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The Use of Contemporary Information Technologies for Coastal Research and Management—A Review

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ABSTRACT

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The need for better monitoring and analysis of the coastal environment has increased dramatically in recent years, in particular along coastal boundaries where human activities are extensive and give rise to numerous adverse impacts. During the last decade, rapid advances in computer technology have revolutionised the processes of data collection and analysis within coastal research. These advances have significantly increased our ability to understand the complex interrelationships between coastal processes and to effectively manage the resources of the coastal zone. This paper describes aspects of four technologies which are at the forefront of the 'information revolution', namely: remote sensing, Global Positioning Systems (GPS), Geographic Information Systems (GIS), and the Internet. Having introduced each technology, the discussion focuses on their current (and potential) uses and the benefits which can accrue from their adoption.

ADDITIONAL INDEX WORDS: *Data, Technology, information management, remote sensing, Global Positioning System, Geographic Information System, predictive models, Internet.*

INTRODUCTION

The development and implementation of integrated coastal management policies is now an established and internationally recognised ideal (SØRENSEN, 1991). The need for integrated management strategies stems from the growing demands which are being placed on the world's limited coastal resources. In the modern era of *sustainable* resource management, it is necessary for environmental protection and conservation to be balanced against the increasing pressure of human developmental activities (MAGOON, 1989; FOSTER, 1991).

For management of coastal resources to be optimal, it is necessary that policies be based on informed decision-making. This, in turn, requires ready access to appropriate, reliable and timely data and information in a form which is suitable for the task at hand. Unfortunately, the comprehensive range of information typically required is seldom available and rarely in the possession of those decision-makers responsible for management within the coastal zone (RICKETTS, 1992). Much of the information is often in the possession of individuals in various government agencies, research institutes and universities. Further, the data are often collected on the basis of very specific (and often narrow) objectives and in a wide variety of formats—including written records, digital and hardcopy maps, satellite imagery, aerial photography, seismic profiles, and a range of electronic media (RICKETTS *et al.*, 1989).

While this situation may prevail, rapid advances made in computer technology over the last decade have produced a variety of computer-based tools and methodologies which offer enormous potential toward meeting the challenges of integrated coastal zone management. Given that the spectrum of technologies now available is enormous, the focus of this paper is dedicated to four technologies which are becoming increasingly used in the monitoring and management of the coastal environment.

Specifically, the paper describes aspects of two data capture technologies: remote sensing, and the Global Positioning System (GPS). Having introduced these sources of spatial data, the role of the Geographic Information System (GIS) as an analytical tool for coastal research and management is described. This is followed by a discussion of the utility of the Internet as a mechanism for

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enhanced networking between coastal scientists and managers at the local, national and global scales. The fundamental elements of each technology are introduced, and applications of each within the coastal environment are reviewed. The paper concludes with an assessment of the potential these technologies present to future coastal research and management.

DATA CAPTURE TECHNOLOGIES

Remote Sensing

The efficient management of marine resources and effective management of activities within the coastal zone is, to a large extent, dependant on the ability to identify, measure and analyse a number of processes that operate or react together in the highly dynamic coastal/marine environments (CRACKNELL and HAYES, 1989). In this regard, measurements are required of various physical, chemical, and biological features of both the coastal and open zones of the oceans.

Since the advent of high resolution, large-scale aerial photography in the 1930s, coastal scientists have made extensive use of data captured using remote sensing devices (SMITH and ZARILLO, 1990). Intrinsically, remotely sensed information offers numerous benefits which have been utilised in a wide variety of coastal and oceanographic applications. These benefits may be broadly classified as follows:

1. *Spatial scale:* Remotely sensed products are available at a wide range of spatial scales for much of the world's coastal margin. This enables analyses to be undertaken at both macro and micro scales, which is often a requisite of coastal research,
2. *Unbiased content:* Remotely sensed data are collected objectively, unlike some conventional methods (*e.g.*, visual estimation of wave height),
3. *Repetitive coverage:* An historic investment in aerial photography means that much of the world's coastal margin has been photographed several times since 1945. More recently, the development of artificial satellites has provided the capacity for continuous coverage of the earth at a variety of spatial (and spectral) resolutions,
4. *Economy and efficiency:* Remote sensing produces spatially continuous snapshots which simultaneously record the conditions within a given study area. Such a facility is often unobtainable using conventional sampling methods (*e.g.*, land-based surveying).

Different remote sensing capabilities exist for the provision of the required information involving one or a combination of measurement techniques. The type of sensor which is utilised is dependent on the spatial, spectral and temporal requirements of a given investigation—with the most common types of sensor used being high-precision aerial mapping cameras and a variety of earth-orbiting satellites (AMERICAN SOCIETY OF PHOTOGRAMMETRY, 1980).

Aerial Photography

Aerial photography is the most widely used form of remote sensing and is a well established source of information within coastal studies. Photographic products (including black and white, colour and infra red imagery) have been used extensively for applications such as morphological and vegetative studies (EL ASHRY and WANLESS, 1967; LYON and GREENE, 1990; BRITSCH and DUNBAR, 1993; FERGUSON *et al.*, 1993), prediction of storm surge penetration (DOLAN *et al.*, 1978), and monitoring of land use change and environmental quality (NIEDZWIEDZ and GANSKE, 1991).

Although aerial photography has been used in a wide range of coastal applications, its most extensive use has been for determining rates of shoreline change (ANDERS and BYRNES, 1991; DOLAN *et al.*, 1991). The information derived from such analyses is necessary for optimal planning of shore protection programs (*e.g.*, beach renourishment projects) and provides a basis for delineating Coastal Hazard Zones (GIBB, 1981; LEATHERMAN, 1983).

Satellite Imagery

Observing the earth from satellites is a more recently established method of data capture than aerial photography, and has undergone a prolific increase in usage over the last decade. This trend is attributable to the following advantageous features.

First, a satellite has both a scale and a regularity of coverage that one could never reasonably expect from an aircraft. Second, the data are collected in an inherently digital form, and are therefore immediately amenable to computer processing. This enables the data to be assimilated and input directly to numerical models such as the global scale, eddy-resolving ocean prediction model described by HURLBERT *et al.*, (1992), or the quasi-geostrophic multilayer models applied by JOHANNESSEN *et al.*, (1993). The digital format of satellite imagery is also important in light of recent advances in the field of photogrammetry—whereby traditionally manual techniques are being displaced by automated, digital methods. Reflecting on the impact of these developments, TROTTER (1991) suggests that airborne scanners currently under commercial development will supplant the large-format aerial camera. The use of airborne scanners is particularly advantageous as it effectively eliminates some of the geometric distortions in the raw imagery and provides digital input direct to Digital Photogrammetric Workstations (DPWS) for final rectification and on-screen mapping. As stated by STUTTARD (1992, p.177):

> For remotely sensed data, the advantages of end-to-end digital processing are enormous, but are only just starting to be realised . . . the aerial photograph is not yet obsolete, but a stronger challenge will emerge from the combination of digital aerial survey with DPWS. . . . .The next few years will see an increasingly widespread adoption of the fully digital approach through the convergence of the software and data, and the gradual replacement of obsolete technology.

Perhaps the most important reason behind the increasing use of satellite imagery lies in their ability to record wavelengths beyond the spectral range of photographic film using a variety of sophisticated onboard sensors. For example the NIMBUS 7 satellite (operational from 1978–1987) carried a Scanning Multi-channel Microwave Radiometer (SMMR) and the Coastal Zone Colour Scanner (CZCS). The CZCS on NIMBUS 7 was an optical and infrared multi-spectral scanner which proved to be extremely important for the study of both meso and regional-scale oceanographic processes such as ocean fronts, eddies, coastal currents and phytoplankton blooms (YODER *et al.*, 1988).

Finally, new remote sensing systems are advancing rapidly and producing new data with increasing spatial and spectral resolution. For instance the infrared and microwave sensors on the European Remote Sensing Satellite (ERS-1) can measure sea-surface temperature to within 0.5°C and water elevation to within 50cm (STUTTARD, 1992). As stated by FU *et al.*, (1988, p.11):

> The . . . ERS-1 data sets provide information about ocean variability with unprecedented accuracy and temporal and spatial resolution. With the recent coupling of sophisticated *in situ* observations, numerical modelling and data assimilation efforts . . . , the decade of the 1990s promises major advances in our understanding of [and subsequently our ability to effectively manage] the world's oceans.

Applications of Satellite Remote Sensing for Coastal Management

Due to the aforementioned reasons satellite remote sensing has been used for a diverse range of qualitative and (more increasingly) quantitative applications. These applications can be broadly classified into those which measure geophysical features and processes, and those requiring the collection of water quality parameters (Table 1).

Although valuable information can be obtained using satellite remote sensing technology, there are substantial difficulties to be overcome and challenges that have yet to be met (YODER *et al.*, 1988). For instance the high concentrations of particulate and dissolved organic matter within estuarine and coastal waters tend to make estimates of chlorophyll concentration within these environments rather unreliable (CURRAN and NOVO, 1988; VAN STOKKOM *et al.*, 1993). Additionally, microscale features are often difficult to resolve using satellite imagery due to the typically low spatial resolutions of current sensors (CRACKNELL and HAYES, 1989).

Concerning the future development of remote sensing technology, it has been recommended that *tunable* sensors be developed which will enable the data-acquisition parameters (such as radiometric and spatial resolution and the number, width and location of spectral bands) to be customised to suit the specific requirements of each application (VAN STOKKOM *et al.*, 1993). In this respect the development and deployment of high-resolution imaging spectrometers and airborne LIDAR systems are regarded as particularly valuable for future coastal research (SCHMITZ-PEIFFER and GRASSL, 1990; BABIN *et al.*, 1991; SUN and ANDERSON, 1993).

Global Positioning System (GPS)

In conjunction with aerial photography, periodic beach surveys provide a crucial source of information which is used to assess beach stability and predict future shoreline positions. In order to effectively monitor and predict these changes accurate measurements of beach morphology incorporating both shore-parallel and shore-normal transects are required. Although it is possible to monitor beach dynamics using conventional land-based surveying methods, it is generally not practical to collect data of sufficient density and resolution to construct a three-dimensional beach change model over long sections of coastline (Welch and Remillard, 1992). Increasingly, coastal scientists are responding to this challenge by employing Global Positioning System (GPS) technology.

General Overview of GPS

GPS is a satellite positioning system that was developed by the U.S. Department of Defence to provide continuous, worldwide, all-weather navigation primarily for military users (Williams, 1990). There are a variety of approaches to using GPS, but the basic positioning concept is equivalent to triangulation with satellites as ranging sources (Morton *et al.*, 1992). The surveying technique which is employed is largely determined by the accuracy requirements of a given application. In those instances where high positional accuracy is not required, a single (or autonomous) GPS receiver may be used to provide measurements to within 30 meters of true location (Williams, 1990).

For applications where high-order accuracy is critical, a differential mode may be used to achieve accuracies in the order of 0.5 cm. Differential GPS is a data collection and processing technique which utilises two or more receivers to track the same satellites simultaneously. One receiver remains stationary at a known location and the position of an unknown point (*e.g.*, a survey mark) is determined relative to the reference point. Because the errors involved in GPS positioning are essentially the same within a 500km radius, an error-factor is calculated by the fixed receiver and transmitted to the mobile receiver (Figure 1).

The utility of GPS surveying techniques has been illustrated in several coastal applications. For instance, Welch and Remillard (1992) used differential GPS to establish ground control for aerial reconnaissance on a remote island where permanent monuments were extremely limited. Recently, Morton *et al.*, (1992) conducted a series of field experiments which evaluated GPS against conventional surveying methods. These experiments employed kinematic GPS surveying techniques whereby the GPS antenna was attached to a roof-mounted bracket on an offroad vehicle. The vehicle was then driven in a quasi-

Table 1. *Overview of important elements of remote sensing for monitoring of the marine coastal environment. Explanation of the acronyms are: near infrared (NIR), thermal infrared (TIR), synthetic aperture radar (SAR), radar altimeter (RA), light detection and ranging (LIDAR). Source: Adapted from* Johannessen et al. *(1993, p. 353).*

Purpose	Surface Monitoring by					Examples
	Visible/NIR	TIR	SAR	RA	LIDAR	
1. Geophysical features and processes						
Temperature fronts		•			ø	Cuq (1993); Babin (1991)
Current fronts	•		ø	ø		Johannessen *et al.* (1993)
Mesoscale eddies	•	•		ø		Hurlburt *et al.* (1992)
Upwelling filaments	•	•	ø			Cracknell (1989)
Sea surface height			ø	ø		Fu *et al.* (1988)
Sea Ice	•	•	ø	ø		Barry *et al.* (1993)
Wind fronts			ø	ø		Johannessen *et al* (1993)
Coastal geomorphology	•				ø	Luczkovich (1993)
2. Water quality						
Algae blooming and spreading	•				ø	Yoder (1988); Johannessen *et al.* (1989)
Surfactants	•		ø		ø	Korenowski *et al.* (1993)
Oil spills	•	•	ø			Bern *et al.* (1993)
Turbidity/sediments	•				ø	Cuq (1993)

• = Cloud and daylight dependent; ø = Cloud and daylight independent

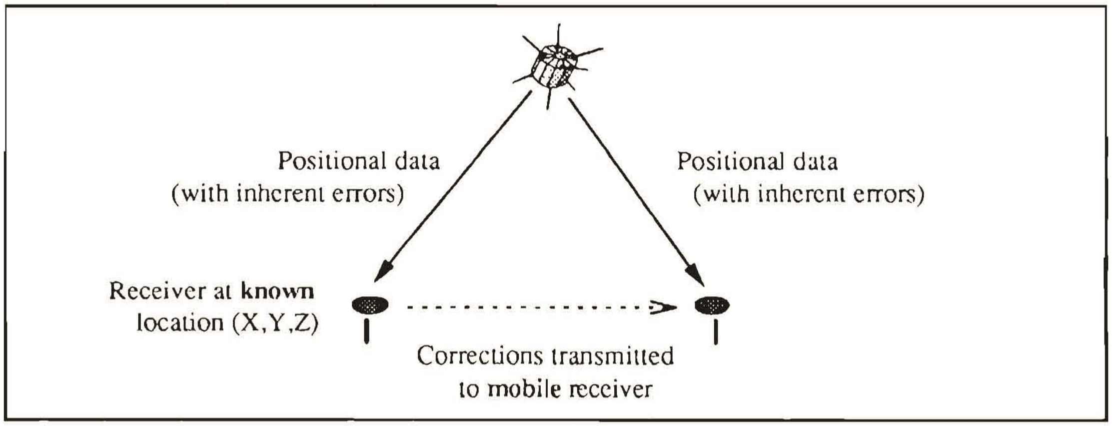

Figure 1. Fundamental elements of the differential GPS technique.

orthogonal pattern that encompassed both shore-normal and shore-parallel profiles, while collecting GPS data at a one second rate. Kinematic GPS surveying techniques were found to be vastly superior to conventional methods (using theodolites or total stations) for a number of reasons.

First, the GPS techniques enabled continuous, centimetre level measurements to be collected over a 6 km field area in only 1.5 hours. Such efficiency cannot be matched by conventional surveying techniques which collect data as discrete, static records. As a result of the continuous sampling and increased resolution provided, alongshore changes in beach morphology were revealed that were undetected using conventional shore-normal profiling techniques. Additionally, GPS-based surveying methods allowed absolute geographic coordinates and elevations to be determined simultaneously without the need for fixed surveying monuments. This feature is particularly important for post-storm surveys and monitoring of rapidly eroding areas. Finally, the inherently digital format of the data enabled it to be directly downloaded to a computer for processing and inclusion into a Geographic Information System for subsequent analysis (MORTON *et al.*, 1992).

DATA ANALYSIS TECHNOLOGIES

Geographic Information Systems (GIS)

As the previous discussion has highlighted, the study of coastal phenomena generally requires large amounts of spatial data analysis. The data sets involved are typically heterogeneous and are often comprised of data sources with differing scales (both spatial and temporal), coordinate systems, and levels of accuracy. Further, the data originate from source material in multiple formats including text, maps, charts, and remotely sensed imagery. For instance, a 'typical' coastal zone management database may contain a combination of the following items:

Topography and terrain: periodic beach surveys, aerial and ortho-photographs, bathymetric charts, soil maps, watershed/catchment information;

Morphological data: side-scan sonargraphs, sediment samples, geological bore log data;

Major infrastructure: inventory of shore protection structures (*e.g.*, seawalls), roads, marinas etc.;

Forestry and conservation: forest reserves, forest types, natural vegetative species, conservation areas, marine reserves;

Coastal fisheries: licensing zones, pelagic and demersal fish distribution, commercial aquaculture;

Oceanography: variety of physical, chemical and biological oceanographic data, (*e.g.*, historical storm parameters);

Environment: point pollution sources, water quality data, industrial site locations, sensitivity analyses;

Socio-economic data: housing location, valuation data, demographic structure, census information; and

Planning: cadastral data, past and present land use information, administrative boundaries, Coastal Hazard Zones, development pressure (industrial, urban, aquaculture, tourism and recreation, sand mining), land use capability, environmental constraints.

The formulation of an *integrated* coastal zone management plan requires an integrated approach to analysing the complex inter-relationships between the various data sets listed above. One aspect of these inter-relationships is the spatial linkages among various parts of the coastal zone, and also between the coastal zone and its hinterland through river systems (PHENG, 1992).

Traditionally, the management and analysis of spatial data has taken place in a hard copy environment. However, the use of paper-based products for complex analytical procedures often proves to be tedious and cumbersome—thereby inhibiting the efficient achievement of goals. In response to this situation, computerised geographic information systems (GIS) are emerging as the spatial data handling tools of choice for solving complex geographical problems (GUPTILL, 1989). A GIS can be broadly defined as comprising a system of computer software, hardware and procedures designed to allow users to collect, manage, analyse and display large volumes of spatially referenced data and associated attributes (COWEN, 1988).

The Utility of GIS Technology

Spatial data sets are unique in providing the geographic locations of features, related to known coordinate systems; in specifying attributes of features that may be independent of location, such as area, cost, and grainsize; and in describing the spatial and topological relations among the elements in the data set. Because GIS are specifically designed to manage and analyse spatial data sets, analysts are able to process and interrelate many more kinds of data than were previously feasible. As a result GIS users have the potential to greatly improve traditional missions such as data collection, research, assessment, and information delivery (GUPTILL, 1989).

Within the framework of the GIS a variety of analytical, statistical and modelling tools may be used to transform data into information suitable for a given application. Figure 2 illustrates the general flow of data for a hypothetical GIS application in which planning approval is sought to build a house behind a frontal dune. RICKETTS (1992) identifies the following as benefits which arise from using GIS technology for coastal and ocean management: (a) providing a receptacle for scattered data from diverse sources; (b) improving the visualisation of such data for space-use management; (c) improving understanding of interactions between uses of and linkages between ocean and land-based processes in coastal areas; (d) supporting statistical, modelling and impact analyses; (e) making better use of remotely sensed data; (f) high quality graphical output for dissemination of information; and (g) development of efficient data and information management infrastructures.

Numerous authors have suggested that the success of GIS lie in their ability to transform representative quantities into sensory stimuli which increase ones ability to visualise and perceive localised phenomena (BUTTENFIELD and MACKANESS, 1992; CASSETTARI, 1992; MACNICOL, 1992) (Figure 3). While this quality is not unique to GIS it is particularly important given that the volume of data collected by existing technologies is increasing at a phenomenal rate.

Applications of GIS Technology within the Coastal Zone

Given its significant advantages over traditional (hardcopy) analytical techniques, GIS technology is rapidly becoming an integral part of coastal management efforts worldwide. To date, coastal-zone applications have concentrated on three types of spatial analysis: 1) characterisation and measurement of linear and areal features, 2) intersection (or overlaying) of spatially referenced data, and 3) proximity analyses.

RICKETTS (1992) reports that the majority of coastal provinces in Canada have developed or are developing some form of coastal GIS. In the United States numerous regional GIS databases have been developed and maintained using Federal government funding. For instance, the National Oceanic and Atmospheric Administration (NOAA) and the US Department of Commerce jointly sponsored the construction of a comprehensive spatial database for Sapelo Island and its bordering marshlands (WELCH and REMILLARD, 1992). Included in the database were 1:5,000-scale topographic maps, 1:24,000-scale land-use/land-cover maps, and digital elevation models (DEMs), for a forty year period spanning 1953 to 1993. WELCH and REMILLARD (1992) report that the high

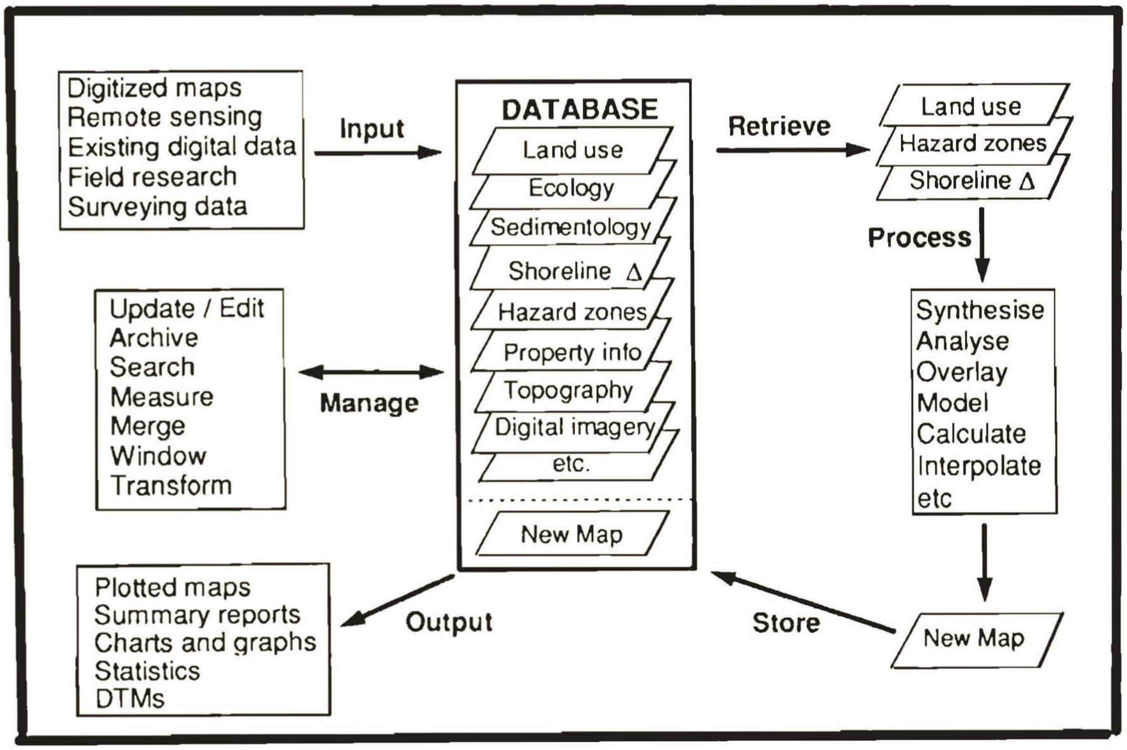

Figure 2. The flow of data during a 'standard' GIS application. Source: Adapted from STUBBS (1985, p. 167).

geometric accuracy and functionality of the resulting data model has greatly enhanced resource management within the study area.

At the national scale, the CoastWatch Change Analysis Project (C-CAP) integrates satellite imagery with GIS technology to monitor land-cover/land-use changes in U.S. coastal wetland habitats and adjacent uplands (JENSEN *et al.*, 1993; LESHKEVICH *et al.*, 1993). The data are systematically captured every 5 years, and annual coverage is applied to those areas identified as experiencing rapid development or environmental crises (such as oil spills). Image products derived from this initiative constitute an important source of real-time information for coastal planners and resource managers throughout the United States (O. WEATHERBY, *pers. comm.*, 1993).

Comprehensive GISs have also been developed for the waters around the British Isles (NATURAL ENVIRONMENT RESEARCH COUNCIL, 1991), the Gulf of Maine (RICKETTS, 1991), and South Johor (Malaysia) (PHENG, 1992). In the United Kingdom, GIS technology has been used to address a wide range of coastal management issues, including offshore sand and gravel mining, coastal erosion management and marine species assessments (RICKETTS, 1992). GIS techniques have also been used to enhance the site selection process for coastal aquaculture by highlighting those locations which meet a predefined set of criteria (ROSS *et al.*, 1993).

Within New Zealand, the majority of local government authorities have recently purchased GIS hardware and software and are currently capturing and inputting data for future analysis. Although coastal managers within these agencies have shown a growing interest toward GIS, the application of the technology has been extremely limited to date. Recently O'REGAN and CHALMERS (1993) used geodetic ground control to rectify a series of scanned aerial photographs within a GIS environment. The GIS was then used to precisely

Figure 3. The diving pattern (vertical lines) and track (horizontal line) of 10 Elephant Seals, shown in relation to ocean bathymetry off South Georgia Island. The track was obtained using an ARGOS satellite-linked time depth recorder attached to each seal. This provided accurate data which was then input to a GIS for subsequent analysis and presentation. Source: The Oceanography Society (1993) (courtesy of Sea Mammal Research Unit, NERC, U.K.).

overlay the rectified imagery with survey and cadastral information and map areas of erosion and accretion. This enabled shoreline changes to be accurately quantified and analysed over a fifty year period for the New Zealand coastal settlement of Te Puru.

Linkage with Predictive Models

In the majority of applications to date, GIS has been used to provide an advanced database system, and an effective means of displaying information. While these databases often contain historical data, they are purely static in terms of their ability to extrapolate trends and model alternate scenarios. The integration of GIS with predictive models holds enormous promise for ecosystem, regional and global resource management efforts. As stated by SORENSEN (1991, p.7):

> The next advance in coastal management techniques will come when a GIS is coupled to an expert system which has simulation tools and on-line data assimilation capabilities. This will enable true cross-disciplinary planning within a regional management strategy.

The greatest challenges for the development of such systems are posed by the array of data structures used by current GISs, and more importantly, by the range of reliability and sources of data (RIPPLE and ULSHOEFER, 1987). Recent advances in satellite technology have produced highly accurate image products which are increasingly being input to GIS-based predictive models.

For instance, LEE and PARK (1992) applied simulation modelling to predict the response of northeast Florida's coastal wetlands and lowlands to changing sea levels. Remote sensing and GIS techniques were used to develop, manipulate, and synthesize model input including land cover, digital elevation data, and site characteristic data. SLAMM3 (Sea Level Affecting Marshes Model) was then used to evaluate the input data, predict responses to inundation and erosion, and determine transfers from one coastal habitat to another on a cell by cell basis. Introduced in 1991, SLAMM3 differs from other wetland models by its ability to predict map distributions of wetland cover under conditions of accelerated sea level rise and by its applicability to the diverse wetlands of the contiguous coastal United States (LEE and PARK, 1992).

TELECOMMUNICATIONS TECHNOLOGY

The discussion thus far has focussed on technologies which have had a spatial component, and are being increasingly used to capture, analyse, and display the information needed for integrated coastal research and management. In many instances the products derived from applied GIS research are enhancing the ability to manage coastal resources within each specific study area. While such an outcome is important, the value of these individual research initiatives is limited unless the knowledge they produce is disseminated to the wider coastal scientific community. As the scope and magnitude of coastal management problems continues to grow, it is becoming increasingly apparent that the key to solving these problems is communication and a constantly open flow of ideas and scientific data between scientists, citizens, schools and nations (MAGOON, 1989). The following section describes an effective means of disseminating both information and knowledge derived from scientific endeavour, using the Internet.

Overview of the Internet

The Internet is a wide area network system which was initially developed by the US Department of Defence to provide real-time access to remote resources (including supercomputers, radio telescopes, weather analysis programs, and scientific databases) (LYNCH and ROSE, 1993). Over the last decade, the Internet has experienced a prolific rate of growth as a multitude of academic, governmental and commercial agencies have become incorporated into the network.

In 1993, the Internet encompassed 1.3 million computers that were used by up to 30 million people in over 100 countries (FEIT and RENADE, 1993). Further, the number of computers joining the network is reported to have doubled every year since 1988 (COOKE and LEHRER, 1993). As a result of this exponential growth the Internet has become an exceptionally useful medium for the rapid exchange of current ideas and information.

The Internet as a Communication Medium

Electronic mail (e-mail) is the mainstay of the Internet. It functions in the same manner as conventional postal mail, but is faster and more efficient. Using conventional methods, it can take several days to transfer a document from one building to a nearby site and up to a week to exchange mail internationally. Conversely, *information* (in the form of alphanumerical text, graphics or sound) can be converted to digital form, compressed and packaged, and conveyed over the network to its recipient. There the process is reversed to produce a result identical to the original. It can arrive at its destination in a matter of minutes anywhere in the world.

Electronic mail provides access to wide audiences of people through the forum of *mailing lists*. Mailing lists, or mailing reflectors, are e-mail services set up to send messages to a group of subscribers automatically (SMITH, 1993). Several mailing lists have recently been established which cover general aspects of coastal management and research, as well as more specialised areas such as coastal-GIS and coastal engineering.

In addition to e-mail and mailing lists, the online *news groups* provide another method of fostering communication and discussion among members of the global coastal community. Within such forums users gather electronically to contribute information and ideas which are debated and consequently refined. Announcements of grant proposal deadlines as well as upcoming conferences and calls for papers are popular, as are reports or comments on new books, papers, methods, or software.

The Internet as a Research Tool

Given its phenomenal rate of growth, the Internet has greatly enhanced the ability for coastal scientists and managers around the world to communicate effectively on a wide range of topical issues. While the various electronic mail procedures are important, the real utility of the Internet lies in the facility for remote login and file transfer capabilities. By enabling members of government agencies, universities, research and commercial institutions to freely access and exchange information, the Internet has effectively revolutionised the research process. As stated by OBRACZKA *et al.*, (1993, p. 325):

> A few years ago, researchers started new research projects by requesting bibliographic searches, contacting fellow researchers, and leafing through conference proceedings and University technical report lists. Today, the Internet has streamlined this process by enabling people to work with each other and with resources (data, computers and instruments) without regard to time or space.

Although the Internet provides access to a plethora of remote resources (both hardware and databases), trying to locate relevant data in this sea of information can be a considerable task. In response to this situation a variety of 'navigational' software tools have recently been developed. For instance, the 'World Wide Web' enables a user to navigate, in an orderly fashion, through the millions of available files using a series of intuitive menus. In addition to streamlining the data location process, the development of such interfaces has also broadened the range of Internet users—enabling non-sophisticated computer users to enjoy the benefits of this modern research medium.

An informal survey was undertaken recently to assess the degree of utilisation of the Internet services among scientists within New Zealand's National Institute of Water and Atmospheric Research (NIWAR). Although admittedly basic, the survey indicated that usage of online services ranged from nil to extensive. Of the latter category, the most common functions utilised were: international communication and transfer of manuscripts for review via e-mail; the transfer of large amounts of scientific data both within the agency and abroad; and interrogation of remote online library catalogues. These results were consistent with those observed in several local government authorities, although rates of Internet usage were found to be lower within these agencies. This was attributable to a lack of familiarity with the Internet command protocols. It is expected that this situation will change with the adoption of graphical user interfaces.

The Need for Centralised Data Storage and Improved Networking

Coastal scientists are using contemporary technologies to ask increasingly complex questions about the coastal environment and its relationship with global weather systems. As a result of this applied research the range and volume of digital information available is growing at a phenomenal rate. In order to efficiently manage and distribute this information, a number of large-scale data repositories have been established in several countries. For instance the NOAA Ocean Data Centre serves as an archive for an extensive array of satellite imagery and derived image products and *in situ* environmental data. Using the Internet, these files may be accessed, downloaded, and displayed using a variety of standard software packages (LESHKEVICH *et al.*, 1993).

It is imperative that such initiatives become more widespread in future for several reasons. First, they provide remote access to both historical and 'living' (current) data, which are often unobtainable from other sources (RICKETTS, 1992). Second, by maintaining an up-to-date, online database, duplication of effort and expenditure (associated with data capture) are significantly reduced (CARTER, 1992). Finally, the use of these online services tends to promote networking between different institutions and machines.

Reflecting on the need for data sharing, CARTER (1992, p.1560) provided the following comments, which are particularly relevant to coastal research:

> With tight budgets and research projects that beg for increasingly large quantities of data, there are growing needs and desires to share data within the scientific community. Building the organisations and institutions that permit people to get together to share data requires great effort. Thankfully, there are many cases where data are shared to the benefit of all . . . . We are continuing to develop tools to permit us to overcome the technical details of sharing data. Likewise, we need to overcome the human and institutional details of data sharing. Each of us should do our part to maintain environments where we and our colleagues will want to create and share data in the future.

CONCLUSIONS AND FUTURE PROSPECTS

The coastal zone presents a unique set of challenges to those professionals charged with its management. Being the dynamic interface between land, air and sea, coastal systems are interrelated in complex ways which, at present, are inadequately understood. An improved understanding of these systems is necessary to develop effective policies for the stewardship and management of the coastal zone. This, in turn, requires ready access to appropriate, reliable and timely data and information, in a form which is suitable for the task at hand.

Rapid developments in computer technologies over the last decade have enhanced our ability to capture, analyse, model and communicate important environmental data. Both remote sensing and GPS are being increasingly used in a wide range of coastal applications to provide contiguous supplies of accurate spatial data. Geographic Information Systems then serve to link these data with spatial attributes (such as geographic location) to create information with which managers and scientists can interact. The integration of analytical GIS, GPS and remote sensing allows detailed tabulations and visualisations of change to be created over large areas. The result is an effective planning tool and a sound basis for continued monitoring.

Although our understanding of coastal processes is advancing steadily it is imperative that research efforts are not duplicated, in view of the increasing pressures that are being placed on the world's limited coastal resources. It is estimated that by the year 2000, some eighty percent of world's largest human settlements will be located within the coastal zone (Van Overeem and Stive, 1991). Accordingly, the concept of integrated coastal management needs to evolve from an ideal to a process which operates at both the local, national and international scales. To assist this transformation, we must strive to overcome the socio-cultural barriers which have inhibited data sharing and exchange in the past.

The title of this final section is Conclusions and *Prospects*. In the author's opinion, the integration of the aforementioned technologies provides unprecedented opportunities for effective research within the global coastal community. The importance of this work, in terms of both management and scientific value, can be enhanced through the use of these tools, providing they are well understood and well utilised. While advances in expert systems, data capture and data storage techniques are forthcoming, it is now incumbent on the coastal scientists and managers themselves to explore the capabilities of contemporary technologies such as GIS.

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