INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

**ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600**

UMI[®]

**Determining the Spatial Data Requirements for a GIS to Support Coastal Zone
Management.**

Cobscook Bay, Maine.

A Case Study.

By

Michael Kostiuk

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Arts**

Carleton University

Ottawa, Ontario

September, 2001.

© 2001, Michael Kostiuk

**National Library
of Canada**

**Acquisitions and
Bibliographic Services**

**395 Wellington Street
Ottawa ON K1A 0N4
Canada**

**Bibliothèque nationale
du Canada**

**Acquisitions et
services bibliographiques**

**395, rue Wellington
Ottawa ON K1A 0N4
Canada**

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-66829-0

Canada

**The undersigned recommend to the Faculty of Graduate Studies
and Research acceptance of the thesis**

**Determining the Spatial Data Requirements for a GIS to Support Coastal Zone
Management. Cobscook Bay, Maine.**

A Case Study.

Submitted by

By

Michael Kostiuk, B. A.

**In partial fulfilment for the requirements for
the degree of Master of Arts**

Thesis Supervisor

Chair, Department of Geography and Environmental Studies

**Carleton University
September, 2001.**

© Michael Kostiuk

Abstract

Geographic information systems (GIS) are a relatively new and potentially valuable tool for coastal zone management. This thesis examines the effectiveness of a GIS to support coastal zone management. A case study approach demonstrated how spatial data in the order of 1:24,000, 1:70,000, 1:100,000, 1:250,000 and 1:1,000,000 produced significantly different results for shoreline length and the number of islands in Cobscook Bay, Maine, USA. A limit of 1:40,000 was selected as the smallest acceptable scale for the accurate depiction of coastal features. Control points were established at the mouth of the bay to determine the geographic extent of the bay and new sets of digital spatial data were created that matched these limits. Shoreline length was 2.1 times greater for the 1:24,000 data versus the 1:1,000,000 data. LANDSAT 5 TM data were also used in the case study although it did not meet the minimum requirements for coastal zone management.

Acknowledgments

I wish to acknowledge the help and support I received from the following people and organizations:

- **My father, Oleksa Kostiuk.**
- **Coastal Zone Canada Association.**
- **Cobscook Bay Resource Center, Eastport, Maine.**
- **Department of Geography and Environmental Studies. Carleton University, Ottawa, Ontario, Canada.**
- **Department of Graduate Studies. Carleton University, Ottawa. Ontario, Canada.**
- **ESRI Canada.**
- **Fraser Taylor. Carleton University, Ottawa. Ontario, Canada.**
- **Maine Office of GIS.**
- **Mike Fox. Carleton University, Ottawa. Ontario, Canada.**
- **Quebec Labrador Foundation and its Atlantic Center for the Environment. Ipswich Massachusetts.**
- **Steve Prashker. Carleton University, Ottawa. Ontario, Canada.**

Table of Contents

	Page
1) Introduction.	1
2) Coastal zones, coastal zone management, and the use of spatial data for coastal zone applications.	12
3) Basic principles of digital spatial data.	34
4) Digital spatial data and cartographic requirements for coastal zone management.	72
5) Vector spatial data case study (case study A): Cobscook Bay, Maine.	93
6) Raster spatial data case study (case study B): Cobscook Bay, Maine.	134
7) Conclusion	170
References	184

List of Tables

	Page
Table 3.1. Comparison of map scale to map resolution.	55
Table 3.2. Various ground pixel resolutions of a scanned 1:10,000 aerial photograph.	62
Table 5.1. GIS-based measurement of Cobscook Bay, Maine, USA.	123
Table 5.2 Implications of the results of table 5.1 for Coastal Zone Management.	132
Table 6.1 Landsat-based measurement of Cobscook Bay, Maine, USA.	156

List of Illustrations

	Page
Figure 3.1. Comparison between 1:1,000,000 and 1:24,000 vector line representation of geographic detail.	65
Figure 3.2. Various vector resolution sizes.	69
Figure 5.1 Location of Cobscook Bay in relation to the Gulf of Maine and the Bay of Fundy.	97
Figure 5.2. Cobscook Bay area map.	98
Figure 5.3. GIS control point locations.	112
Figure 5.4. Shackford Head to Comstock Point clip theme.	118
Figure 5.5. Cobscook Bay Maine. Shoreline from Shackford Head to Comstock Point.	120
Figure 6.1 LANDSAT 5 image reclassified to two zones of land and mean high water.	149
Figure 6.2. LANDSAT image of Carryingplace Cove, Eastport Maine.	151
Figure 6.3 LANDSAT-based analysis of Cobscook bay from Estes Head to Lubec town pier.	155
Figure 6.4. LANDSAT Shoreline. Horizontal testing locations. Cobscook Bay, Maine.	159
Figure 6.5. Comparison between 1:24,000 and LANDSAT-based shorelines. Cobscook Bay, Maine.	160

List of Plates

	Page
Plate 3.1. Carryingplace Cove, Cobscook Bay Maine. Low tide.	88
Plate 3.2. Carryingplace Cove, Cobscook Bay Maine. High tide.	89
Plate 5.1. Cobscook Bay Causeway, Maine.	99
Plate 5.2. Fish pens, Campobello Island, New Brunswick.	102
Plate 5.3. Fish weir, Johnson Cove, Maine	103

Chapter 1

Introduction

Digital spatial data and GIS (geographic information systems) are being used on an increasing scale by various organizations, planners, geographers and other researchers to support environmental planning and coastal zone management applications. The goal of this thesis is to examine, by means of a case study in the Gulf of Maine region, a selection of current and potential uses of digital spatial data for use in coastal zones. Determining the spatial dimensions of geographic features for coastal zone management is not a simple "point and click" operation, but rather, it requires a thorough understanding of cartography, the characteristics of spatial data (analogue and digital) as well as the methods that are employed to process these data. Several different types of computer-based geographic information systems are used in the case study to analyse, measure and test various forms of digital spatial data to demonstrate varying degrees of cartographic accuracy and precision. The Cobscook Bay coastal area in the American state of Maine was used as the specific study area for this thesis.

The coastal zones of our planet are very important places since it is within these areas where much of the world's population, employment and food production are located. It has been estimated that approximately fifty percent of the earth's population lives or works within 150 to 200 kilometres of a coast (Coastal Zone

Canada Association, 2000; Hinrichsen, 1996). This range of 150 to 200 kilometres is somewhat imprecise since a standard definition of what constitutes the coastal zone has not yet been universally accepted. No matter how it is defined, the coastal zone includes the coastline, as well as a landward and a seaward side, and the two sides can be described as follows:

- Depending on the precision definition adopted, the landward side of a coastal zone can be as narrow as a few kilometres from the shoreline, or it can extend hundreds of kilometres inland to include entire watersheds.
- Similarly, on the seaward side, the coastal zone can be limited to the international boundary limit or it can extend beyond this limit to cover a larger economic zone which may include the continental shelf and the areas around offshore islands (OECD, 1993). Other factors affecting the definition include the degree of jurisdiction, enforcement and involvement various levels of government have in the coastal zone. Different definitions of the coastal zone are also recognized by various private interests ranging from subsistence fishers to multi-national corporations (Coastal Zone Canada Association, 2000).

One common element of any coastal zone definition is the coastline, or the narrow interface zone where the land and water meet. In a coastal marine environment, in

which the water level can vary substantially because of tides, the location of what is called the primary shoreline is often based on the average high tide level and a secondary shoreline is designated for the average low tide level (Robinson, Sale, Morrison, 1984). The area between the high and low tide levels is known as the intertidal zone. Most often the shoreline on Canadian topographic maps is represented by the average high tide line (Natural Resources Canada, 1988).

The coastal zone is frequently a particularly resource-rich area. Some resources are found in specific locations in the coastal zone, such as forests and agricultural resources on the landward side, or various fish species from the seaward side. Some resources on the other hand, can occur on both sides of the coastal zone, such as coal seams that extend from the land out under the seabed, or oil and natural gas that are pumped up from the ground on land, or from offshore drilling platforms. The coastal zone is also a primary source of food, with more than ninety percent of the marine catch coming from reaches that are less than 200 miles from the shore (FAO, 1981). The harvest of various wild species of fish has grown from an estimated four million metric tons in 1900 (Borgstrom, 1962, p. 777) to almost 100 million by 1995 (FAO, 1995, p. 186). During this same period, the earth's population has grown from about 1.6 billion to just over 6 billion.

As global population has increased, human activity also increased in the coastal zone. The resources of the coastal zone are either finite, as is the case of non-

renewable mineral resources, or they can be considered as being potentially renewable such as harvesting various natural fish species. However, renewable resources can, and have become threatened if they are harvested beyond their sustainable level. With so many different types of resources being extracted from the coastal zone there is also the problem of competing resource interests within the coastal zone. Some of these competing interests often require the same physical location for their own particular use, which is often in direct conflict with the current, or proposed, activities of another user of the coastal zone. From a human perspective, the users of the coastal zone are people who are often in opposition to other people, while sometimes the competition for the same area of the coastal resource is between people and one or more component of nature. For example, a natural deep water bay can be considered a desirable location to build a port for large ocean going vessels such as freighters and oil tankers. However, this type of coastal development, while benefiting one sector of the economy, may cause a problem with other sectors of the local economy who would argue that such a development could ruin, or diminish, an area's natural endowments. Such opposition may come from the local tourist industry that has relied upon the traditional lifestyle (and way of life) of the community as the main reason why tourists would choose to visit the area. Such a proposed development could also raise fears that an enlarged port might increase the risk of air and water pollution in the area, which would lead to a lower quality of life for the residents. An example of this type of conflict over the use of natural resources occurred in the city of Eastport

Maine in 1968 when there was a plan to build a large oil refinery and port facility on 254 acres of land within the city limits. The proposal for the oil refinery divided the community between those who supported the potential economic benefits and those who feared that it would adversely alter the local way of life and raise the risk of pollution from oil spills. Due to a series of legal challenges and growing local opposition, the plans for the oil refinery were formally withdrawn in 1983 (Holt, 1999).

Since the coastal zone is of primary importance for such activities as human habitation, employment, agriculture, forestry, transportation, port facilities, fishing, aquaculture, industry, recreation, and mineral, oil, and gas extraction, there is a need for proper coastal zone planning and management. The efficient and effective management of the coastal zone is a concern for governments, businesses, non-governmental organizations and people that inhabit these areas. It is also important for those people who consume the resources of these important coastal ecosystems. The meaning of coastal zone management can vary depending on where it is being applied and for what purpose, and it has been argued that there are probably as many definitions of the term coastal zone management as there are coastal zone managers (Hinrichsen, 1998). For example, the OECD (1993) defines coastal zone management as management of the coastal zone as a whole in relation to local, regional, national and international goals. This definition is a good starting point to help understand the overall issue, but it is probably too vague

to be universally applied in every coastal zone management situation.

An important element in the planning process is the use of maps and spatial data to represent the important elements that comprise an area. Maps and digital spatial data are useful aids for planners and managers, since the graphic representation of the coastal zone can help them to better understand the factors that comprise the environment of the coastal zone. Furthermore, the use of digital spatial data also allows the coastal zone manager to use a geographic information system to perform a spatial (geographic) analysis of the coastal zone. Using spatial analysis can help the coastal zone manager better understand the environment of the coastal zone, which in turn aids in the effective and efficient planning and management of the coastal zone.

Efficient planning and proper management of the coastal zone require accurate maps and data. As the 1977 Report of the Group of Experts on Hydrographic Surveying and Nautical Charting Hydrography states: "Precise large-scale surveys also provide the primary data for good coastal zone management" (United Nations, 1977, p. 3). This is a view shared by other organizations such as ACZISC (Atlantic Coastal Zone Information Steering Committee). According to ACZISC's Internet site: "coastal mapping is a prerequisite for integrated coastal zone management" (Atlantic Coastal Zone Information Steering Committee, 2000). The term integrated coastal zone management refers to the process of involving all levels and

jurisdictions of government, science, management agencies as well as private organizations and individuals to be a part of the planning and coastal management process (Coastal Zone Canada Association, 2000). ACZISC is in the process of addressing the need for high resolution coastal base maps as a tool to mitigate natural disasters (such as flooding and storm surges) in the coastal zone.

GIS (Geographic Information Systems) can play an important role in coastal zone management. While coastal zone management has been practised in various forms since at least the seventeenth century (Smith, 1992), the use of GIS has been a “relatively new tool as part of coastal zone management toolbox” (NOAA, 2001). Of course a GIS can be used for applications other than coastal zone use such as forestry, agriculture, demographics and geological mapping. It has been estimated that approximately 80 percent of government and business information has at least one reference to location; however, until recently the power of geographic information has not been widely realized and used for such applications as decision making and the delivery of services (Open GIS Consortium, 2001). A typical GIS should be able to create, manipulate, analyse and store digital spatial data. The GIS should also be capable of integrating common database functions such as query and statistical analysis with the spatial data and to be able to display the results on a computer screen or a printed map. It is this ability of a GIS to integrate spatial data with common database operations that separates it from other types of information systems (Great Lakes Information Network, 2001). A well designed GIS

that combines the benefits of accurate mapping with geographic analysis can be even more useful for coastal zone management than just a precise survey. For example, the such a GIS should allow the user to separate into discrete layers the various elements of the coastal zone environment. This separation of many of the parts that comprise the ecosystem can help the researcher, planner or coastal zone manager with their analysis of the coastal zone environment. This type of analysis is also known as spatial analysis. Any part of the ecosystem can be modelled within a GIS and it can be stored and analysed as a single entity or it can be combined with other elements of the environment. For example, various types of flora and fauna can be shown in a GIS as separate layers and their use of geographic space can be mapped and analysed over a wide period. The GIS can also display and map many of the human and nonhuman elements that may, or may not, interact with each other within this zone. These interactions may be both spatial and temporal in nature. The separation of each map layer also makes it easier for the GIS user to edit the data, as well as to decide which layer should be displayed on the GIS project, or to be included on a printed map.

The aim of this thesis is to explore the potential value of geographic information systems for use in coastal zone management by examining some fundamental qualities of spatial data typically used in coastal zone management projects. The thesis will also identify the cartographic procedures and specifications that must be followed to obtain an accurate spatial measurement in the coastal zone. The validity

of results obtained by using a GIS is dependent to a high degree upon the quality of the spatial data that goes into these systems. As with a map, digital spatial data contain geographic information that is limited by the scale of the database. The reduction of geographic detail on almost all types of maps is a necessary procedure to improve the visual representation of the map. This reduction of geographic detail is known as map generalisation. Map generalisation not only limits the amount of information that can be shown on a map or within digital spatial data, but it can also limit their accuracy as well.

A case study approach is used to explore the potential value of geographic systems for coastal zone management. The area selected for the case study is Cobscook Bay, which is located in the southeastern section of the American state of Maine, near the Canadian province of New Brunswick. This area was selected because of familiarity with both the general area, and some of its important local issues (Lyman & Milliken, 1999). The case study of Cobscook Bay will be used to explore the potential value of geographic information systems for coastal zone management through the following specific objectives:

1. A review of coastal zone management.
2. An overview of the benefits and limitations of digital spatial data.
3. Determine the specific cartographic and data requirements for coastal zone management.

- 4. Determine the availability and quality of spatial data for coastal zone management in the case study area.**
- 5. Evaluate a series of five different sets (1:24,000, 1:70,000, 1:100,000, 1:250,000, 1:1,000,000) of vector data from existing digital spatial databases, and one raster set of digital Landsat 5 TM data to determine the most appropriate map scale for certain types of coastal zone management applications. The water area, the area of the islands, the number of islands and the length of the shoreline of Cobscook Bay will be computed from the supplied digital spatial data to support this analysis. LANDSAT 5 TM data will be used to determine if remote sensing data provides the detail that is required for spatial analysis of the coastal zone, and if it can be used as an alternative source to vector data.**
- 6. Through the case study of Cobscook Bay, Maine, to evaluate the results of a series of spatial analyses (or GIS operations), the potential value of digital spatial data and geographic information systems to provide basic locational data to support coastal zone management.**

A GIS-based analysis is only as good as the input data, and a significant part of the thesis will be devoted to the issue of data accuracy and how this can affect the reliability of the results that a GIS can produce. The digital spatial data of Cobscook Bay have been obtained at six different scales to test the reliability and accuracy of using GIS data to map the area of Cobscook Bay along with the length of its shoreline.

There are two main parts to this thesis:

The first part explores the substantive and technical background of coastal zone management. Chapter two provides a literature review of the coastal zone, coastal zone management and the use of spatial data for coastal zone management applications. Chapter three explains the nature of spatial data, with a focus on two of the many important elements of spatial data, which are spatial resolution and map generalization. Chapter four lists and discusses the specific requirements for the type of spatial data that should be used for the effective spatial analysis of the coastal zone.

The second part of the thesis is devoted to testing the requirements for the effective use of spatial data for coastal zone management through a case study approach. In chapter five, various types and scales of digital spatial data will be used to measure the coast line, and the water area of Cobscook Bay, Maine. In chapter six, Cobscook Bay will be measured using LANDSAT 5 TM data and the results will then be compared to the results in chapter six. LANDSAT 5 TM data were used to compare its potential use for coastal zone management and as a possible alternative to using vector data. Chapter seven will then summarize and discuss the coastal zone management implications of the results that were obtained from the case study approach.

Chapter Two

Coastal Zones, Coastal Zone Management, and the Use of Spatial Data for Coastal Zone Applications

The Coastal Zone

The coastal zone is an important location for human, plants and animal populations. For this reason it is important to understand what the term “coastal zone” means. There is, however, no single, generally accepted definition of the term “coastal zone”, but instead the term is used in a variety of ways, depending on what roles, or responsibilities, an organization defining the zone is mandated to perform, which vested interests are involved, or what area of study is currently being pursued. The OECD (1993) provides a rather flexible definition of the coastal zone that can include an area as small as a few kilometres from the shoreline, or that can extend far inland to include entire watersheds that drain into a coastal area (OECD, 1993). The Coastal Zone Canada Association (2000) prefers the more inclusive definition and it recommends that the coastal zone inland boundary should include all coastal drainage basins. A very precise (and spatially small) definition of the coastal zone comes from the province of New Brunswick’s Department of Environment and Local Government. The Department of Environment and Local Government defines the coastal zone according to the Provincial Land Use Policy for Coastal Lands. The coastal lands in New Brunswick are defined as a “composite of coastal features

occurring landward of the ordinary high water mark as well as a 30 metre coastal features set-back area " (Atlantic Coastal Zone Information Steering Committee, 2001, June). The Provincial Land Use Policy also requires an additional 470 metre coastal development area around their designated coastal lands to act as a protective buffer. Another precise and perhaps arbitrary definition comes from Hinrichsen (1998, p. 2) who defines the coastal zone "as a strip of land 200 kilometres wide measured from the low tide mark inland and extending seaward to include important near-shore ecosystems such as barrier islands, seagrass beds, and coral reefs". Brahtz (1972, p.2) on the other hand, defines the coastal zone as a geographical concept. "Its predominant physical characteristic is the shoreline where land, sea and air, or in geologic terms, the lithosphere, hydrosphere, and atmosphere, join to form a triple interface". This is an area where there is a continuum between the geographic regions of the land and of the sea (Brahtz 1972, p. 2). Brahtz also writes that geologists as a whole do not agree on a universal system for classifying shorelines. Brahtz says that this lack of agreement is due to "analyses by specialists with singular objectives, the classification of a coastal phenomenon tends to be oriented around their objectives and the special constraints of their objectives" (Brahtz 1972, p. 3). Despite the lack of agreement on the classification of the coastal zone, Brahtz writes that most geologists recognize that the coastal zone is one of the most dynamic erosional environments on the planet (Brahtz 1972, p. 4). The erosion of the coastline is of particular importance due to the number of people who live on or near the coasts and who

obtain various types of resources from the coastal areas. With the worldwide rise of the sea level due to such possible factors as global warming there is an increased need to monitor change along coastline. This is especially true for low lying areas of the coast and for islands that have limited topography.

Since there are many users of the coastal zone other than geologists, there are of course many definitions of what constitutes the coastal zone. As Brahtz pointed out these definitions vary according to the interests of different groups and organizations that use or study the coastal zone. Even though there appears to be a wide variety of definitions about what constitutes a coastal zone, Hinrichsen (1998) has written a general definition of the coastal zone that lists what he considers are its most important elements:

No matter how they are defined, coastal areas always include intertidal zones and often incorporate coastal flood plains, estuaries, mangrove swamps, salt marshes, and tidal flats as well as beaches, dune complexes, barrier islands, nearshore seagrass beds, and coral reef (Hinrichsen, 1998, p. 2).

This definition is not the defacto standard that is accepted by all of the parties that are involved with the coastal zone, but it appears to include most of the elements that have been formulated and developed by various other organizations. The case study for this thesis will also use many of the elements of Hinrichsen's definition such as intertidal zones, coastal flood plains, estuaries, tidal flats, beaches and barrier islands. The next section of this chapter discusses the various definitions of

coastal zone management.

Coastal Zone Management

Since the coastal zone is such an important area for human activities there is a vital need for proper coastal zone planning and management. As discussed, there are many definitions of what constitutes the coastal zone, and there are also many definitions of what the term coastal zone management means. Hinrichsen (1998) wrote that "there are probably as many definitions of coastal zone management as there are coastal managers"(Hinrichsen,1998, p. 2). Hinrichsen also argued that coastal zone management, like the processes of erosion, takes time and it is a process that may evolve over a period of several decades. Hinrichsen (1998) quotes the following OECD (1993) definition of coastal zone management as being one of the more succinct versions:

Integrated coastal zone management is most simply understood as management of the coastal zone *as a whole* in relation to local, regional, national and international goals. It implies a particular focus on the interaction between the various activities and resource demands that occur within the coastal zone and between coastal zone activities and activities in other regions (Hinrichsen,1998, p. 3).

While the above gives an overall definition of the term coastal zone management, it does not explain how it should be accomplished. Brahtz (1972) writes that since the use of the earth's natural resources must also cause a modification of a portion of our environment, it is important to learn and understand how much can be taken away before there are harmful effects. Our actions regarding the environment have

consequences that must be understood if we are to use the resources in the coastal zone in a sustainable manner. What is required is a systems approach at all levels of government to provide an objective method for large-scale planning and implementation of selected strategies. The key ingredient according to Brahtz is "excellence in management which is an unmistakable requirement in order to handle the complexities of the coastal zone problem situation" (Brahtz, 1972, p. 3).

Another important requirement for coastal zone management is to develop a viable management rationale as part of the development plan. This is necessary according to Brahtz in order to control "man's activities and therefore the extent of his intervention in the coastal environment" (Brahtz, 1972, p. 3). To accomplish these goals, Brahtz says that the "development planner presumes an understanding of the interactions between natural and artificial systems" (Brahtz, 1972, p. 3). The coastal zone manager must also be able to identify and describe the many effects that the various human activities have upon the environment within the coastal zone. The relationships that are harmful to the environment must be identified and control exercised over the human misuse (Brahtz, 1972, p. 3).

As Hinrichsen (1998) stated above, there are many definitions of coastal zone management and it can be expressed in such terms as: coastal management, integrated coastal zone management, coastal area management and planning, coastal resources management, and integrated coastal zone planning and

management (Coastal Zone Canada Association, 2000, p. 7). Fabbri (1992) wrote that the term “management” refers mostly to the English speaking world along with the term “aménagement” which is used in French. On the international scene the words “management” and “planning” are often used interchangeably and this has contributed to the ambiguity that exists today regarding the definition of the term coastal zone management. For example, in Italian the term “gestione” can be used for administration, management or planning (Fabbri, 1992). In this thesis the term “coastal zone management” will be regarded as a flexible definition that is used to explain the various approaches that organizations use to plan and manage their use of the coastal zone. However, for the case study the coastal zone will be defined to include the landward side of the Mean High Water line up to the extent of the watershed and on the water side to extend to the edge of the continental shelf. Therefore coastal zone management for the study area will include any coastal planning and environmental management application that are in some way associated with the “coastal zone” as defined for the study area. Some of the possible uses of the coastal zone are “economic, recreation, aesthetic, education, science and culture” (Coastal Zone Canada Association, 2000, p. 9). To help illustrate some of the different approaches to coastal zone management the following examples have been provided:

The Geotechnical Engineer

From an engineering perspective, the geotechnical engineer will consider coastal

zone management based on knowledge drawn from geotechnical data. These data are becoming extremely important for the assessment and management of complex coastal ecosystems. According to a 1992 United Nations report on geotechnical applications, geologic conditions have an enormous effect on the economy and development of coastal communities. The effects created by these geologic conditions can have a serious impact on the success of new projects. The lack of knowledge of these possible effects can result in improper land use decisions and resource use conflict. According to this report "urban development of coastal lowlands and deltaic areas has already resulted in major land-use problems stemming from a lack of understanding of the basic geology" (United Nations, 1992, p. 1).

Coastal engineers also build a wide variety of structures such as ports, harbours, wharves, jetties and breakwater structures, urban waterfront and estuarine development, ocean outfalls, as well as conducting dredging operations. Coastal zone management for the geotechnical engineer requires the knowledge of how coastal structures interact with the natural environment. Geologists have to study these potential impacts early in the planning stages of marine engineering work. If any negative environmental impact is predicted, the geologists have the responsibility of reporting such potential impacts to those people or organizations concerned. Geoscientists should also provide the data required that will ensure that the projects are built according to environmentally sound principles (United Nations,

1992, p. 3). Some of the parameters that geotechnical engineers need to be aware of so that they can build projects in the coastal zone include the following:

- Shoreline process such as beach profiles, sediment motion, transport processes and estuarine and deltaic influences.
- The entire water catchment of a wetlands or delta area.
- The coastline and water/substrate interface of a bay or lagoon near a city or in an area where hydrocarbons or coastal minerals are exploited.
- An area of coastal lowlands, beach and deltaic estuarine environment that are threatened by a potential oil or toxic substance spill.
- The impact of the conversion of agricultural activities to urban development in deltaic regions.
- The reclamation of land on or near a river mouth and the conversion of this land into land suitable for agricultural activities.
- The withdrawal or diversion of fresh water for agricultural use and its impact on the coastal system.
- The changing of the natural patterns of tides and longshore circulation by the construction of coastal structures. (United Nations, 1992, p. 3-4).

This list indicates some of the many factors which the geotechnical engineers must consider when they plan, build, or modify structures in or near the coastal zone.

Since coastal zones have different characteristics at different locations around the world, or even during different times of year in the same location, the definition of the coastal zone by a geotechnical engineer can also vary by when and where engineering works are to be planned or constructed.

Hydrographers and the Coastal Zone

Those who survey and map the coastlines may view coastal zone management according to how it fits within the mandate of their professions. One such group of people who survey the coastlines are hydrographers. The hydrographer also

prepares precise charts so that ships and other navigation interests can have safe and efficient navigation. The charts and surveys that these hydrographers create are not only good for navigation but they are also an important for coastal zone management. The 1977 Report of the Group of Experts on Hydrographic Surveying and Nautical Charting states that in addition to navigation purposes: “precise large-scale surveys also provide the primary data for good coastal zone management” (United Nations, 1977, p 3). Hydrography can be defined as “the science of measuring and depicting those parameters necessary to describe the precise nature and configuration of the seabed, its geographical relationship to the landmass, and the characteristics and dynamics of the sea” (United Nations, 1977, p. 3). This same report also defines these aspects of hydrography as encompassing three zones: coastal, offshore and oceanic. Regarding the coastal zone, the hydrographer is concerned with the planning, construction and use of ports and harbours, the effects of coastal erosion on both natural and manmade structures, and with the safe navigation of vessels through coastal waters (United Nations, 1977, p. 3 - 4). Another important point for coastal zone management is that the charts that are produced by the hydrographer provide an accurate delineation of the coastline, including islands and offshore rocks, and this enables the precise determination of baselines used for the establishment of the seaward limits of national jurisdiction (United Nations, 1977, p. 3). The mapping of a nation’s seaward boundary is another function of coastal zone management.

Based upon the above definition the hydrographer views the coastal zone as being part of the larger marine environment. It is important to note that the offshore marine environment is said to include the continental shelf as being an extension of the coastal zone. The inclusion of the continental shelf as a part of the coastal zone has also been noted by other organizations that are concerned with the coastal zone. The Gulf of Maine Council on the Marine Environment for example publishes a map of the Gulf of Maine that includes a coastal zone of a surrounding watershed as well as the dimensions of the continental shelf (Gulf of Maine Watershed, 1992).

It is important here to note that the professions of the geotechnical engineer and the hydrographer must use and create accurate maps and spatial data for various coastal zone management activities. The following are examples from other disciplines that require accurate spatial data for coastal zone management applications.

Creating the Information Infrastructure for Good Governance

The delineation of the coastline which is used for the establishment of the seaward limits of national jurisdiction has been mentioned as one of the duties of the hydrographer to support coastal zone management (United Nations, 1977, p. 3). The term "good governance" is being used to describe the management of a country's resources within their coastal zone. According to Nichols and Monahan (2000) one essential prerequisite that any coastal state must have in order to

provide good governance is to be able to communicate a clear and concise answer to the following three questions:

- i) What resources, living and non-living, are there to govern?
- ii) Where are those resources?
- iii) Who holds the rights and responsibilities for their safe and orderly conservation, distribution and exploitation? (p. 249).

Many coastal states do not have the ability to answer these questions partly because their coastal zones are not adequately mapped. The United Nations Convention on the Law of the Sea also requires that each nation properly delineate the boundary line(s) around their coastlines. In the case of a country that is so geographically diverse, and where there are many levels of aboriginal and provincial jurisdiction, Canada faces even more problems than most of the other coastal nations. Until these questions on governance can be answered, the coastal situation in Canada will be hampered by jurisdictional dispute, undefined and delimited boundaries, and conflicts between the public and private sector (Nichols & Monahan, 2000).

Zoning as a Tool for Coastal Zone Management

Henocque and Denis (2000) reported that environmental zoning is often quite similar to land-use planning methodology. The purpose of zoning is the geographic separation and delineation of different types of land use. For environmental

planning, each zone is categorized as a unit that is related to a natural system (such as hydrology and geomorphology), and the anthropogenic or man-made systems (such as built structures and maritime activities). In order for this environmental zoning to be of use for the various stakeholders in the coastal zone, the decision making process should match the geographic units so that viable solutions to environmental problems can be developed and approved by the various planning agencies. Once the set of problems is identified, the scale of the environmental zoning work is better known, and this in turn will determine what type of data and what level of accuracy are required. The environmental zoning phase is part of a larger environmental process that is written in the Methodological Guide edited by the IOC/UNESCO in 1997 (Henocque & Denis, 2000).

Management Software Developers

Those who develop software for coastal zone management have their opinions about the coastal zone as well. One such opinion comes from Molendijk, Romao, & Scholten (1996) who are the developers of coastal zone management systems called Coastmap. Since many parts of coastal zone ecosystems contain a wide variety of resources they are at the same time very sensitive to human intervention. Policy makers at various levels of government are often faced with the problem of promoting economic growth in the coastal zone but to do so without damaging its environment and sustainability. The creation of a coastal zone management system to analyse, control and evaluate the development of the coastal zone is considered

to be an important asset for managers of the coastal zone (Molendijk et al., 1996). It is their opinion that for coastal zone management, a geographic information system is most useful in the areas of coastal change analysis, exploratory spatial data analysis, stock taking and integration of various data and coastal resource survey and management (Molendijk et al., 1996, p. 141).

Data Sharing

Bellemare, Light and Ogilvie (1994) wrote about the importance of cooperation between various researchers and organizations in the coastal zone to help eliminate the duplication of information gathering and research as it applies to coastal zone management. Currently in Canada, data about the coastal zone are collected by various provincial and federal agencies and government departments as well as many private companies such as “oil companies and private environmental consultants” (Bellemare, et al., 1994, p. 769).

Data Requirements of Water-based and Land-based Maps

Bellemare et al. (1994) reported that for coastal zone management purposes, spatial data must be collected from both the land and the water sides of the coastal zone. This important and basic premise has been adopted by many coastal management organizations and the collection of spatial data now often includes both landward and seaward components of the coastal zone. Bellemare et al. (1994) wrote that there are vast differences between land and water-based data

and how they are collected and recorded by various government and private organizations. One of the most important differences is that land-based and water-based maps use different vertical datums. Due to this fundamental difference, the shorelines that are depicted on land-based maps such as topographic maps are most often not placed at the same location as the shoreline lines on water-based maps such as nautical charts. It is then very difficult to merge or join spatial data from these two (or more) different types of maps since the use of different vertical datums creates an offset shoreline at the point where the spatial data from the landward and seaward side are to be joined. The shorelines that are depicted on various types of land-based or water-based maps can also be called baselines. These baselines are used to set the limits of features such as the edge of water bodies, or the edge of the land, or it may be a reference to a particular water level of an inland water course such as a lake or river. The shoreline baseline may also be set to one of several vertical ocean levels such as the mean high tide level, the mean sea level, or the mean low tide level of the ocean.

Examples of GIS in the Coastal Zone

Before a person or an organization is going to use spatial data for coastal zone management it is useful to investigate the various ways that maps and GIS are being employed by other groups. By looking at what others have already done can provide useful methods and procedures for both the novice as well as the experienced user of spatial data. The following are a selection of recent uses of

spatial data and GIS for coastal zone applications. They comprise a small number of the total possible uses of GIS for coastal zone management.

SeaMap. Canadian Seabed Mapping Proposal.

SeaMap is the name of proposed digital cartographic system that would map Canada's marine and coastal lands. The ultimate goal of SeaMap is to develop an automated mapping system that creates a seamless link between land-based and water-based maps (MacDougall, 2000). Since water-based and land-based maps most often use different vertical datums various features such as the shoreline do not match when these maps are joined together. SeaMap is not a GIS, but the creation of seamless spatial data that would make the use of a GIS a much easier and more practical tool for coastal zone management.

Mapping Coastal Erosion

One of the uses of a GIS is to map changes to the shoreline due to coastal erosion. Roberto, Alessandro, & Gilmo (1996) wrote how IDRISI software as well as cartographic and photogrammetric instruments were used to map sea coast erosion in the Campania region of Italy. The study was based on air photo coverage that was taken between 1954 and 1990. The air photos were enlarged to a scale of 1:25,000 and then the thematic changes in the local environment were geo-coded to match the topographic map base for the study. The results confirmed that this area of the Italian coastline is suffering from the effects of erosion (Roberto

et al., 1996, p. 374).

Georeferenced Decision Support System for Coastal Management

For certain types of organizations that are concerned with issues relating to coastal zone management, specific requirements must be met before a coastal zone management system can be implemented. Videira, Jordao, Santos, & Concalves (1996) wrote that the need for a suitable coastal classification methodology arose as one of the requirements for the implementation of a georeferenced decision support system for coastal management of the Portuguese southwest coast. Their methodology involved the identification of Homogeneous Management Units (HMU) in the case study area, defined according to soil, vegetation and geomorphological attributes, and combining sub-division and agglomeration techniques. This was designed as a closed-loop system that connected management policies, and the acquisition of suitable information and data to support their decisions. The methodology was one that used a coastal classification system that relied upon an extensive use of GIS features. Two different HMU sets were obtained, based on both conservation and agriculture development that applied in the coastal zone. The HMU sets represent spatially integrated information that can be used to support management decisions for the coastal area (Videira et al., 1996, p. 363).

GIS as Part of a Multimedia Decision Support System

Another use for GIS in a coastal zone is when it is incorporated into a multimedia

decision support system. One such system is called Coastmap which is a multimedia based decision support system for coastal zone management. The system explores the possibilities of integrating the functions of a GIS into a multimedia application in a computer aided management approach. The system incorporates a multimedia information system, spatial analysis tools, and computer support cooperative work tools, all integrated through a common and intuitive interface (Molendijk et al., 1996).

Geographic Information Systems as a Tool for Community-based Environmental Management

The recent availability of relatively inexpensive and powerful desktop computers coupled with the development of geographic information system software that can effectively be operated on these computers has given many not-for-profit community-based organizations the ability to use spatial data for their own applications. For those organizations that are interested in the coastal zone, the type of digital spatial data used can range from watersheds, boundary lines (such as political), hydrography, transportation, to other types of thematic information such as fish habitat and contaminant storage areas. Spatial information of this variety can be used in the analytical and decision making processes for such applications as resource management, coastal zone or watershed protection, and for research purposes. Some of the other applications of spatial data that are used for large scale coastal zone projects include Community Coastal Resource Mapping,

Shoreline Response for Oil Spill Contingency Plans, Watershed Mapping for Water Classification, and 911 Emergency Response Mapping (Moore, 2000).

High Resolution Mapping.

Brent Rowley described a multi-organization project that was coordinated by the Atlantic Coastal Zone Information Steering Committee (ACZISC) to supply high resolution remote sensing data coverage of the Maritime provinces of Canada. The participants included various Canadian federal and maritime provincial government organizations, Dalhousie University, the Centre of Geographic Sciences, and private sector companies. One of the purposes of the project was to increase the effectiveness, and efficiency of acquiring spatial data through a cost sharing agreement between the various project participants. The type of data that was obtained included CASI, LandLidar, Marin LIDAR, Ikonos, Airborne Digital camera, and airborne colour video. All of the data are shared between the participants, and some of the applications of the spatial data include integrated coastal management, topographic mapping, agriculture, forestry, wetlands, environment, fisheries, geoscience, geomatics, and emergency preparedness (Rowley, 2000, p. 54).

The Three Dimensional Coastline.

O'Reilly & King (2000) have compared how remote sensing and GPS (Global Position Systems) data are used to create digital elevation models (DEMs) of the

topographic features on the land, and how airborne terrestrial laser (LIDAR) is used to create digital elevation models of the coastline and the inter-tidal zone. The LIDAR is able to produce a DEM that has an accuracy of less than one metre in the horizontal plane and a vertical accuracy that is in the decimeter range. It was suggested that the coastline should not be merely mapped and categorized as a two dimensional geographic feature, but instead it should be considered a three dimensional land form that is experiencing a wide degree of physical change. One of the ways to make use of this new level method of mapping the coastline would be to create high resolution three dimensional mapping in selected low-lying coastal areas that may be vulnerable from flooding, rising levels, or tsunami run-up (O'Reilly & King, 2000).

An Assessment of ArcView 3.1 and Image Analysis 1.0 as Tools for Measuring Geomorphic Change at Three Bay of Fundy Saltmarshes

The change in the saltwater margin and the tidal creek location that covered a sixty year span was studied for three saltwater marshes in the upper Cumberland basin of the Bay of Fundy. The change was analysed using various sets of digitized aerial photographs that provided a sufficient temporal range and coverage. The digitized images were rectified using ESRI's ArcView 3.1 and ESRI/ERDAS's Image Analysis 1.0 software. It was determined that all of the aerial images could be rectified with a total error of less than 5.5 metres and this allowed the researchers to analyse various environmental change in the study areas at both the temporal and

spatial scale (Oilerhead & Rush, 2000).

The Definition of Coastal Zone Management for this Thesis

The above cited examples clearly show that there is no clear definition of the coastal zone, or coastal zone management. There are also many different methods of mapping the coastal zone, and of managing and using digital spatial data for coastal zone management purposes. Coastal zone management in its widest meaning involves a very wide variety of variables, that can include such diverse elements as coastal engineering, monitoring coastal erosion, tracking pollution, mitigating storm damage, flood control, land use planning, planning of setback allowances for the construction of shoreline communities, planning for recreation and parks, evaluation of sand and gravel resources for construction materials, coastal bluff monitoring, landslide susceptibility mapping, hydrography, cartography, tourism, mining and other forms of resource extraction, fishing, aquaculture, shellfish harvesting, habitat assessment, aboriginal claims, economic development, environmental management and oceans governance. However, the study of these substantive issues usually relies on accurate depiction of the shoreline and areas of water bodies. This thesis will examine the issue of the accurate portrayal of this zone: the length of the coastline, areas of tidal flats, and water bodies such as harbours, passages, and bays. No matter how the coastal zone is defined there is also a coastline that is contained within that definition and an accurate measurement of geographic features of the coastal zone such as the coastline is an

important requirement for coastal zone management. This may appear to be a somewhat limited scope for a case study, but as will be demonstrated in chapters three through six, the nature of the data must be understood and a great deal of preparation and planning is required even before the spatial analysis can be performed with a GIS. It has also been shown by coastal zone researchers such as Canessa (1996) that one of the problems that coastal zone managers experience and complain when they use a GIS is “data overload”. Since even some coastal zone professionals find that accessing too much data about the coastal zone can be a challenge, the focus of this thesis has been deliberately limited to the dimensions of the coastline. The spatial analysis of the coastal features in the case study will be shown to be quite tedious and surprisingly labour intensive.

The purpose of using a GIS for coastal zone management is to obtain accurate geographic knowledge about specific features of the coastal zone. The term geographic information is used to describe digital spatial data that also includes some type of attribute. These attributes can be virtually limitless, but they should contain as a minimum its geographic coordinates and a description of the geographic feature. Digital spatial data on the other hand are often stored in a tabular format and they are usually intended to be used in computerised cartographic systems. The importance of a GIS is that it has the capability of transforming spatial data into geographic information which in turn can be used to support coastal zone management. There are many levels of map scales, as well as

accuracy and precision that can affect the ability of a GIS to produce reliable results. Different applications of coastal zone management will require different levels of accuracy and precision. For example, an environmental organization could use a 1:50,000 scale map to identify areas of the coastline that are vulnerable to storm surges, a town near the coastal zone may require a zoning map at a scale of 1:5,000 or a land surveyor may require a cadastral map at a scale of 1:1,000. Other applications of GIS for coastal zone management may not be concerned with high levels of accuracy but they may simply want a GIS to produce a simple map for free distribution. Such an example would be a conservation group that uses a GIS to print maps and information about a nature preserve. The case study for this thesis will be based on the premise that the measurement of the coastline of Cobscook Bay needs to be done at a level of precision and accuracy that will support such coastal zone management functions as pollution tracking, mitigating storm damage, habitat assessment and managing shellfish harvesting. The scale of the spatial data along with other parameters such as map projection, datum, and the type of digital spatial data will be determined in chapter four.

The next chapter will deal specifically with the nature of digital spatial data as an important and useful element of coastal zone management.

Chapter 3

Basic Principles of Digital Spatial Data

Two GIS capabilities that excite enthusiasm among potential users are the ability to change map scales, and the ability to overlay maps at random. Both capabilities are indeed exceedingly useful; they constitute much of the comparative advantage GIS holds over spatial analysis based on analogue maps. Both capabilities may also mislead decision makers who are unaware of the imprecision inherent in all cartography and who are untutored in the ways errors compound when map scales are changed or when maps are merged (Abler, 1987, p. 305).

The above quotation from Ronald Abler was used in the preface to the book titled Accuracy of Spatial Databases by Goodchild and Gopal (1989). These comments are just as relevant today as when they were written back in 1987. Spatial data that are being used for spatial analysis for coastal zone management applications 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 be performed. 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 study for this thesis uses analogue and digital spatial data that has been obtained from various sources and their various features of scale, precision, accuracy and resolution will be explored by using a GIS 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. Computer cartographic and geographic information systems manipulate and process digital spatial data for the purpose of creating maps or to perform various types of spatial analysis. This chapter describes the problems and limitations of using digital spatial data with a GIS to measure various geographic features in the coastal zone. The topics that are covered in this section are: accuracy, precision, measures of uncertainty, identifying type of error, error propagation, area versus point mapping, spatial databases with varying degrees of accuracy, cartographic exaggeration and generalization, and the resolution of spatial data. It should be kept in mind that an error of inaccuracy in a paper (analogue) map is often compounded when it is digitized into spatial data.

Analogue Data Versus Digital Spatial Data

The term analogue was first used to describe a printed map when geographic features began to be stored as sets of data in digital computers. Therefore, a printed map is a form of analogue spatial data. Digital maps, on the other hand, are a form of geographic data that is stored in a computer system, that can be displayed on a computer screen, or printed out at various scales and spatial resolution, as paper maps. These forms of data are known as digital spatial data. While the resultant printed map is in an analogue format, the source data are stored

as digital spatial data.

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 standards quoted by the United States National Map Accuracy Standards appear to be a high level of accuracy, but it has to be pointed out that this level of accuracy refers to the placement of the line on the map sheet. 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 metres;
- ii) For rural areas, the circular horizontal accuracy is 25 metres and;
- iii) For isolated areas, the circular horizontal accuracy is 125 metres

(Geomatics Canada 1987, 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.

Digital maps can be created from measurements at ground level through ground surveys, from aerial photography, and remote sensing, or by the conversion of analogue maps into digital data. The analogue maps are converted into digital form through a process of manual digitizing or by scanning the detail into a computer, and then converting it into digital spatial data. Any inaccuracy that is present in the analogue map will be incorporated into the digital spatial data, and the errors will be increased if the map scale is changed when used in a geographic information system. Thus care must be taken in the use of spatial data to support coastal zone management, and the GIS user must follow a set of carefully designed rules and procedures so that the results of the analysis are both dependable and defensible.

The remainder of this chapter will deal with some of the problems that are associated with digital spatial data as it applies to using geographic information systems for coastal zone management (and specifically for the case study of this thesis). Not all of the following examples of errors in mapping are necessarily applicable to the measurement of the coastline or the size of a water body, but they do have implications for other spatial elements of the coastal zone (such as demographic, forestry, cultural and economic data).

Accuracy

Goodchild and Gopal (1989) wrote about the importance of map accuracy versus digital spatial data accuracy. They listed seven situations in which the processing of digital spatial data in a GIS has led some analysts to make various cartographic and mathematical mistakes, and to misinterpret results. The same seven points regarding spatial accuracy have been used to help illustrate some of the potential problems with spatial data, and they are summarized as follows:

1. The precision of GIS processing is effectively infinite. A GIS can process digital spatial data beyond the finite level of analogue data.

This statement is fairly straightforward and it basically implies that spatial data are only accurate to a certain scale and that they should not be pushed beyond their limits of accuracy or beyond their confidence level. Here, scale is the one of the most important determinants of accuracy. An aerial photograph that has a scale of 1:10,000 normally provides far higher spatial resolution than a satellite image of 1:1,000,000. The user of spatial data should not use the 1:1,000,000 scale satellite spatial data beyond this 1:1,000,000 limit, and the user of the 1:10,000 scale aerial photograph should also not use that spatial data beyond its 1:10,000 limit. Not matter how accurate and how large scale the spatial data may be, there is a limit to how much accurate geographic information can be interpreted and derived from these sources.

2. All spatial data are of limited accuracy.

This statement is similar to the first statement, but it refers to accuracy rather than precision. In cartography precision is used to define the measuring system and the tools and devices that perform these measurements. For example a ruler that is divided into millimetres has a precision of one millimetre. Accuracy in cartography on the other hand refers to the distance an object is from its desired position. For example, a line that is drawn on a topographic map should be within a certain minimum distance from its true position in order for the map to be considered “accurate”. Goodchild and Gopal (1989) have pointed out that many types of measuring units that are used in cartographic systems (such as maps), and in geographic information systems are based on abstract concepts that do not exist in nature. Most boundaries that are shown on maps are artificial creations that are used to help the map user locate and separate objects on the surface of a map. An example of an artificial boundary occurs on a thematic map such as a soil map that has many different types of zones which are indicated by polygons. These polygons on the soil map are shown to have a uniform distribution of that soil throughout its area. In reality, the zone that represents the soil classification will tend to have a soil classification that varies throughout the zone particularly at the edges where it meets a polygon that represents a different soil classification. Goodchild and Gopal (1989) point out that these boundaries are not distinct but rather they are “transition zones”(p. xii).

Another important point about the limitations of accuracy is that the precision of one type of measurement does not directly relate when it is used, or it is combined, with another measurement system that has a different level of accuracy. Goodchild and Gopal (1989) gave the example of a vertical benchmark that is shown on a map. The precision that was used to create the vertical measurement has no bearing whatsoever on the horizontal measurement system that is used to locate the benchmark in its correct horizontal and georeferenced position on a map. A benchmark may have a vertical accuracy to plus or minus 10 feet, while its horizontal position may only be accurate to 100 feet. Therefore it should not be assumed that the same level of accuracy applies to both the horizontal and vertical measurement systems that are referenced to a particular benchmark.

3. The precision of GIS processing exceeds the accuracy of the data.

Goodchild and Gopal (1989) wrote "data should be expressed with a precision which reflects their accuracy" (p. xii). Essentially, this means when data are recorded at one level of accuracy such as with one unit to the right of the decimal point, any calculation, or analysis that uses these data should be rounded off to the same one digit that is to the right of the decimal point. This is a mathematical principle that ensures that the level of accuracy and precision should remain constant throughout the calculation and analysis process. Goodchild and Gopal (1989) reported that this basic mathematical principle is not often adhered to in data processing and that "GIS designers typically carry the maximum precision

through GIS operations, and print results to a precision which far exceeds the level justified by the accuracy of the data" (p. xiii). There may be several reasons why some GIS users would fail to adhere to the mathematical principle of ensuring a match of the precision of data output with the precision of data input, including a lack of systems and methods to track and describe precision, and a reluctance to discard data even though its use cannot be justified (Goodchild & Gopal, 1989). One of the problems of most geographic information systems is that it is just as easy to use small scale data as it is to use medium, and large scale data to manipulate, and to create new data and new geographic information. Unless the basic rules of mathematical precision are adhered to by users of these geographic information systems, then there is a danger that the results will be misleading, imprecise or completely wrong.

4. In conventional map analysis, precision is usually adapted to accuracy.

According to Goodchild and Gopal (1989) the limit to precision on a paper map is based on line thickness or line weight, which is usually 0.5 mm. Paper maps can also shrink or expand depending on such factors as humidity, storage methods, and the quality of the paper itself. These changes can alter the line weight and decrease the accuracy of the map beyond the map's 0.5 mm level of precision. Since paper is not a stable medium for long term storage for map information, other materials, notably various forms of plastics and large contact negatives were, and are still, being used as a permanent base map for archiving purposes. Ideally, these base

maps are stored in climate-controlled areas where possible changes due to humidity are kept to a minimum. For many mapping organizations, the 0.5 mm line weight remains the “target accuracy”(p. xiii) for map compilation and printing their large series maps. Maps tend to be printed at only certain scales within a cartographic organization and the entire production process is designed to produce maps that only cover a small range of scales. For example, Geomatics Canada produces topographic maps in the 1:50,000 and 1:250,000 series, while the United States Geological Service produces topographic maps in the 1:25,000 (or 1:24,000) and the 1:100,000 scale series. Both the producer and some of the users of these maps are accustomed to dealing with these scales, and they understand the level of accuracy that is associated with each scale. Goodchild and Gopal (1989) wrote that conventional map analysis tools such as transparencies, planimetry and dot counting are crude methods of measurement that are consistent with the accuracy limitation of paper maps. They wrote that a planimeter that is used to measure the area of a polygon will produce a result, although approximate, that is consistent with the 0.5 mm level of precision of the printed paper map.

5. The ability to change scale and combine data from various sources and scales in a GIS means that precision is usually not adapted to accuracy.

Unlike a conventional paper map which is generally static in nature, spatial data that are used in a cartographic drafting system, or within a geographic information system can be enlarged, reduced, or combined with other sources of spatial data.

Although precision in paper maps was directly related to accuracy, the same cannot be said for digital data since its scale can be so easily changed and modified within a geographic information system. If the data are used at the same scale as the digital spatial data, then the original level of precision is maintained, and the level of accuracy remains constant as well. The problem arises when digital spatial data are loaded in a GIS, and then they are used to create a base map that is much larger in scale than the input scale, which in turn creates a new set of spatial data that has less accuracy than the original spatial data. Other problems can occur if two sets of digital spatial data that are at vastly different scales such as a 1:24,000 scale digital spatial data, and a 1:1,000,000 scale digital spatial data are overlaid to create a GIS project at a scale of say 1:20,000. According to Goodchild and Gopal (1989), no current GIS warns the GIS user when rules of cartographic precision and accuracy are being violated and no "current GIS carries the scale of the source document as an attribute of the dataset" (p. xiii).

Many GIS also do not automatically adjust the map drafting tolerances when scales change, and the majority of vector-based geographic information systems carry out important functions and operations such as creating buffer zones, and line intersection using the original coordinates, even though the level of accuracy and precision has possibly been substantially reduced. For some organizations, such as those involved in planning and coastal zone management, it is very important to use the digital spatial data at a correct scale, otherwise the results that are

produced by the GIS could fall under suspicion, which may cause an organization or group to lose its influence or credibility.

6. We have no adequate means to describe the accuracy of complex spatial objects.

While positional accuracy and the errors that are created by the digitizing process can be measured for two-dimensional models as well as highly complex objects such as lines and areas, there are no methods for establishing how well the spatial model is able to represent the "relationship between abstract objects and the spatial variation which they represent" (Goodchild and Gopal, 1989, p. xiii).

Digitizing errors also tend to be a relatively small problem regarding accuracy in comparison to errors that are created during the compilation and cartographic process. In the latter process, a great deal of geographic detail is removed due to problems of spatial resolution, and/or map detail is generalized due to the constraints of scale and map size. If better models of the relationships between abstract objects and the spatial areas that they represent are developed, then GIS practitioners would be better able to design methods that both measure the accuracy of spatial digital data in spatial databases, and to be able to track the data to see how it changes, or becomes modified when it is transformed by the various operations within a GIS.

7. The objective should be a measure of uncertainty on every GIS product.

Goodchild and Gopal (1989) wrote that the ideal measurement of accuracy and error in a spatial digital database that is processed in a GIS would be a set of confidence limits that would be applied to the outputs that are created by the users of the GIS. By creating a set of confidence limits, the level of accuracy and precision can be checked and verified so that the GIS user will know whether to continue with the processing of the spatial digital data, or to process the data using other methods and procedures. Depending on the type of GIS operation that is being performed, creating a set of confidence limits can be relatively simple, or so complex that only a rough estimate of accuracy can be calculated to be included with the output from the GIS. An example of a simple method occurs in the estimation of the area of a polygon. Other confidence limits are more difficult to calculate, especially in cases where many different layers are combined during a layering operation in a GIS. In the latter case, many different and complex rules need to be employed for the GIS user to be able to develop a reliable set of confidence limits (Goodchild & Gopal, 1989, p. xiv).

Unfortunately for the user of geographic information systems, Goodchild and Gopal list many problems associated with both the accuracy and precision of spatial digital data and offer only a few solutions to the problem of error and the creation of reliable confidence limits.

Cartographic Exaggeration

Geographic features that are smaller than the resolution size of the map are most often left off a map since they are too small to be properly printed, or to be recognized by the map user. Sometimes, important features such as radio towers, or bridges are shown on a map by the use of a standard map symbol despite the fact that their actual size is too small to be accurately displayed. Line widths for such geographic features as roads, railways, and shorelines may also be exaggerated in size so that they can be more clearly seen on a map. These map symbols and line weights may be much larger in size than is necessary to correctly represent a geographic feature on a map, but the cartographer will exaggerate a feature if it has been determined that the geographic feature is an important and necessary addition to the map. Nevertheless, the cartographer will try to place the map symbol as close as possible to geographic feature's centre position on the map.

Area Versus Point Mapping and Error Modelling

Maps and spatial data that use a polygon to show areas which belong to a specific attribute such as a soil classification, may not be as accurate as maps and spatial data that use a point to represent a geographic feature (Goodchild, 1988). The reason for the possible difference in accuracy is that the polygon which is used to represent the area may not be able to map the feature uniformly across its entire surface. The uniformity in such a polygon often deteriorates at the edges where the

first polygon meets another polygon of a different class. A soil class, for example may not be homogeneous across the actual area on the ground, but it may have been coded that way when it was first created as spatial data . Goodchild (1988, p. 32) calls these types of potential spatial error “error modelling”. The geographic information that is associated with an inaccurate value can be further weakened if two classes that are not 100 percent accurate are merged to create a new compound class. This can happen in a planning environment if a new land use is created as part of a zoning change. For example, if two polygons, each representing a different type of rural land use zoning (such as one class of agricultural land) are merged with another class of agricultural land for the purpose of creating a new zoning classification, the result would be magnification of the errors from each polygon. This, in effect, increases the inaccuracies of the new polygon. Goodchild says that “inaccurate products can lead to false inferences, bad decisions and even litigation” (1988, p. 32). Another problem, according to Goodchild, is that many GIS applications do not have functions that provide statistics on such parameters as measurement error or confidence limits. It is then up to the user of these systems to know what and what NOT to do, and how to interpret the results produced by the GIS.

Spatial Databases with Varying Degrees of Accuracy

Spatial data that are collected from small scale maps are, by nature, less accurate and less precise than large scale data, since the small data only depicts the general

geographic features of an area, while the larger scale data shows more geographic information. Other small scale databases such as the Digital Chart of the World cover wide areas, and the information was compiled from various source maps that used different datums and map projections. The data from these types of data bases may also be out of date and the source maps often have been produced using different levels of spatial accuracy and completeness. Larger scale spatial data may be more accurate, but there may be issues of different horizontal and vertical datums, and there may be problems with accuracy if the data are too old, and it has not been updated on a timely basis. Other problems that are associated with spatial databases are the lack of information about the data (known as meta data), different file formats, different computer systems, and various methods of data storage and retrieval.

Errors in the position of map features can occur at different times during the collection and transformation of selected geographic features into spatial data. If a map was used as the source for data input, errors in position can happen if a manual digitizer was improperly used to enter geographic data in the storage system. The cursor of the digitizing tablet may not have been directly over the object while the spatial data were recorded, and the result would be a false value for the position of that object. Another type of positioning error can occur if the map sheet is not registered properly to the coordinate system that is being used by the geographic information system. If the map sheet is not properly registered, then all

of the spatial data that are collected during the digitization process will have a wrong value. Since all of the spatial data that are collected from these types of positioning errors have the same degree of error, this error problem can be corrected by registering the data set to their proper coordinates. Other errors in the position of objects can occur when spatial data are combined or joined with other data sets that use a different horizontal datum. In this type of error, the position within each dataset, while being correct, will be not be compatible with the other spatial data since it is referenced to another horizontal referencing system. The result will be geographic data that is shifted out of position within each data set. Horizontal positional errors can also cause breaks in the continuity of geographic data that extends across at least two different datasets. This type of error is often quite obvious to locate upon visual inspection as when a linear feature such as a road, railway line, or river is suddenly broken, and it is shifted out of position.

The Resolution of Spatial Data

The resolution of digital spatial data is an important factor that will determine how accurately, and with what level of reliability, a geographic information system can be used to model the geography of a specific area for coastal zone management applications. When digital spatial data are obtained from a source such as a database, or a direct source such as from a scanning device, or from a remote sensing system, the quality of the data is dependent on many factors such as map projections, datums, scale, and spatial resolution. Most of the spatial data used for

the case study in chapters five and six were obtained either from various on-line data bases of vector data, or from an archive of LANDSAT remote sensing data. All of these forms of spatial data have their own level of resolution which may, or may not, be dependent on the original scales of the scanned maps, or the scale of the remote sensing raster data.

The Resolution and Resampling of Scanned Maps

Analogue maps are converted to digital spatial data through various techniques such as manual digitizing or through raster scanning. A typical raster scanner will record information at predetermined equal intervals in the x (normally east-west) and y (normally north-south) coordinate directions, and then store the result in a computer file. The scanning is done on an equal length basis (all directions are scanned at the same scale), and this can cause problems with various map projections that are not equal in area since the grid lines are either converging or diverging at either ends of the map sheet. Every map projection displays the shape of the earth in a different way, and unless there is some correction and modification of the recorded geographic data during the scanning process, the results may be inconsistent and have incorrect values. To overcome the problems of scanning maps that are based on different global projections, the scanned data are converted to a uniform latitude and longitude grid. This conversion technique is known as "resampling" (Tobler, 1988). Resampling does not collect any more data from the newly scanned data, but instead, through the process of interpolation, new

data are added at the points where the standard latitude and longitude grids have been established.

Many different resampling methods are directly associated with the type of grid that is to be converted, and because of this, these types of resampling are similar to coordinate conversion practices (such as those that are incorporated into a GIS application like ArcView). A grid can be resampled from a polar grid to a square, or the other way around, depending on the type of application and analysis that needs to be accomplished.

Resampling is also used to correct errors and distortions from data acquired from remote sensing systems, and to adjust the coordinates when different horizontal datums are combined in a geographic information system. Another use of resampling is to assist in the production of map mosaics, where the surrounding map grids are set to a different projection point, as in the case of the various UTM zones that span the globe (Tobler, 1988).

For the resampling process to be both effective and useful, the integrity of the input data should be thoroughly checked to ensure that missing or incorrect values are replaced in the final data set. Resampling has the potential of increasing or decreasing the storage size of the digital data, and it can be used on vector data as well as raster data. Resampling can be used for other purposes such as to

compare different spatial databases, or it can also be used to convert spatial databases that have different formats into one common format. The most common forms of resampling according to Tobler (1988) are “nearest neighbour interpolation, bilinear interpolation, Lagrangian interpolation, cubic convolution, and bivariate splining” (p. 130).

The most desirable form of resampling occurs when the modification and conversion is done between spatial databases that are similar in scale and coverage area. If the scales of the databases are markedly different (such as a factor of 5 to 1), then the better choice is to resample the larger scaled database down to the smaller scaled database. By using the smaller scaled database as the common database, there is no need to use interpolation since no new data points are required. If the reverse method was applied, and the smaller scaled database was being resampled to join the larger scaled database, then an interpolation method would be needed to add coordinate points to the smaller scaled database. A resampling method that uses the small scale database as the common scale is much preferred to the large scale database, since interpolation is not a reliable method of determining a precise value for an unknown geographic position. Supporting the preference of using the smaller scaled database as the common scale of the resampled database Tobler (1988) wrote that “the resolution of a database should be labelled to be that of the coarsest element(s) in the database” (p. 131). Tobler also noted that the resolution of the database is not improved by

such operations as resampling, or interpolation, and that there should be a distinction between “resampling and enhancement, which by introducing theory or information external to the database, may lead to improved resolution” (p. 131). The problem with many spatial databases is that information about which resampling method was used is often quite difficult both to locate and obtain. The lack of this type of vital information makes it more difficult to assess the accuracy, precision and confidence level of the spatial digital data for use in geographic information systems.

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 millimetre 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 metres, 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 millimetre that a cartographer is able to both represent and print a geographic feature on a map. For example, for a map scale of 1:10,000, the resolution is determined by first dividing the denominator of 10,000 by 1,000 to get a value of 10, which is the detectable size in metres. Then, the value of the detectable size is divided by the number "2", to get the value of the map's resolution, which is 5 metres. 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 are used for the GIS-based analysis of Cobscook Bay, Maine in chapter 5 of this thesis.

Table 3.1

Adapted from Tobler (1988, p. 32)

Comparison of map scale to map resolution.

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

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 kilometre of travel a half kilometre grid is needed. The reason that the grid is set to one half kilometre 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.

Resolution of Aerial Photography and Remote Sensing Images

The resolution of other spatial data such as remote sensing and aerial photography are also important, and like map resolution these other sources of geographic information have finite levels of detection that should be identified and recorded. Regarding a definition of resolution, Tobler (1988) wrote “a dictionary definition of resolution is the capability of making distinguishable the individual parts from the whole” (p. 132). For sources of geographic information such as aerial photography, the level of resolution is based on the resolving power of the photographic

instrument. Tobler (1988) also describes resolving power as “the ability of an optical system to form distinguishable images of objects separated by small angular distances; the ability of a photographic film or plate to reproduce the fine detail of an optical image” (p. 133). It is important to note the resolving power of photographic instruments that are used in the production of aerial images for cartographic purposes, since the vast majority of intermediate and small scale maps were derived from aerial photography.

The resolving power of aerial photography is dependent upon the resolving capability of the aerial camera (optical system), and the resolution of the recording film. The aerial camera’s spatial resolution is based on a system that measures how well the camera’s lens is able to distinguish various lines (or bars), and symbols on a special calibration and measuring chart which is known as a “resolving power test chart” (Lillesand & Kiefer, 1994, p. 141). The resolving power test chart uses various sized sets of three parallel lines, or bars that are placed in the horizontal and vertical plane. The spaces between the parallel lines also have the same width as the lines. These sets of parallel lines are measured in millimetres, and the resolving power is measured in lines per millimetre. The resolving power is then measured by taking a photograph of the chart, and then inspecting the film to see how many sets of parallel lines can be seen with a microscope. The smaller the set of parallel lines that can be clearly distinguished on the film, results in a higher film resolution rating. This rating is sometimes known

by the designation "line pairs per millimetre" (Lillesand & Kiefer, 1994, p. 140).

The effectiveness and accuracy of this procedure also depends on the contrast between the dark and light areas on the film as this factor aids in determining the resolution of the camera system. When the contrast ratio is higher, there will be an increased likelihood of being able to distinguish more detail on the film. Another method of determining the resolution of the camera is to have the film analysed with a microdensitometer. This device will measure what is called the "modulation transfer function of the film" (Lillesand & Kiefer, 1994, p. 140).

The second variable to determine the resolution of aerial photography is the type and quality of the film. The resolution power of even ordinary photographic film for use in handheld cameras is quite good, but the film that is intended for use in aerial photography is of a very high grade. Film for use in aerial photography can also be designed to be sensitive to certain wavelengths such as the two infrared (near, mid) categories which have a range of between 0.7 μm and 3.0 μm (micrometre) and with the thermal infrared band which has a sensitivity rating that is beyond 3 μm . Normal black and white film has a spectral range of between 0.3 μm and 0.9 μm , while colour film has a similar wavelength sensitivity if colour infrared film is also included in the same category). In comparison to these wavelengths, the human eye is limited to receiving light energy in the 0.4 μm to 0.7 μm wavelengths (Lillesand & Kiefer, 1994, p. 6) .

The resolution of film is also directly dependent upon the amount and size of silver halide grains that are part of the film's chemical properties. Photographic films that contain a higher amount of silver halides will produce images that are not as sharp as films that contain less silver halides. Photographic films that contain a lower percentage of silver halides will produce images that are less coarse and are able to resolve fine detail. The advantage of films that contain a greater percentage of silver halides are that they are able to complete an exposure of an image in much less time than film that contains a lower percentage of silver halides.

These factors allow photographic film that is rated as having a high level of resolution to be "enlarged 20 or more times" while still being able to retain enough geographic information to be useful for creating maps and spatial data (Tobler, 1988, p. 133). The utility of an aerial photograph for cartography is dependent on its scale and the scale of the map, and even though a photograph can be enlarged as much as twenty times there is a point where the enlargement has a finite limit. The finite limit of a photograph is reached when a point of empty magnification is reached (Tobler, 1988, p. 133). When the point of empty magnification is reached, the photograph can no longer provide any more useful information for use in cartography, or for analysis with geographic information systems. Tobler (1988) reports that all resolution-based systems have a finite limit, and for optics-based systems the wavelength of light is the limiting factor. However, he correctly points out that features in nature have a much broader range of scale than geographic

systems can provide, and that the scale of the natural world goes well into the microscopic levels and beyond.

The Resolution of Scanned Aerial Photography

The resolution of photography for use in cartography, remote sensing, and geographic information systems often depends on conversion of the analogue images into digital data by use of a scanning device. In other situations aerial photography is used directly in its analogue form to produce data for use in cartography. One of the most common methods of the analogue use of aerial photography originated with photogrammetric instruments (such as stereo plotters) where overlapping stereo pairs of images were used to create a wide variety of maps ranging from engineering plans to topographic maps. The geographic data obtained from these analogue images could then be stored as digital files if the photogrammetric instrument was set up to perform this type of operation. For remote sensing applications, and in the use of most of the current photogrammetric instruments, aerial photography is first scanned, and then rectified into a common map projection. The original resolution of the aerial photography will almost certainly have been modified by the scanning process, and this unfortunately shows how the quality of spatial data can be changed as it is processed and manipulated during the digital map making process.

The resolution of scanned images depends on the density of the scanning device, and this is measured in either dots per inch, or in micrometres. The pixel ground resolution of a scanned image can be calculated in metres by first dividing the scale of the photograph by the resolution of the scanning device. The next step is to divide that result by either 39.37 if the scanning resolution is in dots per inch, or by another formula if the resolution is in micrometres (Jensen, 1996). This metric-based formula first multiplies the scale of the photograph by the scanning resolution in micrometres (μm), and then multiplies this result by 0.000001 (Jensen, 1996, p. 20). For example, if an aerial photograph of 1:10,000 is scanned with a device that had a scanning resolution of 500 DPI (dots per inch) the following formula would be used: $(10000/500)/39.37 = 0.508$ metres per pixel. The formula to determine the ground resolution using the same aerial photograph, but with a device that scans using a scanning resolution of 50.8 μm (which is the equivalent of 500 DPI) is as follows: $(10000*50.8)*0.000001 = 0.508$ metres per pixel. The level of scanning resolution is obviously an important element in determining the quality of spatial data; however, this kind of information is difficult to obtain, especially with digital spatial data obtained from on-line sources. The lack of documentation on how the scanning process was accomplished, and what systems and methods were used, are other problems that a person or organization who wants to use spatial digital data for their application has to consider. In the case of the above example where the 1:10,000 scale aerial photograph was scanned at 500 DPI (50.8 μm) to give a ground resolution of 0.508 metres, the same photograph can also produce different

results if the scanning resolution is set at either a higher or smaller value. Table 2 below is an example of how the ground pixel resolution of a scanned 1:10,000 aerial photograph can vary with a different scanning resolution. The results in this table were obtained by use of the scanning resolution formula that was just described.

Table 3.2

Various ground pixel resolutions of a scanned 1:10,000 aerial photograph.

Scanner Digitizing Units		Scale 1:10,000
Dots Per Inch	Micrometres (μm)	Pixel Ground resolution in metres.
100	254	2.54
500	50.8	0.508
1000	25.4	0.254
2000	12.7	0.127
4000	6.35	0.064

The general rule to consider with the scanning formula is: a high scanning density (dots per inch or micrometres) will result in a more precise numerical value for the ground resolution (based in metres).

The Relationship Between Varying Degrees of Spatial Resolution, Map Generalization and Map Scale

The degree of resolution of spatial data is important for the user of geographic information systems for coastal zone management applications. The spatial resolution of GIS data is also a function of generalization since small scale maps do not usually contain as much geographic detail as larger scale maps, and as a result, the data are most often recorded and stored with less spatial precision.

Unless a map is compiled at a scale that is the same as reality (at a 1:1 ratio), the cartographer is forced to limit the amount of geographic information that can be shown on a map. As a map scale gets smaller, less and less information can be shown on the map due to the limitations of available space, and the problems of depicting a feature at its true size. On smaller scale maps, geographic features such as roads, railways, rivers, shorelines of lakes, coastlines of the mainland and islands are exaggerated, simplified (or they are removed) to make the map easier to read and understand. As the map scale becomes ever smaller, the width of the line that is drawn on the map to represent a geographic feature becomes a major determining factor as to what type of geographic information can be successfully depicted. For example, a line that is printed at a width of 0.8 mm on a 1:1,000,000 scale map to represent a road allowance that is 20 metres wide actually takes up 800 metres of space on the map. It is necessary to exaggerate the dimensions of

many geographic features on small scale maps so that they can be clearly seen by the map user. In the case of the above example, if the road were drawn to its true scale, the line would have a width of 0.02 mm which is far too small for most people to see clearly. Figure 2.1 clearly shows how much of the earth's surface that is actually represented (and obscured) by one of the 1:1,000,000 map based 0.8 mm lines when it is superimposed over a map that is of much larger scale. The map in the background has an original scale of 1:24,000 and the various map features such as roads and shorelines are drawn to 0.5 and 0.8 mm respectively. The vertical grey coloured line with the solid black outline represents the scale of the 1:1,000,000 based-road line that now has a width of 800 metres on this larger scale map. The vertical line that is printed on the map of figure 2.1 graphically shows the extent to which this line (that represents a feature such as a road) has been exaggerated so that it can be seen on a small scale map (such as at a scale of 1:1,000,000).

Figure 2.1 also shows how much ground (and water) space is obscured by the length and width of the 1:1,000,000 line. It is also obvious that the 1:1,000,000 based-line is drawn to such a thick dimension that it is unable to accurately depict any local geographic feature except in only a generalized manner.

Figure 3.1
Comparison between 1:1,000,00 and 1:24,000
vector line representation of geographic detail

The accuracy of detail on small scale maps are also a problem since these lines are so large relative to the features that they are representing. When a small scale map is used as a source for a digital spatial data base such as the Digital Chart of the World, its various geographic features such as roads, shorelines, and railways along with map symbols will not be able to provide satisfactory levels of map accuracy. The smaller a map becomes, then the ability of it to depict geographic features precisely declines and such imprecision is likely to be coupled with inaccuracy. Spatial data based on maps of smaller scales such as 1:1,000,000 are only accurate to a certain degree (as are all forms of spatial data) and the information regarding map accuracy can sometimes be found in the map's meta data file. A map's meta data file contains certain information such as the map projection, the scale of the map, the horizontal and vertical datums, and the level of precision and accuracy of the map. The problems of using digital spatial data derived from small scale maps will be examined in chapter five.

On medium and small scale maps, symbols are also used to represent geographic features that would normally be too small to recognize if they were printed at their true size. On all but the largest scale maps such as 1:2,500 maps (that are also known as plans), many geographic features have to be exaggerated in size in order for them to be clearly seen (Robinson et al., 1978). Map generalisation may be accomplished manually by a cartographer or it can be done through a computerized process. Many large scale maps and plans however, are produced using such

strict and precise survey methods that their accuracy is so good that the map data can “have the validity of legal documents and are the basis for boundary determination, tax assessments, transfers of ownership, and other functions that require great precision” (Robinson et al., 1978, pp. 7-8).

An important fact to note for map generalization is that it can also affect the level of spatial resolution of digital spatial data. For some mapping purposes the degree of mapping precision exceeds the level that is necessary to depict a feature such as a shoreline. During the scanning process small elements of the shoreline may be recorded as data points, but they will not be printed since they are too small for a device such as map plotter to print. Algorithms such as those described by Douglas and Peucker (1973) and currently used by mapping organizations such as Natural Resources Canada reduce the number of data points within such features as shorelines to smooth out the depiction of these features and to save on processing time as well as to reduce storage space for the data. These algorithms remove data points that do not adversely affect the depiction of a feature (such as in the middle of a straight line) and those that would be deemed to be too small to be printed on a map. The user of digital spatial data that have been obtained from organizations that apply such algorithms to their data must keep in mind that these data have been processed for a map printing application and are not necessarily to be used for digital spatial analysis.

An Example of Different Sizes of Spatial Resolution on Vector Data

For vector data, spatial accuracy is a function of how many nodes and vertices are used to record geographic features at a particular map scale. The closer the vertices are to each other, the greater degree of resolution of the spatial data. The farther apart the vertices are from each other, then the reliability of the spatial data to represent geographic features in their true shape and size will diminish accordingly. This relationship is especially true for rivers and coastlines where their shapes and orientation can constantly change. A coarse spatial resolution has the effect of straightening out a meandering feature, which gives it a smoother appearance, and as a consequence, its recorded length becomes shorter as well. Robinson et al. (1978) describes resolution in vector digitizing by "changes in the size of the minimum increments between adjacent data points in the x and y directions. Greater resolution is achieved by specifying finer increments" (p. 417). If a coarse spatial resolution is combined with a small scale map, the spatial data cannot be relied upon to accurately record or to display geographic features. The effect of using different resolution sizes is graphically demonstrated in figure 3.2. In this example three different sizes of increments of spatial resolution are used along a representation of an imaginary coastline. The smallest spatial increment at "a" has a length value of 1, the second increment at "b" has a length value that is twice as large as the first value, and the third increment unit at "c" has a length value that is three times the length of the first value. The effect of using a smaller increment is

Figure 3.2
Various Vector Resolution Sizes

(Imaginary map.)

Legend

	Vector lines		Imaginary shoreline
	Vector nodes and vertices		

that it creates digital spatial data at finer levels of resolution. The smaller the scanning increment unit, the finer the levels of spatial resolution. Finer levels of spatial resolution allow for the creation of higher levels of accuracy for digital spatial data. The reliability of spatial data to accurately represent geographic reality is dependent to a high degree on the level of spatial resolution of the same spatial data. This premise will be explored in chapters five and six.

Conclusion

This chapter discussed the following topics: accuracy, precision, measures of uncertainty, identifying type of error, error propagation, area versus point mapping, spatial databases with varying degrees of accuracy, cartographic exaggeration and generalization, and the resolution of spatial data. This issue of precision and accuracy as it relates to spatial data for coastal zone management was a common thread throughout this chapter. Precision as it relates to spatial data refers to the measurement system to obtain the data, while accuracy refers to what degree the map is referenced to its true geographic position on the earth. Once paper maps or analogue spatial data have been transformed into digital spatial data precision is no longer firmly connected with map scale. Various map features are often removed or modified by generalization techniques or by the use of map symbols. Errors that are found on paper maps can be transferred to digital format or new errors can be created during the transformation process. There are different scales of spatial data and these data have been created with different levels of resolution. Analogue

maps and aerial photographs can be converted to digital format through manual digitizing, or by automated scanning. Digital spatial data can also be created by various types of remote sensing systems as well as another GIS. 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. The resolution of digital data that are obtained from digitizing, scanning or from remote sensing can have varying levels of spatial resolution. The various effects of using different levels of resolution was shown in figure 3.2.

The wide range of potential pitfalls associated with the use of spatial data within a geographic information system to support various coastal zone management applications requires the user of these types of data to gain a firm understanding of the nature, characteristics and limitations of spatial data. Accurate results using good quality digital spatial data can be achieved if proper mathematical and cartographic procedures are followed. The next chapter describes the set of cartographic and data requirements that will be used as the basis for the effective geographic analysis of the case study area.

Chapter 4

Digital Spatial Data and Cartographic Requirements for Coastal Zone Management

Chapters two and three provided a general description of the applications of spatial data for coastal zone management, the basic characteristics of spatial data. In addition, the importance of spatial resolution in such applications was discussed. This chapter is organized around various descriptions of the important spatial data, surveying, and cartographic components that are necessary to provide accurate measurements and analysis of geographic features in the coastal zone. At the conclusion of the description of each of these components, a method will then be chosen, and this will be used as part of the total set of requirements that will be employed to perform the spatial analysis of the case study area. This analysis will be presented in chapters five and six.

For an effective geographic analysis of the study area (Cobscook Bay, Maine), detailed technical requirements need to be established for the following components. These requirements are based in large part on the conclusions from the previous chapters.

- The type of spatial data.
- The scale of the spatial data.

- **The type of map projection.**
- **The measuring unit.**
- **Horizontal and vertical datum for the geographic coordinates.**
- **Metadata.**

The list of components that have been selected for use in the case study have been chosen specifically to measure the length of the shoreline, the area of the surface water and the islands of Cobscook Bay Maine. The selection of the type and scale of spatial data to use for the spatial analysis in the case study will be guided by the characteristics and principles of digital spatial data that were described in chapter three.

These components are to be considered only as a minimum set of variables for use in coastal zone management for the case study. The disciplines of land surveying, geodesy, geology, cartography, photogrammetry, hydrography, remote sensing, and geographic information systems are quite extensive and they can also be complex and highly technical in nature. Other types of coastal zone management may require a different set of components. Depending on the degree of spatial analysis that is to be performed in the coastal zone, a wide variety of parameters could be added to the above list such as demographics, economic data, employment data, fisheries data, forestry data, land use data, tourism, and transportation.

The Type of Spatial Data: Analog Maps and Digital Spatial Data

The usefulness of a paper map (analog data) is limited by its scale, but once a map and its geographic features are stored as digital data it can be modified and loaded into a wide variety of computerized drafting, automated mapping and geographic information systems. According to Jenson (1996), there are basically four types of digital spatial data: 1) Traditional Cartesian vector (sometimes known as spaghetti), 2) Topological vector, 3) Raster, and 4) QuadTree Raster .

The traditional Cartesian vector system stores geographic locations as points, lines and polygons. A point is recorded with an "x" and "y" coordinate. Lines are recorded as a series of segments defined by "x" and "y" coordinates, and polygons are recorded as a series of line segments defined by "x" and "y" coordinates forming a closed loop. The "x" and "y" coordinates are known as vertices. One of the drawbacks of this system is the possibility of over digitizing features when geographic entities share a common border. This type of duplication can result in the creation of geometric errors which are sometimes known as "slivers".

Topological vector systems use a node and arc system to store spatial data. Like Cartesian systems, geographic locations are stored as points, lines and polygons. A line is an ordered set of points that describe the position and shape of a linear element on the map and each line starts at a node and ends at a node (USGS,

1997, p. 16). The beginning and the end of geographic features are designated with a node, and the nodes are linked to other nodes with arcs. If proper procedures are followed, this system does not allow for the duplication of geographical features as is the case with Cartesian based vector systems, and consequently fewer geometric errors are produced.

Raster systems store geographic information as a cell within a grid and each cell within the grid is identified by a row and column. Each cell is also identified by a geographic location and it can also be linked to a particular geographic feature such as a body of water or a type of land cover. These cells are referred to as pixels or picture elements when they are displayed on a computer screen. Cell size can range from the very small (less than a metre) to the very large (over 300 metres). For example there can be raster data in the size of 1 metre (1 x 1 m) resolution for USGS Digital Orthophoto Quadrangle(USGS, 2000), to 30 metre (30 x 30 m) resolution for LANDSAT 5 Thematic Mapper images to 315 kilometre (315 x 315 KM) resolution for NASA TOPEX/POSEIDON Nonimaging radar (Jensen, 1996).

QuadTree raster data are similar to traditional raster data except that larger cells are used to represent areas of adjacent pixels that have the same type of geographic feature and smaller cells are used to encode areas of high spatial heterogeneity (Laurini & Thompson, 1992). QuadTree raster systems can store

data more efficiently than a traditional raster system if the “mapped” area contains zones of homogeneous land cover.

Raster data will typically require more storage space than vector data to cover the same geographic area, and vector data tend to be of a greater geometric accuracy (Berry, 1995). It is also possible for raster data to provide higher levels of geometric accuracy if the size of the raster grid is very small in proportion to the selected area (Jensen, 1996). While vector data are most often a better choice to measure geographic features such as roads and rivers, raster data can be a better choice for other GIS operations such as spatial statistics and map overlay.

Generally these GIS-based operations such as statistics and map overlay are easier and more efficient to calculate in a raster format than a vector format since the operations are being performed on a cell by cell basis (Burrough, 1986; Ehlers, Greenlee, Smith, & Star, 1991; Berry, 1995; Jensen, 1996).

There is no single accepted standard for storing geographic data, and consequently many organizations and GIS companies have developed their own methods for storing spatial data. Not surprisingly, the wide variety of different styles of spatial data has created numerous problems of transferring data from one system to another. To use spatial data from a variety of sources in a GIS, a conversion utility must be used. Some of these utility programs are quite straightforward to use, but unfortunately others can be quite complicated and

tedious to use. When the GIS professional uses certain proprietary programs to convert GIS data from one format to another, there can be problems if the computer code that performs the conversion process is hidden within the utility program. In these situations the GIS user has to assume that the organization which produced the utility used the correct and best set of mathematical algorithms to do the conversion.

Spatial Data Requirements:

Based on the above descriptions of the four types of spatial data that are available, it has been determined that the best choice of digital spatial data to perform the spatial analysis for the case study of Cobscook Bay in chapter five is to use vector spatial data. Vector data records geographic features such as shorelines as a series of line segments, and the length of these segments can be calculated using the functions of a geographic information system.

For the spatial analysis of the case study of Cobscook Bay in chapter six using remote sensing data, the decision here is quite straightforward since spatial data from the LANDSAT 5 Thematic Mapper data archive are being used, and the image is in a traditional raster format.

Scale

A map scale expresses the ratio between a measurement of distance on a map to the corresponding distance in the real world. For example, a map feature that is 2 centimetres long on a 1:50,000 scale map represents an object that is 100,000 centimetres or 1000 metres (1 kilometre) in the real world. As a general rule, as the scale of the map increases, there will also be a potential increase in the accuracy of the map since there is an increase in the amount of spatial resolution, and there will also be an increase in the number of geographic features that can be displayed on the map. When using spatial data for mapping and measuring purposes, it is most often desirable to obtain the largest scale maps and spatial data that cover a selected study area for use in a geographic information system. There is, however, no point in obtaining large scale spatial data such as at 1:10,000 if the end use for the data are to create a printed map at a scale of 1:250,000. On the other hand, if spatial data that were created on a small scale are used to produce a map at a larger scale then this violates how data should be used in a GIS.

Small scale map data may be quite acceptable when geographic information is to be plotted on a regional map, but it is not adequate to accurately measure areas, and to calculate dimensions of geographic features when a higher level of precision is required. By its very nature, coastal zone planning and management is a process that involves many different map scales. The scale of the map data is often

dependent upon the specific requirements and capabilities of individual planning and management organizations (Gaudet, 1989). Cendrero (1989) identified three groups of scales for coastal zone planning:

- macro (1:1,000,000 - 1:2,000,000 scale) level for a large area coverage.
- meso (1:50,000 - 1:250,000 scale) for semi-detailed depiction of features.
- micro (1:5,000 - 1:10,000) level for a high level of accuracy and detail.

Commenting on the above categories, Canessa and Keller (1996) reported that “data for a coastal zone GIS inventory should be collected and explicitly tagged to belong to one of the three planning levels. If collected at one level, they should not be accessed at a larger scale” (p. 106).

For the digital spatial analysis of Cobscook Bay, a high emphasis will be placed on the accurate measurement of the coastline, and therefore it is important to determine a minimum acceptable scale that will be useful for that purpose.

Wainwright et al. (1991) noted that:

The map scale recommended as a “standard” must be appropriate to the most demanding, priority use. That is, other scales could be used for special purposes, but should not be advocated as a broadly applicable standard. 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. On a 1:50,000 scale map a 50 m section of stream would be 1 mm in length. Therefore, mapping at 1:50,000 scale is not suitable for habitat information needs (p. 14).

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).

Scale Requirements

For the GIS analysis of Cobscook Bay, this 1:40,000 scale recommendation will be 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. The results of these different scale-based spatial analyses will then be placed in a table for comparison. It should be noted that the minimum scale of 1:40,000 falls in between the micro and meso map categories described by Cendero (1989).

Map Projections

The earth is a sphere that is slightly flattened in the polar regions. To draw a large portion of the earth's surface on a flat piece of paper has always been a challenge for map makers due to the distortion that results when a spherical graphic is converted (or projected) to a flat graphic. There are over 250 different map

projections and each one has its own particular strengths and specific uses. Some projections are better for the accurate representation of certain regions of the world, while other projections are designed for a specific purpose such as showing true directions for navigation (but not true distance) such as with the famous Mercator projection that many people remember from their school days. All map projections will distort some aspects of the earth's sphere to some degree. This is especially true regarding the representation of angles, area, distances and direction (Robinson, Sale, Morrison, Muehrcke, 1984). The choice of a particular map projection depends on which portion of the world is to be displayed and measured and what properties need to be preserved.

Map Projection Requirements

The map projection chosen for use with the digital spatial data is the UTM (Universal Transverse Mercator) projection. The UTM projection was selected so that metres could be used as the measuring unit, and to have consistency between the various types of GIS data.

The UTM projection is similar to the Mercator projection except that the map cylinder is longitudinal along a meridian (longitude line) instead of the equator. The result is a conformal projection that is divided into 60 zones of six degrees width. The UTM projection's properties allow the accurate depiction of smaller shapes

with a minimal distortion of larger shapes within the zone. Local angles are also true within each zone. These zones are numbered from one to 60 and this provides 360 degree coverage of the earth from 84 degrees North to 80 degrees South. Each zone has its own central meridian and it covers an area of 3 degrees east and west of the central meridian. Horizontal lines are designated using metres that are measured from the equator. North of the equator, the north origin or "northing" is given a false value of zero degrees and south of the equator the origin of the northing is given a false value of 10,000,000. Vertical lines are measured from a "false" point 500,000 metres to the west of each zone. The central meridian has a value of 500,000 metres, and all points to the west of the central meridian decrease in value to the origin at zero while all points to the east of the central meridian increase in value to the zone's limit at 1,000,000. A square grid is placed over this projection, and positions on the map are located using the UTM grid system of eastings and northings along with the zone number. The advantage of using the square UTM grid is its dimensions are the same throughout the projection while the grid of latitude and longitude will show the meridians converge at the north or south poles. Another advantage of the UTM grid is that it is easier to locate and identify a position on a map using a UTM grid coordinate of eastings and northings as compared to using degrees, minutes and seconds of latitude and longitude. The UTM projection's properties make it a popular choice for many mapping agencies such as the United States Geological Service and Natural Resources Canada. The

military users have also developed their own unique reference system for reference on UTM maps called the Military Grid System.

The Measuring Unit

Different maps can be based on different types of map measuring units. Spatial data can be stored in various types of units such as decimal degrees, metres, or feet. It is important to know what unit the spatial data uses so that the correct scale can be applied to the map. If an incorrect measuring unit is applied to spatial data that is loaded into a GIS, then a false map scale will be the result. If the map scale is incorrect, then all measurements using a GIS will be wrong. Spatial data will often be stored using decimal degrees as the map unit, and that makes it easy to project the data into a variety of other map projections. Certain types of spatial data such as GIS data from some local governments in the United States are stored as feet using the State Plane Coordinate system (ArcView GIS 3.2). Other map projections such as the UTM can use metres as the measuring unit. When GIS data are obtained, it is very important to know what the map units are, and this information is usually contained in the information file that comes with the spatial data. The information file is normally named "Metadata".

Map Measurement Unit Requirements

Since Canada has adopted the metric system and this measuring system is also used for by many researchers around the world, the metric measuring unit of *metres* has been selected as the unit to measure the dimensions of the geographic features in the case study of Cobscook Bay, Maine. The UTM projection has also been selected to support the spatial analysis in the case study and because of use of the UTM projection it is then a simple matter to set the geographic information system to work with metres.

Horizontal and Vertical Datums

Map datums refer 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. This list of cartographic components is known as meta data and it is described later in this chapter. Many North American maps have been, or will soon be, converted to a horizontal map datum known as NAD83. This new datum is replacing the older NAD27 which was based on the Clark spheroid of 1866 that was used to represent the shape of the planet.

The centre of this older datum is located on a section of the Meades Ranch in Kansas, and other NAD27 control points across North America were referenced to this location. As more efficient and reliable survey methods were developed over

the years utilising advances in such areas as computer-assisted surveying, to satellite positioning systems, it became apparent that there were substantial horizontal positional errors in the NAD27 datum.

The newer North American datum known as NAD83 is an improvement over the older NAD27, and it is based on the GRS80 (Geodetic Reference System) spheroid. The GRS80 spheroid in turn was developed from the World Geodetic System ellipsoid of 1984. WGS84 is the name of the datum that is based on this spheroid. Global positioning systems use, and are based on, WGS84 (Owens, 2000). The WGS84 and NAD83 spheroids both use the centre of the earth as the location of the datum. The NAD83 and WGS84 datums are essentially the same datums, except that NAD83 is designated for civilian and North American use, while the WGS84 datum is the term used for military users (USGS, 1998). The use of these newer datums has meant that maps that are based on the NAD27 datum can be shifted as much as 150 metres in the horizontal direction as compared with NAD83/WGS84 based maps that cover the same area (ArcView GIS 3.2, 1999). Conversion programs are available that can update the horizontal positions of NAD27 maps to match the horizontal positions of NAD83/WGS84 maps.

Vertical Datums

Along with horizontal datums, maps are also referenced to vertical datums.

According to Wolf and Brinker (1989) a datum is “any level surface to which

elevations are referred (for example, mean sea level). Also called datum plane, though not actually a plane" (p. 108). In the United States of America, the vertical datum known as NGVD29 (National Geodetic Vertical Datum) was established by the U.S. Coast and Geodetic Survey's 1929 General Adjustment (USGS, 1998). In Canada, the vertical datum is expressed in reference to the Mean Sea Level (Canadian Vertical Geodetic Datum) (Canada, Geomatics Canada, 1996).

Mean Sea Level, or MSL, is based on the average height of the sea's surface for the complete tidal ranges over a 19 year period. According to Monahan (2000, p. 16), MSL is used as the standard reference for the location of shoreline for land based maps. Other vertical datums are based on the various Tidal Datums which are used in coastal zones to establish property boundaries of lands bordering waters that are subjected to tides (Wolfe & Brinker, 1989). For example, the Mean High Water or MHW is used by land surveyors for boundary determination (Monahan, 2000, p. 16).

What ever datum is used, it is important for the GIS user to know the meaning of these datums. If many sets of spatial data are to be used in a GIS for spatial analysis it is important that these data are based on the same datum.

Horizontal and Vertical Datum Requirements

The coastline is the geographic centre 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 tide levels. The mean tidal range of Cobscook Bay is 5.7 metres or approximately 18.7 feet, the highest tide that can be observed in the United States of America (Brooks et al., 1999). Examples of the high and low tide levels of Cobscook Bay are shown in plates 4.1 and 4.2. Plate 4.1 shows the low tide level at the Carryingplace Cove area of Cobscook Bay while plate 4.2 shows the high tide level at the same location. Consequently, such a large tidal range as this produces two very different coastlines at the high and low range of the tide cycle.

In this thesis, the measurement of the coastline will be based on the mean high water (MHW) tide levels as is shown on the USGS 1:24,000 scale quadrangle maps, and the Mean Sea Level (MSL) that is used by the 1993 version of the 1:1,000,000 Digital Chart of the World (Maine, Office of GIS, 2000).

For the horizontal datum that is to be used for the case study of Cobscook Bay, the preferred choice is to obtain digital spatial data that is based on the newer NAD83 or WGS84 datum.

Plate 4.1
Carryingplace Cove, Cobscook Bay. Low Tide.

Plate 4.2
Carrying Place Cove, Cobscook Bay. High Tide.

Metadata

GIS data will sometimes come with a file of information that describes the content of the data sets. This particular GIS information file is commonly known as metadata, and it describes the basic features of the GIS data. For the metadata to be useful, it should list the map title, spatial area covered, the map projection, the horizontal and vertical datums, the map units, the version number of the map, the date of the map, mapping specifications, and accuracy limits. The United States Geological Survey document *Standards for the Preparation of Digital Geospatial Metadata* lists the following rules for metadata:

Required elements of metadata are those necessary for identification of the data set and include citation, description, time period of content, status, spatial domain, keywords, access constraints, and use constraints. The identification information is a mandatory element of the data set metadata (USGS, 1997, p. 2-1).

Sometimes the digital spatial data contain no metadata, and this can cause problems when important map features such as datums and map units are required to set the correct operating environment for a GIS or computer-assisted cartography. In other cases, the metadata may be available on an organization's web site, or as a printed set of mapping specifications that is mentioned in the metadata.

Metadata Requirements

Based upon the above definition of metadata, the requirements for the metadata for the digital spatial data used for the case study of Cobscook Bay are that it should contain the following list of information as a minimum:

the map title, spatial area covered, the map projection, the horizontal and vertical datums, the map units, the version number of the map, the date of the map, mapping specifications, and accuracy limits

Summary of the Total Set of Requirements That Will be Employed to Perform the Spatial Analysis of the Case Study Area

Spatial Data Requirements

- For the spatial analysis for the case study (Part A) of Cobscook Bay in chapter five the requirement is to use vector spatial data.
- For the spatial analysis of the case study (Part B) of Cobscook Bay in chapter six using remote sensing data, the decision here is to use raster data from the LANDSAT 5 thematic mapper data archive.

Scale Requirements

- 1:40,000 scale will be used as the desired minimum acceptable scale (designated as the baseline scale) to measure the coastline of Cobscook Bay.

Map Projection Requirements

- UTM (Universal Transverse Mercator) projection.

Map measurement unit requirements

- Metres is the map unit that is designated to measure the dimensions of the geographic features in both case study A and case study B of Cobscook Bay, Maine.

Horizontal and Vertical Datum Requirements

- The preferred vertical datums for use in case study A and case study B of Cobscook Bay, Maine are the mean high water (MHW) tide levels as is shown on the USGS 1:24,000 scale quadrangle maps, and the Mean Sea Level (MSL) that is used by the 1993 version of the 1:1,000,000 Digital Chart of the World (Maine, Office of GIS, 2000).
- For the horizontal datum that is to be used for Case Study A and Case Study B of Cobscook Bay, the preferred horizontal datums are either NAD83 or WGS84.

Metadata Requirements

- The requirements for the metadata for the digital spatial data for the case study A and case study B of Cobscook Bay are that it should contain the following list of information as a minimum: the map title, spatial area covered, the map projection, the horizontal and vertical datums, the map units, the version number of the map, the date of the map, mapping specifications, and accuracy limits

Chapter 5

Vector Spatial Data Case Study (Case Study A): Cobscook Bay, Maine

In this chapter the effectiveness of using vector-based spatial data with a GIS to perform a spatial analysis is assessed. Specifically, the length of the shoreline and the area of the water cover of Cobscook Bay, Maine, are measured using criterion established in chapter four. This case study is designated as case study A and a second case study that is based on raster data is designated as case study B in chapter six. The minimum desirable scale for this aspect of the study was determined in chapter four to be 1:40,000 and a search for digital spatial data that covered the study area located five sets of spatial data: 1:24,000, 1:70,000, 1:100,000, 1:250,000 and 1:1,000,000. The largest scale at 1:24,000 exceeded the required minimum scale of 1:40,000 that was established in chapter four. Separate GIS projects for each of the five scales produced a wide variety of coastal measurements which were also displayed in a graphic format. The 1:24,000 scale data was selected as the baseline (reference) scale, and the other four sets of digital spatial data were also used so that the different results could be compared to evaluate their effectiveness for coastal zone management. The results of these comparisons were tabulated, and the findings and conclusions of the spatial analysis of this aspect of the case study are presented at the end of this chapter. For case study A, ArcView 3.2 by ESRI was used to perform the spatial analysis of Cobscook Bay. Some discussion of the implications of using GIS for the following coastal zone management uses in the case study will include: dispersal of pollutants, assessing cleanup costs, identifying areas of the coast that are

vulnerable to storm damage, mapping habitat areas and managing local fisheries (such as shellfish).

While the methods used in case study A were specifically based on the requirements that were established in chapter four, this methodology can be applied to other similar coastal zone applications as were mentioned in chapter two. Situations where the accurate measurement of coastal features such as the length of the shoreline and the area of water bodies can be crucial include the following:

- Shoreline erosion (Videira et al., 1996);
- Coastal engineering (United Nations, 1992);
- Hydrography (United Nations, 1977);
- Integrated coastal zone management (ACZISC, 2000; Rowley, 2000);
- Mapping areas that are vulnerable from flooding, rising sea levels or tsunami run-up (O'Reilly & King, 2000);
- Community coastal resource mapping, shoreline response for oil contingency plans, watershed mapping for water classification and 911 emergency response mapping (Moore, 2000);
- Oceans governance (Chao, 2000; Nichols & Monahan, 2000);
- Municipal zoning and land use planning (Henocque & Denis, 2000);
- Topographic mapping, agriculture, forestry, wetlands, environment, fisheries, geoscience, geomatics and emergency preparedness (Rowley, 2000);
- Allocation of environmental damage due to oil spills (Clement, 2000).

The length of coastline and the area of water enclosed in bays are cartographic elements of the coastal zone, the accuracy of which can be crucial in many types of surveys. For example the length of the coastline and the area of water (and intertidal zone) are important for such coastal zone management functions as pollution tracking, mitigating storm damage, habitat assessment and managing shellfish harvesting areas. These particular functions require a higher level of geographic knowledge about the coastline since the spatial element is a vital component for such coastal zone management uses as modelling the dispersal of pollutants, assessing cleanup costs, identifying areas of the coast that are vulnerable to storm damage, mapping habitat areas and managing local fisheries (such as shellfish).

While the general concepts of length of coastline and area of bays are simple, it is much more difficult to develop operational definitions of them, and having done so, to assess the implications of manipulating them in a GIS. For example digital spatial data that are of a larger scale will tend to be stored as a group of files with many layers of coverage (i.e. roads, hydrography, culture, boundaries). Since the file size of large scale spatial data are often quite large the area of geographic coverage will often be smaller than medium and small scale data. The direct implication of this premise means that any coastal zone management application that demands larger scale spatial data will require more preparation and planning time before that data can be used for its intended purpose. This can involve the merging of smaller files to create larger files, and/or the removal of unwanted or unnecessary layers of geographic data. Direct examples of these types of preparation and planning steps are demonstrated later on in this chapter.

Since this chapter uses a case study format, a brief description of the area as well as some of the local coastal zone issues, has been provided to help place the demonstration of GIS for coastal zone management into perspective.

A Description of the Case Study Area: Cobscook Bay, Maine

Cobscook Bay is located in the southeast corner of the American state of Maine (Figure 5.1). Cobscook Bay consists of many coves, numerous smaller bays, and harbours, and in addition there are many islands and rock ledges of various sizes throughout the bay (figure 5.2). The largest two communities that border the bay are Eastport and Lubec, each with approximately 2000 people. Eastport and Lubec are the eastern-most city and town, respectively, in the continental portion of the United States of America. Eastport is located on Moose Island which is connected to the mainland via a causeway. A portion of this causeway is shown in plate 5.1. Eastport was once the home to a thriving sardine canning industry at the turn of the 19th and 20th centuries when it could once boast having as many as 18 sardine canneries (Holt, 1999). Between the two world wars, however, the number of canneries was reduced from 18 to five through mergers and the elimination of unprofitable and inefficient operations. Eastport had a population of 5,311 in 1900, but the city experienced a steady decline in the early decades of the 20th century, and the crash of the sardine industry in the 1950s further reduced both the number of sardine canneries and the population of Eastport (Holt, 1999). The last operating sardine cannery in Eastport closed

Figure 5.1
Cobscook Bay, Maine.
Location Map

200 0 200 400 600 Kilometers

Figure 5.2
Cobscook Bay Area Map

Legend

----- U.S.A.- Canada boundary line

----- Shoreline

Plate 5.1
Cobscook Bay Causeway, Maine.

in 1983, while there is still one cannery operating at Lubec. Today, the aquaculture industry has replaced many of the traditional fisheries in the area, and Cobscook Bay is an important location for this new industry since its sheltered bays are ideal for the location of the fish-pens. Cobscook Bay was also once an important location for the harvesting of various types of shellfish such as the many clam and scallop species that are native to the area. Unfortunately, many of the clam beds are closed periodically due to faecal coliform bacteria pollution. At other times the shellfish cannot be sold on the commercial market if they have become contaminated with one of the various diseases such as PSP or paralytic shellfish poison and it can often be connected with the appearance of alexandrium fundyense or red tide; DSP or diarrhetic shellfish poisoning and ASP or amnesic shellfish poisoning (Mallet & Myrand, 1995). There is also a concern that the high concentration of aquaculture fish-pens has contributed to algae growth (such as enteromorpha that grows on the tidal flats) in the local area by adding excess nutrients into the water column of Cobscook Bay and the surrounding waters. A study of tidal currents in Cobscook Bay by Brooks et al. (1999) reported that "the tidal-mean flushing times for neutral surface particles in Cobscook Bay vary from less than one day in the eastern arm near Moose Island to greater than one week in the extremities of the inner arms of the bay" (p. 663). Currently, most of the aquaculture sites are located in the centre or eastern part of the bay where the tidal cycle is strong enough to "carry away the waste products, and to also bring in new supplies of dissolved oxygen" (Brooks et al, 1999 p. 664). There are increasing reports that aquaculture, if not properly managed, can cause harm to the local environment. Rosenthal, Scarratt and McInerney-Northcott (1995) reported that such negative effects as the accumulation of sediments and nutrient loading has caused a severe loss of oxygen in the water column in and around aquaculture

pens. An example of several types of aquaculture pens are shown in plate 5.2. The rectangular shaped pens on the left side of the photograph allow for more efficient maintenance since the square design enables the pens to be grouped in a tight and close formation. The disadvantage of this design is that the fish sometimes become disoriented in the corners of the pens. The circular-shaped aquaculture pens on the right side are placed further apart and this round design allows the fish to swim in a more natural circular pattern. The appearance of so many aquaculture pens in the area have also increased the tension between traditional weir-based fishers and the newer aquaculture industry. A fish weir is a traditional method of catching fish that uses a simple heart-shaped enclosure to corral free swimming fish for capture in a net (Plate 5.3). The weir is built by driving long poles in the shallow water in a "heart shape" pattern with an opening that faces the shore. Another series of poles are driven into the bottom and perpendicular to the shoreline to create a fence-like structure. Nets are then strung along the poles to prevent fish from swimming between them. When fish such as herring encounter the fence they are diverted into the heart-shaped enclosure and due to their circular swimming habits they are unable to find their way out. Once a sufficient number of fish are caught within the weir another net is drawn to close the opening and the fish can then be loaded into a nearby fishing boat. The weir fishery has been mostly displaced by aquaculture fish-pens, and the remaining weir fishers complain that the location of the fish pens has harmed the water quality, altered the fish grounds and changed the swimming patterns of the local commercial fish species (Miller & Aiken, 1995).

Plate 5.2
Fish Pens, Campobello Island, New Brunswick.

Plate 5.3
Fish Weir. Johnson Cove, Eastport, Maine.

Sources of Digital Spatial Data, and the Geographic Information System That Was Used to Measure Cobscook Bay

The purpose of this case study is to accurately measure and compare at different scales, the shorelines of the mainland of Cobscook Bay, the shorelines of the islands of Cobscook Bay, and the area of Cobscook Bay at the mean high tide level (MHW). It is therefore necessary to use vector spatial data with the following attributes: minimum scale of 1:40,000, UTM projection, metres as map measurement unit, NAD83 or WGS84 horizontal datum and MHW for the vertical datum.

The Geographic Information System

Cobscook Bay was analysed using ESRI's ArcView 3.2 geographic information system running on a 450 MHZ Pentium III based microcomputer. The ArcView geographic information system was chosen for several reasons. First, ArcView has been chosen by many colleges and universities (such as in the Department of Geography and Environmental Studies at Carleton University) for use in geographic information studies and it is also widely used in the private sector. The ArcView system also has the ability of using many different formats of spatial data, and since there is such a large group of people and organizations who use the system, many add-on software functions are available. Some of these add-on functions are freely available programming scripts that extend the capability of ArcView, and allow complex geographic (spatial) analysis to be performed. Some of these scripts were used in the spatial analysis of this case study area, and they are described later in this chapter.

Digital Spatial Data

To obtain digital spatial data of the study area in a vector format that meets the requirements that were specified in chapter five, 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 these types of digital spatial data are as follows:

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. The Maine Office of GIS organises their spatial data according to map layer features and various types of coverage areas. Each type of spatial data is identified by a geographic name, an attribute such as road or shoreline, and a map scale. Five different map sets were needed to cover the extent of Cobscook Bay for the 1:24,000 scale digital coverage. The names of the map sheets as well as the date of the last update are as follows:

- Eastport, 1977.
- Pembroke, 1977.
- Lubec, 1977.
- West Lubec, 1949.
- Whiting, 1977.

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 metres 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 metres in ground terms. Two

different map sets were needed to cover the extent of Cobscook Bay for the 1:100,000 scale digital coverage. The names of the map sheets, and the compilation dates are as follows:

- Eastport, 1989.
- Machias, 1989.

The map projection for the Maine GIF digital spatial data is based on the UTM projection, Zone 19, the horizontal Datum NAD83 , and the units are in metres.

The United States Geological Service Coastline Extractor Spatial Data

The spatial data that were obtained from the United States Geological Service Coastline Extractor were zipped Arc Ungenerate format files that can be used by the ESRI ArcInfo GIS. 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 world wide 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 1:70,00 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 metres 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).

The 1:250,000 data use the WGS84 horizontal datum and the horizontal accuracy requires that 90% of all significant shoreline features are to be located within 500 metres (or 2.0 mm. at 1:250,000 map scale) circular error of their true geographic positions. The vertical datum is based on the mean high water mark (MHW).

The original source of these 1:70,000 and 1:250,000 coastline data is the former US Defence Mapping Agency now known as the National Imagery and Mapping Agency or NIMA (Soluri & Woodson, 1990).

Digital Chart of the World (DCW) Spatial Data

As the name implies, the Digital Chart of the World (DCW) contains digital spatial data of the world. The scale of the DCW spatial data is 1:1,000,000. The spatial data were obtained from the Pennsylvania State University's Map Library site and it was also in the form of zipped ArcInfo format files. The spatial data were downloaded as one single file that covered the entire state of Maine. Elevation datum is Mean Sea Level (MSL). The horizontal datum is WGS84, and the horizontal accuracy, "at a 90 percent confidence level for circular error, ranges from 1,600 feet to 7,300 feet. The vertical accuracy, at a 90 percent confidence level for

linear error, ranges from 160 feet to 2,100 feet” (Environmental Systems Research Institute, Inc. 1993, p. 2-13).

The Limits of Cobscook Bay

The delineation of the coastline, as it pertains to boundaries and borders, often depends on the use of a recognizable landmark known as a headland. A typical headland is in the form of a peninsula or another part of the coastline that juts out into the water. These headlands are frequently used to mark the entrance of a river or the mouth of an area of water such as a bay. Headlands are also used as a reference point in boundary disputes between different jurisdictions and they are combined as headland-to-headland lines. A case in point was the Canada-Alaska boundary dispute of 1896. Canada used the headlands-to-headlands boundary principle to claim that an inlet named Lynn Canal that was used to gain access to the Klondike was in Canadian territory. The United States of America argued that the boundary should follow the coast and an international tribunal ruled in favour of the American position (Compton's Encyclopaedia Online, 1998).

A more precise definition of headland and headland-to-headland is cited from the Florida Division of Marine Fisheries:

Headland means a point on the mean high water line of a coast at or near the mouth of a creek, canal, cut or other waterway, at which there is an appreciable change in direction of the general trend of the coast.

Headland-to-headland line means a straight line joining the headlands on either side of the mouth of a creek, canal, cut or other waterway and utilized for the purpose of establishing a boundary line between the waters of such creek, canal, waterway or cut and the waters of the adjoining ocean, bay or sound (Florida, 2001).

The headland principle can be also used to delineate the boundary of Cobscook Bay and the three headlands used for the case study are Comstock Point, Shackford Head and the Lubec town pier (which is on a headland known as the Lubec Neck) as shown on figure 5.3. The precise boundary and extent of Cobscook Bay is not agreed upon by local people or by various mapping organizations such as the Maine Office of GIS or the United States Geological Survey, and there are at least three definitions of its geographic limits. For example, the Maine Office of GIS produces an ArcInfo coverage file named "MEDRDVD.E00" that contains the spatial information for watersheds of the state of Maine (Maine Office of Geographic Information Systems, 2000). One of the records that is part of the data table for this spatial information covers the "Eastern Coastal Rivers drainage area" which includes Cobscook Bay. The eastern boundary of this drainage area extends from Estes Head in the north through Treat and Dudley Islands, then down to the main town pier in the town of Lubec. A different definition of the extent of the Cobscook Bay is found on various 1:24:000 USGS (United States Geological Survey) maps that cover the area. The USGS map titled Eastport, ME that covers the city of Eastport has large bold letters that indicate the water body "Cobscook Bay", but this reference ends approximately 9.5 kilometres west of Shackford Head (Eastport Maine, 1949). There are no boundary lines or symbols to separate the different bodies of water on these USGS maps and therefore these USGS maps do not provide a precise separation of one water body from another.

The three definitions used in this case study of Cobscook Bay include all of the inner bays and individually extend to the following limits:

- Comstock Point to Shackford Head ('A' on figure 5.3).
- Comstock Point to Estes Head ('B' on figure 5.3).
- Estes Head to the town pier in Lubec, Maine (via Treat and Dudley Islands) ('C' on figure 5.3).

Figure 5.3 shows the location of these headlands along with GIS control points at the eastern end of Cobscook Bay. The control points at Estes Head, Comstock Point, Shackford Head, the Lubec town pier and the four control points on Treat and Dudley islands are indicated with solid circle symbols. Of the two islands, Treat is the larger, and it is located to the north of Dudley Island. In order to perform the analysis of this case study in a thorough manner, all three boundaries of Cobscook Bay were measured using the digital spatial data that was obtained for this study. Since there is no agreed upon definition of what the limits of Cobscook Bay are, the one guarantee that correct measurements are made is to simply measure all three limits. Perhaps this is an example of one of the ambiguities that exists within the practice of coastal zone management.

The results of this analysis are listed in the table in the conclusion of this chapter.

Figure 5.3
GIS Control Point Locations

Legend

---	Cobscook Bay Boundary	—	Shoreline
●	GIS Control Points	---	USA-Canada border
—	Roads		

Spatial Analysis of Cobscook Bay Maine

Methodology

The same basic methodology was used on each set of spatial data to obtain the various measurements of the lengths of shorelines, and the areas of the three different Cobscook Bay limits; however, there were some detailed differences in the way that the individual GIS projects were created, and they are described throughout this section of the chapter. The purpose of the following processes is to create special purpose files of spatial data so that measurements can be made of selected areas along the coastline of the study area. It is necessary to describe the steps in this procedure in order to outline the standards that were adopted and the decisions that were taken in the preceding chapters. As a result, the description may resemble an operations manual, but it also illustrates the substantial amount of data preparation required to implement spatial analysis in the coastal zone.

Step One. Converting the Data to ArcView Shape File Format

The first step in the process was to convert the spatial data into an ArcView shape file, so that the data can be loaded as a shape file into an ArcView GIS project. A shape file is the name of the file format that is specifically used with the ArcView GIS. This first step involved using a program to uncompress the files that were in compression format known as *zip*. The files that were extracted from the zip files were in an ArcInfo format, and a utility named *Import 71* was used to convert these

files into an ArcView shape file. The exceptions to this process are the data files that were obtained from the site of the USGS Coastline Extractor. The spatial data from this source first needed to be converted from Arc Ungenerate format files to an ArcInfo format before the *Import71* utility could be used. This conversion was done using a script file named *gen2shap1.ave*. The vector data that were obtained from these locations were also in the form of point, line and polygon coverages.

Step Two. Setting the correct map projection.

The next step was to change the default map projection of the ArcView geographic information system from a standard geographic projection (degrees, minutes, seconds) to a UTM (Universal Transverse Mercator) projection. This step is done for each of the separate GIS projects that are used to execute the spatial analysis of Cobscook Bay. The UTM projection was selected so that metres could be used as the measuring unit, and to have consistency between the various types of GIS data. The UTM zone was set to zone 19, which covers the area of Maine, and the map's horizontal datum was set to NAD83.

Step Three. Creating new GIS project files.

Depending on the scale and type of digital spatial data that was used for each GIS project, the digital spatial data files had to be either joined to form one larger single spatial file to cover the extent of Cobscook Bay, or they were separated and cut away from digital spatial data files that covered areas that were many times larger

than the study area. In the case of the latter, the digital spatial data files were reduced in size to save on storage space and to speed up the processing time, since there was no need to use geographic data that extended beyond the limits of the case study area.

For the geographic projects such as those based on the 1:24,000 and 1:100,000 scale data, the various shape files had to be joined together to create larger, single shape files to cover the extent of Cobscook Bay. To join these shape files together using ArcView, certain procedures had to be followed as described below:

The ArcInfo files (coverages) for each of the GIS projects were composed of many individual digital spatial data files that were associated with the Cobscook Bay area of Maine. The files included hydrography, transportation, airports, communications, geology, forestry, fishing, to shorelines and water coverage. The names of each of the ArcInfo files were based on a geographic coverage (extent) designated by the appropriate town or township name in Maine. The ArcInfo format files were downloaded from the Internet site of the Maine Office of GIS, converted to shape files using the *Import 71* utility, and then later changed to a shape file format using the *convert to shape* file function within ArcView. The shape files were then joined together to form one single shoreline shape file using ArcView's geo-processing wizard function. The selection chosen for this procedure was the *merge themes together* operation.

The same procedures were used to merge the polygons of the Cobscook Bay area, but the following extra step was required: the table for the water shape file was accessed (or opened) using the ArcView table editor, and then the various water features were joined together by use of *Edit/Combine Graphics* function. To perform this operation the table must be in "editing mode".

The Digital Chart of the World 1:1,000,000 scale spatial digital data was downloaded as a single zipped file that contained multiple digital files for the entire state of Maine in ArcInfo format. Since the digital spatial files covered the entire state, there were no files to join once the spatial data were converted to a shape file. The selected area for the case study was cut away from the rest of the Maine spatial data with a procedure known as the clip theme operation. This technique is described in step four of the spatial analysis procedure.

Data from the United States Geological Service Coastline Extractor were converted into Arc ArcInfo format, and *Import 71* was used to convert these files into an ArcView shape file. The United States Geological Service Coastline Extractor allows the Internet user to specify the size of the spatial data to download that is based on the geographic coverage (or extents) of the selected area. The extents for the coastline data are entered as longitude and latitude at the four corners of the coverage area and a new digital spatial data file is created based on these extents. The spatial data sets for these types of coverages can then be created to match the area of a case study, and no additional data files are required to be joined, nor is

there any need to trim off any excess or unwanted data. A spatial data file that has been created in this manner will also reduce the amount of editing and storage space when it is incorporated into a GIS project.

Step Four. Creating spatial limits for the three extents of Cobscook Bay

For the next step in the process, the spatial data were matched to the same geographic limits of Cobscook Bay. This was accomplished by a technique known as the clip theme operation, or also known as the “cookie cutter approach”. A template that matches the limits of Cobscook Bay is created, and then saved as a polygon shape file. This template is used to cut away the excess spatial data from the selected spatial data set, and the output is saved as a new ArcView shape file. This technique works for both line and polygon data. Point data can also be selected using a theme-on-theme selection process, or by using the geoprocessing wizard that comes with ArcView 3.2. An ArcView programming script called *calcapl.ave* is run on the new spatial data for the purpose of recalculating the lengths, areas and perimeters of geographic features. The results of these operations are then saved in their associated database tables. If these new measurements are not made, then the dimensions of the geographic features will be based on their previous extents.

Figure 5.4 shows the perimeter of one of these polygon clip templates that is used for establishing the length of the shoreline of Cobscook Bay. In this example, the template is being used to create new shape files that are based on the geographic extent of the study area. These shorter versions of Cobscook Bay are defined by each of the three limits of the bay which in this case is from

Figure 5.4
Shackford Head-Comstock
Point Clip Theme

Legend

	Shackford-Comstock Clip Theme		Shoreline
	USA-Canada boundary		Roads

Comstock Point to Shackford Head. Figure 5.5 shows the end result of the clip theme operation with a new shape file of the shoreline of Cobscook Bay that is based on the Comstock Point to Shackford Head limit. The table of data that is associated with this shape file lists the total number of line segments that make up the total length of the shoreline. A line segment is the length between vertices in a vector data file. Several examples of vector line segments can be seen in figure 3.2 in chapter three. The length of the shoreline is obtained by selecting the top level of the data field in the data table and then a function in ArcView can be set to calculate the total length of the field for the new shape file. This exemplifies how dimensions of geographic features are measured with a geographic information system such as ArcView.

Step Five. Measuring and Calculating the Dimensions of Cobscook Bay

The end result of the operations from step four are new sets of spatial data that contain tables of geographic data, spatial coordinates, and thematic attributes that match the specified limits of Cobscook Bay. The operations in step four were run three times so that all three limits for each of the data sets of Cobscook Bay could be measured. Control points designated "GIS Control Points" that represented the three limits of Cobscook Bay were established on the 1:24,000 scale GIS files of Cobscook Bay (the largest scale and most accurate set of spatial data). These GIS control points were located in the approximate centre of the three headlands on the mean high water (MHW) line to conform with the headland-to-headland line principle. The UTM coordinates of the GIS control points were obtained by running a program script called *Addxyco*. These GIS

Figure 5.5
Cobscook Bay, Maine.
Shoreline from Shackford Head to
Comstock Point

5 0 5 10 Kilometers

Legend

GIS Control Points

Cobscook Bay Shoreline

control points were then copied to the other four scale-based sets of GIS files. In this way, the templates that were used to create the new data sets for each scale of GIS data used the same control point (based on UTM coordinates) on each map. Since there were a total of five scale-based datasets and each dataset was measured for the three extents of Cobscook Bay, a total of fifteen measurements were made of the various shoreline lengths of Cobscook Bay.

Similar procedures were used to measure the water area and the islands of Cobscook Bay as were employed to determine the lengths of the shoreline. Unfortunately the area calculation could only be performed on three of the five datasets for the following reasons:

- The digital spatial data (1:70,000 and 1:250,000) that were obtained from The United States Geological Service Coastline Extractor contained only vector data for the shoreline.
- The digital spatial data that were obtained from the Maine Office of GIS, and the Digital Chart of the World (DCW) data contained vector data for the shoreline, as well as polygon data for such geographic features as water bodies and various areas land features.

The lack of any polygon spatial data from the United States Geological Service Coastline Extractor is the reason why the tables of the results of the spatial analysis show no values for the areas of the bay or of the islands. Therefore only three GIS projects were used to measure and calculate nine separate area dimensions of the water coverage, and of the islands of Cobscook Bay.

Step Six. Using the New Spatial Data for Spatial Analysis

These new sets of spatial data can be used to find the lengths of shorelines and areas of water bodies and islands of Cobscook Bay, Maine. There are several methods of retrieving the measurements and calculations from the ArcView GIS such as using a *query* function in the corresponding map tables, or by selecting the features on the computer screen and going back to the tables to see the results. The *query* function allows for a more flexible approach as many variables and parameters can be selected to produce a specific output. The second approach is more straightforward and it involves selecting the specific geographic feature on the computer screen with the computer mouse. A corresponding spatial data table for the selected geographic feature is loaded as a new window on the screen and the record or records that apply to the selected feature are highlighted in yellow. Multiple records in the data table can be calculated to produce results such as calculating the length of a shore line or the area of a body of water. The results that are displayed in table 5.1 were obtained by use of both of these query and display methods.

Commentary on the Results of the Spatial Analysis of Cobscook Bay

The spatial analysis of Cobscook Bay 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. 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

Table 5.1
Dimensions of Cobscook Bay, Maine, USA.

Scale	24000 Baseline Scale	70000	100000	250000	1000000
Length of Mainland shoreline (metres)					
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 (metres)					
Comstock Pt.-Shackford	57,482	51,674	31,786	20,884	0
Comstock Pt.-Estes Hd.	57,593	51,674	31,786	20,884	0
Estes Hd.-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 Hd.	171	87	29	10	0
Estes Hd.-Lubec Pier	186	95	33	13	1
Area of Cobscook Bay (metres ²)					
Comstock Pt.-Shackford	89,946,703	N/A	90,197,323	N/A	94,019,162
Comstock Pt.-Estes Hd.	92,070,024	N/A	92,297,120	N/A	95,991,320
Estes Hd.-Lubec Pier	100,536,850	N/A	100,534,727	N/A	105,004,516
Area of Islands (metres ²)					
Comstock Pt.-Shackford	2,404,855	N/A	1,962,162	N/A	0
Comstock Pt.-Estes Hd.	2,405,224	N/A	1,962,162	N/A	0
Estes Hd.-Lubec Pier	2,639,025	N/A	2,181,156	N/A	201,450

example, the length of the mainland shoreline varies from a value of 380,900 metres using the 1:24,000 scale digital spatial data, to a length of 180,019 metres that is based on the 1:1,000,000 scale digital spatial data. This is a difference of 200,881 metres 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 5.1 the accurate depiction of the geographic reality of Cobscook Bay is directly dependent upon the scale of a particular set of digital spatial data.

The calculated length of the shoreline becomes shorter as the scale becomes smaller due to a combination of factors not least of which is map generalization. As was reported in chapter 3 (figure 3.2) certain amounts of geographic detail are removed from every type of map due to the limitation of space. As the scale of the map becomes smaller a greater percentage of the geographic information is either simplified in a generalization procedure or it is removed from the map entirely. The more a geographic feature - such as a shoreline - is generalized, the less it is able to accurately represent both the shape and dimension of that feature. The other main factors affecting the length of the shoreline are map scale and spatial resolution.

As was mentioned with map generalization, the scale of the map will determine the amount of geographic detail that can be displayed on the map and in turn, the scale and the level of map generalization will affect the spatial resolution of the map. The resolution of spatial data will become less detailed as the scale of the map becomes smaller and this will result in a smaller and less

precise spatial data set since there are fewer vertices or raster cells to represent geographic features. The ability of a map to accurately represent a portion of geographic reality can be also be compared to a statistical sample. In statistics, the larger sample size will result in a higher reliability factor for the use of those data for statistical analysis. Digital spatial data are similar to sample sets of statistical data in that small spatial data sets can only give a rough approximation of geographic detail. Larger spatial data sets like sample sets of statistical data cover more geographic detail and the accuracy increases as the resolution and the scale becomes ever larger. Based on this premise it is not surprising to find that the length of the shoreline of Cobscook Bay has larger dimensional values for the larger map scales such 1:24,000 and 1:70,000 and smaller dimensional values for the 1:250,000 and 1:1,000,000 sets of digital spatial data.

Another interesting and important finding in table 5.1 are the number of islands that are reported in Cobscook Bay. The number of islands vary far more relatively than the lengths of the shoreline between the five scale-based sets of digital spatial data. Due to such factors as map scale, map generalization and spatial resolution, the number of islands in each scale-based set of digital spatial data increase in number as the scale becomes larger and decrease in number as the scale becomes smaller. The number of islands in each set of digital spatial data also will affect the value for the dimensions of the islands since an island that is removed from the data set cannot be measured for either area or length of shoreline.

Using the Comstock Point to Estes Head limit of Cobscook Bay as an example, the count of islands ranges from 169 using the 1:24,000 scale digital spatial data, to a count of 29 for the 1:100,000 scale digital spatial data, to a value of 0 for the

1:1,000,000 scale digital spatial data. As a comparison to the results in table 5.1, a manual count of the islands in Cobscook Bay using the five 1:24,000 USGS paper maps (Eastport, Maine,1977; Lubec, Maine,1977; Pembroke, Maine,1977; West Lubec, Maine,1975; Whiting, Maine 1977) that cover the area produced the following results:

- Comstock Point: 132.**
- Estes Head:133**
- Lubec Town Pier: 144**

The difference in the count of islands between the 1:24,000 USGS maps and the 1:24,000 State of Maine digital spatial data are likely due to different methods of classification of islands, rocks and rock ledges between the two mapping organizations. Even though the scales of the analogue and digital spatial data are the same (1:24,000) the geographic reality is apparently interpreted to different mapping classification standards. The state of Maine creates maps and digital spatial data according to its own local knowledge and technical expertise while the USGS creates maps and digital spatial data that are based on national mapping standards. In situations when analogue maps and digital spatial data that are at the same scale produce two (or more) different results, it is then up to the end user to decide which source of the spatial data has more validity and is more appropriate for their application. The above is an example where metadata or data about the data becomes a useful reference tool in the use of spatial data.

The results in table 5.1 show that smaller geographic features like islands will disappear from maps and sets of digital spatial data as the map scale becomes ever smaller. As with the length of the shoreline, table 5.1 shows that the

geographic knowledge regarding of the number of islands within Cobscook Bay will vary according to the scale of a particular set of digital spatial data. Depending on the scale-based set of digital spatial data that is used, the implications for the user of these data can be a false value for the length of a shoreline, a false value for the area of the island or a false count of the number of area of islands within a study area. For organizations that need to plot the distribution of plant and animal species, the removal of islands from a map or a set of digital spatial data will result in a lower level of accuracy and reliability. Habitat assessment is one of the functions of coastal zone management and if the spatial data cannot display or map habitat areas it is not useful for that aspect of coastal zone management (Levings et al., 1999). The smaller scale data does not have the resolution and it simply lacks the space necessary to contain smaller features of the coastal zone such as islands. This is especially true for the 1:1,000,000 scale data where, except for the largest extent of the bay, no islands were reported during the spatial analysis of the study area.

Accurate shoreline length is also important for coastal zone management applications such as mapping the shoreline to measure shoreline erosion and deposition, coastal bluff mapping and landslide susceptibility mapping. (Komar, 1984; Maine Department of Conservation, 2001). The problems of shoreline erosion and the potential damages from storm surges are receiving more attention due to the effects brought on by global warming such as changes in weather patterns and sea level rise (Maine State Planning Office, 2000). Emergency planning agencies in the United States such as the National Flood Insurance Program and the Federal Emergency Management Agency require accurate spatial data to map areas that are at risk to floods (FEMA, 2001) . The Atlantic

Region Sensitivity Mapping program in Canada uses spatial data for the accurate depiction of the shoreline (Environment Canada, 2001). For these types of coastal zone management applications only spatial data that are of a sufficiently large scale are suitable for the task.

Other coastal zone management applications that require the accurate depiction of the coastline are the tracking of dispersal of pollutants, and assessing the damage due to oil spills (Kennish, 1994). Regarding oil spills, the following will demonstrate how the use of accurate spatial data can affect how much money should be assessed to the polluters for the damage they have caused.

Clement (2000) described how to allocate the environmental damage due to oil spills in terms of a dollar value. In 1998 alone, there were 1,806 oil spills reported to the Atlantic Canada Environmental Emergencies Section. In order that the public should be protected from the damages due to these oil spills, the polluter is charged with the cost of the cleanup. This is often referred to as the “polluter pays principle”. A formula is used to calculate the damage to the environment that is based on several variables such as the size of the habitat area that is affected, what grade of oil was spilled (i.e. heavy or light crude), the sensitivity of the habitat to oil spills, and the value of the habitat that is lost due to oil spills. The calculation to determine the restoration cost for an oil spill is as follows:

Environmental Damages = Baseline Habitat Value (per m²) X Habitat Sensitivity Factors X Oil classification Factor X Affected Area (m²).

It is apparent that one of the essential variables in this calculation is the level of spatial accuracy that is employed to map and measure the area that is affected by

an oil spill. A higher degree of spatial accuracy will produce a more accurate environmental cost that the polluter is required to pay to the public agency.

Obviously if small scale data are used in a GIS to determine the size of the habitat area the cost that is determined by the formula will be less than is actually required to repair the damage.

While the various scales of the digital spatial in table 5.1 resulted in quite different results for the shoreline length and the number of islands in Cobscook Bay, the values for the water area of Cobscook Bay showed much more consistent results. As was mentioned earlier in this chapter, the area of Cobscook Bay was only measured using three of the five sets of scale-based digital spatial data. Using the Comstock Point to Estes Head limit of Cobscook Bay as an example, the water area of the bay varied from 92,070,024 square metres using the 1:24,000 scale set of digital spatial data to 95,991,319 square metres using the 1:1,000,000 set of digital spatial data. This is a difference of 3,921,295 square metres or 0.96 times the area of the bay for the 1:24,000 digital spatial data over the use of the 1:1,000,000 digital spatial data. Unlike the values of the length of the shoreline which showed a ratio of 2.1 for the use of the 1:24,000 scale spatial data over the 1:1,000,000 scale spatial data, the smaller scale-based set of digital spatial data produced a slightly larger result. The result of measuring the area of Cobscook Bay is not consistent with measuring its length since the scale of the digital spatial data did not produce values that varied to the same degree. One of the possible reasons for the consistency of the measurement of the water area of Cobscook Bay is that as the scale decreased, the number of islands were generalized and/or removed, while the broad outer shape of the bay remained essentially the same. This meant that areas of water that were lost due to changes in the shoreline were offset by

additions to the water area when the islands that were removed as the scale became smaller were reclassified to water. Since only three sets of spatial data were used to measure the water area of Cobscook Bay the reason(s) why the water areas do not vary as much as shoreline length can only be properly determined by further testing. This testing would include the use of a wider range of scales as well as maps of different coastal areas. Only by rigorous testing can it be determined why the water area did not vary as much as coastline length in the case study. As it stands the results of the case study regarding water area are inconclusive.

Not unexpectedly the area of the islands (which paralleled the number of islands) more closely matched the results of measuring the shoreline line of Cobscook Bay. Using the Estes Head to Lubec town pier limit of Cobscook Bay as an example, the area of the islands ranged from 2,639,025 square metres for the 1:24,000 set of digital spatial data, to 2,181,156 square metres for the 1:100,000 set of digital spatial data to 201,450 square metres for the 1:1,000,000 set of digital spatial data. This is a difference of 2,437,575 square metres or 13.1 times the area of the islands of the bay for the 1:24,000 digital spatial data over the use of the 1:1,000,000 digital spatial data. A major contributing factor to this difference in measurement is due to map generalization which has removed the number of islands as scale became smaller. Islands that are not included in a data set cannot be measured and this factor will directly affect the comparison of the calculation of the dimensions of the islands between the various sets of scale-based digital spatial data.

An example of the use of area calculation for coastal zone management purposes is for the issuing of commercial shellfish licences by towns in the state of Maine.

Towns in Maine play an important part within the state's conservation programs as many have their own approved shellfish conservation programs. Once a town has an approved program they can issue commercial shellfish licences as long as the total acreage of the lease sites do not exceed 25 percent of the total intertidal zone within the town's limits (Underwood, 1995). For proper environmental planning the measurement of the town's intertidal zone will require a precise knowledge of the town's boundary as well as the accurate location of both the high and low tide lines for the shoreline. If these three conditions are met then a GIS can be used to allocate the proper number of shellfish licences. Unfortunately the data that were used in case study B can only supply two of these parameters: town boundary and mean high water mark (MHW). There is no data for the lower tide line and without this vital piece of information the size of the intertidal zone cannot readily be measured. Data for the lower tide shoreline can be determined by obtaining hydrographic charts in digital form or by digitizing the required detail from hydrographic charts.

Summary

The results of this chapter clearly show that the using a GIS for coastal zone management applications is not a simple "point and click" procedure, but it is a multi-step process that also utilizes a set of specific cartographic requirements to obtain reliable and useful results and requires an understanding of how spatial data are manipulated with a GIS. The results of table 5.1 illustrate that map scale, map generalization and spatial resolution have an enormous effect upon shoreline length as well as being able to depict geographic reality for smaller geographic features such as islands. The implications of the results in table 5.1 for coastal zone management in the study area are summarized in table 5.2

Table 5.2
Implications of the Results of Table 5.1 for Coastal Zone Management

Scale	Application	Success or Failure
24,000	Map Shoreline Reaches	Success
70,000 to 1,000,000	Map Shoreline Reaches	Failure
24,000	Habitat Mapping	Success
70,000 to 1,000,000	Habitat Mapping	Failure
24,000	Change Detection	Success
70,000 to 1,000,000	Change Detection	Failure
24,000	Measure Tidal Flats	Failure. Mean Low water line is also required to map tidal flats
70,000 to 1,000,000	Measure Tidal Flats	Failure
24,000	Landslide Susceptibility Mapping	Success
70,000 to 1,000,000	Landslide Susceptibility Mapping	Failure
24,000	Allocating Costs for Environmental Damage	Success
70,000 to 1,000,000	Allocating Costs for Environmental Damage	Failure

The results of table 5.1, on the other hand, do not show as large a difference for the measurement of water area when different sets of scale-based digital spatial data are used as the source for spatial analysis. From these observations, it can be concluded that when sets of digital spatial data that are based on different scales are being compared for accuracy, it is better (if possible) to measure a geographic feature's length as opposed to its area. Map scale will determine what type of geographic feature is included on a map as well as the degree of accuracy and spatial resolution of a map or of digital spatial data.

While the length and area of a geographic feature is important for use in various coastal zone management applications, the accuracy of the actual geographic position of a geographic feature such as the shoreline is also an important element. Therefore, when comparing the different results of length and area in table 5.1 it is also important to note the accuracy of the horizontal position of the geographic feature. Referring back to the meta data for each set of scale-based digital spatial data, it is apparent that there is a huge difference in horizontal accuracy between the large scale and small scale digital spatial data. The 1:24,000 scale-based digital spatial data has a horizontal accuracy of 12.19 metres while the 1:1,000,000 scale-based digital spatial data has a horizontal accuracy that ranges anywhere from 487.68 to 2225.04 metres (USGS, Part 1, 1997, p.1. D-2; Environmental Systems Research Institute, Inc. 1993, p. 2-13).

Clearly, the larger scale-based digital spatial data provides not only a more precise measurement of coastal features such as shoreline length but it also maps the

horizontal location of a geographic feature to a much higher level of accuracy as well. In the case of measuring geographic area where there was much less of a difference in the results (table 5.1), the larger scale-based digital spatial data still provides a more accurate representation of the horizontal location of geographic features.

Comparing small and large map scales are like comparing a summary to a detailed story. A small map scale provides a basic description of an area while a larger scale map provides much more geographic information. The utility of each map scale depends on how the map is to be used. For the case study in this chapter it was determined that a map scale of 1:40,000 was needed as the minimum needed so that accurate and reliable results could be obtained (Wainwright et al., 1991). Since the largest map scale that was obtained was at 1:24,000, the minimum requirement was not only met, but surpassed. This 1:24,000 scale-based digital spatial data was then used as the baseline scale to carry out the various GIS operations such as measuring the length of the shoreline and the area of the bay. It can then be concluded that since the baseline scale exceeded the minimum requirements established by Wainwright et al. (1991) the results obtained for the 1:24,000 scale-based digital spatial data are suitable for coastal zone management applications.

Chapter 6

Raster Spatial Data Case Study (Case Study B): Cobscook Bay, Maine

The purpose of this chapter is twofold. First it explores the suitability of using digital remote sensing data (such as LANDSAT 5 TM satellite data) within a GIS for coastal zone management applications. Digital remote sensing data may be an alternative source for coastal zone management applications if the needed digital spatial data are unavailable. And second, this chapter demonstrates the transition of spatial data into geographic information through the use of the LANDSAT 5 TM data within a GIS. However, it needs to be stated that since the LANDSAT 5 TM data are approximately at a 1:1,000,000 scale it cannot be used for coastal zone management for the study area since it does not meet the minimum 1:40,000 requirements. These LANDSAT 5 TM spatial data have been included to show the methods which can be used on sources of remote sensing data that offer better scale and resolution. Examples of such remote sensing data as RADARSAT and IKONOS both of which were too expensive to be used for this thesis.

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. In chapter five it was demonstrated how digital spatial data from on-line databases, already in a GIS-compatible format, can be used within a geographic information system to measure various shoreline and embayed features of the coastal zone. However, available sets of digital spatial data are sometimes not suitable or are not available in the required scale or file format. Some users may want geographic detail that are mapped at the low tide level, but

this may not be available since most existing maps show the shoreline at the mean high water level. This problem was identified in the previous chapter where the measurement of the area of an intertidal flat that is within a town's limits requires the location of both the high and low tide shorelines. In other situations the available digital spatial data may be quite out of date and a method is needed to detect whether there have been any changes to the coastal geography of the area. For example, there are situations where certain areas of the coastal zone experience rapid geographic change due to storms and unstable geological conditions. Storms and wave actions can both erode a coastline as well as deposit vast quantities of new material on them. Such storm- and geologically-induced changes may not yet be shown on currently available sets of spatial data and maps, and methods are needed to obtain spatial data on a more timely basis.

A method is therefore often needed to either locate or create new spatial data. The search for digital spatial data for case study A in chapter five was also helped by the availability of free spatial data that were provided from the Maine Office of GIS on their Internet site. Unlike the State of Maine, not every state in the United States of America provides free access to their digital spatial data, and even in case of Maine, users who need access to large amounts of spatial data are encouraged to purchase the data in bulk form, rather than trying to download it from the Internet site of the Maine Office of GIS.

For areas outside the United States of America, it can be much more difficult to locate and obtain digital spatial data. Most of the digital spatial data that were used in case study A are not available for coastal zone use outside of the United States of America except for the 1:250,000 USGS coastline data, and the 1:1,000,000

Digital Chart of the World (DCW) data. As was evident from their use in case study A, these two sources placed severe limitations on the level of precision and how accurately the shoreline and water areas of Cobscook Bay could be mapped. The 1:250,000 coastline data only depict the shorelines of the oceans and there are no other data for other geographic or cultural features at the time of this writing. The 1:1,000,000 Digital Chart of the World data, as its name implies, covers the entire world, and it also contains many layers of geographic coverage such as coastlines, major road and railways, drainage systems, utility networks, major airports, elevation contours, international boundaries and populated places. The DCW is currently the only digital spatial database that has world wide coverage at a scale as large as 1:1,000,000; however, its depiction of the shoreline is highly generalized, and the horizontal accuracy is not acceptable for use in large and medium scale spatial analysis to support coastal zone management. The Digital Chart of the World data on the other hand is quite suitable for use in the creation of small scale maps for use in such applications as regional planning and analysis, in the creation of maps for special reports, or in the production of an atlas.

The spatial data used for the spatial analysis in chapter 5 ranged in scales from 1:24,000 to 1:1,000,000 and they were based on different mapping specifications. For example, these spatial data were based on different horizontal and vertical datums, and different levels of map accuracy. As well, they differed in the type of ground and water features that were mapped, and the temporal coverage varied from one data set to another. All these sets of digital spatial data have some information that is clearly out of date. For example 1:24,000 scale spatial data that still shows the various railway lines that connected the city of Eastport to the mainland. According to Holt (1999) the railway service in Eastport came to an end

in November, 1978, and the tracks were soon removed, but they are still shown on both the 1:24,000 USGS *Eastport map* as well as on the digital spatial data from the Maine Office of GIS. This same “temporal mistake” of showing the former railway lines are also shown on the 1999 edition of the 1:50,000 Natural Resources Canada map titled *Campobello Island* which displays the far eastern portion of Cobscook Bay including the city of Eastport. This is an example of how out-of-date geographic information can be propagated across more than one set of spatial data. Other types of information that were out of date on the GIS data sets included some of the older docks and wharfs along Cobscook Bay. Since there can be a wide range of currentness of various levels of geographic detail on a map or within a set of digital spatial data it is important to cross reference the meta data to determine when the spatial data was created or last updated. For organizations that are engaged in coastal zone planning and management there is a need for up-to-date geographic information, and spatial data that are 50 years old may not provide the best results if there have been substantial changes to the coastline since the area was last mapped. A method to update the spatial data to reflect the current geographic reality of the coastal zone will help the coastal zone planner and manager to better perform their duties. For these reasons there are situations when it may be necessary to create new spatial data for use in geographic information systems to support coastal zone management applications. The next section will determine if remotely sensed data such as LANDSAT 5 TM data can be successfully used for coastal zone management purposes.

Using LANDSAT 5 TM Data for Coastal Zone Management. Case Study B.

Case study B is based on the use of LANDSAT 5 TM images as the source data to create NEW spatial information to use for coastal zone management applications in

Cobscook Bay, Maine. LANDSAT 5 TM data were chosen for use in this case study since, unlike the free sources of digital spatial data that were used in chapter six, much of remotely sensed data are only available by purchasing it through a distributor of spatial data. The LANDSAT 5 TM data in particular were selected since its purchase price of \$US425.00 fell within the budget allocated for thesis. LANDSAT 7 data which are more current is priced at US\$600.00. The scale of the LANDSAT 5 TM images is approximately 1:1,000,000 and the image data are recorded in a raster format in which the pixels have a ground coverage of thirty by thirty metres. The goal of case study B is to use LANDSAT 5 TM raster data to create georeferenced images that can be processed with the ArcView geographic information system so that the length of the shoreline and the areas of the islands and Cobscook Bay can be measured as was done in case study A. An important question to be resolved about the use of LANDSAT 5 TM data for this purpose is "how effective will it be to measure the geographic features of Cobscook Bay"? The results of the LANDSAT 5 TM-based spatial analysis will then be compared to the results that were obtained from the five different scale-based sets of spatial data that were used to measure Cobscook Bay in chapter five. The comparison of the results from case study A and case study B will determine how accurately and with what level of precision the coastal features of Cobscook Bay can be mapped using LANDSAT 5 TM data.

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:

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. Depending on the type of remote sensing system that is being used, it may not be easy to obtain remote sensing data that supplies an image that contains the required information. In the

case of LANDSAT 5 TM images, haze, clouds, pollution, the time of year, and the time of day can affect the quality of the remote sensing image. Fortunately, since there are 7 spectral bands for LANDSAT 5 TM data it is possible to use the special qualities of each band to delineate and to separate areas of water and land as well as the intertidal zones.

For case study B an attempt will be made to set the vertical datum to the MHW (mean high water) tide level since this is the standard vertical datum for coastlines that are used at the national level for both Canadian and American topographic maps. The MHW level was also chosen as the vertical datum for the LANDSAT-based case study B since the MHW was also used as the vertical datum for the 1:24,000 baseline scale for case study A in chapter five. It is 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 are based on a consistent methodology.

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. The EROS system allows the user to preview the images to determine if the data set covers the correct geographic area, and if there are no clouds, or other objects, such as air pollution that obscure the detail on the ground. The EROS system has a search and display capability that retrieves a selection of data that closely matches a set of parameters that the user has chosen from a list of requirements.

For case study B, the search parameters were set to obtain LANDSAT 5 TM images that covered the area of Cobscook Bay using longitude and latitude coordinates. The image characteristics were then selected to the lowest level of cloud cover so that a clear image of the ground and water areas of the bay would be obtained. A LANDSAT 5 TM data file that closely matched the requirements for the case study was selected and the data were ordered from the EROS Center.

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.

Methodology of the Spatial Analysis of the Case Study of Cobscook Bay, Part B.

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. PCI's *Image Handler*, as well as other PCI image processing applications were selected as the system to process the LANDSAT 5 data since the GIS lab in the Department of Geography and Environmental Studies at Carleton University was equipped with this system. 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 suite of PCI programs are also used by many governmental and private organizations to process digital spatial data.

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.

Step Three: Identifying Separate Areas of the Coastal Zone

Method I:

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 grey 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.

Many features on the earth's surface 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). The Image Handler application maps the locations and the reflectance values of all of the pixels of the subset data file in a table of rows and columns. The Image Handler creates one table for each of the spectral bands. Spectral response values of many of the geographic features in and around Cobscook Bay such as deep water, shallow water, trees, rock, roads and runways were recorded so that a consistent comparison and analysis of the important

elements could be accomplished. 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 land mass. 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.

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 colours such as dark blue for water, reddish tones for tidal flats and various greens for the islands and the mainland. These different colour combinations made it much easier to perform a visual identification and classification of some of the more important coastal zone features (see fig 6.2 on page 150).

The next step was to reclassify the pixels of the LANDSAT 5 subset to three groups of land, intertidal zone and water. The reclassification of the converted LANDSAT 5 image can be done through an unsupervised or supervised method. According to the PCI Enterprises (1998) training manual *Introduction to Using PCI Software* the "goal is to use your knowledge of the area to 'train' the computer to recognize the different classes" (p. 106). The training areas that are chosen have identifiable features such as roads, buildings or water cover. When these known features are used in the supervised training procedure it is known as ground verification and this

information can come from maps, aerial images or by inspecting the site in person (PCI, 1998). The unsupervised method of reclassification mainly differs from the supervised classification method in the absence of the training stage. Instead of relying on a training stage, the unsupervised reclassification is based on groups of pixels that are analysed by a specified algorithm (PCI, 1998, p. 123). The unsupervised method is quicker but the supervised method tended to be much more reliable. It was concluded by testing the two methods that there were serious problems of representing the shoreline of Cobscook Bay when the unsupervised method of classification was employed. (the 1:24,000 spatial data were used to reference the location of the shoreline with the results from the above methods of classification).

While the supervised classification method produced better results than the unsupervised method, some areas of the shoreline were still not well represented, and a procedure known as class editing was used to modify the value of the incorrectly reclassified pixels to their correct group of land, intertidal zone or water. The reason why even the supervised reclassification method assigned some of the pixels to the wrong classification of land, intertidal or water was due to the problem of different features having the same or similar reflectance value. For example using LANDSAT 5 TM band 4 with PCI's Image Handler set to the 8-bit unsigned integer format, various parts of the tidal flats in Cobscook Bay had values that ranged from 21 to 49; however, some of the roads had values that ranged from 50 to 92, the airport runways had values that ranged from 46 to 90 and bridges had reflectance values of 15 to 18. Areas of deeper water cover had values that ranged from 8 to 20. The same procedure was done with the other bands, but since they have different spectral ranges the results were different. Since there were overlapping

values for many of the different land, intertidal and water areas, this resulted in some pixels being incorrectly assigned to the one of the other two classes.

This lack of accuracy in the reclassifying of various features lies in the nature of the size of the LANDSAT 5 TM pixel. The LANDSAT 5 TM pixel has a ground resolution of 30 by 30 metres and when it straddles two or more features a reflectance value that represents this combination is created. The pixels that are composed of combined ground features may create a pixel value that appears to belong to another feature. Due to these types of problems class editing is often required after the use of supervised reclassification, and it also shows the value and importance of human participation in the processing of remote sensing spatial data.

After the editing stage the LANDSAT 5 TM images were reclassified to three zones of land, intertidal zone and water. The next step was to join the intertidal zone to the water area which left just one classification for land and one for water cover. 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.

A copy of this two-class image of Cobscook Bay showing the land and the mean high water level is shown in figure 6.1.

Figure 6.1

Landsat 5 Image Reclassified to Zones of Land and Mean High Water

Identifying Separate Areas of the Coastal Zone

Method II:

Another method to prepare a LANDSAT 5 image for use in a geographic information system is to load various LANDSAT 5 bands into the Image Handler such as 1,3, 4 and 5. Then a linear enhancement feature is applied within Image Handler which increases the contrast of the colours displayed on the screen. The brighter colours makes the land, water and the intertidal zones much easier to recognize. As with the supervised and unsupervised methods for reclassifying LANDSAT 5 images, the LANDSAT 5 TM (Thematic Mapper) Bands of 1, 3, 4, and 5 were used because these bands have spectral ranges that assist the user in identifying areas where water and land meet. With this method, photo interpretation skills are used to map the edge of the shoreline based on the LANDSAT 5 bands that are known to be associated with a particular coastal zone feature. For case study B, band 5 was used to identify the tidal flats since these features showed up quite well as a red colour when the linear enhancement function of Image Handler was used in the PCI system. The purpose of using the linear enhancement function is to stretch out the representation of the spectral values of the satellite image. This procedure only affects the visual display of the LANDSAT 5 TM image for the viewer while the actual values of each pixel remains the same as before. This procedure produces a clearer image which facilitates interpretation. An example of the effectiveness of using these three colour combinations can be see in figure 6.2. In this example water is shown as a very dark colour and the land is clearly distinguishable from the water as various green colour tones. The darker red colours along the shoreline shows the tidal flats quite well, and the shoreline can

Figure 6.2
Landsat Image of Carryingplace Cove, Eastport Maine.

be mapped at the high tide level by using this red zone as the upper tide line. The lighter red or pinkish tones represent various roads as well as the x-shaped runway of the Eastport airport which is located in the bottom right corner of the image. The bay in the centre of the image with a red coloured shoreline and tidal flats is Carryingplace Cove. The table to the right of the image shows three LANDSAT 5 TM bands that are displayed as red (band 3), green (band 4) and blue (band 5). The white cursor in the centre of the image is placed on a pixel and its reflectance value for each of the red, green and blue bands are shown in the accompanying table.

If stereo pairs of the image are available, they can also be ortho-rectified to remove any distortions caused by the topography. Since the case study only deals with the shoreline and the highest nearby topographic relief is only 325 feet the effect of distortion is minimal. All of the converted LANDSAT 5 TM images, whether they are stereo pairs or single images, can also be geo-referenced so that it can be exported to a geographic information system. The georeferencing can be done to either of the images that were just described as method I and method II of step 3 . The georeferencing procedure is explained in step four.

Step Four: Georeferencing the Converted LANDSAT 5 Images

Before the converted LANDSAT 5 images are to be imported into a geographic information system for processing and analysis they should be georeferenced. The PCI Geomatics system has a function named *CGI* which creates a georeferenced PCI image by using another source such as an ArcView shape file that covers the same area as the converted LANDSAT 5 image. The converted LANDSAT 5 TM

image is georeferenced by selecting the same geographic features on both the image on the ArcView shape file. Appropriate geographic features to use with this process are road intersections since they are relatively easy to recognize on both the ArcView file and the LANDSAT 5 TM image. These points are designated as “gcp” (ground control points), and better results are obtained when a minimum of twenty gcp points are used (PCI, 1998, p. 146).

Next, bands 1, 3, 4 and 5 were loaded into the CGI function of the converted LANDSAT 5 image, and 20 gcp points were selected to georeference the image to a 1:24,000 scale ArcView shape file of the Cobscook Bay area. No values of greater than a RMS (root mean square) error 1 were accepted and the maximum RMS was 0.85. According to the PCI Enterprises (1998) manual Introduction to PCI Software an RMS of less than 1 is usually acceptable to georeference an image (p. 150). Since an RMS of 1 is equal to one pixel value, this means that the maximum positional error of each pixel were within 85 percent of the dimension of the LANDSAT 5 TM's 30 by 30 metre position at ground level. The results of this procedure were saved to a new file that was in a GeoTIFF format. The GeoTIFF format allows the georeferenced spatial data from PCI to be exported to other types of remote sensing and geographic information systems for further processing and manipulation. This new georeferenced image was then imported into ArcView to be used as a base for the creation of vector digitizing the features of Cobscook Bay. This procedure is explained in step 5.

Step 5: Loading the GeoTIFF File into ARCVIEW for Spatial Analysis

The new GeoTIFF image was loaded 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 GeoTIFF file is a format for a type of image that can be viewed in a geographic system such as ArcView, but these types of images also contain geographic coordinates, and because of this feature, they can be used for in the creation of geographic projects.

A new ArcView project was then created that used the same cartographic specification as the geographic projects had in chapter five. The map and measuring units were set to metres. 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. The two-colour image of Cobscook Bay that is shown in figure 6.1 was also used as a reference for the location of the shoreline at the high water mark. Then, as was done with the digital spatial data in chapter five, the length and areas of features were calculated based on the three extents of Cobscook Bay. A clip theme was again used to create three new shape files that were based on the precise lengths of the shorelines' limits and to also create three water area shape files of Cobscook Bay. An example of the spatial analysis of the LANDSAT image is shown in figure 6.3.

The results of the spatial analysis are shown in table 6.1.

Figure 6.3
Landsat-based Analysis of Cobscook Bay From
Estes Head to Lubec Town pier.

Legend

—	Mainland Shoreline	●	GIS Control Points
—	Island Shoreline		Water Area

Table 6.1
LANDSAT-based Analysis of Cobscook Bay

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

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

As was demonstrated in chapter five the horizontal accuracy of spatial data can vary considerably by scale and data source. The values in table 6.1 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.

This GIS project used the 1:24,000 scale vector data of Cobscook Bay 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 metres 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 metres.

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 locations of these 50 control points are shown in figure 6.4. 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 metres 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 6.5. 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 metres 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 metres to 314.3 metres with the average horizontal accuracy being 58.3 metres. Referring back to the rule of detection and resolution size that was described in chapter three, the detection size of case study B will be 60 metres since 30 metres is the resolution size. Since the horizontal error is 58.3 metres 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). To use the analogy of a fishnet, the LANDSAT 5 TM data's resolution of 30 metres can be compared to the size of the mesh of the fishnet, and the 60 metre unit is the smallest size of geographic unit that can be "caught" or detected. The horizontal accuracy of 58.3 metres 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.

Figure 6.4
Landsat Shoreline.
Horizontal Accuracy Testing Locations
Cobscook Bay, Maine.

Legend

- Offset Point
- Landsat-based shore
- Water area

Figure 6.5
Comparison Between 1:24,000 and
Landsat 5 TM-based shorelines.
Cobscook Bay, Maine.

Legend

—	Landsat based-shoreline	—	Landsat-based islands
—	1:24,000 scale shoreline	■	Landsat-based water area

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 storm surges.

Creating the Meta Data for Case Study B

Since meta data is an important element of spatial data it follows that the spatial data that were created in case study B should also have its own set of meta data. The following list contains the important elements that contributed to the creation of the digital spatial data for case study B. It is at this stage in the case study where the raw LANDSAT 5 TM “data” have now become transformed into “geographic information” with the completion of the meta data.

Meta Data for Case Study B

- Project name: Cobscook Bay LANDSAT 5 TM derived shoreline.
- File format: ArcView 3.2 shape file.
- Compiled scale: 1:1,000,000 LANDSAT 5 TM data. 30 metre ground resolution.
- Date created: January 15, 2000.
- Created by: Michael Kostiuk. MA Candidate, Department of Geography, Carleton University Ottawa, Canada.

- Horizontal datum: NAD 83. Horizontal detail is accurate to 58.3 metres of geographic position as referenced to 1:24,000 USGS spatial data .
- Vertical datum: Mean High Water mark. Referenced to high water mark determined from LANDSAT 5 TM data.
- Source data: LANDSAT 5
- Date of data acquisition: 14:41:12.1375 GMT. July 21, 1989.
- Sensor: TM
- Ground resolution: 30 metres.
- Map Projection: UTM
- UTM Zone : 19
- Earth Ellipsoid: WGS84
- Detection unit: 60 metres

Discussion of the Spatial Analysis of Case Study B

The results of the spatial analysis of case study B show that the use of remote sensing data is an option when the only digital spatial data that are available of the coastline is of a very small scale, such as with the 1:1,000,000 Digital Chart of the World data.

The values for the length of the shoreline and the water area features of Cobscook Bay that were obtained from the LANDSAT 5 TM analysis are much better than the results that were obtained from the 1:1,000,000 scale Digital Chart of the World digital spatial data that were demonstrated in chapter five. In some cases, the measurements that were created by the spatial analysis with ArcView 3.2 produced

results that were better than the results that were obtained by using the 1:250,000 digital spatial data; however the results were not as good when compared with the measurements that were obtained from the 1:100,000 digital spatial data. These results can be found in tables 5.1 and 6.1.

The results that were obtained by using the LANDSAT 5 TM data were quite different from the results that were obtained by using the 1:24,000 scale digital spatial data in chapter five. For example the length of the shoreline of Cobscook Bay that used the Lubec town pier limit showed a value of 288,489 metres for the LANDSAT 5-based data while the 1:24,000 spatial data has a result of 380,900 metres. This was a difference of 92,411 metres 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 1:1,000,000 and the resolution of the pixel size is 30 metres x 30 metres 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 metres (such as 4 metres). There are such data available and one source is provided by the new IKONOS remote sensing satellite. For example, the current cost for IKONOS precision 1 metre panchromatic or 4 metre multi-spectral imagery is US\$55.00 per square kilometre in North America and US\$136.00 per square kilometre internationally with the minimum order being 100 square kilometres. The size of the study area is approximately 30 kilometres X 30 kilometres or 900 square kilometres.

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

Cobscok 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?".

Another reason for the difference in measurements that were obtained in case studies A and B could be due to the different vertical datums that were used to reference the coastline. In a coastal environment where there are extensive tidal flats such as in Cobscok Bay, measuring the shoreline at different periods during the tidal periods will produce different shoreline measurements. The more extensive the tidal flats are in a high/low tide zone area, the more variability will there be in the location of the high and low tide shorelines. Variations in the location of the mapped shorelines around tidal flats are due to vertical changes in the water level which will then create a change in the horizontal position of the shoreline. If the spatial data for the coastal zone analysis is based on more than one vertical datum then it will be very difficult to compare the location of the shoreline to other sources of spatial data.

One more possible reason for the difference in measurements between the LANDSAT 5 TM data analysis of Cobscok Bay in this chapter and the results that were obtained from spatial analysis of the bay in chapter five is the way in which the

geographic features were digitized in case study B. In case study B a method known as on-screen digitizing was used to create the shoreline features of Cobscook Bay from the GeoTIFF image. The on-screen digitizing method that was used with the ArcView geographic information system uses a manual technique to enter vertices in the system. On the other hand, the spatial data that were used in chapter five were converted into digital format through a scanning process which used a specific scanning resolution for each scale. As was noted in chapter three the number of vertices that are entered to represent a geographic feature will affect how accurately that same geographic feature can be measured. The number of vertices that are entered into the geographic information system in this situation is dependent upon the ability of the operator of the geographic information system to accurately depict the geography of an area that is to be spatially analysed.

The results of case study B should not be directly compared with the levels of accuracy and precision that were used to create such data as the 1:24,000 scale data that were obtained from the Maine Office of GIS. Topographic maps are produced by large teams of professionals with a diverse range of talents and abilities. As was shown in chapters three through five these maps are produced according to rigorous standards with many levels of checking accuracy and verifying precision. For example, the typical workflow of producing a national topographic map in Canada involved the following steps: planning, field survey,

computations, aerial photography, aerial triangulation, photogrammetric compilation, inspection and editing, photography, scribing or digitizing, scanning, names type preparation, colour proofing, editing, plate making (for paper maps), printing and distribution. Once these maps were printed and/or the digital data are made available to the public they come under scrutiny from the map users who sometimes report mistakes. Newer editions of these maps will incorporate up-to-date information as well as making the corrections that the map users have provided. In comparison to these methods the results of case study B, while being useful to a certain extent, obviously lacks the rigorous testing and editing that goes into producing data from a professional organization. Despite these limitations, there are times when “doing it yourself” is the only option if the needed data are not available.

Conclusion

Coastal zone management requires accurate data and information, and geographic information have an important role to play in this discipline. In order for geographic information systems 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 were outlined in chapter four and 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.

The results of the case study B show that LANDSAT 5 TM data should not be used for the coastal zone applications as recommended by Wainwright et al. (1991). However this assumes that better (i.e larger scale and higher resolution) spatial data are available. The results of the spatial analysis case study B are inferior to results that were obtained from the 1:24,000 scale data in chapter 5 (which provided a superior level of accuracy and precision). If the new data from case study B were to be used for coastal zone management applications the result would be a false measurement of the shoreline, a false measurement of the area of the bay and a false count of the number of islands (as compared to spatial data of larger scales).

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 planning 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.

Chapter 7

Conclusion

The aim of this thesis has been to explore the potential value of geographic information systems for use in coastal zone management by examining some fundamental qualities of spatial data typically used in coastal zone management projects. A case study of Cobscook Bay, Maine was used to support this aim through the following specific objectives:

1. A review of coastal zone management.
2. An overview of the benefits and limitations of digital spatial data.
3. Determine the specific cartographic and data requirements for coastal zone management.
4. Determine the availability and quality of spatial data for coastal zone management in the case study area.
5. Evaluate a series of five different sets (1:24,000, 1:70,000, 1:100,000, 1:250,000, 1:1,000,000) of vector data from existing digital spatial databases, and one raster set of digital LANDSAT 5 TM data to determine the most appropriate map scale for certain types of coastal zone management applications.
6. Through the case study of Cobscook Bay, Maine, to evaluate the results of a series of spatial analysis (or GIS operations), the potential value of digital spatial data, and geographic information systems to provide basic locational data to

support coastal zone management. The thesis was then structured to support its objectives by dividing the topics into appropriate chapters. These chapters are summarized as follows:

In chapters one and two it was shown that there is no single accepted definition of the coastal zone nor of such related terms as coastal zone management, or coastal zone planning. Various definitions of the coastal zone were given that ranged from a strip of land a few hundred metres along the high water mark of the coastline to several hundred kilometres wide. It was noted that the mean high water mark is often used to designate the location of the coastline on various types of maps. The coastal zone was noted for its importance for many types of resources and as a place where 50% of the world population resides. Since there is an ever increasing world population and combined with such effects as global warming and rising sea level these factors puts an increasing strain on the coastal zone. Accurate and up-to-date spatial information was shown to be a necessary component for various types of management and planning functions in the coastal zone. New developments in the field of coastal and nearshore mapping were described such as: the use of accurate spatial data to support oceans governance, the growing importance for cooperation between different groups to exchange data, the development of applications such as SeaMap to create seamless links between land-based and water-based maps, the use of IDRISI software to map coastal erosion in Italy, new types of high resolution systems such as CASI, LandLidar,

Marine Lidar, IKONOS, Airborne Digital camera and colour video to produce higher quality maps of the coast and nearcoast areas of the sea, and the use of LIDAR to create accurate digital elevation models of the coast and the inter-tidal zone.

Chapter three gave an overview of the basic principles of digital spatial data.

It was noted that digital maps can be created from measurements through ground surveys, aerial photography, and remote sensing, or by the conversion of analogue maps into digital data. An important fact that applies to all spatial data is that they are of limited accuracy. It was noted that there are quality standards for printed maps such as those standards that are used by the United States Geological Survey and Natural Resources Canada. The quality of the digital spatial data regardless of source is dependent on many factors such as map projections, datums, scale, and spatial resolution. The resolution of digital spatial data was demonstrated to be an important factor that will determine how accurately a geographic information system can be used for coastal zone management applications. The resolution of a map or an image was defined as the smallest individual feature that can be clearly identified. 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 spatial resolution of GIS data was also shown to be a function of generalization since small scale maps do not usually contain as much geographic detail as larger scale maps, and as a result, the data are most often recorded and stored with less spatial precision.

In chapter four the requirements that should be used as the basis for an effective geographic analysis of the study area of the coastal zone were described. The chapter was organized around various descriptions of some of the important spatial data, surveying, and cartographic components that are necessary to provide accurate measurements of geographic features in the coastal zone: type of spatial data, the scale of the spatial data, map projections, measuring unit, horizontal datum, vertical datum and metadata. Wainwright (1991) reported that a minimum acceptable scale to portray the coastline should be at a 1:40,000 scale and larger. This minimum requirement was also selected as the minimum acceptable scale to use for the spatial analysis of the Cobscook Bay for the case study. The largest scale that was obtained for the case study was 1:24,000.

In chapter five a case study approach of Cobscook Bay Maine was employed using the criteria that were established in chapter four to measure the length of the shoreline plus the area of the water cover and the area of the islands. The scale of the digital spatial data were: 1:24,000, 1:70,000, 1:100,000, 1:250,000 and 1:1,000,000. All of the spatial data were used to measure Cobscook Bay according to its three definitions of Shackford Head, Estes Head and the Lubec town pier. The 1:24,000 scale digital spatial data were selected as the baseline or reference scale. It was concluded that since the baseline scale exceeded the minimum requirements established by Wainwright et al. (1991) the results obtained for the 1:24,000 scale-based digital spatial data are suitable for coastal zone

management applications. Examples where the 1:24,000 scale spatial data are suitable for coastal zone management applications include: monitoring coastal erosion, tracking pollution, mitigating storm damage, flood control, land use planning, planning of setback allowances for the construction of shoreline communities, planning for recreation and parks, evaluation of sand and gravel resources for construction materials, coastal bluff monitoring, landslide susceptibility mapping, hydrography, tourism, fishing, aquaculture, shellfish harvesting, habitat assessment, aboriginal claims, economic development, environmental management and oceans governance. While not suitable for coastal zone management as described by Wainwright et al. (1991), the spatial data that ranged in scale from 1:70,000 to 1:250,000 are suitable for use as planning aids on a regional scale and the 1:1,000,000 scale data are ideal for use in the production of an atlas to illustrate and describe various aspects of the coastal zone.

Chapter six described the use of LANDSAT 5 TM spatial data to measure Cobscook Bay as was done in chapter five. A two colour image as well as a four colour GeoTIFF file of Cobscook Bay were created by combining TM bands 1, 3, 4 and 5. The GeoTIFF file was used as a base for the on-screen digitizing of the features of Cobscook Bay. The results of the spatial analysis also included an assessment of horizontal accuracy. The final procedure was the creation of metadata to describe the new spatial data that were created in case study B. It was

concluded that the LANDSAT 5 TM-based spatial analysis should not be used for coastal zone management applications that require at least a 1:40,000 scale.

Implications of the Case Study

The methods that were used to perform the spatial analysis in case studies A and B were specifically based on the requirements that were established in chapter four which was to map the coastline at a scale that is no smaller than 1:40,000. This same methodology of measuring the dimensions of Cobscook Bay and its islands can be applied to other similar coastal zone applications such as monitoring shoreline change. Shoreline change can occur as a net gain or a net loss action along the coastal zone depending on whether material is being removed from the shore by the forces of erosion or whether material is being deposited onto beaches and shorelines (Videira et al., 1996). This has applications in the areas of municipal zoning where the first priority is to map areas that are hazardous for the construction of buildings and second, to implement local by-laws to prohibit or to remove the dwellings from these hazardous areas. Since sea-level rise is one of the possible consequences of global warming this has the potential of causing major impacts on the population which resides along the coast line. Planning for such consequences requires accurate sets of spatial data since errors that could relate from the use of wrong data could be catastrophic.

A reliable assessment of shoreline change is dependent upon accurate and up-to-date spatial information. This spatial information can be in the form of analogue maps, digital spatial data or it can be in the form of newly acquired data from sources such as global positioning systems, aerial photographs or remote sensing. It is clear from the spatial analysis from case study A that digital spatial data that is of a larger scale such as 1:24,000 will provide a far better representation of geographic reality than spatial data that are of smaller scales such as 1:100,000, 1:250,000 or 1:1,000,000. The tradeoff for using larger scale data is that it takes longer to process than medium and small scale data. The storage space for large scale data can also be considerably larger than for medium and small scale data. It is therefore important to only use spatial data that are at a scale and/or resolution that are sufficient for the required task, otherwise the spatial analysis may take much longer to complete than is necessary. The use of remote sensing data is an option if there are no suitable data available, although it takes more expertise and time to derive geographic information from remote sensing data than it does from existing digital spatial data.

The need for larger scale spatial data depends of course on the particular application that a coastal planning or management organization is performing. In particular are those applications that are involved with the safe passage of ships. Obviously up-to-date spatial information about coastal features is vital for navigation. Accurate data for navigation will help avoid or reduce the negative

consequences from ships such as oil tankers running aground and spilling their contents into the sea. Once these accidental spills do occur accurate spatial data are needed to track the spread of pollution and to organize clean-up efforts. The costs of these cleanups and any fines and penalties can only be properly determined with accurate spatial data. Habitat assessment also requires accurate spatial data, and as was shown in case study A the smaller scales could not be used to accurately measure the length of the shorelines or even of mapping the dimensions of smaller geographic features such as islands. Different species require different types of ecosystems with varying degrees of space. Spatial data must provide a minimum resolution of geographic detail to support the assessment of selected species otherwise the analysis will most likely be flawed.

Limitations of the Case Study.

Since the coastal zone is such a large area with many different uses the case study could only cover a fraction of the possible uses of spatial data.

In particular the description of the implications of the use of accurate spatial data for coastal zone management applications would benefit from a categorized list of all the uses of spatial data in the coastal zone. From such a list it would be then possible to determine what spatial data are being used for and what levels of accuracy and precision are needed to perform their various tasks. For example is the 1:40,000 minimum scale requirement by Wainwright et al. (1991) adequate for coastal zone management applications or is it only relevant for a few coastal zone

applications such as depicting shoreline reaches? To answer this important question would require a detailed assessment of the implications of shoreline inaccuracies for a wide range of coastal zone management applications.

Unfortunately a thorough assessment such as this would be beyond the scope of this thesis.

The case study was also limited to using only five sets of spatial data and one set of LANDSAT 5 TM data. It would have been interesting to use spatial data at larger scales such as 1:10,000 and 1:5,000 and to obtain other sources of remote sensing data such as from RADARSAT and IKONOS. These other sources were not used because the larger scales could not be located (if they exist at all for the study area) while the prices of the these remote sensing data were well beyond the budget allocated for this thesis. However, if these other sources of spatial data were used the case study may have taken a different focus. For example the use of other forms of remote sensing data might have produced a more evenly balanced spatial analysis of the study area as compared with the GIS data. This may have involved the direct use of raster data to measure features in the coastal zone. This type of option would not necessarily require the use of a GIS to create vector lines as the resolution of data from such sources as RADARSAT and IKONOS can provide a better depiction of the shoreline than LANDSAT 5 TM data.

There were also limitations on the methods used to convert the LANDSAT 5 TM data into ArcView for spatial analysis. A manual digitizing method was used to create the shoreline. The use of a digitizing table that utilized an automatic recording of vector points might have produced a better determination of the shoreline.

Regarding the shoreline, another limitation of the case study is that it did not map the shoreline at the lower tide level. Since many coastal zone management applications such as conservation, fisheries and habitat assessment require mapping of the intertidal flats this requires the location of the lower tide line. As was demonstrated in chapter five, the lack of a lower tide shoreline prevented the use of spatial data to measure the area of the intertidal flats that are within the boundaries of towns in the state of Maine.

Future Avenues for Additional Research

The limitations that were outlined illustrate that there are still questions that need to be answered regarding the use of spatial data for coastal zone management applications. The first item on this list would be a categorised directory of all of the possible uses of spatial data by coastal zone management organizations. From such a directory it would then be possible to create a set of cartographic/GIS specifications that can be applied to the particular uses of spatial data for coastal zone management. These cartographic/GIS specifications would be designed to

reflect the necessary degree of accuracy and precision that would be required for all of the uses of spatial data for coastal zone management. The specifications would include a listing of the minimum levels of scale and resolution that should be met if spatial data are to be used for specific coastal zone management applications.

Another recommendation for future use of spatial data for coastal zone management is to add the lower tide shoreline line to maps. Since the coastline is a dynamic environment with a coastline that is always in motion there is no sense in limiting the shoreline to the mean high water limit. The coastal zone exists on both sides of the shoreline and this has to include as a minimum, the high and low tide lines. Such a recommendation would be automatically include the intertidal flats that exists along many areas of the coastal zone. To assist in the visualization of the dynamic nature of the coastline, raster data could be used to show the range of water during the high and low tide cycles.

Another item that would benefit from more analysis would be to determine if the proportions between the different scale-based measurements of the shoreline that were displayed table 6.1 are consistent with other coastal areas or are just relevant to the study area. In table 6.1 using the Estes Head to Lubec town pier for example, the length of the mainland shoreline varies from a value of 380,900 metres using the 1:24,000 scale digital spatial data, to a length of 180,019 metres that is based on

the 1:1,000,000 scale digital spatial data. This is a difference of 200,881 metres 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. Is this ratio of 2.1 applicable to other coastal areas as well? If it is, then the ratio could be used to modify the measurements of the coastline that have been derived from Digital Chart of the World data. Unfortunately this ratio would not be useful to add island data since these smaller geographic features do not tend to be depicted to a high degree on the DCW data.

Another possible area for research would be to use existing spatial data to determine the total length of the world's coastlines. Using the premise that larger scale data produces more reliable measurements of coastal features than smaller scale data it would be interesting to find out what the current estimate of worldwide shorelines are based upon. If these estimates are based on smaller scale data then it is possible that the coastlines of many parts of the world are actually longer and comprise more islands than have been currently estimated.

Other avenues for research could be in the areas of visualization techniques to help coastal zone managers better understand the spatial dynamics of the coastal zone, the use of GIS for recording spatial data, more research on the effects of scale and resolution, plus the issue of free versus fee-based access to spatial data are all items that are of importance to users of spatial data in the coastal zone.

Conclusion

Along with an overview of coastal zone management, this thesis explored the various characteristics of different types of spatial data such as analogue versus digital, vector versus raster, scale, data conversion, scanning, digitizing, resolution, map projections, datums, and metadata. Much of the problem with using existing forms of digital spatial data lies in the uncertainty about the reliability of these data. As was explained in chapter three, spatial data can be changed, modified and converted into different digital formats and this information is either difficult to obtain or is non-existent. However, depending on the source of these spatial data, relevant information about the spatial data such as datum, projection, map units, date the map was created or last updated, and map accuracy can be located through the accompanying metadata. This information can also be found by contacting the owner of the spatial data such as the USGS or Natural Resources Canada.

It is important to note that whatever type of spatial data are obtained, there are certain to be issues of varying degrees of map inaccuracy or missing information. The fact that spatial data may not necessarily provide the exact accuracy or resolution that is required is simply due to the nature of spatial data itself. While cartography, remote sensing and the rest of the geomatics industry has come a long way in recent years to improve methods of data collection, data display and spatial analysis, the spatial data is still only a representation of geographic reality.

Some forms of spatial data are better at depicting geographic reality than others, but it is still just a representation or a sample of reality. It is therefore important to realize that while the data is useful it is not perfect and the imperfections that are part of the spatial data are a fact that users of spatial data must live with (Openshaw, 1989).

As was demonstrated in the case study of Cobscook Bay, the user of spatial data can obtain better (larger scale/higher resolution) sources of data to measure coastal zone features, but even the best spatial data have errors of accuracy or geographic representation. The user of spatial data for coastal zone management applications has to weigh the importance of data quality versus the time that is required to process these data. Canessa & Keller (1994) argued that there needs to be a compromise between those who use any type of spatial data without checking its quality and suitability, and the GIS experts who spend an enormous amount of time and expense testing the reliability of the data. The user of spatial data for coastal zone management applications has to decide what level of GIS reliability and accuracy is required for their specific uses. It is the geographer and other geomatics professionals who are trained in the use of spatial data that can provide the useful guidance and advice.

References

- Abler, R. F. (1987). The National Science Foundation National Center for Geographic Information and Analysis. International Journal of Geographical Information Systems 1, 303,26.
- Alfred Wegener Institute for Polar and Marine Research, (2001). Arctic Coastal Dynamics. Science and Implementation Plan. Results of an International Workshop (Working Draft). Potsdam Germany: Author.
- Anders, A. B., & Jensen, J. O. T. (1986) Biological, Chemical and Organoleptic Changes during Maturation of Farmed Atlantic Salmon, *Salmo salar*. Aquaculture 53 7-20.
- Anderson, N. (2000). Marine Geospatial Data Infrastructure: The Potential. Coastal Zone Canada 2000. Book of Abstracts. (p. 58) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.
- ArcView GIS 3.2. Computer Software. ESRI(Environmental Systems Research Institute, Inc.) (1999).

Aronoff, S. (1991). Geographic Information Systems: A Management Perspective (p. 294) Ottawa: WDL Pub.

Atlantic Coastal Zone Information Steering Committee. (2001, June). Inventory of Atlantic Coastal Mapping Projects [On-Line]. Available:
<http://www.dal.ca/aczisc/czmproj>.

Atlantic Coastal Zone Information Steering Committee. (2000). A Guide to Coastal Information in Atlantic Canada [On-line]. Available:
<http://is.dal.ca/aczisc/aczisc>, or <http://www.dal.ca/aczisc/>.

Bardach, J., E. (Ed.). (1997) Sustainable Aquaculture. New York: John Wiley and Sons, Inc.

Bardach, J. E. (1997) Aquaculture, Pollution, and Biodiversity. In J.E. Bardach (Ed.). Sustainable Aquaculture. (pp. 87-99). New York: John Wiley and Sons, Inc.

Barker, C. H. (1999). The NOAA Trajectory Analysis Planner: TAP 11. In Oceans '99 MTS/IEEE . Riding the Crest into the 21st Century. Conference Proceedings. (pp. 1256-1261). Escondido, California: Holland Publications.

Barroso, L. V., Abdo, O. E., & Xavier-da-Silva, J. (2000). Geographical Information System for Lagoonal Systems Situated at Rio De Janeiro State, Southeastern Brazil. Coastal Zone Canada 2000. Book of Abstracts. (p. 73) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Basta, D.J., & Ehler, C. N. (1994). Bridging the Gaps Among Science, Management, and Public Policy. In P.G. Wells & P.J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 847 - 859). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Bedard, Y. (1987). Uncertainties in Land information Systems Databases. Proceedings, Auto-Carto 8 175-184.

Bellemare, P., Light, E., & Ogilvie, M. (1994). Cooperation in the Management of Coastal Information. The Atlantic Canada Approach. In P.G. Wells & P.J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 769-773). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Berry, J. K. (1995). Raster is Faster, but Vector is Corrector. GIS World, 8 (6), 35-36.

Bjerkelund C., Tittley B., & Elizondo, C. B. (1994). Potential of Airborne C-Band SAR Monitoring and Mapping Coastal Dynamics Along a Section of the Pacific Coast of Costa Rica. In P.G. Wells & P.J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 784-794). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Bogden, A. D. (Ed.). (1995). Cold-Water Aquaculture in Atlantic Canada. 2nd ed. Sackville, New Brunswick: The Tribune Press Ltd.

Borgstrom, G. (1962). Fish as Food. New York: Academic Press.

Brandes, K. M. (1998). Maine Handbook. Chico, California: Moon Publications, Inc.,

Brooks, D. A., Baca, M. W., & Lo, Y.-T. (1999). Tidal Circulation and Residence Time in a Macrotidal Estuary: Cobscook Bay, Maine. Estuarine, Coastal and Shelf Science 49, 647-665.

- Brown, S. K., & Butler, M. J. A. (1994). ECNASAP: Towards International Collaboration in Strategic Environmental Assessment. In P. G. Wells & P.J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 860-874). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.
- Burrough, P. A. (1986). Principles of Geographical Information Systems for Land Resources Assessment. Oxford: Clarendon.
- Burrough, P. (1989). Data Quality, Errors and Natural Variation. Accuracy of Spatial Databases. London: Taylor And Francis.
- Calado, H., & Porteiro, J. (1996). Application of a GIS to the Management of Furnas Lake (Azores): An Effort to Control Eutrophication. Geographical Information. From Research to Application Through Cooperation. IOS Press Amsterdam.
- Campobello Island. Canada, United States of America. 21B/15 & 21B/14. [1:50,000 Map]. (1999). Ottawa: Centre for Topographic Information, Natural Resources Canada.
- Canessa, R. R. (1998). GIS Decision Support for Integrated Coastal

Management. Oceans Conservation Report Series. Integrated Coastal Zone Management. Marine Protected Areas. Marine Environmental Quality. Ottawa: Department of Fisheries and Oceans.

Canessa, R. R., & Keller, P. C. (1996). Information Taxonomy and Data requirements for Coastal GIS to Support Coastal Planning and Management. In GIS Applications in Natural Resources 2. A Selected Compilation of Unedited Papers from the GIS '92-'95 Symposia held in Vancouver, British Columbia. (pp 102-109). Fort Collins, Colorado: GIS World Inc.

Canessa, R. R. & Keller, P. C. (1994). A Metadata Strategy For Coastal GIS Quality Management. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 879-895). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Carvalho Junior. O. (1994). Remote Sensing as a Tool in Coastal Management in Latin America Countries. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 928-935). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Carvalho Junior, O. (1994). Preliminary Study of the Dynamic Processes in the North and South Bay of Sant Catarina Island, Brasil using LANDSAT Satellite Imagery. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 1020-1037). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Cendrero, A. (1989). Mapping and Evaluation of Coastal Areas for Planning. Ocean and Shoreline Management 12, 427-462.

Chao, G. (2000). The Emergence of Integrated Coastal and Ocean Management in Canada's Oceans Act: Challenges of Integrating Fragmented Resource Sectors in George's Bank, Nova Scotia. Coastal Zone Canada 2000. Book of Abstracts. (p. 236) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Chopin, T. & Wells, P. G. (Eds.). 2001. Opportunities and Challenges for Protecting, Restoring and Enhancing Habitats in the Bay of Fundy. Proceedings of the 4th Bay of Fundy Science Workshop, Saint John, New Brunswick, September 19-21, 2000. Environment Canada, Atlantic

Region Occasional Report Number 17, Environment Canada,
Dartmouth, Nova Scotia.

Chrisman, N. R. (1989). Modelling Error in Overlaid Categorical Maps. In M. Goodchild & S. Gopal [Eds.] The Accuracy of Spatial Databases (pp. 35-44). New York: Taylor And Francis.

Chrisman, N. R. (1987). The Accuracy of Map Overlays: A Reassessment. Landscape and Urban Planning 14, 427-439.

Chua, T. E. (1997). Sustainable Aquaculture and Integrated Coastal Management. In J. E. Bardach (Ed.). Sustainable Aquaculture. (pp. 177-199). New York: John Wiley and Sons, Inc.

Chua, T. E. (1993). Elements of Integrated Coastal Zones Management. Ocean and Coastal Management, 21, 81-108.

Coastal Zone Canada Association. (2001). Beyond 2000: An Agenda for Integrated Coastal Management Development. Post-Conference report of the Coastal Zone Canada 2000 International Conference. Saint, New Brunswick, September 17-22, 2000. Dartmouth, Nova Scotia: Coastal Zone Canada Association.

Coastal Zone Canada 2000 (2000). Baseline 2000. St. John, New Brunswick:

**Coastal Zone Canada 2000 Conference Secretariat, New Brunswick
Department of Environment and Local Government, and Coastal Zone
Canada Association.**

Coastal Zone Canada 2000. (2000). Book of Abstracts. St. John, New

**Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New
Brunswick Department of Environment and Local Government, and
Coastal Zone Canada Association.**

**Colby, N. G. (1881). Atlas of Washington County, Maine. Compiled, drawn and
published by Official Plans and Actual Surveys by George N. Colby and Co.,
Houlton and Machias, ME. 1881. Original printing by L. H. Thompson, Inc.
1878. No Place: Cherryfield-Narragausus Historical Society, Inc. 1978.**

Compton's Encyclopaedia Online. (1998). Alaska Boundary Dispute [On-line].

Available:

**[http://www.comptons.com/encyclopaedia/ARTICLES/0000/00044544_A.ht
ml](http://www.comptons.com/encyclopaedia/ARTICLES/0000/00044544_A.html)**

**Contanza, R. (1991). Ecological Economics: The Science and Management of
Sustainability. New York: Columbia University Press.**

Cowey, C. B. & Cho, C. Y. (Eds). **Nutritional Strategies and Aquaculture Waste. Proceeding of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste.** (pp. 275) University of Guelph, Guelph, Ontario.

Clement, P. G. (2000 a). **Environmental Damages from Small Oil and Chemical Spills. Coastal Zone Canada 2000. Book of Abstracts.** (p. 259) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Clement, P. G. [Poster]. (2000 b). **A Framework for Valuing the Environmental Damages from Small Scale Coastal Oil Spills.** Halifax: Environmental Emergencies, Environment Canada, and School for Resource and Environmental Studies, Dalhousie University.

Davis, H. A. (1974). **An International Community on the St. Croix (1604 -1930).** Orono, Maine: Maine Studies no. 64 University of Maine at Orono.

De Lisle, D. A., & Drapeau, G. (1994). **Coastline and Nearshore Features Delineation Using Remote Sensing.** In P. G. Wells & P. J. Ricketts (Eds.),

Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 992-1004). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Dolan, R., Hayden B. & May, S. (1984). Erosion of the U.S. Shorelines. In. CRC Handbook of Coastal Processes and Erosion. (pp.285-299). Boca Raton, Florida: CRC Press Inc.

Donaldson, E. M. (1997). The role of Biotechnology in Sustainable Aquaculture. In J. E. Bardach Sustainable Aquaculture. (101-126). New York: John Wiley and Sons, Inc.

Douglas, D. H., & Peucker, T. K. (1973). Algorithms for the Reduction of the Number of Points Required to Represent a Digitized Line or its Caricature. The Canadian Cartographer. Volume 10, Number 2, 112-122.

Eastport [Map]. (1894). Sanborn Map of Eastport, ME. New York: Sanborn-Perris Map Co., Limited 117 Broadway, New York.

Eastport, Maine. [1:24,000 Map]. (1949, Photorevised 1977). Denver, Colorado: United States Geological Survey.

Eastport for Pride. (1983). SALT (Journal of New England Culture), Volume VI, Numbers 1 and 2. (Double issue) SALT Inc. Kennebunkport, Maine: SALT(Journal of New England Culture).

Ehlers, M., Greenlee, D., Smith, T. & Star, J. (1991). Integration of Remote Sensing and GIS: Data and Data Access. Photogrammetric Engineering and Remote Sensing, 57 (6) 669-675.

Environment Canada. Atlantic Region, (May, 2001). Atlantic Region Sensitivity Mapping Program. [On-Line]. Available: <http://www.ns.ec.gc.ca/mapping/over1.htm>

Environmental Systems Research Institute, Inc. (1993). The Digital Chart of the World for use with ARC/INFO. Data Dictionary. Redlands, CA: Author

Fabbri, P. (Ed.). (1992). Ocean Management in Global Change. Barking, Essex, England: Elsevier Science Publishers Ltd.

Fabbri, P. (1992). From Coastal to Ocean Management: Policies and Planning Issues. In P. Fabbri (Ed.), Ocean Management in Global Change. (pp. 169-183). Barking, Essex, England: Elsevier Science Publishers Ltd.

FAO.(1995). Aquaculture Production Statistics, 1984-1993. Fisheries Circular 815, Rev. 7. Rome: Food and Agriculture Organization of the United Nations.

FAO.(1995). The State of the World Fisheries and Aquaculture. Rome: Food and Agriculture Organization of the United Nations, P 7.

FAO. (1995) Fisheries Statistics, Catches, and Landings. FAO Fisheries Series 76. Rome: Food and Agriculture Organization of the United Nations,

FAO. (1991). Environment and Sustainability of Fisheries. COFI/91/3. Document presented at the 19th Session of the Committee on Fisheries, April 1-12. Rome: Food and Agriculture Organization of the United Nations.

FAO. (1981). Atlas of the Living Resources of the Sea. Rome: Food and Agriculture Organization of the United Nations.

FEMA (Federal Emergency Management Agency). (2001, May). Flood Hazard Mapping. [On-Line]. Available:
http://www.fema.gov/mit/tsd/FQ_map01.htm

Ferrante, A. J., & Brebbia, C. A. (1996). Coastal Environment. Environmental Problems in Coastal Regions. Boston:Computational Mechanics Publications.

Finkl, Jnr., C. W., & DaPrato, G.W. (1994). Application of Remote Sensing and GIS/LIS in the Decision-Making Process for Coastal Zone Management: An Example From an Urbanized Coastal Corridor in Subtropical Southeast Florida, USA. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 769-773). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Florida. (2001). Spiny Lobster Sanctuary - CHAPTER 68B-11 - Biscayne Lobster. CHAPTER 68B-11. Biscayne Bay-Card Sound - Spiny Lobster Sanctuary [On-line]. Available:
<http://www.state.fl.us/fwc/marine/Ch68B-11.htm>

Franks, P. J. S. & Anderson, D., M. (1989). Sampling Coastal Dinoflagellate Blooms: Equipment, Strategies and Data Processing. In Hallegraeff, Gustaaf, M. & Maclean, Jay, L. (Eds.) Biology, Epidemiology and Management of Pyrodinium Red Tides. Proceedings of the Management and Training Workshop Bandar Seri Begawan, Brunei Darussalm, 23-30

May 1989. (pp. 235-256). Manila, Philippines: Fisheries Department, Ministry of Development, Brunei, Darussalam and International Center for Living Aquatic Resources Management, Makati, Metro Manila, Philippines.

Friedheim, R. L. (1999). Ocean Governance at the Millennium: Where we have been - Where We Should Go. Ocean and Coastal Management, 42, pp.747-765.

Gaudet, R. J. (1990). Mapping the Coastal Zone - Can One Base Satisfy Many Issues? GIS for the 1990s. Proceedings of the Second National Conference in Geographic Information Systems. pp 1357-1361. Ottawa.

GeoInformation International. (1997). Getting to Know ArcView GIS. The Geographic Information System for Everyone. Cambridge: Author.

Geomatics Canada.(1997). Standards and Specifications of the National Topographic Data Base. (ed. 3.1) Sherbrooke (Québec): Minister of Supply and Services Canada.

Gillespie, R. MGDI: Information Infrastructure for the Maritime Community. (2000). Coastal Zone Canada 2000. Book of Abstracts. (p. 59) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New

Brunswick Department of Environment and Local Government, and
Coastal Zone Canada Association.

Goodchild, M. F. (1988). The Issue of Accuracy in Global Databases. In H.
Mounsey & R. F. Tomlinson, (Eds.), Building Databases for Global
Science. (pp. 31-48). London: Taylor And Francis Ltd.

Goodchild, M., & Gopal, S. (Eds.). (1989). Accuracy Of Spatial Databases.
London: Taylor & Francis.

Great Lakes Information Network. (2001). Maps and GIS of the Great Lakes
Region [On-Line]. Available: [http:// www.great-lakes.net/gis/](http://www.great-lakes.net/gis/)

Gulf of Maine Watershed [Map]. (1992). Augusta, Maine: Maine State Planning
Office.

Henocque, Y., & Denis, J. (2000). Zoning as a tool for Coastal Management.
Coastal Zone Canada 2000. Book of Abstracts. (p. 261) St. John, New
Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New
Brunswick Department of Environment and Local Government, and
Coastal Zone Canada Association.

Hinrichsen, D. (1998). Coastal Waters of the World. Trends, Threats and Strategies. Washington, D. C.: Island Press.

Holt, J. (1999). The Island City. A History of Eastport, Moose Island, Maine. From its Founding to Present Times. Lewiston, Maine: Penmore Lithographers.

Inglis, J. T. (Ed.). (1993). Traditional Ecological Knowledge. Concepts and Cases. Ottawa: International Program on Traditional Ecological Knowledge, Canadian Museum of Civilization and the International Development Centre.

Intergovernmental Panel on Climate Change. (1991). Climate Change - IPCC Response Strategies. Washington DC: Island Press.

International Council for Local Environmental Initiatives (I.C.L.E.I.). (1996). The Local Agenda 21 Planning Guide. An Introduction to Sustainable Development Planning. The International Council For Local Environmental Initiatives (ICLEI) Toronto, The International Development Research Centre (IDRC), Ottawa and The United Nations Environmental Programme (UNEP) Nairobi: N.P.

Jensen, J. R. (1996). Introductory Digital Image Processing. Upper Saddle River, NJ: Prentice Hall, Inc.

Judd, R. W., Churchill E. A., & Eastman, J. W. (1995). Maine, The Pine Tree State. From Prehistory to The Present. Orono, Maine: The University of Maine Press.

Kearney, J. F. (1983). Common Tragedies: A Study of Resource Access In The Bay of Fundy Herring Fisheries. Halifax: Thesis. Institute For Resource And Environmental Studies, Dalhousie University.

Kennish, M. J. (Ed.). (1994). Practical Handbook of Marine Science. (2nd Ed.). Boca Raton, Florida: CRC Press.

Kilby, W. H. (1992). Eastport and Passamaquoddy. A Collection of Historical and Bibliographical Sketches. Eastport, Moose Island, Maine: Edward E. Shead And Company. Eastport, Maine 1888. Eastport, Maine: Reprinted by Waterfront Research Committee, Border Historical Society.

Komar, P. D. (Ed.). (1984). CRC Handbook of Coastal Processes and Erosion. Boca Raton, Florida: CRC Press Inc.

Komar , P. D. (1984). Beach Process and Erosion. An Introduction. in P. D.

Komar (ED.). CRC Handbook of Coastal Processes and Erosion. (pp.1-20). Boca Raton, Florida: CRC Press Inc.

Kostiuk, M. (2001). The Use of Geographic Information for Coastal Zone

Management. Cobscook Bay, Maine - A Case Study. In T. Chopin & P.

G. Wells (Eds.), Opportunities and Challenges for Protecting, Restoring and Enhancing Habitats in the Bay of Fundy. Proceedings of the 4th Bay of Fundy Science Workshop, Saint John, New Brunswick, September 19-21, 2000. Environment Canada, Atlantic Region Occasional Report Number 17, Environment Canada, Dartmouth, Nova Scotia

Kucera, H. & Panyszak, M. (2000). Marine Geospatial Infrastructure: The

Technology. Coastal Zone Canada 2000. Book of Abstracts. (p. 60) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Laurini, R., & Thompson, D. (1992). Fundamentals of Spatial Information

Systems. New York: Academic Press.

Lee, R. & Fowler, B. (2001). Mapping Canada. Airforce Magazine 24 (4),16- 21.

Levings, C. D., North, M. S., Piercey, G. E., Jamieson, G., & Smiley, B.
 (1999). Mapping Nearshore and Intertidal Marine Habitats with Remote
 Sensing and GPS: The Importance of Spatial and Temporal Scales. In
Oceans '99 MTS/IEEE . Riding the Crest into the 21st Century.
Conference Proceedings. (pp. 1249 - 1255). Escondido, California:
 Holland Publications.

Lillesand, T. M., & Kiefer, R. W. (1994). Remote Sensing and Image
Interpretation (3rd ed.). New York: John Wiley & Sons, Inc.

Lubec, Maine. [1:24,000 Map]. (1949, Photorevised 1977). Denver, Colorado:
 United States Geological Survey.

Lyman, M., & Milliken, S. (1999). Tools for Change in Northern New England.
Compass. Volume 10, Number 1, Fall 1999. Ipswich, Maine: Quebec
 Labrador Foundation and its Atlantic Center for the Environment pp 4 -
 5,12.

Lynch, M. P. (Ed.). (1998). Minding the Coast: It's Everybody's Business.
Proceedings Of The Sixteenth International Conference of the Coastal
Society. Alexandria, VA: The Coastal Society.

MacDougall, R. (2000). SeaMap. Canadian Seabed Mapping Proposal.

Developing Useful Information Infrastructure for Seabed Research and Management. Coastal Zone Canada 2000. Book of Abstracts. (p. 61) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Mahapatra, K., Sudarshana, R., & Ch. Das, N. (1994). Remote Sensing Based Study on Spatio-Temporal Variabilities of the Coastal Lagoonal Features - A Case Study at Chilka Lake, India. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 936-949). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Maine Department of Conservation. (2001, May). Coastal Marine Geology Programs. [On-Line]. Available:

<http://www.state.me.us/doc/nrimc/mgs/marine/marproj.jtm>

Maine Flood plain Management Program. (2001, May). Maine Floodplain Management Program. [On-Line]. Available:

<http://janus.state.me.us/spo/flood/brochure.htm>

Maine. Office of Geographic Information Systems (2000). Data Catalogue and Metadata, Coast: Mean high water coastline from USGS 1:24,000 scale quads, Coast Coverage Information [Online]. Available:
<http://apollo.ogis.state.me.us/catalog/catalog.htm>

Maine State Planning Office. University of Maine. (2000). State of Maine Climate Change Action Plan. NP: Maine State Planning Office.

Mallet, A., & Myrand, B. (1995). The Culture of the Blue Mussel in Atlantic Canada. In A. D. Bogden (Ed.), Coldwater Aquaculture in Atlantic Canada. (pp. 257- 296). Sackville, New Brunswick: 1995.

Marsh, R., & Butt, K. (1994). Communication Satellite Applications for Coastal Zone Management. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 980-991). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

McCann, S. B. (Ed.). (1980). The Coastline of Canada. Littoral Processes and Shore Morphology. Paper 80.10. Ottawa: Minister of Supply and Services. Geological Survey.

McKenna, R. H., & Squires, K. E. (1994). An Examination of the Use of Spaceborne SAR Imagery and Local Expertise in Nearshore Current Mapping. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 950-964). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

McRae, D. & Munroe, G. (eds.). (1989). Canadian Oceans Policy: National Strategies and the New Law of the Sea. Vancouver: University of British Columbia Press.

Medyckyj, S. D. & Hearnshaw, H, M. (Eds.). (1983). Human Factors In Geographical Information Systems. London: Belhaven Press.

Miles, E. L. (1999). The Concept of Ocean Governance: Evolution Toward the 21st Century and the Principle of Sustainable Ocean Use. Coastal Management. 27, 1-30.

Millar, C., & Aiken, D. E. (1995). Conflict Resolution in Aquaculture: A Matter of Trust. In A. D. Bogden (Ed.), Coldwater Aquaculture in Atlantic Canada. (pp. 619- 645). Sackville, New Brunswick: 1995.

Milne, P. H. (1972). Fish and Shellfish Farming in Coastal Waters. London:
Fishing News (Books) Ltd.

Molendijk, M., Romao, T. & Scholten, H. (1996). Coastmap: A Collaborative
Multimedia Environment For Coastal Zone Managers in Geographical
Information. From Research to Application Through Cooperation.
Amsterdam: IOS Press.

Monahan, D. (2000). Zones in the Sea. From Shoreline to Shelf Edge. A
Workshop on Article 76 of The United Nations Convention on Law of the
Sea (UNCLOS) for Participants in CZ2000 Version Zero(0). Canadian
Hydrographic Service & Department of Geodesy and Geomatics
Engineering, University of New Brunswick. [On-Line] Also Available:
<ftp.chs-shc.dfo-mpo.gc.ca/Outgoing/MonahanD/Coastal>.

Moore, S. (2000). Geographic Information Systems (GIS) - A Tool for
Community-based Environmental Management. Coastal Zone Canada
2000. Book of Abstracts. (p. 214) St. John, New Brunswick:
Coastal Zone Canada 2000 Conference Secretariat, New Brunswick
Department of Environment and Local Government, and Coastal Zone
Canada Association.

Mounsey, H., & Tomlinson, R., F. (Eds.). (1988). Building Databases for Global Science. London: Taylor And Francis Ltd.

National Film Board of Canada (Producer). (1995). Where the Bay Becomes the Sea [Video Tape]. Montreal: National Film Board of Canada's Atlantic Centre in association with the Canadian Broadcasting Corporation.

National Flood Insurance Program. (2001, May). FEMA: National Flood Insurance Program - Guide to Flood Maps. [On-Line]. Available:
<http://www.fema.gov/NFIP/readmao.htm>

National Oceanic and Atmospheric Administration. (2001, May). Coastal GIS Bibliography. Coastal Management. A Bibliography of Geographic Information System Applications. [On-Line]. Available:
<http://www3.csc.noaa.gov/gisprojects/biblio/>

National Oceanic and Atmospheric Administration. Coastal Services Center. (2001, April). Where was LIDAR Collected? [On-Line]. Available: <http://www.csc.noaa.gov/crs/tcm/misions.html>

National Oceanic and Atmospheric Administration. (2000). Coastal Programs Division. FY 2000 Annual Operating Plan. Pre Budget Allocation Final

Edition. February 2000. NP: Author

Natural Resources Canada. (1988). Geomatics Canada. Centre for Topographic Information. National Topographic system 1/50 000 Polychrome Map. Standards and Specifications. Version 1.0. SPC-01. Ottawa: Author.

National Research Council. Committee on Engineering Implications of Changes in Relative Mean Sea Level. (1987). Responding to Changes in Sea Level. Engineering Implications. Washington DC: National Academy Press.

Nichols, S. & Monahan, D. (2000). Creating the Information Infrastructure for Good Governance in Canada's Offshore. Coastal Zone Canada 2000. Book of Abstracts. (p. 249) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

OECD (1993). Coastal Zone Management - Integrated Policies. Paris : OECD.
pp 19 -124.

Oilerhead, J., & Rush, R. (2000). An Assessment of ArcView 3.1 and Image

Analysis 1.0 as Tools for Measuring Geomorphic Change at Three Bay of Fundy Saltmarshes. Coastal Zone Canada 2000. Book of Abstracts. (p. 127) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Opadeyi, J., & Fabres, B. (1994). Database Design and Requirements for Integrated Coastal Fisheries Management (ICFM) in the Gulf of Paria. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 784-794). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Open GIS Consortium. (2001). OGC Vision, Mission, Goals, Values. [On-Line]. Available: www.opengis.org/info/mv.htm

Openshaw, S. (1989). Learning to Live with Errors in Spatial Databases. In M. Goodchild & S. Gopal (Eds.), Accuracy of Spatial Databases (pp. 263-276). London: Taylor & Francis.

O'Reilly, C. (2000, April). Defining The Coastal Zone From A Hydrographic Perspective. Backscatter. Observing Marine Environments, 20-24.

O'Reilly, C. T., & King, G. A. The "3-D" Coastline of the New Millennium. (2000).

Coastal Zone Canada 2000. Book of Abstracts. (p. 62). St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Owens, T. (August, 2000). Datums and Projections: A Brief Guide. [On-line].

Available: <http://biology.usgs.gov/geotech/documents/datum.html>

Pauly, D., & Christensen, V. (1995). Primary Production to Sustain Global Fisheries. Nature. 374, 255-257.

PCI Enterprises. (1998). Introduction to Using PCI Software. Richmond Hill, Ontario: Author.

Peck, D. L. Williams, S. J. (1992). Sea Level Rise and its Implication in Coastal Planning and Management. In P. Fabbri (Ed.), Ocean Management in Global Change. (pp. 57.73). Barking, Essex, England: Elsevier Science Publishers Ltd.

Pembroke, Maine.[1:24,000 Map]. (1949, Photorevised 1977). Denver, Colorado: United States Geological Survey.

Percy, J. A. (1994). The Annapolis Basin Coastal Zone Project. In P. G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 774-783). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Pido, M. D., & Chua, T.-E. (1992). A Framework for Rapid Appraisal of Coastal Environments. In Chua, and Scura (Eds.), Integrated Framework and Methods for Coastal Area Management. ICLARM Conference Proceedings 37. (pp. 135-148) Manila.

Ponsford, DR. A.M., & Premji, DR. A. (1994). A Demonstration of Integrated Maritime Surveillance on Canada's East Coast. In P.G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 965-979). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Pushkar, N. K & Cook, R. H. (Eds.). (1978). Drugs and Food from the Sea: Myth or Reality. Oklahoma, Okla.: The University of Oklahoma.

Rhind, D. W. (1973). Generalisation and Realism Within Automated Cartographic Systems. The Canadian Cartographer. Volume 10, Number

1, 51-62.

Ricketts, P. J., & Fenton, D. G. (1994). The Role of Strategic Environmental Assessment in Coastal and Ocean Management. In P.G. Wells & P. J. Ricketts (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. (pp. 828-846). Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

Roberto, B., Alessandro, B., & Gilmo, V. (1996). GIS in the Study In The Study of a Densely Populated Area Along the Coast of the Campania Region (ITALY) Geographical Information. From Research to Application Through Cooperation. Amsterdam: IOS Press.

Robinson, A. H., Sale, R. D., Morrison, J. L. & Muehrcke, P. C. (1984). Elements of Cartography (5th ed.). New York: John Wiley & Sons.

Rockwell, G. (2000). Seabed Resource Mapping Program (SeaMap). Coastal Zone Canada 2000. Book of Abstracts. (p. 102). St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Rohmann, S.(August, 2000) NOAA's Medium Resolution Digital Vector

Shoreline. [On-Line]. Available:

<http://seaserver.nos.noaa.gov/projects/shoreline/shoreline.html>

Rosenthal, H., Scarratt, D. J. & McInerney-Northcott, M. (1995). Aquaculture and the Environment. In A. D. Bogden (Ed.), Coldwater Aquaculture in Atlantic Canada. (pp. 453-500). Sackville, New Brunswick: 1995.

Rowley, B. R. (2000). High Resolution Coastal Mapping. Workshop: Information Management in Support of ICM. Coastal Zone Canada 2000. Book of Abstracts. (p. 54). St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Saunders, R. L. (1995). Salmon Aquaculture: Present Status and Prospects for the Future. In A. D. Bogden (Ed.), Cold-Water Aquaculture in Atlantic Canada 2nd ed. (pp. 37-81). Sackville, New Brunswick: The Tribune Press Ltd.

Shang, Yung, C. And Tisdell, Cleam, A. (1997). Economic Decision Making in Sustainable Aquacultural Development. In J. E. Bardach (Ed.), Sustainable Aquaculture. (pp.127-148). New York: John Wiley and

Sons, Inc.

Smith, H. D. (1992). Theory of Ocean Management. In P. Fabbri (Ed.), Ocean Management in Global Change. (pp.19-38). Barking, Essex, England: Elsevier Science Publishers Ltd.

Smith, M. J. (1949). A History of Maine. From Wilderness to Statehood. Portland, Maine: Falmouth Publishing House.

Soluri, E. A., & Woodson, V. A. (1990). World Vector Shoreline. International Hydrographic Review, [On-Line], LXVII(1). Available: <http://crusty.er.usgs.gov/coast/wvs.html>

Stein, T. I. (Ed.). (1997). A Scientific Vision For Sustainable Development. IGARSS'97 Remote Sensing. Piscataway, NJ, USA: IEEE operations Center.

Stickney, R. R. (1997). Advantages of Offshore Mariculture Systems. In J. E. Bardach (Ed.), Sustainable Aquaculture. (pp. 53-86). New York: John Wiley and Sons, Inc.

Swift, D. R. (1985). Aquaculture Training Manual. Farnham, Surrey, England:
Fishing News Books Ltd.

The Story of the Fire. (1886, Wednesday, November 10). Eastport Sentinel. No 48.
Page 1.

Tobler, W. (1988). Resolution, Resampling, and All That. In Mousey, H. &
R. F. Tomlinson (Eds.), Building Databases for Global Science. The
Proceedings of the First Meeting of the International Geographical Union
Global Database Planning Project. (pp.129-137). London: Taylor and
Francis.

Treasury Board of Canada. (1989) Comptroller General. Guide to the Costing of
Outputs. Ottawa: Office of the Comptroller General. Communications
Division, Treasury Board of Canada.

Trimble Navigation Limited. (1996). Mapping Systems. General Reference. Part
Number: 24177-00. Revision B. Sunnyvale, California: Trimble Navigation
Limited.

Trites, R. W., Loucks, R. H., Gilroy, J. & Cahoon, P. Some Physical
Environmental Factors Relevant to Spilled Oil in the Vicinity of Eastport.

Maine USA. Dartmouth , N. S. Coastal Oceanography Division, Bedford
Institute of Oceanography, 1973.

Underwood, J. M. (2001, July). Legal Considerations Regarding Restoration of
Productive Clam Flats in Maine [On-Line]. Available:
<http://mli.usm.maine.edu/clam.htm>

United Nations. (1977). Meeting of the Group of Experts on Hydrographic
Surveying and Nautical Charting 5- 16 December 1977, New York: United
Nations.

United Nations. (1992). Study on Benefits to be Obtained from Rational Coastal
Resource Management: Geoscientific Applications. New York: Economic
and Social Commission for Asia and the Pacific, United Nations.

United States Environmental Protection Agency. (1981). Initial Decision in the
Matter of the Pittston Company NPDES permit application no.
ME0022420. Boston: N. P.

U.S. Bureau of The Budget. (1947). United States National Map Accuracy
Standards. United States of America: U.S. Bureau of The Budget.

USGS (United States Geological Survey). (July, 2000). Digital Orthophoto

Quadrangles, Fact Sheet C39-00 [On-line]. Available:

<http://mapping.usgs.gov/mac/isb/pubs/factsheets/fs03900.html>

USGS (United States Geological Survey). (1999, December). Horizontal

Positional Accuracy. [On-line]. Available:

http://edcwww.cr.usgs.gov/glis/hyper/glossary/h_#hpa

USGS (United States Geological Survey). (1998). Part 2 Specifications

Standards for Digital Elevation Models. National Mapping Program

Technical Instructions. United States of America: U.S. Department of the Interior. U.S. Geological Survey. National Mapping Division.

USGS (United States Geological Survey). (1997). Part 1 Standards for

1:24,000-Scale Digital Line Graphs-3 Core Part 1: Data Description and Template Development National Mapping Program Technical Instructions.

United States of America: U.S. Department of the Interior. U.S. Geological Survey. National Mapping Division.

USGS (United States Geological Survey). (1997). Part 3 1:100,000-Scale Digital

Line Graphs Standards for the Preparation of Digital Geospatial Metadata.

National Mapping Program Technical Instructions. United States of America: U.S. Department of the Interior. U.S. Geological Survey.

National Mapping Division.

- Van Houtte, A. (1995). Fundamental Techniques on Environmental Law and Aquaculture Law. In FAO and NACA. Report on a Regional Study and Workshops on the Environmental Assessment and Management of Aquaculture Development. Food and Agriculture Organization of the United Nations, Bangkok (pp. 451-457).
- Varma, H., Harding, J., Gareau, P., MacNab, R., Fadaie, K., Milne, T., & O'Brien, D. (2000). Data in Jeopardy. Coastal Zone Canada 2000. Book of Abstracts. (p. 57). St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.
- Veregin, H. (1989). Error Modelling for the Map Overlay Operation. In Goodchild, M. & Gopal, S. (Eds), Accuracy of Spatial Databases (pp. 3 - 18). London: Taylor and Francis.
- Videira, N. Jordao, P., Santos, R., & Concalves, P. (1996). Environmental Policy And Ecosystem Spatial Classification in Coastal Areas. Geographical Information. From Research to Application Through Cooperation. Amsterdam: IOS Press.
- Vitousek, P. M., Ehrlick, P.R., & Matson, P. A. (1986). Human Appropriation of the Products of Photosynthesis. Bioscience 36(6). 368-373.
- Wainwright, P., L. G. L Limited. Canada Department of Fisheries and Oceans; Fish Habitat and Information Program (Canada). (1991). Fisheries

Habitat GIS Strategy. Vancouver: LGL Ecological Research Associates.

Webster, T., & Maher, B. High Resolution Imaging and Terrain Extraction along the Bay of Fundy Coastal Zone, Nova Scotia, Canada. (2000). Coastal Zone Canada 2000. Book of Abstracts. (p. 106) St. John, New Brunswick: Coastal Zone Canada 2000 Conference Secretariat, New Brunswick Department of Environment and Local Government, and Coastal Zone Canada Association.

Weiss, N. A. (1993). Elementary Statistics. 2nd ed. Reading, Massachusetts: Addison-Wesley Publishing Company Inc.

Wells, P. G. & Ricketts P. J. (Eds.), Coastal Zone Canada '94. Cooperation in the Coastal Zone. Conference Proceedings. . Dartmouth, Nova Scotia: Coastal Zone Canada Association, Bedford Institute of Oceanography.

West Lubec, Maine.[1:24,000 Map]. (1949, Photorevised 1975). Denver, Colorado: United States Geological Survey.

Whiting, Maine.[1:24,000 Map]. (1949, Photorevised 1977). Denver, Colorado: United States Geological Survey.

Wolfe, P. R., & Brinker, R. C. (1989). Elementary Surveying. 8th ed. New York: Harper Collins Publisher Inc.

Zhang, A. & Reilly-Row, P. (1998) Building A Link Between Geomatics And Sustainable Development Policy Making. GIS' 98/RT '98 Pathways to Knowledge Integration. Toronto: GIS world Inc.