

USING REMOTE SENSING DATA TO DETECT SEA LEVEL CHANGE

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ABSTRACT:

Remote sensing data and Geographic information systems (GIS) are relatively new and potentially valuable tools for coastal zone management. This paper examines the effectiveness of using remote sensing data to detect sea level change. Since resolution is such an important and vital element of spatial digital data for use in geographic information systems, it is important to know how to assess its quality, accuracy and level of precision. Using remote sensing data to detect sea level change also requires accurate historical baseline spatial data and knowledge of how the coastline is defined and mapped. Map datum refers to the various locations to which geographic measurements are referenced. This referencing system is an important item on the list of cartographic components that help to identify and categorize individual maps. For example, many North American maps have been, or will soon be, converted to a horizontal map datum known as NAD83. Along with horizontal datum, maps are also referenced to vertical datum. The choice of vertical and horizontal map datum along with other cartographic elements such as map projection, scale and meta data will determine to what level of precision coastal change can be accurately measured. This paper will explain how to select the most appropriate baseline spatial data as well as the type of the remote sensing data that will provide the most reliable results for the detection of sea level change. Cobscook Bay, Maine was used for two case studies to demonstrate some of these coastal mapping parameters.

1. INTRODUCTION

Recent improvements in the field of remote sensing now allows for the acquisition of high resolution images for use in a wide variety of applications that require the accurate determination of geographic location. Any application of Remote Sensing data that ascertains land use and delineates features will benefit from higher degrees of accuracy. Often the interface between one type of land use and another type is "fuzzy" or imprecise and the boundary line is placed in a somewhat arbitrary location. This often occurs on soil and vegetation maps where there is usually a gradually transition from one type to another rather than the blunt transition that is indicated by the edge of a polygon. In other cases the interface between one land use type and another type is much more apparent such as when a land use of urban development suddenly stops at a set location and a land use of a greenbelt then starts. Other places where there are even more dramatic changes in the interface between land use occur along the coastal zones of the seas and oceans. At these locations the distinction between the land-side and the water-side of the coastal zone is very clear. However, the coastal zone is also a dynamic environment where due to such factors as coastal erosion and deposition, tides, storms, biological activities within coral reefs, volcanism, plate tectonics and intervention by man have created conditions where the location of the land-sea interface or coastline is constantly changing. Lillesand and Kiefer (1994, p28) define two temporal forms of spatial data acquisition: "time-critical and time-stable". Time-stable measurements are made in conditions that do not (except in exceptional cases such as natural disasters) experience rapid changes in position such as with fixed geological formations. Time-critical measurements are made of areas that experience constant change such as animal migration, automobile usage on highways or the tides of the world's oceans. It is this last element that is of particular concern when attempting to measure changes in the sea level. A case study approach is used in this paper to demonstrate some elements of coastal mapping.

2. VERTICAL DATUMS

Since the sea level changes from a maximum high tide to a maximum low tide a variety of vertical datum have been created for special purposes by many different types of organizations around the world. According to the USGS and NOAA (August, 2002) there are 27 different vertical datums in use. These different datum are either based around an Orthometric (geodetic) level which is based on Mean Sea Level (MSL) or they are based on tidal measures of the high and low water line at the land and sea interface. The advent of GPS has added a newer form of vertical datum and since it is based on 3 points it is referred to as a 3-D datum. Some other types of datum are Mean Higher High water (MHHW), Mean High Water (MHL) and Mean Lower Low Water (MLLW). Mean Lower Low Water level is also referred as Chart datum for hydrographic charts. Mean Sea Level (MSL) is used by the USGS as the vertical datum for the production of its topographic maps. These specific MSL orthometric levels are known as North American Geodetic Datum 1929 (NGVD) or the newer North American Vertical datum (NAVD 88). The choice and use of different vertical datum by various mapping organizations around the world means that there are many definitions of where the shoreline is located. Since at least one reliable cartographic baseline is required to measure sea level change it is vitally important to select the same vertical datum for both the reference geographic data and the newly acquired remote sensing data. Otherwise any attempt at change detection will be adversely affected by the different vertical datums. Once a vertical datum has been selected the next step is to acquire reliable and accurate geographic data of the shoreline to use as a baseline reference.

3. SELECTING BASELINE DATA

Spatial data that are being used for spatial analysis for coastal zone management applications such as detecting sea level change can come from a wide variety of sources and they may be used for purposes that the spatial data were not designed to support. The type of spatial data that are selected should be matched to the specific coastal zone management task that is to

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be performed (such as sea level change). For example, small-scale spatial data should be used for the creation of maps for an atlas, medium scale maps should be used for spatial analysis on an urban or regional scale, and large-scale maps should be used for various civil operations such as in road building or for the construction of bridges. The case studies described for this paper uses analogue and digital spatial data that has been obtained from various sources and their various features of scale, precision, accuracy and resolution were explored by using an GIS (ArcView) to measure the area and length of the coastal area of Cobscook Bay, Maine. Spatial data can come in many forms and it can also cover a wide variety of temporal periods and geographic areas. It should be kept in mind that an error or inaccuracy in a paper (analogue) map is often compounded when it is digitized into spatial data.

3.1 Map Accuracy

Analogue maps generally have two forms of accuracy standards applied to them. The first mapping standard is the level of precision at which the geographic features were measured and recorded, and the second mapping standard refers to the accuracy level regarding the actual drawing of the geographic features on the map. For example, the United States National Map Accuracy Standards that were established in 1941, and later revised in 1947 state the horizontal accuracy for maps on publication scales larger than 1:20,000 to be “not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch” (U.S. Bureau of The Budget, 1947). This specification uses the printed map to measure how close the drawn line or object should be to the true position of the geographic feature that is being depicted on the map. The levels of accuracy that are applied to the measuring and collection of the geographic features at the source are done according to a different set of standards. These standards are based on the scale of the map and the intended use of the map. For example a 1:24,000 scale map is required to have at least 90 percent of horizontal points tested to be accurate to within one-fiftieth of an inch on the map, which at this scale equate to a horizontal accuracy level of 40 feet on the ground. Other mapping specifications refer to how accurate the map is to the actual position on the ground. The Standards and Specifications of the National Topographic Data Base of Geomatics Canada, version 3.1, refers to horizontal accuracy of its 1:50,000 scale maps according to geometric accuracy as the “difference between the position of the geometric representation associated with an entity and the real ground position of the corresponding topographic feature, as measured with respect to the geodetic network” (Geomatics Canada, 1997, p. 10). In addition to this requirement, the horizontal accuracy is further divided into three subclasses that relate to the population density of the map sheet. This produces a variable accuracy requirement that increases for populated urban areas, and decreases for rural and isolated areas. The horizontal accuracy standards for Geomatics Canada’s 1:50,000 maps are such that it **aims** to meet the following accuracy requirements: “i) For urban areas, the circular horizontal accuracy is 10 meters; ii) For rural areas, the circular horizontal accuracy is 25 meters and; iii) For isolated areas, the circular horizontal accuracy is 125 meters” (Geomatics Canada 1997, p. 101). These mapping specifications show that accuracy levels that can vary even when they are at the same scale and they have been obtained from the same source.

3.2 Determining the Resolution of Spatial Data

Since resolution is such an important and vital element of spatial digital data for use in geographic information systems, it is important to know how to assess its quality, accuracy and level of precision. The resolution of a map or an image is defined by the smallest individual feature that can be clearly identified. It is a relatively straightforward process to check the spatial resolution on paper maps because there is a fairly obvious ratio between the map scale and its printed resolution. The spatial resolution on a map is determined by simply measuring the smallest printed feature on the map, and then comparing that value to the scale of the map. According to Tobler (1988) the smallest mark that a cartographer can make on a map is “approximately one half millimeter in size” (p. 131). From this observation Tobler reported that the resolution of a map scale can be quickly and easily determined by the use of a simple formula. To determine the resolution of a map, the denominator of the map scale is divided by 1000. This will produce a value for the detectable size of the map in meters, and the resolution of the map is obtained by further dividing the value of the detectable size by the value of 2. This formula will give a value that corresponds to the smallest size of one half millimeter that a cartographer is able to both represent and print a geographic feature on a map. The following table shows the relationship between map scale, detectable size, and map resolution. **Note:** These are the same values as the five scales that were used for the GIS-based analysis of Cobscook Bay, Maine (Kostiuk, 2001a, 2001b).

**Table 1. Adapted from Tobler (1988, p. 32)
Comparison of map scale to map resolution.**

Map Scale	Detectable Size	Map Resolution
24000	24 meters	12 meters
70000	70 meters	35 meters
100000	100 meters	50 meters
250000	250 meters	125 meters
1000000	1,000 meters	500 meters

The calculations that produced the above table are also based on the mathematical rule of the sampling interval (Tobler, 1988). The sampling rule requires that data should be collected using a measurement system that is at least one half the unit of the data that are to be recorded. The reason for this particular rule of statistics is to prevent the loss of data that can occur if the geographic feature is located between two points on a grid. To illustrate the sampling theory Tobler (1988) noted that to detect the movements of a thunderstorm cell for every one-kilometer of travel a half-kilometer grid is needed. The reason that the grid is set to one half kilometer is to prevent the thunderstorm from passing between two stations, and in doing so, it would not be recorded. The same sampling rule is applied in the calculations that produced the above table, where the value of the detection is twice the size of the value of the map resolution.

4. TESTING THE ACCURACY AND RELIABILITY OF THE BASELINE DATA.

For the digital spatial analysis of Cobscook Bay (Case Study A), a high emphasis was placed on the accurate measurement of the coastline, and therefore it was important to determine a minimum acceptable scale that will be useful for that purpose. Wainwright et al. (1991, p.14) noted: "Water bodies must possess enough resolution to describe reaches. Coastlines must have enough detail to describe shoreline units. Reaches may be as small as a 50 m section of a stream. Shoreline units are normally larger, but may be as small as a 100 m section of shoreline". Wainwright reported that a minimum acceptable scale to portray the coastline should be 1:40,000 and larger, and that the minimum scale for watershed mapping should be 1:20,000 (Wainwright et al., 1991).

4.1 Scale Requirements

For the GIS analysis of Cobscook Bay (Case study A), this 1:40,000-scale recommendation was used as the desired smallest acceptable scale (designated as the baseline scale) to measure the coastline of Cobscook Bay. A search for digital spatial data was then necessary to locate any sources of data that met or exceeded this 1:40,000 requirement. Digital spatial data that represents a range of map scales and sources were also located to determine how close, or how accurately they are able to represent the size and dimensions of the bay.

4.2 Horizontal and Vertical Datum Requirements

The coastline is the geographic center of the coastal zone and it is also the location from where the coastal zone is defined. The location of the coastline depends on which datum is used for the sea level, and whether the High tide, Mean Sea Level, or the Low tide level is to be used as the point of reference. In the case of Cobscook Bay, like the Bay of Fundy, there is a large difference between the Low and High tide levels. The mean tidal range of Cobscook Bay is 5.7 meters or approximately 18.7 feet, the highest tide that can be observed in the United States of America (Brooks et al., 1999). Consequently, such a large tidal range as this produces two very different coastlines at the high and low range of the tide cycle.

5. SOURCES OF DIGITAL SPATIAL DATA USED TO MEASURE COBSCOOK BAY

5.1 Digital Spatial Data

To obtain digital spatial data of the study area in a vector format that meets the requirements that were specified, a search of the Internet produced the following freely available sources of data:

- 1) Maine Office of GIS Internet site at <http://apollo.ogis.state.me.us>
- 2) The United States Geological Service Coastline Extractor at <http://crusty.er.usgs.gov/coast/getcoast.html>
- 3) Digital Chart of the World (DCW) data from the Pennsylvania State University's Maps Library site at <http://ortelius.maproom.psu.edu/dcw/>.

A more detailed description of the larger sets of digital spatial data is as follows:

5.2 Maine Office of GIS Spatial Data

The digital spatial data from the Maine Office of GIS were downloaded as compressed ArcInfo (GIS made by ESRI) format files at scales of 1:24,000 and 1:100,000. These data were digitized and referenced to the Mean High Water (MHW) line as are shown on USGS 1:24,000 scale quadrangle maps. The accuracy limits for the 1:24,000 scale data is that "not more than 10 percent of the points tested shall be in error by more than 0.02 inch, measured on the publication scale" for horizontal accuracy (ground scale), and "that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval for vertical accuracy" (USGS, Part 1, 1997, p.1. D-2). For a 1:24,000 scale map, the horizontal accuracy of 0.02 inch on the map equates to 40 feet or 12.19 meters on the ground. The accuracy limits for the 1:100,000 scale data are that at least 90 percent of points tested are within 0.02 inch of the true position (ground scale) for horizontal accuracy, and that at least 90 percent of well-defined points tested should be within one-half contour interval of the correct value for vertical accuracy (USGS, Part 3, 1997, pp. 3-12, 3-13). For a 1:100,000-scale map, the horizontal accuracy of 0.02 inch on the map represents 166.7 feet or 50.8 meters in ground terms.

5.3 The United States Geological Service Coastline Extractor Spatial Data

The data were in the form of NOAA/NOS Medium Resolution Digital Vector Shoreline at a scale of 1:70,000. These data were a portion of a larger data set that covers the entire United States of America. These data were digitized from NOAA nautical charts. The other set of spatial data set were a portion of the World Vector Shoreline, which is at the 1:250,000 scale. These data can be used for worldwide coverage. Both of these data sets contain only line information, and since no polygon features are included with these data sets, only the lengths of features can be easily measured. For the 1:70,000 data, the horizontal datum is NAD83, and the vertical datum is NAVD29 which is based on the mean high or mean higher high shoreline position that is published on nautical charts. The spatial resolution of the data is set to a minimum adjacent vertex spacing of five meters ground distance. The source of the spatial data is from the master copy of the National Ocean Service's coast charts, and they are supposed to meet or exceed National Map Accuracy Standards (Rohmann, 2000).

5.4 The Results of the Spatial Analysis of Cobscook Bay: Case Study A

The spatial analysis of Cobscook Bay (Table 2) that was based on the five scale-based sets of digital spatial data clearly show a wide range of results that can be directly attributed to map generalization, spatial resolution and map scale. There are also at least three different opinions on the extent of the bay and therefore the spatial analysis measured Cobscook Bay three times for each set of spatial data. Not unexpectedly, the length of the shoreline of both the mainland and the islands of Cobscook Bay show decreasing lengths as the scale of the spatial data becomes smaller. Using the Estes Head to Lubec town pier limit of Cobscook Bay as an example, the length of the mainland varies from a value of 380,900 meters using the

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TABLE 2. DIMENSIONS OF COBSCOOK BAY, MAINE, USA (Kostiuk, 2001a, 2001b).

Scale	24,000 Baseline Scale	70,000	100,000	250,000	1,000,000
Length of Mainland shoreline (meters)					
Comstock Pt.-Shackford	357,856	315,816	299,445	192,493	168,850
Comstock Pt.-Estes Hd.	363,499	321,249	304,562	198,361	171,969
Estes Hd.-Lubec Pier	380,900	335,820	317,125	220,612	180,019
Length of Island shoreline (meters)					
Comstock Pt.-Shackford	57,482	51,674	31,786	20,884	0
Comstock Pt.-Estes Head.	57,593	51,674	31,786	20,884	0
Estes Head.-Lubec Pier	60,860	55,709	35,737	25,917	1,223
Number of Islands					
Comstock Pt.-Shackford	169	87	29	10	0
Comstock Pt.-Estes Head.	171	87	29	10	0
Estes Head.-Lubec Pier	186	95	33	13	1
Area of Cobscook Bay (meters ²)					
Comstock Pt.-Shackford	89,946,703	N/A	90,197,323	N/A	94,019,162
Comstock Pt.-Estes Head.	92,070,024	N/A	92,297,120	N/A	95,991,320
Estes Head.-Lubec Pier	100,536,850	N/A	100,534,727	N/A	105,004,516
Area of Islands (meters ²)					
Comstock Pt.-Shackford	2,404,855	N/A	1,962,162	N/A	0
Comstock Pt.-Estes Head.	2,405,224	N/A	1,962,162	N/A	0
Estes Head.-Lubec Pier	2,639,025	N/A	2,181,156	N/A	201,450

1:24,000 scale digital spatial data, to a length of 180,019 meters that is based on the 1:1,000,000 scale digital spatial data. This is a difference of 200,881 meters or 2.1 times the length of the shoreline for the 1:24,000 digital spatial data over the use of the 1:1,000,000 digital spatial data. Based on the results of table 2 the accurate depiction of the geographic reality of Cobscook Bay is directly dependent upon the scale of a particular set of digital spatial data.

6. USING REMOTE SENSING DATA (CASE STUDY B): COBSCOOK BAY, MAINE

The purpose of Case Study B was twofold. First it explored the suitability of using digital remote sensing data (such as LANDSAT 5 TM satellite data) within a GIS for coastal zone management applications (as in detecting sea level change). Digital remote sensing data may be an alternative source for coastal zone management applications if the needed digital spatial data are unavailable. And second, it demonstrates the transition of spatial data into geographic information through the use of the LANDSAT 5 TM data within a GIS. The data that are provided from LANDSAT 5 are in a raw format and it needs to be processed with a GIS so that ground features can be properly identified. Once the LANDSAT 5-based ground

features are identified and georeferenced they become geographic information.

7. USING LANDSAT 5 TM DATA FOR COASTAL CHANGE DETECTION. CASE STUDY B.

7.1 Establishing the Vertical Datum

A first step to consider when using aerial images and remote sensing data such as LANDSAT 5 TM data to measure a coastal zone area is to decide on which vertical datum to use to define the shoreline. A statement on the vertical datum is not normally supplied with the LANDSAT 5 data, and some method must be found to establish the preferred vertical datum for the coastline. One method of determining the preferred location of the coastline is to acquire the images when the tide is at its maximum high tide cycle. This can be done by checking the tide tables to see when the high tide period is going to occur. Acquiring aerial images during the high tide cycle is a method used by mapping organizations to identify the location of the coastline. The Geomatics division of Natural Resources Canada's National Topographic System 1:50,000 Standards and Specifications manual defines the high water mark (MHW) according to various conditions such as:

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Tidal waters:

- i) The water's edge at the time of photography, if the tide is high according to the tide tables of the Canadian Hydrographic Service.
- ii) The demarcation line caused by the change in vegetation or the deposit of sea debris if the tide is not high according to the tide tables of the Canadian Hydrographic Service.
- iii) The zero contour if the tide is not high and the demarcation line cannot be seen. (Geomatics Canada, 1997, p. 25/34).

The MHW is used to define the coastline on other topographic maps such as the USGS 1:24,000 scale-based quadrangle maps that cover the coastline of the United States of America. Another method to locate the high tide line on aerial images is to use historical tide records of the area, and then to locate an archived aerial image or remote sensing image that was taken during a peak high tide cycle. It is also much easier and more practical to compare the LANDSAT digital spatial data to other forms of digital spatial data if they contain the same parameters such as map projections, map units and horizontal and vertical datums. Using the same cartographic specifications in both case studies also ensures the spatial analysis is based on a consistent methodology.

7.2 Locating, Selecting and Obtaining LANDSAT 5 Data

The data were obtained from the EROS Internet site of the United States Geological Service through a search of the historical archive of LANDSAT 5 data. Cross referencing the LANDSAT 5 data to the historical tide data indicated that the image taken at 14:41:12.1375 GMT on July 21, 1989 was two hours after the high tide. The metadata for the LANDSAT 5 TM data contained the following information:

- Sensor: TM (This is a short form for Thematic Mapper which is one of the internal sensors of LANDSAT 5).
- Processing Level: Systematic Geocorrection (The type of correction performed on the LANDSAT 5 data).
- Map Projection: UTM (Universal Transverse Mercator projection).
- UTM Zone: 19 (The number of the UTM zone).
- Earth Ellipsoid: WGS84 (A horizontal datum which is equivalent to NAD 83).
- Image Lines: 6299 (The number of lines in the LANDSAT 5 data file).
- Image Pixels: 6864 (The number of pixels in the LANDSAT 5 data file).
- Interleaving: BSQ (This stands for Band Sequential).

Since the LANDSAT 5 TM image was not taken when the water level in Cobscook Bay was at the high tide level, a method was developed to map the coastline at the MHW level. The development and application of this method forms the basis for the spatial analysis of Cobscook Bay in case study B.

8. METHODOLOGY OF THE SPATIAL ANALYSIS OF THE CASE STUDY OF COBSCOOK BAY, PART B.

8.1 Step One: Selecting a System That Can Interpret and Process the LANDSAT 5 Data

There are various computer programs that allow the viewing and processing data from remote sensing systems such as PCI

Geomatic's Image Handler. The PCI program is able to read the LANDSAT 5 data, and it then converts these data to its own format for processing and manipulation. The suites of PCI programs are also used by many governmental and private organizations to process digital spatial data.

8.2 Step Two: Creating a Subset

A subset covering the study area was created from the large image and the most suitable spectral bands for delineating the coastline at the MHW (Mean High Water) level were selected. An explanation of the properties of the preferred spectral bands are shown in step three.

8.3 Step Three: Identifying Separate Areas of the Coastal Zone.

PCI's Image Handler can display LANDSAT 5 images in 8-bit unsigned integer, 16-bit signed integer, 16-bit unsigned integer and 32-bit floating-point real image channels. The 8-bit data format is designated as 8U and this format is most often used for air and satellite imagery (PCI Enterprises, 1998, pp. 22,27). The spectral range of each LANDSAT 5 TM band that is set to the 8-bit format is converted to 256 possible gray levels starting at 0 and ending at 255. The levels are numbered by row and column. Each of these pixels represents a particular light reflectance characteristic of the feature (or features) it represents on the earth's surface. Depending on the size of an object on the earth's surface, it is possible that a LANDSAT 5 TM pixel may be representing more than one ground or water feature and this can affect the reliability of the reflectance value of the pixel.

LANDSAT 5 TM (Thematic Mapper) bands 1, 3, 4, and 5 were used to create the three elements of the coastal zone since these bands have spectral ranges that help in identifying the water and land interface. The wavelengths and characteristics of these LANDSAT 5 TM bands as summarized from Lillesand & Kiefer (1994, p. 468) are as follows:

- Band 1 has a wavelength of 0.45 to 0.52 μm and it has a nominal spectral location of blue. Band 1 can penetrate water, which makes it appropriate for mapping coastlines. Band 1 is also useful for the identification of soils and plants including forests, as well as cultural features.
- Band 3 has a wavelength of 0.63 to 0.69 μm and it has a nominal spectral location of red. Band 3 can detect chlorophyll, which aids in plant identification.
- Band 4 has a wavelength of 0.76 to 0.90 μm and its nominal spectral location is the near infrared. Band 4 is useful for interpreting different types of vegetation, detecting moisture in soils and for the delineation of water and land.
- Band 5 has a wavelength of 1.55 to 1.75 μm and its nominal spectral location is the mid-infrared. Band 5 can be used to detect the moisture content of various plants and soils.

By arranging these LANDSAT 5 TM bands in various combinations with Image Handler, different features of the coastal zone were easy to recognize as specific colors such as dark blue for water, reddish tones for tidal flats and various greens for the islands and the mainland. These different color combinations made it much easier to perform a visual identification and classification of some of the more important coastal zone features. Many features on the earth's surface

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including vegetation, soils, rocks, and water have a reflectance value that is visually more noticeable in some LANDSAT 5 TM bands than in the other bands (the interpretation of images using remote sensing often requires the human eye to aid in identifying and classifying a feature on the earth's surface). Using a program such as Image Handler, the various pixels that are contained within the converted LANDSAT 5 TM image were reclassified into three zones of water, land and intertidal. This method was chosen since these three zones were relatively easy to classify based on their spectral values. Then the water and intertidal zones were joined to create a zone that marks the MHW (mean high water) or high tide zone. All of the ground features that made up the mainland such as trees, rocks, roads, airport runways, docks, bridges, wharfs, buildings and grass have different spectral characteristics, but since it is only necessary to identify the land as a whole, these elements can be combined into a single and larger group of pixels that are designated with one value. This new single group of pixels has a spectral range that represents features that are associated with the landmass. The same technique was used on pixels that represented the spectral characteristics of the water areas as well as those pixels that represented the features in the intertidal zone. Once the original LANDSAT 5 TM image is

converted to a two-zone image it is then saved as a new layer within the PCI Image Handler, and this new layer can then be prepared for use in a geographic information system where the coastal zone features can then be mapped.

8.5 Step Four: Loading the GeoTIFF File into ARCVIEW for Spatial Analysis

The PCI file was exported as a GeoTIFF image into ArcView for the purpose of being a georeferenced image for the on-screen digitizing of the shoreline of the mainland and of the islands of Cobscook Bay. A new ArcView project was then created that used the same cartographic specification as the geographic projects had in Case Study A. The map and measuring units were set to meters. The map datum for this project was set as NAD83, which is essentially the same map datum as WGS84 for the original LANDSAT 5 TM image. The GeoTIFF file was used as a base image so that the digitizing of shorelines and the creation of polygons for water areas could be accomplished within ArcView. Then, as was done with the digital spatial data in Case Study A, the length and areas of features were calculated based on the three extents of Cobscook Bay (Table 3).

TABLE 3. LANDSAT 5-BASED ANALYSIS OF COBSCOOK BAY (KOSTIUK, 2001A).

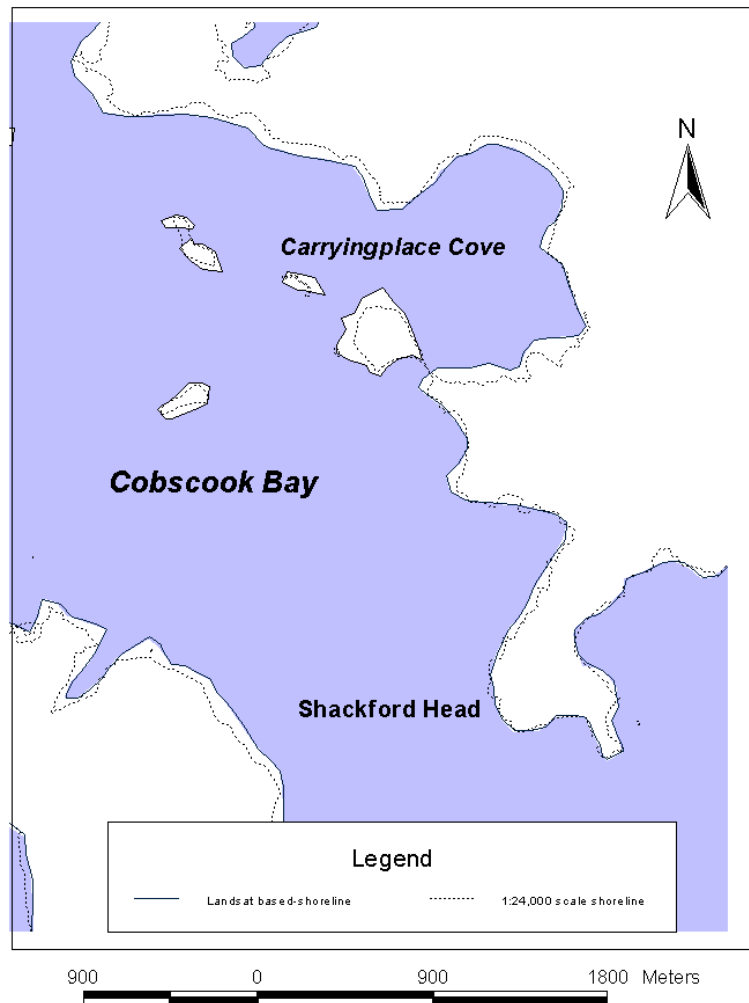
Dimension or count.	Comstock Point to Shackford Head	Comstock Point to Estes Head	Estes Head to Lubec Town Pier
Length of Mainland Shoreline. Meters	271,208	276,142	288,489
Number of Islands.	41	41	46
Length of Island's Shorelines. Meters	39,762	39,762	45,202
Area of Islands. Square Meters	2,624,631	2,624,631	2,937,095
Area of Cobscook Bay. Square Meters	81,147,847	83,289,246	91,275,792

8.4 Checking the Horizontal Accuracy of the Spatial Analysis of Case Study B

As was demonstrated in Case Study A the horizontal accuracy of spatial data can vary considerably by scale and data source. The values in table 3 show the results of using remote sensing data with a GIS to obtain measurements of length and area. What is lacking in the spatial analysis of case study B is an assessment of the accuracy of the location of the shoreline. In order to determine the horizontal accuracy of the geographic representation of the shoreline of Cobscook Bay that was based on LANDSAT 5 TM data a new GIS project was set up. The 1:24,000 scale vector data of Cobscook Bay was used to reference the horizontal position of the shoreline that was created from the LANDSAT 5 TM data. Referring to the metadata that was written by the USGS, the horizontal

accuracy of the 1:24,000 data is 40 feet or 12.19 meters on the ground (USGS, Part 1, 1997, p.1. D-2). Therefore, the level of inaccuracy that is present in the 1:24,000 data limits the measurement of the horizontal accuracy of the shoreline that was created from the LANDSAT 5 TM data to 12.19 meters. Fifty control points were established at random locations across Cobscook Bay so that the position of the 1:24,000-based and LANDSAT 5 TM-based shorelines could be measured and recorded. The difference in the location of the two shorelines at the fifty control points were measured by vector lines and the length of the line segments were calculated in meters using the *calcapl* script. An example of the horizontal offset between the 1:24,000-based and the LANDSAT 5 TM-based shorelines are shown in figure 1. The 1:24,000 shoreline is dotted while the LANDSAT shoreline is a solid line.

Figure 1



The statistics function of ArcView was used to calculate various elements of the horizontal accuracy of the LANDSAT 5 TM-based shoreline and they are shown below:

- Count: 50 (the number of control points used for measuring the offset of the two shorelines).
- Mean: 58.327 (the average distance in meters of the offset of the two shorelines).
- Maximum: 314.301 (the largest offset between the two shorelines).
- Minimum: 5.811 (the smallest offset between the two shorelines).
- Range: 308.490 (the difference between the largest and smallest offset).
- Standard Deviation: 54.697 (the standard deviation of the offsets).

The horizontal accuracy of the shorelines that were created in case study B ranged from 5.8 meters to 314.3 meters with the average horizontal accuracy being 58.3 meters. Referring back to the rule of detection and resolution size that was described in earlier (see table 1), the minimum detection size of case study B will be 60 meters since 30 meters is the resolution size. Since the horizontal error is 58.3 meters this is an acceptable (and expected) error because it conforms to the detection and

resolution formula where the detectable unit is twice that of the resolution unit (Tobler, 1988). The horizontal accuracy of 58.3 meters also is a validation of the methods used to identify the shoreline in case study B since the error fell within the expected limits according to the detection and resolution rule. However, since the detection size is 60 meters no apparent change of the coastline can be attributed to the analysis of Cobscook Bay by the LANDSAT 5 data. This is because the measurements of the horizontal location of the shorelines between Case Study A and Case Study B are within the expected error rate of the detection grid. Therefore, only remote sensing results that are greater than the size of the detection grid should be used to measure sea level and shoreline change.

Knowing the level of accuracy of spatial data is obviously useful for particular coastal zone management applications where the actual geographic position of the coastline is important. For example, horizontal accuracy of spatial data are important for the analysis and mapping of shoreline erosion, detecting shoreline change, tracking and clean up of oil spills, habitat assessment and mitigating damage due to storm surges.

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9. DISCUSSION OF THE SPATIAL ANALYSIS OF CASE STUDY B

The results that were obtained by using the LANDSAT data were quite different from the results that were obtained by using the 1:24,000 scale digital spatial data in Case Study A. For example the length of the shoreline of Cobscook Bay that used the Lubec town pier limit showed a value of 288,489 meters for the LANDSAT 5-based data while the 1:24,000 spatial data has a result of 380,900 meters. This was a difference of 92,411 meters and this clearly shows that LANDSAT 5 TM images cannot be relied upon to map a shoreline feature at the same resolution as is displayed on 1:24,000 spatial data. Since the minimum acceptable scale for using digital spatial data for use in a geographic information system to measure coastline features was determined by Wainwright (1991) to be 1:40,000 the results that were obtained from the LANDSAT 5 TM-based spatial analysis clearly shows that it does not meet these requirements. The LANDSAT 5 TM-based spatial analysis also did not produce results that are as good as those that were produced from the 1:100,000 scale digital spatial data.

There are several reasons why the LANDSAT 5 TM images do not meet the minimum requirements, and the two main reasons are scale and resolution. The scale of the LANDSAT 5 TM image is approximately 1:1,000,000 and the resolution of the pixel size is 30 meters x 30 meters which limits how much detail can be clearly seen and/or interpreted correctly. When the LANDSAT 5 TM images were used for spatial analysis with both the PCI and ArcView systems, the ability to see and recognize fine ground detail such as residential streets and small buildings was limited. Personal knowledge and experience of the study area made it slightly easier to recognize certain features, and this helped in determining where such features as the normal high and low tide lines were located. LANDSAT 5 TM data have limited resolution and it is only appropriate to provide a regional view. If remote sensing data are to be used for effective coastal zone management purposes such as measuring coastline features then the image pixels must provide a ground resolution much larger than 30 meters (such as 4 meters). There are such data available and one source is provided by the new IKONOS remote sensing satellite. For example, the IKONOS data has a precision of 1-meter panchromatic or 4-meter multi-spectral imagery. Using the rule of the sampling interval would mean that IKONOS Remote sensing data should have a detection accuracy of 2 meters for the panchromatic (1-meter) and 8 meters for the multi-spectral imagery (4 meters). Another reason for the difference in the measurements of the features in Cobscook Bay is due to the boundary that was arbitrarily set for the interior limits of the bay. The location of the coastline on the 1:24,000 scale data was taken from USGS maps which used the Mean High Water (MHW) line and "the extent of tidal features was determined by a group of marine specialists familiar with Maine's coast (Maine Office of GIS, 2000). Unfortunately, no such methods of ground verification were used for the case study. Consequently, during the process of on-screen digitizing for case study B there were varying degrees of difficulty to determine where the coastline stopped and the rivers began. The areas where the inner limits of Cobscook Bay were assumed to be located may have been, in many cases, premature. This type of error would mean that a shorter shoreline and a smaller water area would be measured during the spatial analysis stage. This problem is one of the

yet to be defined questions of the coastal zone such as: Where does the coastline, or coastal zone begin or end?

10. CONCLUSION

Detecting sea level change requires accurate data and information, and Remote Sensing data can have an important role to play in this discipline. In order for Remote Sensing data to be able to play an important and vital role for coastal zone management purposes there must be a set of minimum acceptable standards for the use of spatial data (Standards like those that formed the basis of case studies A and B are a good example). The type and scale of spatial data that are used in geographic information systems must match a set of cartographic requirements and conditions in order for them to be considered as being reliable and useful. Therefore it is important to know what level of precision and accuracy is required for every coastal zone management application that needs the use of spatial data. Acquiring the image at a point in time that matches the selected Vertical datum will also ensure a more reliable result as well as reducing the time required to perform the spatial analysis.

Remote sensing data such as LANDSAT 5 TM satellite images can be useful for reconnaissance purposes to check if there has been significant change in a coastline or to detect various types of environmental conditions such as storm surges, sediment transport along the coast, or to track the spread of oil from ships or land based sources. If the detection unit of the spatial data (twice the resolution unit) matches the scale that is being used for an application then the spatial data can be used for direct updating of maps or digital spatial data. If the spatial data do not meet minimum acceptable requirements then more accurate sources and images should be used in geographic information systems. Management and analysis of the coastal zone require both an accurate and defensible spatial analysis of various coastal features. Remote sensing data have a potentially valuable role to play in this field especially as the scale and the resolution of the images improve over time.

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