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The Use of Remote Sensing Techniques and Geographic Information Systems by Coastal Managers in Rhode Island

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THE USE OF REMOTE SENSING TECHNIQUES AND GEOGRAPHIC INFORMATION SYSTEMS BY COASTAL MANAGERS IN RHODE ISLAND

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Abstract

Planners and managers must understand the physical and anthropogenic changes taking place within the coastal zone to provide effective management. Remote sensing techniques and Geographic Information Systems (GIS) are excellent tools for contributing data and analytical capabilities to identify possible conflicts within the coastal zone. This study examines the potential and actual use of these technologies by coastal managers within Rhode Island.

Potential usage is discussed in terms of the range of data available and the feasibility of using the data for coastal problems. Also, GIS capabilities in Rhode Island are explored. Finally a survey designed to measure the actual use of remote sensing and GIS is presented.

Results of the survey show that aerial photography has been used quite extensively by coastal managers in Rhode Island and will continue to be used in the future. Satellite derived data are used only for research purposes because of several factors including high cost and lack of need. GIS use is expanding rapidly throughout the state. The successful implementation of GIS is attributed to continued cooperation between state agencies and the University of Rhode Island's Environmental Data Center which operates Rhode Island Geographic Information System.

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INTRODUCTION

Planners and managers responsible for developing and implementing effective coastal zone management programs must have an accurate understanding of the physical environment of the coastal area. Typically, planners use a wide range of scientific data to guide their decisions. In Rhode Island, research conducted by the universities, federal, state and local agencies (acting both jointly and independently) and by several non-governmental organizations (NGOs) have provided much understanding of the coastal zone. This research has included both in-situ measurements and the use of remotely sensed data.

The Rhode Island coastline is relatively easily accessible which allows for frequent direct observation of important coastal features such as beach profiles, wetland inventories and wildlife assessments. However, even with easy access, direct (in-situ) measurement techniques have disadvantages such as expense, small area coverage and difficulty of obtaining synoptic measurements. For these and other reasons, in-situ data have been increasingly augmented by remotely sensed data, traditionally from aerial photography although satellite derived data also are being used.

Many studies have illustrated the utility of satellite derived data for a variety of coastal management projects.[1]

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[1]See for example, Gregory Behie and Peter Cornillon, "Remote Sensing, a Tool for Managing the Marine Environment:

Some of these techniques are applicable to problems in the Rhode Island coastal area while others may be less relevant given the uniqueness of the state's coastal zone.

Meanwhile another technology is playing an ever increasing role in Rhode Island's resource management programs. A Geographic Information System (GIS) is being used to establish an impressive database of environmental and land use information. This program is being developed at the University of Rhode Island in cooperation with the state's Department of Environmental Management (DEM) with other state agencies increasingly utilizing and submitting data to the system. This GIS is a powerful tool for resource management because of its ability to store and display large volumes of environmental data and analyze the interaction between uses and resources in terms of identifying possible conflicts and problems in resource management.

The purpose of this paper is to analyze remote sensing (both aerial and satellite) as tools for the coastal resources managers in the state of Rhode Island and to study the effect of GIS on the capability of effectively integrating remotely sensed data with other environmental data to aid both managers and policy makers. This paper is organized into five parts. The first section following the defines many of the terms used throughout the paper and

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Eight Case Studies" (Narragansett, RI: Ocean Engineering NOAA/Sea Grant University of Rhode Island, 1981), Marine Technical Report 77, which describes several projects incorporating aerial and satellite data.

describes the political, legal and legislative motivations for a better understanding of the coastal zone. Section two differentiates between various types of remote sensing techniques and discusses studies which illustrate the utility of remote sensing. In section three, GIS capabilities are defined, the GIS facilities available in the state are described and studies showing the utility of GIS in resource management and the link between remote sensing and GIS are discussed. Section four is a description of the design and implementation of a survey of coastal managers in Rhode Island who use or may potentially use remote sensing and GIS. The last section describes the results of the survey and makes recommendations regarding the future use of these technologies.

I. CONCEPTS

Definition of Terms

The development of the remote sensing field has led to the development of a specialized vocabulary. Perhaps the best place to start is to define the term remote sensing. This is not quite as simple as it first appears. Indeed, just the process of defining the term has generated controversy and discussion.[2] Definitions may be all

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[2]Jay Fussel, Donald Rundquist, and John A. Harrington, Jr., "On Defining Remote Sensing," Photogrammetric Engineering and Remote Sensing 52, no. 9 (September 1986): 1507-1511.

inclusive such as "remote sensing is the acquiring of data about an object without touching it"[3] or may qualify specific characteristics like type of platform; method of data acquisition; techniques for processing and analysis etc. Some scientists have expressed the opinion that the lack of a single, concise, universally acceptable definition may be hurting progress in the field in terms of getting adequate attention and funding for research. This is because funding decisions are often made at a political level where it is imperative that decision makers understand the objectives of the projects they fund.

For the purposes of this paper remote sensing refers to the process of gathering information about an area either by plane or by satellite. "Remotely sensed data" is used interchangeably with "remote sensing data" indicating the product of that process whether it is in the form of a photograph, computer tape or other form of read out. Here remote sensing is considered a tool or technique to be applied to coastal management, rather than a science or art.[4]

Since one object of this work is to determine the need for satellite data and its relative importance given the extensive use of aerial photography in the state, in most cases a distinction will be made between data acquired by plane and from satellites. In describing data from planes,

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[3]Ibid., 1508.

[4]Ibid., 1509.

several terms are used interchangeably in the literature including aerial photography, air reconnaissance, air photographs and photogrammetry[5] and this convention is adopted here.

Other terms must also be defined at the outset because of their frequent use in the literature. A sensor is any device capable of measuring a given quality or characteristic. For example, a camera mounted on a wing of an airplane is a sensor, so too is the sophisticated instruments in satellites used to measure electromagnetic radiation from the earth. Spatial resolution is defined as the minimum distance between two objects which allows the sensor to distinguish between them: the smaller the distance the greater the resolution. A pixel (picture element) is a term used often in digital image processing to describe the minimum size or area a sensor can identify. In other words a pixel which is one kilometer (km) long and one km wide indicates a spatial resolution of one km. The value of that pixel is actually the average value of the measured characteristic throughout the whole area of the pixel. As described later, while it is important to have good spatial resolution (small minimum distance; small pixel size) achieving this may mean compromising in other areas such as frequency of data (how often the same area is measured).

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[5]The term photogrammetry specifically refers to the technique of taking measurements from photographs and indicates specific standards to be followed in mapping.

Temporal resolution is a measure of how often measurements are obtained from a given area. In terms of satellite data this is usually expressed as the period or repeat cycle, indicating how often the satellite returns to measure a given geographical area. Generally, satellites which offer greater spatial resolution have a lower temporal resolution (i.e. LANDSAT has a spatial resolution of 30 meters and a repeat cycle of 16 days while NOAA 7-11 provide images with a 1 km resolution and a 12 hour frequency or period.) The definitions given above are used extensively in the literature. They help describe the characteristics of the remote sensing data. Other terms will be defined as they are introduced throughout the paper.

The scope of the terms coastal planner and coastal manager must also be defined for the purposes of this study. These terms are used here in a very general sense to describe anyone (including federal, state, local officials; academic researchers and private sector workers) whose duties include describing, understanding, controlling, monitoring and/or otherwise protecting or working with resources within the coastal zone. Resources include natural features such as beaches, wetlands, coastal water ways, watershed areas which feed coastal waters and biological resources (both fisheries and terrestrial creatures). Resources also include man-made features such as buildings, roadways and water structures. The scope of these definitions is purposely made very broad. As discussed later, tools such as remote sensing and GIS provide data and analyses for a wide variety of uses relating to the coastal zone.

Motivation For Better Understanding: Policy Needs

Concern over the deterioration of resources in the coastal zone has developed over the past 25 years. The need for tools such as remotely sensed data and GIS has also increased dramatically to help control land use and protect the coastal environment. The scientific and sociological data have become important parts of our understanding of natural and man-made changes to the environment. The data have also become part of the task of monitoring attempts to control and cleanup the coastal environment.

This section identifies some of the national and state policies which motivate the need to use tools such as remote sensing in coastal management. Federal laws such as the Coastal Zone Management Act and the National Environmental Policy Act are discussed. Also Rhode Island state laws and programs are examined.

The Stratton Commission report, Our Nation and the Sea, published in 1969, focussed attention on the nation's coastal area and the need for long term planning and management to protect the valuable resources.[6] Pointing to mounting pressure on the coastal zone for shoreline

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[6]Report of the Commission on Marine Science, Engineering and Resources (Stratton Commission), Our Nation and the Sea (1969), 49.

development, industrial processes, increased offshore oil and mineral exploration and conflicting fisheries uses, the Commission recommended the establishment of a comprehensive federal policy to deal with these increasing demands. Specifically, the Commission recommended the enactment of a coastal management act which would "provide policy objectives for the coastal zone and authorize federal grants-in-aid to facilitate the establishment of state coastal zone authorities empowered to manage the coastal waters and adjacent land."[7]

The Coastal Zone Management Act of 1972 (CZMA) sought to codify the recommendations of the Stratton Commission. As stated in the preamble, the Act was to "establish a national policy and develop a national program for the management, beneficial use, protection and development of the land and water resources of the Nation's coastal zones."[8] The Act provided funding to the states to establish and implement coastal management programs to meet the overall objectives of the law. Fulfilling the objectives meant that states would need to gather the data necessary to understand the coastal environment and hence develop efficient and effective management policies.

Under section 305 of the CZMA state programs were required to include: "identification of the boundaries of

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[7]Ibid., 57.

[8]Coastal Zone Management Act of 1972, (P.L. 92-583) U.S. Code, vol. 16, sec. 1451, preamble.

the coastal zone"; "definition of ... permissible land uses and water uses"; "inventory and designation of areas of particular concern"; and planning processes for protection of the beaches among others things.[9] All of these requirements meant that states needed to map and inventory coastal resources and land uses. Thus, tools such as remote sensing were necessary for the completion of management tasks.

In Rhode Island, the legislature addressed the need for coastal zone management by establishing the Coastal Resources Management Council (CRMC).[10] The council was given responsibility for planning and management of the state's coastal resources. The council's duties included: identifying and evaluating all coastal resources; determining uses and problems and formulating and implementing standards and management programs to protect the state's resources.[11] Again, a variety of tools, including remote sensing were needed to carry out the objectives of the legislation.

Another important use for remotely sensed data is in the preparation of environmental impact statements (EIS) as required by the National Environmental Policy Act (NEPA).[12]

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[9] Ibid., Section 305.

[10] R.I. General Law 46-23-1.

[11] Ibid., 46-23-6.

[12] National Environmental Policy Act, (P.L. 91-190) U.S. Code, vol. 42, secs. 4321, 4331-4335, 4341-4347 (1969).

The Act requires that an EIS be prepared for proposed federal activities which potentially impact the natural environment.[13] An EIS must include a description of present resources, which could require remote sensing and GIS analysis.

Rhode Island also has a state-wide planning program to establish "strategic plans for the physical, economic and social development of the state."[14] Although the legislation does not specifically enumerate coastal zone management as a policy objective the planning program is intended to be comprehensive and therefore encompass components such as environmental concerns and resource management in the coastal zone. As part of the strategic planning program, state and local planners need information about present land use zoning requirements and resource protection needs. Some of the answers to such questions are to be obtained through the use of aerial photography and satellite data and integrated into a geographic information system.

Other federal legislation such as the Clean Water Act[15] and the Coastal Barrier Resources Act[16] require that coastal

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[13]Ibid., Section 102(2)(c).

[14]R.I. General Law 42-11-10 (Statewide planning program).

[15]Clean Water Act, (P.L. 95-217) U.S. Code, vol 33, sec. 1251, note 1254 et seq. (1977).

[16]Coastal Barrier Resources Act, (P.L. 97-348) U.S. Code, vol 42, sec. 3501, note 3501 et seq. (1982).

managers understand processes and resources of the coastal zone. While field surveys may often be the primary method of obtaining environmental data, remote sensing and GIS technology can significantly augment the coastal manager's understanding of this complex system.

Federal agencies responsible for environmental protection and coastal engineering include the Environmental Protection Agency (EPA), Army Corps of Engineers and the National Oceanic and Atmospheric Administration (NOAA). State agencies interested in resource management include the Department of Environmental Management (DEM), Division of Planning (DOP) within the Department of Administration, Department of Transportation (DOT), Department of Health, and the Coastal Resources Management Council (CRMC). All of these agencies along with local town planners and zoning commissions benefit from the use of remote sensing and GIS to fulfill policy objectives of various local and state-wide environmental laws including but certainly not limited to those already mentioned.

II. REMOTE SENSING TECHNOLOGY

Characteristics of Sensors

This section is included to provide a brief overview of the types of remote sensing data available. For a more detailed discussion of this subject please refer to Appendix A which describes specific characteristics of some sensors and lists sources for the data. Aerial photography is described first, then other aerial sensors and finally satellite sensors.

Aerial sensors range from simple 35 mm cameras operated by hand to sophisticated devices such as side looking airborne radars. Although much surveying is done in planes over the ocean and coastal areas using standard cameras and long lenses,[17] we are more concerned here with the types of aerial surveys used to classify and inventory resources on the shore side of the coastline. These types of surveys must be accurately designed and flown so that critical parameters such as photographic scale, aircraft altitude and attitude are known.

There are three basic types of cameras used for aerial photography. The conventional aerial camera consists of: a film magazine which holds the film; a drive mechanism to advance the film; a cone to position the lens with respect to the film; and the lens itself. The focal length is the perpendicular distance from the film to the lens which is determined by the length of the cone and the characteristics

[17]For example sea turtle and marine mammal surveys such as the one described in: Cetacean and Turtle Assessment Program, "A Characterization of Marine Mammals and Turtles in the Mid- and North- Atlantic areas of the U.S. Outer Continental Shelf Annual Report 1979," prepared under contract to the U.S. Bureau of Land Management #AA551-CT8-84.

of the lens. Often, aerial cameras use interchangeable cones to change focal lengths of a single camera magazine.[18]

The panoramic camera is used to photograph a large area in a single exposure at a high spatial resolution. The lens views only a narrow angle field at any one time, however the lens pans across (perpendicular to) the flight path providing a view of a wide swath of terrain for each exposure. The film is held in an arc rather than being kept flat, to compensate for the arc cut as the lens is swept from side to side. Although this design causes some problems with change of scale in an image, the advantages of obtaining high resolution, wide area coverage often outweighs its disadvantages.[19]

The multiband camera represents an important change in the technology of aerial remote sensing. This technology recognizes the advantages of viewing the earth at several different bands of wavelength throughout the visible and near Infrared (NIR) spectrum. By taking simultaneous exposures of the same terrain at different wavelengths, many interesting characteristics of the terrain can be determined by comparing and contrasting the resulting different images. Each band of wavelength is imaged using the appropriate film and filter combination to obtain information for the given spectral zone while filtering out energy from the other

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[18]Joseph Lintz, Jr. and David S. Simonett, eds., Remote Sensing of the Environment (Reading, MA: Addison-Wesley Publishing Company, 1976), 136.

[19]Ibid., 138.

spectral zones.[20] An important improvement for both conventional and multiband cameras is the ability to compensate for the forward motion which the aircraft travels during any one exposure. By compensating for that forward motion, today's aerial photographic techniques result in sharper images with less smearing or blurring of the images.[21]

The cameras used in aerial photography must have adequate focal length, film negative size and shutter speed,[22] but perhaps more important is the choice of films used. Film types include black and white, color, thermal infrared, and false color infrared to name a few. Each film type is most suitable under certain circumstances given the objectives of the survey.[23] Also different filters may be applied to enhance the photographic imagery.[24]

Other, much more sophisticated sensors are also used to obtain imagery from aircraft. A multispectral scanner (MSS) measures the radiance coming from the earth's surface.[25]

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[20]Ibid., 138-141.

[21]Ibid., 141.

[22]Robert G. Reeves, ed., Manual of Remote Sensing (Falls Church, VA: American Society of Photogrammetry, 1975), 5.

[23]Behie, 10.

[24]Reeves, 6-7.

[25]Radiance is defined as the total energy radiated by a unit area per solid angle of measurement. See Paul J. Curran, Principles of Remote Sensing (New York: Longman Inc., 1985), 239.

The scanner collects data in a line perpendicular to the line of flight of the aircraft and as the plane moves forward successive scan lines of data are recorded, thus building a two dimensional image of the ground area below.[26] As the term multispectral indicates, data are collected in several wavelengths or bands. The bands are processed separately and combined with other bands to illustrate various characteristics of the area that has been imaged.[27] Digitally processed MSS imagery may be applied to a variety of problems such as vegetation mapping and water body monitoring.

The thermal infrared line scanner is another aerial sensor used in environmental and resource management. This instrument measures energy emitted by the earth in the thermal infrared wave band. It is often used to either detect temperature differences or to estimate temperature.[28] Examples of specific applications include locating thermal plumes and outfalls, locating heat loss from buildings and mapping soil moisture and ground water.[29]

Another type of aircraft sensor is called a sideways looking airborne radar (SLAR). The SLAR senses the terrain to the side of an aircraft trackline by sending out long wavelength energy pulses and then measuring the return time

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[26]Curran, 102.

[27]Ibid., 108.

[28]Ibid., 111-114.

[29]Ibid., 114.

and strength of the reflected energy. The distance of an object which has reflected the outgoing energy is calculated from the time of response and the known velocity of the energy wave. The use of RADAR technology has big advantages over other types of sensors in that the long wave lengths of energy used are not affected by clouds or bad weather so RADAR can be used under any weather conditions. Also, since RADAR is an active system, i.e. it provides its own source of energy (the emitted wave pulse), RADAR does not need daylight to provide a source of energy and hence can be flown at night.[30]

In general, aerial remote sensing, using any of the systems described above, is an important means of providing environmental data for coastal resource management problems. Technology in this field has progressed rapidly so that now the resource researcher has several tools available. Selection of which system to use is dependent on such factors as spatial and spectral resolution needed, and cost and time of acquisition, processing and interpretation. Indeed, each of these systems is the best for specific tasks.

The development of satellite remote sensing is in many ways, a direct outgrowth of the technology developed for some of the aerial sensors just discussed. The history of the early development of satellite technology is truly fascinating; for it provides an interesting look at the

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[30] Ibid., 115-117.

motivation of the early players (the US and USSR) and insight into the present and future objectives of remote sensing. However, the present discussion is limited to the sensors themselves, particularly those most useful to the field of resource management in the coastal zone.

A useful sensor for coastal zone management measures reflected energy in several wave bands along a swath of ground area. Several satellite borne sensors are capable of making such measurements. The following discussion outlines the characteristics of the major sensors and satellites of interest to the coastal zone manager.

The Unites States' LANDSAT series of environmental satellites began with the launch of ERTS 1 (Earth Resources Technology Satellite, later renamed LANDSAT 1) in July 1972.[31] The first three satellites in the series, LANDSAT 1,2 and 3, carried a multispectral sensor analogous to the MSS flown on aircraft. The sensor measured energy in four channels or wavebands; 2 visible (green and red) and two near infrared. A single scene covered a ground area of 185 km by 185 km and had a spatial resolution of 79 meters. These satellites had a repeat cycle of 18 days.

LANDSAT 4 and 5 (launched 16 July 1982 and 1 March 1984,[32] respectively) carry a second important sensor in addition to the original MSS. The Thematic Mapper (TM)

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[31]Lintz and Simonett, 324.

[32] Ray Harris, Satellite Remote Sensing: An Introduction (London and New York: Routledge and Kegan Paul Inc., 1987), 67.

records radiances in seven spectral bands. The bands are more narrowly defined than the MSS and in addition, record energy in the lower, blue/green band, and a total of three bands in the near and middle infrared range. The TM has a spatial resolution of 30 meters in all bands except for the thermal infrared, which has a spatial resolution of 120 meters.[33]

The earlier LANDSAT satellites also carried a television camera system known as the return beam vidicon (RBV). The cameras recorded scenes in three different wavebands. Unfortunately the majority of images collected by the RBV were of poor quality. While some of the data proved useful for special projects, the data was not used for general purposes because of the poor quality.

In 1985, the operational aspects of the LANDSAT series were turned over to a private firm, EOSAT. Presently data acquisition requests are handled through EOSAT. While EOSAT is a private company, much of its funding comes from the federal government.[34]

In 1985, the French space agency, Centre National d'Etades Spatiales (CNES) launched the SPOT 1 satellite. SPOT 1 uses a sensor which is mechanically very different than the MSS or TM. The satellite is equipped with two high resolution visible (HRV) instruments which can record information in either a panchromatic mode or a multiband

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[33]Ibid., 69.

[34]Ibid., 71.

mode. In the panchromatic mode, black and white images with a 10 meter ground resolution are produced. In the MS mode, data is recorded in three spectral bands at 20 meter ground resolution.

There are several advantages to having the twin HRVs aboard the satellite. The HRVs are capable of off-nadir viewing, meaning the HRV can be programmed to tilt away from the vertical (nadir) and record information about the ground to either side of the actual ground track of the satellite. This allows for much more frequent coverage of the ground. By using the off-nadir viewing capability the repeat time can be reduced to about five days. Since the satellite's orbit is sun synchronous, the resulting images will be recorded at the same sun angle on each successive pass. This allows for direct comparison between images (excluding cloud effects). Although the LANDSAT Satellites also have sun synchronous orbits, their sensors are fixed vertically and therefore can only view along the nadir track.

The off-nadir view also allows for stereoscopic imagery. The imagery can be analyzed in three dimensions by looking at different aspects (different viewing angles) of the same ground area. This technique is also used in aerial photography for mapping and terrain interpretation.

Data from the SPOT satellite offers many advantages over LANDSAT data. The ground resolution of SPOT is 10 and 20 meters while the resolution of LANDSAT is 30 m for TM and 79 m for MSS. However, SPOT data do not include a thermal infrared channel, which is included in TM data. Choice of which data to use depends on many other factors as well including which satellite collected data closest to the target date and location of the project area and the need for spectral and spatial resolution. Unfortunately, one major disadvantage common to both sets of data is their very high cost. Digital data costs on the order of two to three thousand dollars per scene while other products are very costly as well (see appendix A for ordering information).

NOAA operates a series of polar orbiting satellites known as TIROS-N or NOAA series. These satellites are designed as tools for meteorological studies. The main sensor is the Advanced Very High Resolution Radiometer (AVHRR) which collects data in four or five channels in the visible, NIR, mid IR and Thermal IR portions of the spectrum. The data from the thermal IR channel(s) are processed to produce sea surface temperature (SST) fields while the visible and NIR data show cloud cover. Because the primary purpose of the AVHRR is to provide meteorological and oceanographic data, frequent coverage is more important than spatial resolution. Each satellite makes two passes of the same area each day with a ground resolution of 1 km. Presently three of the satellites are still operating: NOAA-9,10 and 11; providing repeat ground coverage several times each day.

Since the NOAA series AVHRR data have 1 km ground resolution it is generally too coarse to provide the detail needed for land use mapping. However, several projects (discussed later) have shown how this data can be used for a variety of coastal studies. In the coastal and shelf waters along the east coast AVHRR SST data are used quite frequently to monitor water mass movements and SST fluctuation in terms of fisheries studies.[35] The data from the visible channels may be used to map very large land areas as well.

The Coastal Zone Color Scanner (CZCS), flown on the NIMBUS-7 satellite, was designed for oceanographic applications. The CZCS measured energy in six wavebands of the visible, NIR and Thermal IR at a ground resolution of 800 meters.[36] The channels were designed so that after appropriate processing, estimates of chlorophyll and hence primary productivity can be calculated (among other things). This data set has proven to be very useful for biological oceanographic studies. Unfortunately the CZCS stopped collecting data in the summer of 1986,[37] and although scientists have expressed great interest in continuing to collect such data, budgetary and political problems have

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[35] See for example, Margaret H. Sano and Carol P. Fairfield, "Anticyclonic Warm-Core Gulf Stream Rings of the Northeastern United States during 1988", NAFO SCR Doc 89/g4, Serial No. V1644, Scientific Council Meeting, June 1989, Dartmouth, Nova Scotia.

[36] Lintz and Simonett, 166.

[37] James A. Yoder, Wayne E. Esaias, Gene C. Feldman and Charles R. McClain, "Satellite Ocean Color - Status Report: Considerable Progress has been Made" in Oceanography Magazine 1, (July 1988): 18-20.

thus far prevented the launch of any new satellite with similar capability.

Other satellite sensors are flown (or have been flown) by the U.S. and several other nations. Although many sensors are designed for special projects, some of the data may be useful for a variety of coastal applications. The Heat Capacity Mapping Radiometer, for example, provided thermal inertia data used for geologic mapping. The GOES satellites provide meteorological information on a real time basis. Although the GOES imagery is much too coarse (8 km resolution) to assist in land use mapping, it certainly provides coastal resource managers with valuable advance information on severe storms and hurricanes through local weather forecasting.

Applications of Remote Sensing Data

This section looks at how remotely sensed data are being applied to a variety of environmental, resource and oceanographic studies. In this context, it is noted that land resource management has already benefitted a great deal from remotely sensed data especially in terms of large area land use mapping and agricultural projections. Likewise, the oceanographic research community has developed an extensive program of applications particularly for satellite derived data. The coastal zone, the interface between the land and the sea, is unique in many ways offering special resources as well as presenting specific problems. So far remote sensing has been used much less frequently in the coastal zone. The purpose of this section is to look at the types of problems which can be addressed in the coastal zone. Some of the studies reviewed here directly relate to Rhode Island coastal problems. Other studies show a range of uses which suggest future utility for the state.

Aerial photography has been used extensively in Rhode Island as a tool for understanding coastal processes. One such study by Donald Regan, measured long term locational changes of two important beach features, the high tide line and the dune line, along the state's southern coast.[38] The coastline has seen many changes both gradual and catastrophic. This type of study has implications for establishment of shoreline protection programs as well as setting construction restrictions and set back limits.

Regan analyzed aerial photographs from the years 1939, 1959, 1963 and 1975. Problems of variability of photographic scale due to aircraft orientation (pitch, roll and yaw), altitude changes and ground relief displacement were mitigated using ground control measurements. Distances between control points such as buildings were measured in the field. The corresponding photographic distances were

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[38]Donald R. Regan, "An Aerial Photogrammetric Survey of Long-Term Shoreline Changes of the Southern Rhode Island Coastline" (Unpublished masters thesis, Department of Geology, University of Rhode Island, 1976), 3-5.

measured also, then photographic scale was calculated as a ratio of the two distances.[39]

After the photographic scale was accurately determined, measurements were made on the photographs from reference points to the high tide line and again to the dune line. The high tide line was chosen as the change in gray tone on the photograph representing the difference in water content. The line of debris, often left by the last high tide, was also used to identify the high tide position. The dune line was taken as the seaward base of the vegetated sand dune also distinguished by differences in gray tone.

This method of photogrammetric analysis was quite successful. Annual and mean changes in shoreline location between survey years and throughout the entire study period were calculated. Evidence of gradual coastline changes and specific effects of major storms (i.e. 1954 hurricane) were apparent. The study concluded that the southern coastline has been erosional since 1939, although erosion rates have varied significantly during the time and locally, some accretion occurred as well.[40]

A similar study used aerial photographs from 1939 and 1975 surveys to measure the change in area of certain beach zones.[41] The purpose of this study was to determine the

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[39]Ibid., 9-10,18.

[40]Ibid., 62-63.

[41]Elizabeth J. Simpson, "A Photogrammetric Survey of Backbarrier Accretion of the Rhode Island Barrier Beaches"

relative importance of overwash and tidal fan deposition on the overall sediment budget. Areas were calculated using a ruled square or grid method, in which beach zones were drawn on acetate overlays then a grid was placed over the acetates and the number of squares per zone were counted. The measurements showed that much of the barrier beach loss due to erosion can be accounted for by deposition in the washover and tidal fan areas of the coastal ponds.

Aerial photogrammetric studies such as those just discussed describe how the coastline has changed over time. The studies also show the importance of beach processes and coastal features in providing a buffer against erosion and storm action. With this knowledge, managers can design appropriate set back limits to provide adequate safety for construction. Also, programs can be developed to protect the dunes (which in turn protect the coast) from storms and maintain the natural sediment budget processes.

Aerial photography and satellite imagery have been used elsewhere in the United States to describe beach processes. A Florida study demonstrated the feasibility of using digital image analyses to monitor changes in coastal geomorphology. Using georeferenced LANDSAT TM data (band 4) the land-water interface was identified. The pixels which appeared to contain an even amount of water and land were chosen as the interface, meaning that the high water mark was assumed to be within the 30 by 30 meter pixel. Using

(Unpublished masters thesis, Department of Geology, University of Rhode Island, 1977), 24.

this technique the researchers identified and quantified changes in beach morphology.[42]

In less accessible areas satellite imagery have been very useful in monitoring coastal changes. In one study, shoreline changes along the Nile delta coast were measured using digital differencing techniques on four LANDSAT MSS data sets. Using this technique, an acceleration of coastal change following the completion of the Aswan high dam in 1964 was measured. The annual changes were often large enough to be identified in LANDSAT MSS data. Although the MSS data resolution of 80 m was not always adequate for quantifying year to year changes, the method provided a means of identifying areas requiring more focussed investigation using aerial photography and ground activities.[43]

Land use and land cover classification objectives benefit greatly from the use of satellite derived data. Both NOAA and GOES satellite data have been used for vegetation indexing.[44] NOAA AVHRR data have also been used

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[42]Gail A. McGarry, Kenneth D. Haddad, and Larry J. Doyle, "The Potential Use of Satellite Imagery for Monitoring Coastal Beach Processes" in Technical Papers 1986 ACSM-ASPRS Annual Convention, Washington D.C, 328-337.

[43]H.W. Blodget, P.T. Taylor, and J.H. Roark. "Satellite Mapping of Nile Delta Coastal Changes" in Proceedings 1989 ACSM-ASPRS Annual Convention, Baltimore MD., April 2-9, 1989 vol. 3, 321-327.

[44]H. W. Yates et al., "The Role of Meteorological Satellites in Agricultural Remote Sensing," Remote Sensing of Environment 14 (1984): 219-233.

to map lake ice, snow cover and water quality.[45] Although these procedures are not particularly suited for Rhode Island because of poor spatial resolution, they do illustrate the range of possibilities available with meteorological satellites.

LANDSAT and SPOT imagery have been extremely well suited for land use and land cover classification studies. In New Jersey for example, LANDSAT MSS imagery were used to classify land use in the Cape May area by the state Department of Environmental Management as part of its coastal zone management program. At least 38 different land cover types were identified by supervised classification schemes at an accuracy of about 1.1 acres (later analyses using TM data greatly improved spatial resolution.)[46] Several other land use and land cover mapping projects have been described in SPOT Image Corporation promotional literature.[47]

Wetlands mapping and inventories have been aided by aerial photography and satellite derived data. A University of Connecticut study analyzed false color infrared aerial photographs to identify seasonal differences in plant

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[45]U.S. Department of Commerce, National Earth Satellite Service, Use of NOAA/AVHRR Visible and Near-Infrared Data for Land Remote Sensing, by Stanley R. Schneider, David F. McGinnis, Jr., and James A. Gatlin. (Washington, D.C.: NOAA Technical Report NESS 84, September, 1981), 5-31.

[46]Behie, 42.

[47]See Appendix A for available information and address of SPOT Image Corporation.

species coverage of wetlands. Satellite imagery were then processed to confirm wetlands boundaries and classify land use types in the surrounding uplands areas.[48]

Digital differencing techniques were used in studies of the Grand Bayou, Louisiana (Cameron-Creole watershed) to quantify changes in marsh zone area. LANDSAT MSS data from 1972 and 1981 were processed to develop a land/water classification. A gridding procedure was then used to measure differences in land and water coverage from 1972 to 1981. The results indicated significant land loss in the marsh zone due to salt water intrusion from marshland subsidence.[49]

In many of the landward studies just discussed, aerial photography when available, is more suitable than satellite data because of its greater resolution. Although, there are times when satellite data may be as accurate for boundary designation and biomass identification. One study which compared the performance of several types of remotely sensed data indicates that both the LANDSAT TM and SPOT data are reliable for mapping salt marshes, coastal land use, wetlands biomass and tidal inundation.[50]

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[48]Behie, 15.

[49]R.E. Pelletier and D.D. Dow, "A Gridding Approach to Detect Patterns of Change in Coastal Wetlands from Digital Data" in Proceedings of the of the ASPRS Annual Convention. Reno, Nevada. October 4-7, 1987, 119-128.

[50]M.A. Hardisky, M.F. Gross, and V. Klemas, "Remote Sensing of Coastal Wetlands" Bioscience 36, (July/August 1986): 453-460.

On the water side of the coastal zone, remote sensing techniques are even more important to the researcher because of the added difficulty and expense of gathering in-situ data on the water. Aerial photography has been the traditional method of collecting data, however, satellite data have been used in a number of studies and in some cases may be the preferred technology. Many of the studies discussed here have direct application to problems in Narragansett Bay, the coastal ponds and nearshore oceanic processes in Rhode Island.

The Chesapeake Bay is perhaps the most well studied estuary in the U.S. After more than a century of pollution and degradation from a variety of sources, the Chesapeake is an example of many of the problems associated with coastal development and human impact. Perhaps because of its deteriorated state, the Chesapeake has become the test site for new methods to understand environmental processes and monitoring water quality. Several studies have used aerial photography and satellite data as tools to understanding the changes taking place in the Chesapeake. Some of these studies are discussed below.

Submerged aquatic vegetation (SAV) is a key component of the Chesapeake's ecosystem. SAV provides nursery areas and shelter for many species of fish and shellfish. It is an important food source for water fowl. SAV also reduces shoreline erosion by dampening the impact of wave action. Because of SAV's role in the ecosystem, it is important to be able to map accurately the distribution of SAV and measure distribution changes over time.

The first effort to produce a comprehensive inventory of the SAV in the Chesapeake began in 1958. The study was conducted by boat, which was inadequate because of the limited coverage possible. Other boat station surveys were attempted, but these also could not provide the areal coverage needed. In 1978, EPA funded a project to inventory the SAV using aerial photography coupled with a seaplane sampling program.[51]

The 1978 survey used aerial photographs taken at 12,000 feet with black and white negative film and a yellow filter to first classify the different species of SAV and map their areal extent. The seaplane team then gathered ground truth data to clarify species distinction on the aerial photographs. The result of this two step program was the completion of a 3,825 square mile inventory at a lower cost and with more accuracy than previous in-situ methods. The distribution maps that were produced were then used for several other bioassessment projects including water fowl counts.[52]

An important measure of coastal water quality is the amount of nutrients and sediments suspended in the water column. Unfortunately, the areal extent of nutrient and sediment suspension change rapidly because of factors such

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[51]Behie, 9.

[52]Behie, 10-12.

as winds, river discharge and circulation patterns. It is therefore difficult to measure such quantities accurately using shipboard measurements because of the need to cover large areas synoptically. Remote sensing techniques may provide the means to make needed measurements, however an important factor in the utility of any data source is the need for very frequent data collection (on the order of several hours to days.) AVHRR data provide the needed frequency with a repeat time of between once and twice a day, however appropriate algorithms are needed to estimate suspended sediment and chlorophyll contents.

Researchers at NOAA have developed algorithms for the AVHRR data to estimate the amount of suspended materials and have tested their methods on the waters of the Chesapeake Bay. Results showed that application of the algorithm can provide acceptable estimates of both suspended sediment and chlorophyll contents in turbid coastal waters. Although these estimates may not be as accurate as shipboard measurements they provide important synoptic data particularly useful for input into models. Also the algorithms developed may also be used with other satellite data such as LANDSAT TM and SPOT to allow estimates in smaller estuaries, like Narragansett Bay, where the 1 km spatial resolution of AVHRR is too coarse.[53]

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[53]U.S. Department of Commerce, National Environmental Satellite Data and Information Service, Application of AVHRR Satellite Data to the Study of Sediment and Chlorophyll in Turbid Coastal Water, by Richard P. Stumpf. (Washington,

Another use of remotely sensed data is the study of circulation patterns and plume interaction in coastal waters. Understanding water circulation may help in siting assessments for energy plants and other industrial activities. Also fisheries studies may be enhanced by knowledge of water circulation patterns. Studies of this type include both regional large area mapping and specific local projects for site assessments.

In a regional study, LANDSAT MSS data and scenes from the Heat Capacity Mapping Mission (HCMM) were analyzed visually to identify plumes and turbidity and temperature boundaries in six coastal areas along the U.S. Atlantic Coast. The areas selected included Long Island Sound, the Chesapeake, Delaware, New York, Massachusetts and Narragansett Bays. Other environmental data including wind data and tidal records were used to help describe the behavior and movement of identified plumes. Through analysis of the imagery, major circulation patterns were characterized and seasonal changes in turbidity were identified. In addition, plume interaction with waste disposal areas (dredge spoil sites and sewage sludge dumpsites) were also identified and described.[54]

D.C.: NOAA Technical Memorandum NESDIS AISC 7, March 1987), 49pp.

[54]U.S. Department of Commerce, NOAA Estuarine Programs Office, LANDSAT Analysis of Coastal Turbidity Dynamics Along Northeastern North America, by John C. Monday, Jr and Michael S. Fedosh. (Final Report Contract NA-80-FA-C-00051, October, 1989), 2-19.

Two other studies have shown the utility of remote sensing data for specific project siting analysis. The first study took place in the coastal ponds of southern Rhode Island. The New England Power Company commissioned a survey of coastal ponds to determine possible effects of constructing a nuclear power plant along the coast. Potential environmental impacts of such a project included the thermal changes caused by the plant's cooling system and entrainment of organisms by the plant's intake system. A survey was therefore needed to measure water circulation patterns in the coastal ponds.[55]

Researchers analyzed aerial photographs collected using a thermal mapper with a spatial resolution of 2.5 meters. Ground truthing and calibration were obtained using in-situ temperature monitoring stations located at the mouth of the Charlestown breachway and just offshore. The results showed that the aerial photography was useful in monitoring water movements in the coastal ponds. With appropriate in-situ measurements thermal discharge rates and flushing rates were also calculated.

In the second study, aerial photography in conjunction with dye-buoy placement was used to map coastal circulation to facilitate the location of an outfall. In this project, the dispersion rates and water circulation patterns for Newport News Point, Virginia were identified in order to help choose a site for a sewage outfall for a proposed

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[55]Behie, 16.

sewage treatment plant. Small dye releasing buoys were placed in the water at several locations, sequential aerial photographs were taken which showed the dispersion pattern of the dye at various times after release. Results indicated that the proposed location of the outfall would have harmful effects on nearby oyster beds. The outfall site was subsequently moved further north to better protect the oyster beds.[56]

The purpose of this section has been to illustrate the wide range of uses for various types of remotely sensed data. It is evident that aerial photography and satellite derived data play an important role in coastal studies ranging from large area mapping to small site specific projects. The selection of the type of data to be used depends on the requirements of the task at hand. Coastal problems in Rhode Island may be better addressed by aerial photography because of the need for greater spatial resolution. However, satellite data especially LANDSAT TM and SPOT imagery may be used to augment in-situ data and aerial photography.

Given the promising results discussed in the literature it is logical to ask about the extent to which these tools are being used in Rhode Island. Furthermore, is there a need to increase the use of these techniques in problems confronting the coastal zone? These are the questions to be addressed in the survey section of this paper. First

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[49]Behie, 25-27.

however, It is important to consider another important technology being used in Rhode Island, geographic information systems (GIS). The next section discusses GIS in detail including the present capabilities within the state and potential uses, especially in conjunction with remotely sensed data.

III. GEOGRAPHIC INFORMATION SYSTEMS

The purpose of this section is to describe how a GIS works, what its capabilities are and how these are applied to problems of coastal area management. The discussion is mainly focussed on the ARC/INFO software package by ESRI[57] because of its popularity among regional users and because of its virtual monopoly within Rhode Island. The facilities of URI and joint programs with state agencies are also described. Studies within and outside of the state showing the feasibility of GIS and the link between GIS and remote sensing are reviewed.

It is important to understand why GIS is included within the overall scope of this study. Although the original intent was to assess the use of various remote sensing techniques within the state, it quickly became obvious that many obstacles to their use hinged on the inability to integrate remotely sensed data with other

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[57]ARC/INFO is the registered trade name of the GIS product produced by Environmental Sciences Research Institute, Redmond, CA.

environmental and resource data. This problem is particularly acute for satellite data due in part to the very technical nature of the processing procedures. GIS offers a key link between satellite data and other data. It also provides analytical capabilities otherwise not available. There is no attempt here to equate GIS with remote sensing data or to suggest that one technology cancels the need for the other. In fact the two techniques are quite complementary and as described later, combining these technologies makes them both more powerful tools to the coastal manager.

Definition of GIS

The term GIS has a variety of meanings in the literature, all with a common thread. Some authors describe GIS as a computer system capable of handling spatial data. Others have concluded that GIS is more broadly defined as an "information technology, which stores, analyzes and displays both spatial and non-spatial data."[58] Although it is debatable whether GIS is a technology or a system, perhaps all agree that several components make GIS unique and distinct from computer aided mapping and databases taken separately.

The main requirements of a GIS are: spatial data input and display capabilities; the capacity to perform spatial

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[58]H. Dennison Parker, "The Unique Quality of a GIS" Photogrammetric Engineering and Remote Sensing 54 (November 1988): 1547.

analysis of many data sets; and the ability to produce hard copy output such as maps and other products of the spatial analyses.[59] The range of combination of hardware and software available to accomplish these tasks is enormous. It is the ability to provide the four requirements, particularly spatial analysis, that distinguishes a GIS from other technologies such as computer aided design systems. Although these tasks may sound fairly easy to accomplish, it is really quite complicated to digitally define and analyze spatial relationships. A key element of the importance of any GIS is its ability to input data an any scale and store it independent of its scale. This means that analyses of different data sets can be done quickly without the need to convert between map scales.

There are two different ways of storing information in a GIS, the raster based method and the vector based scheme. The term raster refers to a regular spaced grid which divides an area into equal size cells. A raster based GIS stores spatial data in terms of these cells or pixels. The vector based GIS defines spatial features in terms of points, lines and polygons. Many of the studies described in the next section use vector based GIS (the format of ARC/INFO.) The raster based data structure provides the simplest method of storage. One major disadvantage of the

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[59] D.F. Marble "Geographic Information Systems: an Overview" in Pecora 9 Proceedings Spatial Information Technologies for Remote Sensing Today and Tomorrow, IEEE. Sioux Falls, SD, October 2-4, 1984, 18-24.

raster system is the inability to divide pixels, therefore area and volume calculations must be based on whole pixel counts. Vector storage on the other hand, attempts to represent objects as exactly as possible through the use of coordinate space. Another disadvantage of a raster system is that it requires a much greater storage capacity (of the host computer) than the vector approach. The vector method uses "implicit coordinates that allow complex data to be stored in a minimum of space."[60]

The difference between raster and vector data structures and the relative advantages of each are very complex. The distinction between the two structures is important because most satellite data processing systems are raster based while the more common GIS packages are vector based. The ability to link the two structures is an important aspect of the potential use of remote sensing data.[61]

The Rhode Island Geographic Information System (RIGIS) project has been developed using the ARC/INFO software package. ARC/INFO is hardware independent and therefore may be installed on a variety of machines ranging from personal

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[60]P A Burrough, Principles of Geographical Information Systems for Land Resource Assessment (Oxford: Oxford University Press, 1986), 1.

[61]For a more complete discussion of the differences between vector and raster based GIS see G. Maffini, "Raster versus Vector Data Encoding and Handling: A Commentary" Photogrammetric Engineering and Remote Sensing 53 (October 1987): 1397-1398. and S. Tilley and S. Sperry "Raster and Vector integration" Computer Graphics World (August 1988)

computers (pc) to main frames. The software package consists of two major sub-components. ARC is the software which is used to enter, analyze and output spatial data. INFO is a relational data management software which stores and selectively retrieves the descriptive or attribute data associated with the geographical features input in ARC.

Information about a given set of environmental or land use characteristics is entered into ARC/INFO basically in two steps. First the areas or geographical units are digitized as points, lines or polygons. For example, state and town jurisdictional boundaries are digitized as polygons. Then the attribute data associated with each shape are entered into the system. This combination of geographical units and attribute data is called a data layer or coverage. ARC/INFO automatically creates a number of files for each data coverage which are needed in order to manipulate the spatial data.

ARC/INFO is capable of analyzing all of the data coverages entered in the system to produce a variety of outputs. For example the system allows the user to quickly analyze and display locations of municipal wells together and with known sources of industrial pollution. Without the aid of the GIS such an analysis would be tedious and time consuming. Obviously, GIS is a powerful tool for many different resource management problems in coastal areas.[62]

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[62]This basic description of ARC/INFO is interpreted from personnel communication with Peter August and taken

Rhode Island GIS

RIGIS began as a joint project of the Department of Natural Resources (DNR) at URI and the state Department of Environmental Management (DEM) in 1985. DEM had already completed a feasibility which provided recommendations about GIS products to meet specific needs of the department. The agency recognized the many advantages of combining the technical expertise and computer resources at URI with their own data inventory and funding sources. The original agreement called for DEM to design and prioritize applications for the GIS and for URI to develop the database and carry out GIS analysis.

In 1986 the Environmental Data Center (EDC) was established within the Department of Natural Resources (DNR) at URI. The first ARC/INFO package was purchased for installation on a prime minicomputer and necessary peripheral hardware (terminals, digitizers, plotters) were purchased. RIGIS became operational with the short term goals of developing coverages for fundamental data layers and the ultimate objective of making GIS an integral part of the overall effort to protect and manage the state's natural resources.[63]

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from notes provided during a short course in ARC/INFO taught by Dr. August in November 1989.

[63]Peter August, William R. Wright, and Robert L. Bendick, "Incorporating GIS Methods in the Natural Resource Manager's Toolbox: Lessons From the Rhode Island GIS Project" in Proceedings of the International Geographic Information System Symposium: The Research Agenda, NASA, 1987, 477-478.

Today, RIGIS is a strong cooperative program with the following five major users: Department of Environmental Management (DEM); University of Rhode Island (URI); Department of Transportation; Solid Waste Management Corporation; and the Division of Planning (DOP) within the Department of Administration. An executive committee oversees RIGIS policy. The committee is chaired by the state GIS coordinator and has representation from each of the major contributing agencies as well as the private sector.[64]

The state's environmental database includes over 25 different data layers in various stages of completion. All of the data are maintained on the URI computer except for transportation data which are kept at DOT. These data layers have been entered into the system either by EDC staff or by contracting consultants. The data are made available to state agencies at little or no cost. In addition, local municipalities can also receive the data for only nominal fees to cover tape processing costs.[65]

Indeed, since 1986 RIGIS has grown considerably and continues to play an ever increasing role in the protection and management of the state's natural resources. Many different groups within the participating agencies are

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[64]Presently, John Stachelhaus serves as State GIS coordinator, under contract to DOP. The State Legislature is considering providing funding to establish a permanent position within the DOP. (Personal Communication, John Stachelhaus.)

[65]Personal Communication, Peter August.

finding new uses for the GIS database. At URI, GIS has become an integral part of the Natural Resources Department's ability to conduct research and provide teaching opportunities. In addition, several other academic departments including Community Planning, Marine Affairs, Geology and Civil Engineering, have used the facilities of the EDC for research in other disciplines.[66]

In 1989 three URI departments were jointly awarded a grant from the Champlin Foundation to further expand the capabilities of GIS by providing a software link to satellite derived data. The DNR, the Department of Marine Affairs (MAF) and the Oceanographic Remote Sensing Laboratory (ORSL) at the Graduate School of Oceanography (GSO) were awarded the money to purchase ERDAS, a raster based processing package, and the linking software to integrate ERDAS processed data into the ARC/INFO GIS.

The EDC has already installed the ERDAS package as part of a PC based ARC/INFO station. Although the station has not been used operationally yet, a recent demonstration illustrated how powerful this tool will be in the future especially for updating some of the data layers already in use. The ORSL and MAF are in the process of purchasing and installing the needed software and it is expected that all three systems will be operational in late 1990.[67]

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[66]Personal Communication, Peter August.

[67]Demonstration of ERDAS and LIVELINK by Peter August.

GIS Applications

Various examples of successful GIS development are found in the literature. GIS databases have become an important component in many different areas of resource management and use planning. In addition, specific policy decisions have been improved by GIS analyses. This section describes some of those successes including studies which integrate remote sensing techniques with GIS.

An early test of GIS utility for resource management took place in north-central Connecticut in 1984. The project was a joint venture of the US Geological Survey (USGS) and the Natural Resources Center within the Connecticut Department of Environmental Protection.[68] The purpose of this study was to use GIS to improve traditional methods of handling many sources of natural resource data. ARC/INFO was chosen because it was already in use at other USGS locations and because the state officials were familiar with the database management portion already in use within the state. Data coverages for geologic, biologic and water resource inventories as well as land use and cultural information were entered into the database. Original data sources came from both USGS and the state. Several applications of the GIS were then tested.

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[68]David A. Nystrom et al., "USGS/Connecticut Geographic Information System Project" in Technical Papers 1986 ACSM-ASPRS Annual Convention, Washington D.C, 211-219.

The Connecticut GIS was successful in automating processes needed for industrial site selection. The GIS evaluated all potential industrial sites within the study area considering factors such as wetland location, flooding, environmentally sensitive areas and species, water supply and infrastructure availability. The final product was a map identifying suitable sites and a list of characteristics for each site. GIS analyses were equally successful in groundwater availability determination and two modelling efforts.[69]

In another demonstration project, the state of Vermont used an ARC/INFO database to address three specific problems associated with groundwater resources and pollution threats. The analyses were conducted using the computer facilities at the University of Vermont and incorporating several data coverages already available on the University's ARC/INFO system. The analyses produced results regarding the identification of pollution sources, distribution of radon contamination in water supply wells and waste water treatment facility siting. The results were used in a number of policy and management decisions by the state Health Department and other agencies.[70]

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[69] Ibid.

[70] William Hendrix and David Buckley, "Geographic Information System Technology as a Tool for Ground Water Management" in Technical Papers 1986 ACSM-ASPRS Annual Convention, Washington D.C, 230-239.

The Florida Department of Natural Resources, burdened with the awesome task of managing the state's coastal wetlands, realized the need for a GIS to more effectively map and inventory all of the wetland resources. ELAS, a raster based image processing and GIS package, was chosen because of its capability of processing and analyzing satellite images, a major source for much of the resources database. Data sets such as wetlands boundary maps, vegetation cover, sediment distribution, topography, biological habitats, and water characteristics were entered into the database from various sources including classified satellite imagery. Pilot studies showed the utility of the GIS as a tool for managing the wetlands especially in the face of increased pressure from development and population growth.[71]

As the potential uses for GIS became apparent through the many feasibility studies and pilot projects, researchers turned their attention to providing operational support for GIS including improving methods and sources of database input and updating. An important input was obviously satellite imagery and other forms of remotely sensed data. Several studies examined the link between remote sensing and GIS, developing new techniques and applications for integration of the two. A few of these studies are discussed here.

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[71]Kenneth D. Haddad and Barbara A. Harris "A Florida GIS for Estuarine Management" in Technical Papers 1986 ACSM-ASPRS Annual Convention, Washington D.C, 2-11.

After initial input into GIS databases, information must be continually updated. This is particularly important in areas where development and population growth occur at a very rapid pace. SPOT MS and panchromatic data can provide the frequency of coverage at adequate resolution to detect change and update existing data layers. Researchers in Maine demonstrated the potential of using SPOT data for this purpose. The study area, near Portland, ME underwent significant growth and development over a ten year period, such that existing land use maps were out of date.[72] Processing of a recent SPOT image included merging the MS and panchromatic data to enhance spatial resolution, georeferencing the digital data to USGS topographic maps and classification of land cover types. Land use classes were then verified with visually interpreted aerial photographs and the resulting classes were then digitized into the GIS database. Growth analysis was accomplished by statistical comparison between the 1986 and 1975 land use data layers. Results were used in land use planning and management decisions.[73]

Research at the Canadian Centre for Remote Sensing has included much work in the integration of remote sensing data and GIS. Sophisticated raster based image analysis systems have been used to process and classify LANDSAT TM and SPOT

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[72]Mark A. Jadkowski and Manfred Ehlers, "GIS Analysis of SPOT Image Data" in Proceedings 1989 ACSM-ASPRS Annual Convention, Baltimore MD, April 2-9, 1989 65-74.

[73]Ibid.

data. Researchers have used the extensive GIS database to aid in the classification schemes for the satellite data. Then the results have been input to the vector based GIS. Several difficulties of integrating remote sensing and GIS which require the development and use of expert systems have been identified. In general however, integration procedures have shown great promise and are considered to be essential in aiding resource managers in maintaining resource databases.[74]

There are many other studies cited in the literature which describe integration methods and applications. Clearly both remote sensing and GIS technology are important tools in resource management. Integration of these two tools provides an added dimension to their effectiveness for planning and management. The projects described here have direct and indirect relevance for resource management in Rhode Island's coastal zone. Processing and analysis techniques are adaptable to many of the conditions found in this state. The next section describes the design and implementation of a survey to measure coastal managers' use of various remote sensing techniques and GIS in Rhode Island.

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[74]David G. Goodenough, "Thematic Mapper and SPOT Integration with a Geographic Information System" Photogrammetric Engineering and Remote Sensing 54 (February 1988): 167-176.

IV. SURVEY METHODS

One of the purposes of this study was to determine the actual use of various remote sensing techniques and GIS by coastal managers and planners in Rhode Island. It was determined that the most efficient method of collecting this information was by survey. This section outlines the methods followed in survey design, testing and implementation.

Survey Design

Telephone interviews were chosen as the primary method of conducting this survey. The telephone technique offered several advantages over other alternatives. Mail back questionnaires were unsuited because they did not allow for flexibility in questioning format and precluded interaction between the interviewer and the interviewee. It was determined that such interaction would be critical especially since the intended audience had a wide variety of knowledge and familiarity with the subject matter. Another problem with mail back questionnaires was it did not allow for elaboration of answers as deemed necessary. Finally due to the time requirement of mail back questionnaires it did not allow for adding new names to the survey list throughout the process.

In-person interviews were ruled out because of the expense and time of travel and because of the difficulties in scheduling appointments. The telephone method allowed interaction and further explanation when necessary and was also the most time efficient. Given the nature of the study, statistically rigorous results were not expected. Instead it was anticipated that general perceptions and practices would be identified.

A survey questionnaire was designed. The form consisted of three main sections: Aerial photography; satellite data; and GIS. Each section contained questions about the use of the technology and the factors involved in deciding whether or not to use it. Follow up questions about the use of integration techniques and participation in joint projects were included.

Pilot Testing

In order to test the clarity of questions and overall effectiveness of the survey, pilot testing was conducted. Several coastal managers from federal and state agencies outside of Rhode Island were interviewed. Pilot testing showed a number of general problems with the survey as well as specific problems related to clarity and comprehension of the questions.

One major design flaw was the flow of questions after a negative response from the initial use question in each category. If a respondent had not used the technology before, often s/he was not able to answer the follow up questions. This problem was particularly apparent in the satellite data section. A major reason for not using satellite was the need for greater resolution. When this response was given, the remaining questions often became moot. Rather than removing the negative follow up questions from the survey, it was decided to retain them in a modified form. If the answer to the lead questions were such that follow-up questions would be ineffective then the questions would be omitted from the interview.

Another observation made during the pilot testing was that the three technologies were often handled by different people within a group. Often an interviewee would defer questions for a technology to a co-worker. Since the overall objective was to explore perceptions (rather than perform rigorous statistical analyses of the results) this was not a major problem. It simply meant that more people would have to be interviewed.

The phone interview often became a general discussion. Sometimes it was hard to keep to the format of the survey during the interview. The only problem with this was the possibility of missing some key information. This was considered to be a problem with the interview technique and not a deficiency of the survey questions. It was decided that the interviewer should try to follow the format as closely as possible but not disregard information given during a more general discussion.

Responses to questions about the types of projects using the techniques were very general. Further questioning sometimes led to more detailed descriptions but often the respondents had difficulty describing specific projects because of an apparent desire to avoid technical discussions. One method of improving the response was to ask directed questions about a project. This technique was adopted in the final version of the actual survey.

The use of aerial photography was almost universal among pilot test subjects. This often made it difficult to describe in detail specific projects for which it was used. Instead answers were usually very general such as 'land use studies' and 'as base maps for siting projects.' Continued use in the future was always expected, so the question about future plans often did not need to be asked.

The satellite data use section required the most additional (supplementary) explanation by the interviewer. Respondents occasionally were not familiar with the types of satellite data available. More often, the respondents wanted to discuss remotely sensed data other than satellite imagery. Techniques such as side scan sonar and moored buoys were mentioned as other means of obtaining data remotely. Although the scope of this project did not encompass such methods it was interesting to note their use.

In general, the pilot testing helped to improve the effectiveness of the survey by identifying possible problems in the survey design. The respondents were very cooperative and showed significant interest in the subject matter. Respondents often provided names and phone numbers of other workers who would be appropriate as survey subjects. The changes discussed here were implemented during actual survey interviews. Additional changes were made as the interviews proceeded. The final survey form is given in appendix B.

Survey Implementation

Most of the phone interviews were conducted during a three week period in February and March 1990. An initial list of survey subjects was generated after receiving suggestions from Dr. Peter August. More names were added after interviewing John Stachelhaus who is in contact with many GIS users throughout the state. A list of private sector survey subjects was generated from appropriate listings in the telephone book. Also, planners from several towns were added to the list. During the survey more names were added to the contact list at the suggestion of some of the early respondents.

A total of twenty people were interviewed for the survey. The respondents represented a cross section of agencies and groups interested in coastal zone management including: Department of Environmental Management; Department of Transportation; Division of Planning; Rhode Island GIS; Narragansett Bay Project; Coastal Resources Management Council; private environmental consulting firms; engineering firms; Coastal Resources Center; and town officials from several municipalities. Some of the private firms contacted were not familiar with any of the technologies, therefore their responses were disregarded.

Some of the problems encountered during pilot testing continued to be apparent. Answers to initial questions often led to general discussions, however the interviewer always attempted to use the questionnaire as a check list at the end of each interview to ensure that no major points were missed. Since many of the respondents used aerial photography so extensively, some of the original follow-up questions from the survey form were too general and vague (i.e. how often; what kinds of projects; plans for future use). Instead the interviewer asked the user to describe how aerial photography was being used in daily operations. The discussion which followed provided the required information on the range of present and planned future use.

Responses to the GIS section almost always indicated either a direct link to RIGIS or knowledge of the system. Therefore, questions about the type of hardware and software used often referred to the facilities of EDC and RIGIS. In many cases where GIS was being used or was planned, especially at the local level, data coverages were just being entered into the database. Most application projects had just begun so follow-up questions were answered with speculation about the possible operational utility of the GIS.

Responses to the satellite data section were rather vague. No one was using satellite data for specific projects (because of perceived lack of need, see Results and Discussion) so all of the follow-up questions focussed on the factors for choosing not to use the technology. Interviews with other researchers may be needed to further investigate this area.

Respondents from state agencies were most cooperative during the interviews. Town officials and private sector representatives appeared to be somewhat bewildered by some of the questions. This may have been due to the fact that the local and private sector coastal managers have more limited interests than state officials. If the technology did not offer immediate utility to their objectives, the respondents tended to be less responsive, perhaps because of lack of familiarity with the technology. However, at least at the local level, the lack of familiarity with GIS may simply be due to the relative newness of the technology. Several communities, including East Greenwich, Narragansett and Portsmouth, are in the process of incorporating GIS in their planning functions. See the next section for further discussion of how these communities are using GIS.

In some cases, the survey form was only very loosely followed. A more general discussion technique was much more useful for some of the people surveyed. This was the case for people who provided a specific service or data product to other coastal managers. For example, workers at a large photogrammetry company were asked questions related only to the cost and production of their aerial photography services and products. Although these discussions did not follow the format of the survey, the responses are included as results where appropriate.

V. RESULTS AND DISCUSSION

In general, the survey results show that various types of aerial photography are being used at all levels of resource planning and management. On the other hand satellite imagery is virtually unused except in a few research oriented tasks associated with URI. Geographic information systems are considered to be a critically important tool for coastal management and the vast majority of those surveyed either are using GIS or have plans to gain access to a GIS in the near future. Specific discussion of the results is divided into the three main categories of the survey.

Aerial Photography

Most of the respondents indicated wide use of aerial photography. The sources of data ranged from using the state archive to flying specific areas for greater resolution. State agencies use what is available through the DOP. In most cases the individual departments have obtained duplicate sets of photographs from DOP. The state archive at DOP includes complete sets of air photography surveys from 1988, 1981, 1975, 1970 and 1965 as well as earlier photographs from specific sites. In addition, the state is participating in an aerial survey to be conducted in 1990 through the USGS, and photographs from that survey will also be included in the DOP archive.

At the local level, town planners have accessed photographs from the state inventory, however in some cases the towns have commissioned their own photogrammetric survey for specific projects. The Town of Narragansett, for example, recently flew the entire town at 1:100 scale and received the data in both planimetric form as well as digital format for later input to a GIS.

The most common uses mentioned for aerial photography were: conversion to base maps for site reviews; land cover classification; wetland delineation; construction permitting reviews; historical database for site violation studies; and as a data source for input to a GIS. All the users expected to continue using aerial photography in the future for similar projects. Cost was not a major constraint on its use since many respondents had ready access to existing photographs. However, the cost of commissioning aerial surveys is not inconsequential. The Narragansett survey described earlier, for example, cost approximately $115,000.

One photogrammetry company which has flown extensively in Rhode Island provided some insight into typical costs of implementing a photogrammetric survey. At a flight altitude of 4200 feet (flight scale: 1 inch = 700 feet) eight flight lines totalling 100 to 200 photographs cost approximately $3000. A full survey of 200,000 acres (approximately 312 square miles) in a densely populated area costs approximately $500,000. The services included in such a survey would include flying, controlling and processing and delivery of products such as topographic maps, planimetric data, tax mapping data and parcel information. It is important to point out that these figures were given only as very general estimates and actual costs could vary significantly depending on the needs of the community and objectives of the survey.

Satellite Data

Satellite derived data and imagery are virtually unused in Rhode Island for coastal zone management. The most common reason for not using it is that present satellites do not provide high enough spatial resolution to be adequate for coastal needs. To put this in perspective, Narragansett Bay is approximately 5-20 km wide, the spatial resolution of NOAA AVHRR data is 1 km meaning that only a few pixels would cover the entire width of the bay making differentiation of characteristics within the bay very difficult or impossible. On the other hand, even the relatively high resolution of LANDSAT TM (30 meters) and SPOT MS (20 meters) data is not adequate for site specific mapping such as boundary identification. LANDSAT and SPOT imagery are not particularly suitable to marine applications because their spectral bands are designed for land use and are therefore not sensitive to measurements of water characteristics.

Although factors of cost and lack of technical expertise constrain the use of satellite imagery, they are not major factors. The most important reason for not using imagery is the perceived lack of need by coastal managers. Most respondents simply indicated that they did not need to use the satellite data because aerial photography and other data sources were available which provided adequate coverage.

The only place where imagery is being used is at the EDC at URI. As mentioned earlier, software has just been installed to provide a link between the satellite imagery and GIS. It is expected that the imagery will be used to update many of the data coverages already available. The high cost of obtaining LANDSAT and SPOT data will preclude any near-real time continual use of the image, however it is expected that the data will play an important role in off-year updates.

Geographic Information Systems

The use of GIS is blossoming throughout the state. Coastal planners and managers at the state and local levels are extremely interested in building data coverages and of course, accessing coverages already available through RIGIS. At this stage many local coastal managers are just beginning to establish their own GIS foundation so most application projects are still in the planning phase.

Several state agencies have already purchased workstations and software with technical assistance from RIGIS. The Department of Transportation uses ARC/INFO on a main frame computer and trades data layers with RIGIS. DOT plans to use GIS in a variety of ways including preparation of environmental impact statements, wetlands mapping, and analysis of highway upgrade projects. The Division of Planning also has ARC/INFO available on a workstation and uses it for planning functions and updating the State's open space inventory.

Local planners are looking into ways of gaining access to the database either by purchasing hardware and software or by establishing joint projects with researchers at EDC. Narragansett is using GIS analysis in its comprehensive plan and for projects such as harbor management, the Narrow River Project, and growth management. Portsmouth will use GIS analysis to develop a new zoning map and parcel base data, tracing building permits and water hookups, reviewing site plans and designing a comprehensive plan. Other towns such as North Kingston and East Greenwich are also actively incorporating GIS into their planning and management functions.

The smaller private consulting and engineering firms are less likely to have their own GIS because of the cost of purchasing or building the data coverages. The engineering firms usually are hired to work on individual projects and therefore do not need the wide areal coverage available through GIS. Some consultants are providing technical expertise to town and state agencies that are in the process of establishing a GIS. These consultants generally do not maintain their own coverages and systems, instead they work directly on the systems that their clients are establishing.

Technical training in GIS is provided by URI through a semester long graduate level course, and by private companies including ESRI, the maker of ARC/INFO. Most respondents indicated that private training was quite expensive and whenever possible workers were sent to the URI course to receive more extensive training. Another source of technical training and support was in the form of informal contact with other more experienced GIS users. For some survey respondents, on-the-job training was the most important method of learning about GIS technology.

Other Observations

A few other questions were included in the survey. Respondents were asked to comment on topics such as general funding sources and constraints and the level of joint projects with other sectors (federal, state, local, academic and private.) Often these topics were also discussed as part of answers to other questions.

Funding constraints are seen at all levels, however surprisingly, budget problems are not always the primary reasons for limited use of a given technology. More often factors such as time, and lack of adequate staff are more important. Although, lack of staff can certainly be related to budget constraints.

Several joint projects between state, federal and university researchers are ongoing. The Narragansett Bay Project is perhaps the best example of a joint study, involving EPA, DEM and URI researchers. In some cases, formal joint projects are lacking but informal cooperative plans have been established for the exchange of data and technical advise. A major factor in the success of these exchanges is the state's obvious commitment to the ultimate goal of making GIS an integral part of resource management decision making process. This is clearly seen by the establishment of outreach programs and funding for positions such as the state GIS coordinator. The state has made a further commitment to GIS by providing access to the database by towns working on the comprehensive plans.

Summary

The results of the survey indicate that the traditional tool of aerial photography is widely used and will continue to be used by coastal planners and managers. GIS as a tool for resource management is progressing very rapidly and its use is being encouraged through state initiatives. Satellite data are not being used to any significant extent and their use is not likely to increase tremendously in the future. The one major exception to the lack of need for satellite data is as an input to GIS as a means of updating land use and land cover data sets through integration processes.

One objective of this study is to determine if steps should be taken to increase the use of remotely sensed data, particularly satellite imagery, by coastal zone managers. After analyzing the responses from the survey and reviewing the literature it does not appear to be appropriate to recommend any action to increase the use of satellite data at this time. The needs of coastal managers are being met with other technologies. The commitment to operational use of satellite data represents a heavy financial burden which is not justified here. Coastal planners and managers already have access to high spatial resolution data to provide much of the input to GIS databases.

It is recommended that the level of research use of satellite data be maintained or strengthened where ever possible. This use will receive a significant boost when the Department of Marine Affairs and the Oceanographic Remote Sensing Laboratory at the Graduate School of Oceanography install the ERDAS and ARC/INFO packages. These systems will complete the link with the EDC and certainly add to the level of research use of satellite data.

The purposes of this study have been to present a description of the characteristics and potential use of three important technologies and to investigate the use of these tools within the state of Rhode Island. It has been shown that aerial photography, satellite data and GIS all play a role in the protection and management of valuable resources in the state's coastal zone. Survey results have indicated that coastal managers are very interested in incorporating these tools as efficiently as possible in order to provide a better understanding of our physical environment and man's effect on it.

As is the case for most studies of this type, more work is needed to fully understand the roles and interactions of the technologies described here. Further surveys will help to chart the continued use of these tools and perhaps indicate patterns of use not identified here.

Appendix A

Satellite Characteristics and Ordering Information

LANDSAT Series: There have been five LANDSAT satellites launched to date. The first generation included LANDSAT 1, 2 and 3. LANDSAT 4 and 5 are considered second generation because of the addition of the Thematic Mapper sensor as well as other improvements. The Return Beam Videocon cameras flown on the first generation satellites were found to be less useful than expected and were discontinued on LANDSAT 4 and 5.

LANDSAT 1:
- Launched: July 23, 1972 (originally called ERTS-1)
- Terminated operation: January 6, 1978
- Primary sensor: Multispectral Scanner (MSS) 4 channels
- Spectral range: .5-.6, .6-.7, .7-.8, .8-1.1 microns
- Ground resolution at nadir: 79x79 meters (effective resolution 56x79 meters due to overlap.)
- Swath width: 185.3 km.
- Altitude: 920 km.
- Repeat cycle: 18 days
- Descending equatorial crossing time: 8:50 am.
- Also operated Return Beam Videocon camera for high resolution television pictures of the earth

LANDSAT 2:
- Launched: January 22, 1975
- Terminated Operation: July 27, 1983 (interruption in 1979-80)
- Operational characteristics same as LANDSAT 1.

LANDSAT 3:
- Launched: March 5, 1978
- Terminated operation: September 7, 1983 (Standby mode from March 31, 1983)
- Operational characteristics same as LANDSAT 1 with addition of Thermal Infrared Channel at 10.4-12.6 microns and a ground resolution of 237 meters. (The TIR channel proved to have a low signal to noise ratio and therefore not very useful.) Also two RBV cameras were used.

LANDSAT 4:
Launch date: July 16, 1982
Sensor: MSS, same spectral characteristics as first generation, slightly different ground resolution (82x82meters)
Sensor: Thematic Mapper (TM) 7 channels:
Spectral range: .45-.52, .52-.60, .63-.69, .76-.90, 1.55-1.75, 10.4-11.7, 2.08-2.35 microns
Ground resolution at nadir: 30 meters (except TIR band 6: 120 m.)
Altitude: 700 km.
Repeat cycle: 16 days
LANDSAT 4 Had several technical problems including the failure of the TM sensor in 1986.

LANDSAT 5:
Launched: March 1, 1984
Operational characteristics similar to LANDSAT 4.

Contact for LANDSAT imagery and products:

EOSAT
4300 Forbes Boulevard
Lanham, MD 20706
301-552-0500 or 800-344-9933

SPOT series: Presently only SPOT 1 has been launched and is operating, however others in the series are planned for launch. The two sensors aboard SPOT are identical, however because one can be tilted from the vertical, the satellite can image the same area several times per week. This off-nadir viewing is controlled on the ground therefore users can request specific coverage for an area.

SPOT 1:
Launched: February 21, 1986
Sensors: 2 high resolution visible instruments (HRV) 3 channels in MS mode
Spectral resolution: Panchromatic .50-.73 microns; MS .50-.59, .61-.68, .79-.89 microns
Ground resolution: Pan. 10x10 m,; MS 20x20 m.
Swath width: 60km./instrument; 117 km. combined
Altitude: 832 km.
Repeat cycle: 26 days (possible repeat time 2-5 days)

Contact for SPOT data and products:

SPOT Image Corporation
1897 Preston White Drive
Reston VA 22091
703-620-2200

TIROS-N series (NOAA series): The TIROS-N series is the third generation of the NOAA polar-orbitting satellites. The Prototype (TIROS-N) was launched in 1978. Since then, NOAA-6,7,8,9,10 and 11 have been launched. The even numbered satellites have four different channels (data from channel 4 is repeated on channel 5) and the odd numbered satellites have five different channels providing nearly continuous sea surface temperature information since 1982. Presently, NOAA-9 is still in orbit, however its data are received only occassionally. NOAA-10 and NOAA-11 continue to operate normally. Since many of the operating characteristics are similar in all of the satellites in the series only the data for NOAA-11 are presented here.

NOAA-11:

Launched: September 24, 1988
Primary sensor: Advanced Very High Resolution Radiometer (AVHRR) 5 channels
Spectral range: .58-.68 .725-.1.1 3.55-3.93 10.5-11.3 11.5-12.5 microns
Ground resolution at nadir: 1.1 km.
Swath width: 2240 km.
Altitude: 864 km.
Repeat cycle: 1 day (12 hours between ascending and descending passes)

Contact for data and products:

Dr. Richard Legeckis E/RA13 (for ocean products)
Chief Ocean Sciences Branch
NOAA/NESDIS, Room 310
Suitland Professional Center
Washington D.C. 20233
301-763-4244

Dr. J. Dan Tarpley (for land products)
Chief, Land Sciences Branch
NOAA/NESDIS
Room 712, World Weather Building
Washington, D.C. 20233
301-763-8042

Mr. Andrew Horvitz (Archival data, digital tapes, prints)
National Climatic Data Center
Satellite Data Services Division
Room 100, Princeton Executive Sq.
Washington, D.C. 20233
301-763-8400

NIMBUS-7: The NIMBUS series of satellites measure a variety of meteorological and environmental data. NIMBUS-7 carried the Coastal Zone Color Scanner which provided the first ocean color (chlorophyll) pictures. Although the sensor was designed as a proof of concept mission, it continued to operate for over seven year, producing a long-term data set which is available for research purposes. There have been several efforts to put another CZCS type sensor in orbit, however to date none have been launched.

NIMBUS-7:
Launched: October 24, 1978
Terminated operations: Summer, 1986
Sensor: Coastal Zone Color Scanner (CZCS) 6 channels
Spectral range: .433-.453, .510-.530, .540-.560, .660-.680, .700-.800, 10.5-12.5 microns
Spatial resolution: 825 meters
Swath width 1566 km.
Repeat cycle: 1 day

Contact for CZCS data and products:
Gene Feldman
NASA/GSFC (Code 636)
Space Data and Computing Division
Greenbelt, MD 20771

Contacts for other data sources:

National Aerial Photography Program:
Customer Services - NAPP
USGS - EROS Data Center
Sioux Falls, SD 57198
605-594-6151

Aerial photographs and contract flights:
Aerial Data Reduction Associates
33 Alexander Ave.
East Providence, RI 02914
401-434-0134
(hqtrs in N.J. 609-663-7200 or 800-257-7960)

Image analysis and GIS integration:
ERDAS, Inc
2801 Buford Highway
Suite 300
Atlanta, GA 30329
404-248-9000

State Archive of Aerial Photography:
Division of Planning
Rhode Island Department of Administration
265 Melrose Street
Providence, RI 02907
401-277-6449

APPENDIX B

FINAL SURVEY FORM

A. Do you use any aerial photography?

If yes, then:

1. For what types of projects?
2. How do you acquire it (buy, borrow, commission surveys)?
3. How much do the data cost?
4. Do you plan to continue using aerial photography in the future?

If no, then:

1. Are you familiar with possible utility of aerial photography?
2. Have you considered using it in the past?
3. Do you have plans to use it in the future?
4. What factors, including cost, have influenced your decision not to use it?

B. Do you use satellite derived data?

If yes, then:

1. Who supplies the data and in what form?
2. Do you process/analyze in digital or analog form?
3. For what types of projects?
4. What training do you and others in your group have (is it adequate)?
5. Have you received technical support from vendors?
6. Are you planning to use satellite data in future projects

If no, then:

1. Are you familiar with the possible utility of satellite data in your work?

2. Have you considered using sat. data in the past (in what way)?

3. Do you have plans to use the data in the future?

4. Have you spoken with consultants who provide the data or processing/analysis service?

5. what factors, including cost have influenced your decision not to use satellite data?

C. Do you use GIS?

If yes, then:

1. What system do you use?

2. Do you know about the Rhode Island GIS?

3. Who supplies the system/training?

4. Is there enough technical support from the vendors?

5. What kinds of project are you doing with GIS?

If no, then:

1. Are you familiar with GIS technology?

2. Have you considered applications for GIS?

3. Do you plan to use it in the future?

4. Have you spoken with consultants who provide GIS analysis or other services using GIS?

5. What factors, including cost have influenced your decision not to use GIS?

D. Have you considered/used software that combines remote sensing technology and GIS analysis?

E. Please comment on the following:

Your/your colleagues technical expertise in the use of these tools.

Funding possibilities/problems for resource management research

Your participation in joint projects with state/federal/local/university/private sector researchers.

APPENDIX C

SURVEY RESULTS

The following organizations were represented in the survey:

State:

Rhode Island Department of Environmental Management

R. I. Department of Administration (Division of Planning)

R. I. Department of Transportation

Coastal Resources Management Council

Coastal Resources Center

Narragansett Bay Project

Universty of Rhode Island Cooperative Extension

U.R.I. Department of Natural Resources

Local:

Town of Narragansett

Town of East Greenwhich

Town of Portsmouth

Town of North Kingston

Aquidnick Foundation

Private:

Aerial Data Reduction Associates

Databasics

Environmental Consultants

Garofalo Environmental Services

AET Corporation

The following is a list of responses given for each survey questions. This information is presented in a qualitative sense only. (No attempt has been made to quantify the frequency of any response and no statistical analysis has been performed therefore statistical significance can not be determined.)

Aerial Photography:

Range of uses?
- Base maps
- Update GIS
- Highway projects
- Harbor management
- Special Area Plans
- Land Use analysis
- Site reviews
- Hearing evidence
- Water quality
- Visual display
- Comprehensive plan
- Site violation reviews
- Site assessment
- Facility identification
- Planning park projects
- Coastal watershed mapping
- Subdivision planning
- Environmental Impact Statements
- Boundary delineation

How Data are acquired?
- From State Archives (borrow and copy)
- Commission own flights
- From USGS surveys

Data Costs?
- {Highly variable}

Future Uses?
- Extensive (see above list of present uses)

Satellite Derived Data:

Range of Uses?
- Research purposes
- updating GIS coverage

Data supplied by?
- Direct ordered from EOSAT and SPOT corporations.

Factors for not using satellite data?
- Cost
- Resolution not acceptable
- Information provided by other means
- No technical expertice
- No time to learn

Possible future uses?
- Update GIS
- Chlorophyll, suspended sediments
- Watershed mapping
- longterm monitoring
- Forrest/land cover classification

GIS:

Software/system used?
- ARC/INFO
- Main frames
- Personal Computers
- Workstations

Training?
- RIGIS
- URI
- On-site training by vendor
- Trial and error

Technical support from vendors?
- Adequate
- Not used extensively
- No need for technical support

Present/future uses?[1]
- Comprehensive Plans
- Land use planning
- Wetlands mapping
- Analytical tool for highway upgrades
- Environmental Impact Statements
- Watershed/water quality
- Inventory coverages
- Critical Area delineation
- Quohog mapping field checking
- Shellfish management areas
- Tracing indicators on Providence River
- Open Space inventory updates

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[1]Present and future uses of GIS have been combined here since many respondents described projects that were either just getting underway or were already secheduled but had not yet begun.

Present/future uses (cont'd.)?
- Assessments of salt ponds and Bay
- Harbor management
- Growth management
- Economic development planning
- Marketing tool
- Zoning maps
- Parcel bases

Other Comments:

Technical expertises with tools generally adequate for the technologies in use. Lack of technical expertise in specific field usually coincident with lack of use of that technology.

Most funding came from within the agency, i.e. towns provided funding for their own planning activities in the budget. Some respondents briefly discussed possible outside funding sources such as Federal agencies.

Joint participation on an informal basis. Sharing of data and expertise common both between agencies within Rhode Island and with agencies outside of the state, i.e. federal and other states. Also many of the projects described depended on first establishing the needed data layers and coverages. Also joint participation between federal and state agencies on Narragansett Bay Project.

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