPointA(round2).Point(counter)
                        Set pP2 = pMultiPointA(round2 + 1).Point(counter)
                        Dim hyd As Integer
                        hyd = pP1.Z

                        pLine.PutCoords pP1, pP2

                        hyd = pLine.FromPoint.Z
                        hyd = pLine.ToPoint.Z

'get the feature class

                        pSegCollection.AddSegment pLine
                        hyd = pPolyline.FromPoint.Z
                        hyd = pPolyline.ToPoint.Z

                Next

                        Set pyline.Shape = pPolyline
                        pyline.Store
                        pStatusBar.StepProgressBar

                Next

End Sub

Private Sub length_sub()

        Set pMXdoc = Application.Document
        Set pMap = pMXdoc.FocusMap
        Set pActiveView = pMap
```

```
        Set pFeatureLayer = pMap.Layer(0)
        Dim pFCursor As IFeatureCursor
        Set pFCursor = pFeatureLayer.Search(Nothing, False)
        Dim pFeat As IFeature
        Set pFeat = pFCursor.NextFeature

        Do Until pFeat Is Nothing

                Dim pPolyline As IPolyline
                Set pPolyline = pFeat.Shape

                Dim distance As ILine
                Set distance = New Line
                Set pP1 = pPolyline.FromPoint
                Set pP2 = pPolyline.ToPoint

                distance.PutCoords pP1, pP2

                pFeat.value(pFeatureLayer.FeatureClass.FindField("length")) = distance.Length
                pFeat.Store

                Set pFeat = pFCursor.NextFeature
                pStatusBar.StepProgressBar

        Loop

End Sub

Private Sub azimuth_sub()

        Set pMXdoc = Application.Document
        Set pMap = pMXdoc.FocusMap
        Set pActiveView = pMap
        Set pFeatureLayer = pMap.Layer(0)
        Dim pFCursor As IFeatureCursor
        Set pFCursor = pFeatureLayer.Search(Nothing, False)
        Dim pFeat As IFeature
        Set pFeat = pFCursor.NextFeature

        Do Until pFeat Is Nothing

                Dim pPolyline As IPolyline
                Dim pLine As ILine
                Dim pi As Double

                Set pPolyline = pFeat.Shape
                Set pLine = New Line

                pi = 4 * Atn(1)

                pLine.PutCoords pPolyline.FromPoint, pPolyline.ToPoint
                Dim azimuth1, azimuth2 As Double
                azimuth1 = pLine.Angle * 180 / pi
                If azimuth1 < 90 Then
                        azimuth2 = 90 - azimuth1
                        ElseIf azimuth1 > 90 And azimuth1 < 180 Then
```

```
                azimuth2 = 360 - (azimuth1 - 90)
                ElseIf azimuth1 > 180 And azimuth1 < 270 Then
                azimuth2 = 270 - (azimuth1 - 180)
                ElseIf azimuth1 > 270 And azimuth1 < 360 Then
                azimuth2 = 90 + (360 - azimuth1)
            End If

            pFeat.value(pFeatureLayer.FeatureClass.FindField("azimuth")) = azimuth2
            pFeat.Store
            Set pFeat = pFCursor.NextFeature
            pStatusBar.StepProgressBar
        Loop

End Sub
```

VITA

César Augusto Arias Morán

Date of Birth: June 5, 1972

Address: Instituto Oceanográfico de la Armada
Base Naval Sur Av. 25 de Julio vía al Puerto Marítimo
Guayaquil-Ecuador

Education:

2003 M.S. in Geography, Texas A&M
2001 Hidrógrafo, Instituto Oceanográfico de la Armada, Guayaquil-Ecuador
1994 B.A Escuela Superior Naval, Salinas-Ecuador