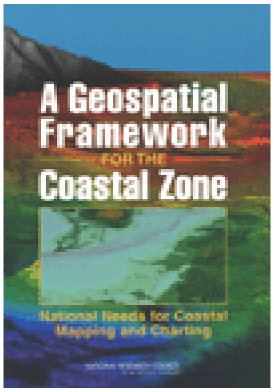

A Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting

Committee on National Needs for Coastal Mapping and Charting, Mapping Science Committee, National Research Council

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A Geospatial Framework for the Coastal Zone

National Needs for Coastal Mapping and Charting

Committee on National Needs for Coastal Mapping and Charting
Ocean Studies Board
Mapping Science Committee

Division of Earth and Life Studies

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Preface

While the academic community will long debate the relative roles of science and technology in fostering an understanding of the world around us, there can be little doubt that every so often there are concomitant technical developments that set the stage for a major leap in scientific understanding. This is indeed the case with respect to remote sensing, mapping, and data-handling technologies, where remarkable advances in the development of satellite-positioning systems, terrestrial and marine mapping sensors, and the digital manipulation of mapping data using geographic information systems have revolutionized our ability to collect, distribute, analyze, and visualize geospatial data. Along with these technological developments has come an evolution in our understanding of the fundamental importance of the coastal zone to the social, economic, and environmental well-being of the nation. With this increased understanding has also come a new appreciation for the complexity, sensitivity, and interconnectedness of the coastal zone system. This convergence of technology and scientific awareness heralds a new era of geospatial data handling and products that, for the first time, may allow us to address some of the key challenges faced by those charged with understanding and managing the coastal zone. Recognizing these technological advances, the critical importance of the coastal zone to the well-being of the nation, and the fundamental role that mapping and charting plays in understanding and managing the coastal zone, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the U.S. Environmental Protection Agency asked the National

Academies to provide an independent assessment of national coastal zone mapping and charting activities and needs.

With at least 15 federal agencies, almost all coastal states, and innumerable local agencies, academic institutions, and private companies involved in coastal mapping and charting, this assessment has been a very large and difficult task. Through a series of information-gathering exercises and meetings, we attempted to understand the short- and long-term mapping needs of the coastal zone community and to determine how well current activities are meeting these needs. We explored roadblocks to generating the information needed in appropriate forms, and sought approaches for maximizing the efficiency of data collection and the value of data products. While we cannot be assured that we covered every need and activity, we are confident that we have addressed the major issues and hope that the recommendations we make will help establish an infrastructure for U.S. coastal zone mapping activities that will allow us to efficiently and effectively manage and preserve our wonderful coastal environments.

Larry Mayer
Chair

Acknowledgments

This report was greatly enhanced by the participants at the four public committee meetings held as part of this study. The committee would first like to acknowledge the efforts of those who gave presentations at the meetings: Robert Ader, RADL Chris Andreasen, Rebecca Beavers, Doug Bellomo, Jim Bennett, Randall E. Billy, Nancy J. Blyler, James Brokaw, Darrell Brown, Stephen K. Brown, William S. Burgess, Margaret A. Davidson, Janet Freedman, Jason Freihage, John W. Haines, Tony LaVoi, W. Jeff Lillycrop, Daniel T. Mates, Bruce McKenzie, Anne Hale Miglarese, Mark E. Monaco, Bruce Parker, Derrick R. Peyton, Abby Sallenger, George F. Sharman, Kathy A. Shield, Karen Siderelis, Robert W. Smith, Joseph Stinus, E. Robert Thieler, Leland F. Thormahlen, and Charles Trees. These talks helped set the stage for fruitful discussions in the sessions that followed.

The committee is also grateful to a number of people who provided important information, commentary, and material for this report: Anne Ball, Jerry Bailes, Lenny Coats, Kim Cohen, Greg Colianni, Cindy Fowler, Norman Frommer, Keith Good, Walter R. Johnson, Jim Kendall, Charles Kovach, Pat Leahy, Michael Plastino, Barbara S. Poore, Nancy Rabalais, Steve Raber, Kevin Schexnayder, Miki Schmidt, Gregg Serenbetz, Greg Snyder, Richard W. Spinrad, David Stein, Megan Treml, Bill Walker, Erika Washburn, Pace Wilber, and James Woodley.

The committee would also like to thank the National Research Council (NRC) staff: David Feary, Yvonne Forsbergh, Morgan Gopnik, Kristen Krapf, Byron Mason, Alison Schrum, Terry Schaefer, and Winfield Swanson for helping us wend our way through the often complex maze of NRC reports.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

John D. Bossler, Center for Mapping, The Ohio State University, Columbus
David J. Cowen, Department of Geography, University of South Carolina, Columbia
Joseph J. Cox, Chamber of Shipping of America, Washington, D.C.
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Nancy Musgrove, Management of Environmental Resources, Inc., Seattle, Washington
Richard Pickrill, Marine Environmental Geoscience, Natural Resources Canada, Dartmouth, Nova Scotia
Walter Schmidt, Florida State Geological Survey, Tallahasee
Karen L. Steinmaus, Pacific Northwest Center for Global Security, Pacific Northwest National Laboratory, Richland, Washington

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Raymond A. Price, Department of Geological Sciences and Geological Engineering (emeritus), Kingston, Ontario, Canada. Appointed by the National Research Council, he was responsible for ensuring that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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National Needs for Coastal Mapping and Charting

Executive Summary

The coastal zone is of enormous importance to the well-being of the nation, as our lives and economy are inextricably linked to the features and activities that occur within this dynamic region. Fourteen of the country's 20 largest urban corridors occur along the nation's coast; a major portion of the U.S. economic infrastructure is located near or on the ocean, and yet the coastal zone also encompasses forests, rivers and streams, wetlands, estuaries, beaches, barrier islands, and ocean habitats. The enormous importance of the economic, environmental, and recreational components of this complex area places tremendous demands and responsibilities on those charged with its management and maintenance. In order to understand and address the effects of natural and anthropogenic forces in the coastal zone, a holistic multidisciplinary framework is required to account for the interconnectivity of processes within the system. The foundation of this framework is accurate geospatial information—information that is depicted on maps and charts.

Science, education, commerce, planning, and resource management have relied for centuries on the availability of accurate maps. In coastal regions, high-quality maps are essential for safe navigation, resolving jurisdictional boundaries, understanding processes, mitigating hazards, tracking environmental changes, establishing inventories of resources and habitats, and developing new programs and policies. Historically, the fundamental geospatial data needed in the coastal zone have been captured and portrayed onshore as "maps" and offshore as "charts." Unfortunately, differences in scale, resolution, cartographic conventions and projections, and particularly reference datums currently inhibit the seamless combination of existing onshore and offshore data. The result is a lack of standardized, uniform geospatial products that span the coastal zone. This inability to produce a seamless map (or chart) across the land-water interface is a severe impediment to understanding the many processes that are continuous across the shoreline. The lack of standardization has also led government agencies, the research community, and the private sector to undertake the expensive and time-consuming task of separately generating new data and maps to accompany almost all new studies and initiatives. The lack of coordination of coastal zone mapping efforts inevitably leads to the potential for redundancy of surveys or products.

At least 15 federal agencies are involved in the primary collection or use of coastal geospatial data, often with responsibilities shared among multiple divisions within the same agency. In addition, a plethora of state and local agencies, academic institutions, and other organizations also gather and use coastal zone information. This has resulted in a chaotic collection of potentially overlapping, and often uncoordinated, coastal mapping and charting products that can frustrate the efforts of users to take advantage of existing datasets and build on past studies.

In response to this situation, and believing that an independent external evaluation could provide valuable new ideas, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), and the U.S. Environmental Protection Agency (EPA) requested that the National Academies undertake a study of national needs for coastal mapping and charting. The study committee was charged to identify and suggest mechanisms for addressing national needs for spatial information in the coastal zone, incorporating an analysis of the major spatial information requirements of federal agencies as well as the principal user groups they support. The committee was tasked to identify high-priority needs, evaluate the potential for meeting those needs based on the current level of effort, and suggest steps to increase collaboration and ensure that the nation's need for spatial information in the coastal zone is met in an efficient and timely manner.

In order to understand the needs and activities of the very large and diverse community involved with spatial information in the coastal zone, the committee and staff sought information and perspectives from agencies and individuals involved in numerous aspects of coastal zone mapping. Despite the complexities of the numerous issues raised by the many providers and users of coastal zone data, the consistency of needs and concerns raised permitted the committee to quickly converge on a vision for the future of coastal mapping and charting. This vision requires the development of an integrated and coordinated coastal mapping strategy for the nation, based on a foundation—a reference frame—upon which all data collection, analyses, and products can be built. To establish this foundation, there must be a national effort to collect the information and develop the tools necessary to seamlessly blend topographic (onshore) and bathymetric (offshore) data. These data and tools will permit the establishment of a nationally coordinated digital database across the land-sea interface consisting of seamless elevation and depth data that can be referenced or transformed to common vertical and horizontal datums. This database will provide the basic geospatial framework for all subsequent data products, much like the USGS topographic sheet basemaps have formed the onshore foundation for a multitude of subsequent studies. Unlike the USGS topographic sheets, however, a coastal zone database must be "tide aware" and be able to reconcile the differences between onshore and offshore datums.

Our vision for the future of coastal zone mapping and charting also includes mechanisms to ensure communication among all the agencies and entities involved in order to minimize redundancy of efforts and maximize operational efficiencies. There will be national and perhaps international standards and protocols for data collection and metadata creation and readily available tools for data transformation and integration. With these tools the user community will be able to evaluate the accuracy and timeliness of data, change scales and projections, and seamlessly merge disparate datasets. The database and data integration tools will be easily accessible to all users, public and private, from a single digital portal accessible through the Internet.

This is a bold vision but at the same time an obvious one. Who would argue with a system that is efficient and produces easily accessible, fully interchangeable, accurate, and timely data? The vision may be simple to define, but its implementation will be anything but simple. The recommendations that follow are intended to address the root causes of the existing problems, help overcome the barriers to their solution, and begin to turn this vision into reality.

A SEAMLESS BATHYMETRIC/TOPOGRAPHIC DATASET FOR ALL U.S. COASTAL REGIONS

One of the most serious impediments to coastal zone management is the inability to produce accurate maps and charts so that objects and processes can be seamlessly tracked across the land-water interface. Differences between agency missions, onshore topographic versus offshore bathymetric mapping techniques, differing vertical reference frames, and the inherent difficulty of collecting source data in the surf and intertidal zones have combined to produce this fundamental incompatibility. It will be nearly impossible to properly understand processes, undertake planning, and establish boundaries in the coastal zone while two sets of disparate and nonconvergent maps and charts are being separately maintained.

The barrier to the production of continuous integrated mapping products across the land-sea interface is the inherent difference in the horizontal and vertical reference surfaces (datums) and projections used for maps and charts. Horizontal datum and projection issues can be readily resolved with existing transformation tools, although these tools must be made more readily available to the user community. However, vertical datum issues present a serious challenge. In order to seamlessly combine offshore and onshore data, vertical datum transformation models must be developed. These models depend on the establishment and maintenance of a series of real-time tidal-measuring stations, the development of hydrodynamic models for coastal areas around the nation, and the development of protocols and tools for merging bathymetric and topographic datasets.

The Tampa Bay Bathy/Topo/Shoreline Demonstration Project, a collaborative effort between NOAA and the USGS, has developed a suite of such tools (called Vdatum) and has demonstrated the feasibility of generating a seamless bathymetric/topographic dataset for the Tampa Bay area. This project has also demonstrated both the inherent complexity of such an undertaking and the substantial benefits that arise from interagency collaboration and coordination.

Recommendation 1: In order to combine onshore and offshore data in a seamless geodetic framework, a national project to apply Vdatum tools should be initiated. This will involve the collection of real-time tide data and the development of more sophisticated hydrodynamic models for the entire U.S. coastline, as well as the establishment of protocols and tools for merging bathymetric and topographic datasets.

This dataset must be documented and disseminated in such a way that it can become the base for a wide range of applications, including the definition of local, regional, and national shorelines. As a result of this effort, it will be possible to merge data collected either on land or offshore into a common geodetic reference frame while at the same time allowing application-specific maps and charts to be generated that maintain traditional tidal-based datums (e.g., for navigational charts) or orthometrically based datums (e.g., for topographical maps).

SHORELINE DEFINITION PROTOCOLS

Numerous agencies have identified the lack of a consistently defined national shoreline as a major barrier to informed decision making in the coastal zone. While a consistent shoreline is certainly desirable, many different definitions of the shoreline remain embedded in local, state, and federal laws, making it impractical to call for a single "National Shoreline." Rather, the key to achieving a consistent shoreline is the seamless geodetic framework referred to in Recommendation 1. With a seamless bathymetric/topographic dataset across the land-water interface, appropriate difference or tidal models, and consistent horizontal and vertical reference frames, any shoreline definition can be transformed and integrated within the common framework. The Vdatum tool kit and associated Web sites will be the key to establishing internally consistent shorelines between and among disparate surveys and studies.

Recommendation 2: To achieve national consistency, all parties should define their shorelines in terms of a tidal datum, allowing vertical shifts to be calculated between and among the various shoreline definitions, while at the same time permitting different agencies and users to maintain their existing legal shoreline definitions. In situations where legislation or usage does not preclude it, the committee recommends that the internationally recognized shoreline established by NOAA's National Geodetic Survey be adopted.

The committee encourages the Marine and Coastal Spatial Data Subcommittee of the Federal Geographic Data Committee (FGDC) to pursue implementation of this recommendation.

EASY ACCESS TO TIMELY DATA

Easy access to timely data is an essential component of effective coastal zone management. Many agencies have created Web sites that offer access to data in a variety of forms, as well as data manipulation tools. However, these sites still represent only a small percentage of existing coastal zone data.

Recommendation 3: A single Web portal should be established to facilitate access to all coastal mapping and charting data and derived products. The site should be well advertised within federal and state agencies, state and local governments, academic institutions, nongovernmental organizations and conservation groups, and to other potential users. The portal should work well with all Web browsers and on all computer platforms, to make it easily accessible to all users.

The single portal is not intended to host all coastal data. Rather, it should serve as a focal point that links to many distributed databases maintained by individual agencies or organizations. This site would represent the one place where users, particularly new users, could begin their search for coastal data and derived products. A single, easily accessible data portal with appropriate data manipulation tools should also promote timely entry and retrieval of data. Coordination of such a site logically falls under the purview of the FGDC and is fully consistent with the Geospatial One-Stop concept.

DATA INTEGRATION, INTERCHANGEABILITY, AND ACCURACY

Providing easy access to data through a single Web portal is a critical starting point for addressing the needs of the coastal zone community. However, users must also be able to combine and integrate data collected by different agencies using a range of sensors and often based on different datums or projections. Users must also be able to assess the attributes and accuracy of the data provided. Integration of data and assessment of data quality are made possible by the establishment of data and metadata standards and the application of tools for data transformation.

Recommendation 4: All thematic data and other value-added products should adhere to predetermined standards to make them universally accessible and transferable through a central Web portal. All sources should supply digital data accompanied by appropriate metadata.

The FGDC is in the process of establishing a series of standards for the National Spatial Data Infrastructure (NSDI) that will be applicable to all coastal zone data. Unfortunately, implementation of the NSDI continues to be problematic for the coastal/marine community due to highly variable levels of commitment by different agencies and insufficient incentives to fully implement its principles. This may, in part, be due to structural and budgetary barriers, the inability of a single set of standards to serve all applications, and disconnects between those developing the standards and the user community. One approach to addressing this issue is for additional involvement of the private sector.

Recommendation 5: The private sector should be more involved in developing and applying data standards and products. Agency procurement requirements can be used to encourage the private sector to deliver needed products in a timely fashion.

The committee is aware of numerous examples where private-sector initiatives established well-accepted and easily used data protocols—in effect de facto standards—that significantly enhance the effectiveness of data products. The private sector is often capable of greater speed and efficiency in the adoption of standards and tools than its government agency counterparts. Access to data, metadata, and data standards must be complemented by readily available tools to easily convert between and among different data formats, scales, and projections.

Recommendation 6: Government agencies and the private sector should continue to develop tool kits for coastal data transformation and integration. This will facilitate data analysis and the production of a range of value-added products. The tools should be accessible through the Web portal.

Documentation of the tools and techniques used to process data must also be provided to help the user community understand the limitations and appropriate uses of various datasets. A variety of training courses and workshops will be essential to provide end-users with the knowledge and tools necessary for intelligent application of the available data.

IMPROVED COORDINATION AND COLLABORATION

Any activity that involves multiple federal, state, and local agencies, academic researchers, and the private sector has the potential for redundancy and overlap of effort. This is amplified when the activity requires expensive platforms, technologies, and sensors. In the area of coastal zone mapping and charting, the large number of agencies involved, their differing histories, the breadth of their mandates, and the complexity of the task offer ample opportunities for redundancy and inefficiency. Because data acquisition is unquestionably the most expensive aspect of coastal zone mapping, elimination of redundancy and overlap in this area is likely to yield large savings. Ensuring that all relevant agencies are aware of each other's activities will be an important first step toward improved coordination.

Recommendation 7: All federally funded coastal zone mapping and charting activities should be registered at a common, publicly available Web site. This combined registry should be accessible through the single Web portal for coastal zone information.

Each entry in the registry should include a description of the mapping activity, its location and purpose, the agency collecting the data, the tools to be used, the scales at which data will be collected, and other relevant details. Nonfederally funded agencies conducting coastal mapping activities should be encouraged to register their activities at the same site. A section of the registry should be dedicated to descriptions of planned but unfunded coastal mapping activities, as well as a "wish list" of coastal areas where surveying would be particularly helpful to state or local agencies. Technically, components of such registration may already be required under Office of Management and Budget (OMB) Exhibit 300, but Recommendation 7 suggests a considerably expanded effort focused on making all federally funded coastal zone mapping efforts more widely known.

Once implemented, this registry could serve as the focal point for national coordination of geospatial data collection and analysis efforts. Individual agencies would continue to set their own priorities, but through the registry process, overlapping efforts could be quickly identified and avoided. The registry would also facilitate increased efficiency by highlighting opportunities for "incremental" surveys, where one agency takes advantage of the mapping activities of another agency in a region of common interest by providing a small amount of additional funding to achieve an additional objective. Such piggyback efforts would allow additional agencies to acquire data to meet their needs at minimal incremental cost.

Recommendation 8: To be effective, coordination should be carried out among all the primary agencies involved in coastal zone mapping, it should be mediated by a body that has the authority and means to monitor and ensure compliance, and it should involve people who are knowledgeable enough to identify the most critical issues.

Structurally, the FGDC appears to be an appropriate body to oversee such coordination, but many concerns remain about its effectiveness. Some restructuring of the FGDC, and perhaps an empowered Marine and Coastal Spatial Data Subcommittee, will be required to allay these concerns. In this light the committee endorses the recommendations of a recent design study team that calls for major structural and management changes for the FGDC (FGDC, 2000). A less appealing alternative might be either a new government office or an extragovernmental body charged with establishing oversight of all national coastal mapping and charting activities.

Recommendation 9: Whichever body is charged to carry out the needed coordination activities, dedicated staff personnel should be assigned to maintain the Web portal (Recommendation 3), the activities registry (Recommendation 7), and associated Web sites, and to proactively search for areas where efforts can be coordinated, supplemented, or combined to increase efficiency.

Specific areas where better coordination among federal agencies is urgently needed include high-resolution topographic and bathymetric data acquisition at the land-water interface, including aerial and satellite imagery, Light Detection and Ranging (LIDAR) surveys, bathymetric surveys, seamless topographic/bathymetric Digital Elevation Models (DEMs)/Digital Depth Models (DDMs), and derived products for mapping shoreline change, habitat change, hazard vulnerability, and coastal erosion and inundation.

INCREASED DATA COLLECTION

There is a widespread need for more and better data to be collected in the coastal zone. The single most consistently cited need, among the agencies and the user community, is for enhanced bathymetric data, particularly in very shallow coastal waters. These data provide the basic geospatial framework for almost all other studies and are a key component for derived products such as offshore habitat maps.

> **Recommendation 10: The fundamental reference frame data for the entire coastal zone should be collected, processed, and made available. The dynamic nature of the coastal zone requires that there should be specific plans for repeat surveys over time. The important role of qualified private survey contractors in coastal zone mapping and charting should also be acknowledged. Much of the work done by this sector is contracted by government agencies, and accordingly the prioritization and tracking of surveys can be coordinated by the body called for in Recommendation 8.**

Given the number of agencies and private-sector companies involved in coastal mapping and their disparate missions and budget directives, it is unrealistic to expect agreement on one unified and prioritized national mapping initiative. While each agency has responsibility for its own mapping priorities, a strong and enforceable mechanism for tracking and coordinating existing, ongoing, and planned mapping efforts (Recommendation 7) would increase efficiency to the point where considerably more survey work could be carried out for each dollar spent. Inconsistencies in scale and resolution for new data collection efforts could be resolved by the coastal zone coordinating body called for in Recommendation 8. After surveying agency needs, the coordinating body could determine whether the incremental value of collecting data over a larger area or in a slightly different form (e.g., at higher resolution) warrants modification of a planned surveying effort.

Severe challenges remain for those attempting to map the coastal zone. As well as the fundamental conceptual problem of reconciling terrestrial and tidal datums, there are also a number of logistical challenges, including shallow depths, waves, turbid waters, and longshore currents, all of which make it difficult to operate survey vessels and other equipment safely, accurately, and efficiently.

Recommendation 11: New remote sensing and in-situ technologies and techniques should be developed to help fill critical data gaps at the land-water interface.

There are a number of promising new technologies and techniques: integrated bathymetric/topographic LIDAR, multispectral, hyperspectral, and photographic imaging systems; sensors deployed on autonomous underwater vehicles; "opportunistic" mapping using volunteer recreational boats equipped with specialized mapping sensors approved by issuing agencies; autonomous bottom-crawling vehicles; improved satellite-imaging capabilities; and data fusion capabilities. Continued support from funding agencies for development of coastal remote sensing tools, combined with an increased emphasis on coastal needs, will greatly accelerate the development and implementation of these critically needed technologies. The private sector can play a major role in addressing this recommendation.

The recommendations and strategies outlined above call for the establishment of a consistent geospatial framework and the application of innovative new acquisition, integration, and data management technologies that should allow coastal zone scientists, engineers, and managers to efficiently produce easily accessible, fully interchangeable, accurate, timely, and useful geospatial data and mapping products that seamlessly extend across the coastal zone. The recommendations also suggest simple mechanisms to enhance collaboration and cooperation among those charged with acquiring data in this complex region. These mechanisms should facilitate efficiency gains that will allow most of the nation's coastal zone to be mapped in a timely manner. While simple in concept, implementation of the suggested strategies will require a focused effort on the part of the coastal zone community. If implemented, however, the committee believes that a major step will have been taken toward assuring the long-term well-being of the coastal zone.

1

Introduction

The coastal zone[1] represents only 17 percent of the land area of the United States, yet it is one of the nation's greatest environmental, social, and economic assets. Our lives and economy are inextricably linked to the features and activities found in the coastal zone. It is a nexus for tourism and industry, including activities such as shipping and boating; commercial and recreational fishing; exploration and extraction of oil, natural gas, gravel, and sand; recreational use of beaches; and wildlife observation (see Box 1.1). The coastal zone is densely populated and highly developed, and yet it is also where important habitats such as forests, rivers and streams, wetlands, estuaries, beaches, barrier islands, and the coastal ocean occur. These habitats, which individually support their own unique assemblages of plants and animals, are also complexly linked with—and dependent on—the coastal environment.

More than 80 percent of the American population lives within 50 miles of the coast, a population component that has doubled in the past decade. By 2010 the population density along ocean shores is projected to reach 400 people per square mile, compared to less than 100 per square mile for the rest of the nation. Fourteen of the country's 20 largest urban corridors are along the nation's coasts, and a major portion of the U.S. economic

[1]For the purposes of this report, the coastal zone is the region bounded landward by the inland boundary of a coastal county or parish and seaward by the outer limit of the U.S. territorial sea. The coastal zone includes the U.S. component of the area around the Great Lakes.

BOX 1.1
Economic Value of the Coastal Zone

- The movement of waterborne cargo contributes more than $742 billion to the U.S. gross domestic product and creates employment for more than 13 million individuals (USDOT, 1999).
- Commercial and recreational fishing contributes more than $111 billion to the economy annually (USDOT, 1999).
- Rapid population growth and the resulting increase in coastal development during the past 50 years have resulted in greatly increased natural hazard risk to 160 million Americans and more than $3 trillion in coastal property (Heinz Center, 2002).
- A 1992 study calculated that the coastal zone in California alone provided an annual economic contribution of $17.3 billion and 370,000 jobs (CSC, 2001).
- In 1996, Americans spent $18.1 billion on activities related to wildlife observation in the coastal zone (USDOT, 1999).
- In 1997, about 78 million Americans participated in recreational boating, using about 16 million boats and spending $19 billion on boats and boating activities (USDOT, 1999).
- The economic impact of cruise lines is estimated at $11.6 billion per year (USDOT, 1999).

infrastructure is located near or on the ocean (Hinrichsen, 1999). More than 95 percent of overseas trade between the United States and other nations moves by ship, including 9 million barrels of oil per day and over 98 percent, by weight, of all non-North American Free Trade Agreement (NAFTA) goods imported into the country. As gateways to our nation and the focal point of commerce, our ports and harbors are critical and vulnerable components of the nation's infrastructure and homeland security.

Beyond its formal, spatially delimited definition, the coastal zone is inextricably linked to a complex web of environments extending from the upper parts of watersheds out to the open ocean. Variations in watershed outflows influence the types and concentrations of dissolved and suspended materials in coastal waters. Physical, chemical, and biological processes control the distribution of nutrients, the transport of sediment, and the water circulation in coastal waters. Human activities have often resulted in increased sediment and pollution loads to coastal waters, decreased water quality, alteration of physical environments, loss or change of habitat (both onshore and offshore), depletion of fish stocks and other resources, and degradation of coastal aquifers. Thus the coastal zone provides a critical and sensitive indicator of environmental perturbations and disruptions.

Weather and climate also have a major impact on the coastal zone. Between 1980 and 2001, total economic losses in the coastal region due to weather-related events exceeded $280 billion (Ross and Lott, 2000). Most climate change models predict a rise in sea level and an increase in the frequency and severity of weather-related events over the coming years, which would put even more pressure on the fragile coastal zone (IPCC, 2001).

The importance of the coastal zone to the well-being of the nation places tremendous demands and responsibilities on those charged with management of this critical environment. In order to understand and address the effects of complex natural and anthropogenic forces in the coastal zone, a holistic multidisciplinary framework must be developed to adequately describe the interconnectivity of processes in the system. At the base of this framework will be accurate information about the locations of important features and processes, both onshore and offshore.

COASTAL ZONE GEOSPATIAL DATA—MAPPING AND CHARTING

The locations of features in space are described by geospatial data. These data—whether in the atmosphere, on or below the earth's surface, or within the water column—are referenced to a specific position in space and then linked to information about the attributes associated with that position. Such geospatial data are usually presented in the form of maps or charts.

Science, education, commerce, planning, and resource management have relied for centuries on the availability of accurate maps and charts. In coastal regions, high-quality maps and charts are essential for safe navigation, resolving jurisdictional boundaries, understanding processes, mitigating hazards, tracking environmental changes, establishing inventories of resources and habitats, and developing new programs and policies. Ideally, to accomplish all of these goals it will be necessary to combine disparate coastal zone information (e.g., land features, water depths, salinity, currents, bottom type, habitat type, infrastructure) into a single distributed information system that uses spatial coordinates as a common reference frame. These data can then be depicted on maps and charts or brought into Geographic Information Systems (GISs), or other spatially referenced software applications, for analysis. While simple in concept, the reality of this integration of coastal zone data is extremely complex. Those interested in truly understanding the complexities of the coastal zone will need to reach beyond traditional geographic, disciplinary, and political boundaries to develop a new suite of methods, analytical tools, and products.

Historically, the fundamental data needed in the coastal zone have been captured and portrayed onshore as "maps" and offshore as "charts." Unfortunately, differences in scale, resolution, cartographic conventions and projections, and particularly reference datums currently inhibit the seamless combination of existing onshore and offshore data. The result is a lack of standardized uniform geospatial products that span the coastal zone. This inability to produce a seamless map (or chart) across the land-water interface is a severe impediment to studying the many processes that are continuous across the shoreline, particularly studies of coastal change. The lack of standardization has also led government agencies, the research community, and the private sector to undertake the expensive and time-consuming task of separately generating new data and maps to accompany almost all new studies and initiatives. The lack of coordination of coastal zone mapping efforts inevitably leads to the potential for redundancy of surveys or products.

At the national level, at least 15 federal agencies are involved in the primary collection or use of coastal geospatial data (see Appendix A), often with responsibilities shared among multiple divisions within the same agency. In addition to these federal agencies, a plethora of state and local agencies, academic institutions, and other organizations also gather and use coastal zone information. This has resulted in a chaotic collection of potentially overlapping, and often uncoordinated, coastal mapping and charting products that can frustrate the efforts of users to take advantage of existing datasets and build on past studies. Add to this mix an increasingly educated and interested public, with growing demands for information to meet their diverse interests (including environmental protection, commerce, and recreation), and it becomes even more critical for the nation to pursue integrated coastal and ocean mapping in a cost-effective, well-coordinated, and strategic manner.

Fortunately, recent advances in mapping technologies, remote sensing, global positioning, data handling, and computing technologies—particularly the rapid development of GISs—have radically changed the density, accuracy, timeliness, and inherent nature (now mostly digital) of coastal mapping data and data products. In addition, programs and entities such as the National Ocean Partnership Program (NOPP) and the Federal Geographic Data Committee (FGDC) are promoting a greater spirit of partnership among those involved in coastal zone studies. These new tools and mechanisms, together with the implementation of appropriate and well-designed standards, should enable a more thorough, integrated, and organized approach to coastal zone mapping.

COMMITTEE CHARGE AND SCOPE OF THE STUDY

Recognizing both the difficulties and opportunities described above, and believing that an independent external evaluation could provide valuable new ideas, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), and the U.S. Environmental Protection Agency (EPA) requested and funded this assessment by the National Academies of national needs for coastal mapping and charting (see Box 1.2).

The mandate of the committee can be summarized in four questions:

- What are the mapping needs of the coastal community?
- Who is doing what?
- Are there gaps or overlaps in existing efforts?
- How can the needs of the community be met in the most efficient and effective way possible?

BOX 1.2
Statement of Task

This study will identify and suggest mechanisms for addressing national needs for spatial information in the coastal zone. By examining the major spatial information requirements of federal agencies, as well as the principal user groups they support (e.g., state and local coastal managers, urban planners, resource managers, maritime industry), the committee will identify high priority needs, evaluate the potential for meeting these needs based on the current level of effort, and suggest steps to increase collaboration and ensure that the nation's need for spatial information in the coastal zone is met in an efficient and timely manner.

In particular, the committee will identify:

1. Primary datasets and their attributes, such as scale and resolution, as well as value added products, that are needed to support decision making in the coastal and ocean environment;
2. Gaps or overlaps among the federal and state programs currently in place to collect this information, as well as barriers to effective coordination; and
3. Techniques and technologies currently or soon to be available that could expand the capability to acquire, archive, and disseminate information to the user community.

Identifying the needs and activities of the U.S. coastal zone community is an immense task. To conduct this assessment, the committee held four regional meetings at which representatives of agencies involved in all aspects of coastal zone mapping made presentations and offered their perspectives on the needs and activities of their agencies. In addition to these presentations, the committee communicated with and received written and oral submissions from individuals involved in coastal zone mapping activities. The requirement in the committee's statement of task for an assessment of the major spatial information requirements of federal agencies, as the basis for federal support of a wide range of user groups, has led to the committee's focus on making recommendations that predominantly apply at the federal level. Nevertheless, underpinning the committee's recommendations is an appreciation that a broad range of user groups, including state and local agencies, constitute the "frontline" for coastal zone activities and that improved federal-level mapping and charting activities must have the provision of improved information at these other levels as its focus.

The committee was required to prepare an interim report (NRC, 2003a) that focused on a compilation of the coastal mapping and charting activities of federal agencies and offered some very preliminary observations. A tabular summary of the agency activity compilation that constituted a major component of the interim report is presented in Appendix A.

Despite the complexities of the numerous issues raised by the many providers and users of coastal zone data, the consistency of needs and concerns permitted the committee to quickly converge on a vision for the future of coastal mapping and charting. This vision requires the development of an integrated and coordinated coastal mapping strategy for the nation, based on a foundation—a reference frame—upon which all data collection, analyses, and products can be built. To establish this foundation, there must be a national effort to collect the information and develop the tools necessary to seamlessly blend topographic (onshore) and bathymetric (offshore) data. These data and tools will permit the establishment of a nationally coordinated distributed digital database across the land-sea interface consisting of seamless elevation and depth data that can be referenced or transformed to common vertical and horizontal datums. This database will provide the basic geospatial framework for all subsequent data products, much like the USGS topographic sheet basemaps have formed the onshore foundation for a multitude of subsequent studies. Unlike the USGS topographic sheets, however, a coastal zone database must be "tide-aware" and must be able to reconcile the differences between onshore and offshore datums.

Our vision for the future of coastal zone mapping and charting also includes mechanisms to ensure communication among all the agencies and entities involved in order to minimize redundancy of efforts and maximize operational efficiencies. There will be national—and perhaps international—standards and protocols for data collection and metadata creation and readily available tools for data transformation and integration. With these tools, the user community will be able to evaluate the accuracy and timeliness of data and change scales and projections, as well as seamlessly merge disparate datasets. The database and data integration tools will be easily accessible to all users, public and private, from a single digital portal accessible through the Internet.

This is a bold vision, but at the same time an obvious one. Who would argue with a system that is efficient and produces easily accessible, fully interchangeable, accurate, and timely data? The vision may be simple to define, but its implementation will be anything but simple. As discussed in the following chapters, there are serious impediments to attaining this vision. It is the committee's hope, however, that the strategies outlined here will help the nation to get there. The long-term sustainability of our coastal resources may well depend on it.

2

Coastal Mapping Needs and Activities

One of the more difficult challenges for the Committee on National Needs for Coastal Mapping and Charting was the identification of the needs and activities of the extremely large and diverse community involved with spatial information in the coastal zone. The intersection of these needs and activities formed the basis for identifying gaps and overlaps in coastal zone data collection and processing. In order to assess both the needs and activities, committee members and National Research Council (NRC) staff interviewed representatives of, and solicited written submissions from, agencies involved in coastal zone mapping and charting. In addition, a series of presentations were made to the committee by representatives of a wide range of agencies and organizations that use and/or produce information related to the coastal zone. Valuable additional information was also extracted from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) surveys of coastal resource managers (CSC, 1999; 2002); a CSC-sponsored study of the benefits of Geographic Information Systems (GISs) for state and regional ocean management (Good and Sowers, 1999); and a National Marine Sanctuaries evaluation of the status and needs of spatial information in marine sanctuaries (NOAA, 2002).

Based on this data collection and information-gathering process, the committee identified at least 15 federal agencies, almost all coastal states, and innumerable local agencies, academic institutions, and private companies involved in the collection or production of coastal mapping and charting data or products. While an attempt was made to quantify expenditures on coastal mapping and charting (each agency was asked to provide a reliable estimate of its annual expenditures on coastal mapping and charting), the inconsistency of responses made it impossible to provide a precise (or even approximate) total. It is clear, though, that hundreds of millions of dollars are spent each year on coastal zone mapping and charting activities. The Office of Management and Budget (OMB) had hoped to compile a comprehensive accounting of the federal dollars spent on geospatial data collection in 2002, for publication in early 2003. However, difficulties encountered when attempting to collect these data resulted in the comprehensive compilation being deferred, with the intention that 2003 data should be available in early 2004. Therefore, although not available at the time of publication of this report, the information contained in the OMB study should finally allow a quantitative assessment of the amount of federal money spent on coastal zone mapping activities.

The information presented to the committee is summarized in Appendix A, based on the more extensive compilation presented in the committee's interim report (NRC, 2003a). This information was reviewed by each agency for accuracy, but the perspective is ultimately that of this committee. Although state and local agencies play a key role in the acquisition and use of coastal geospatial data, the breadth and diversity of these activities prohibited an exhaustive review of each coastal state's activities and needs.[1] The committee found considerable commonality of needs and activities among the states and local agencies and accordingly has included a "generic" section on state and local needs and activities. An overarching expression of the needs of state and local agencies is probably best presented in the recent Coastal States Organization (CSO) submission to the U.S. Commission on Ocean Policy, which called for "complete mapping of the nation's coastal areas, including near-shore topography and coastal watersheds, at a scale and in a form that is readily available and usable by the states and territories with an initial focus on critical areas under threat to the public or critical coastal or ocean resources." The CSO also states that such a mapping program is needed because of the "lack of accurate mapping of flood plains, erosion zones and shorelines and accessible information to enable states and communities to make well-reasoned, cost-effective, long-term decisions" (CSO, 2002, p. 17).

While the committee has made every attempt to be as complete in its analysis as possible, the magnitude of coastal mapping activities across this nation is such that it is possible that some activities and needs have

[1]A state-by-state review of some activities is presented in the CSC-sponsored study of GISs for ocean management (Good and Sowers, 1999).

been missed. Nonetheless, the committee is confident that the *major* needs and activities of those involved in coastal mapping and charting in the United States have been addressed and, in so doing, a basis has been established for evaluating the gaps, overlaps, and major issues associated with current activities.

Analysis of the agency activities presented in Appendix A revealed that, while coastal zone mapping and charting applications are as varied and diverse as the user community, there is a strong thread of consistency and commonality in important elements of the communities' needs. These commonalities include a need for:

- A consistent spatial framework for coastal data that allows a seamless transition from onshore to offshore, including clarification of offshore boundary definitions.
- A standardized definition of "the shoreline," to the extent possible in the context of federal and state legal restrictions.
- Increased collection and availability of primary thematic data, including such elements as shallow-water bathymetry, acoustic and satellite imagery of the seafloor, bottom type, habitat distribution and classification standards, land use, land cover, and coastal change data.
- Easy access to up-to-date digital geospatial data, imagery, and mapping products.
- Compatibility among data formats, or standards and transformation protocols that allow easy data exchange, and a means to evaluate the accuracy of geospatial data.
- Increased inter- and intra-agency communication, cooperation, and coordination.

Addressing these critical issues, which are described in more detail below, will provide the basic reference frame, source data, and tools necessary to create the wide range of derivative products needed to efficiently and effectively manage the coastal zone.

COASTAL GEOSPATIAL DATA, TECHNOLOGY, AND PRODUCTS

The fundamental reference information for all geospatial data consists of the position of each data element in three-dimensional space. Within this context it is important to acknowledge the revolutionary advances in positioning capability that have taken place over the past 30 years. With the advent of universally available, relatively inexpensive global positioning system (GPS) receivers, almost all modern coastal zone data can now be collected with unprecedented accuracy (on the order of

10 meters for single-point GPS, 3 meters for differential and WAAS[2]-enabled GPS, and at the centimeter level for kinematic or carrier positioning systems[3]). As will be discussed later, the introduction of GPS also provides for a continuous vertical reference frame from which offshore and onshore data can eventually be compared. The ability to precisely locate the position of measurements removes an important level of uncertainty from coastal zone surveys and greatly aids in the ability to make meaningful repeat surveys (for time-series studies). It also emphasizes the critical need to understand and document the positional accuracy associated with historical data, especially when comparing GPS-positioned data to non-GPS-positioned data.

Throughout this report, this positional information will be referred to as *reference frame data*. Onshore, the vertical component of a position has involved measurements of the *dynamic earth surface,* determined by measuring the elevation of the land surface. Offshore, the vertical component is determined by measuring both the *dynamic earth surface* (the depth of water to the seafloor) and the *dynamic water surface,* determined by monitoring tidal levels (the water level with respect to an established reference surface [datum] at a given moment in a tidal cycle). Both horizontal and vertical measurements must be made relative to established horizontal and vertical reference frames (the vertical and horizontal datums) that have to be defined within the context of a survey. The Federal Geographic Data Committee (FGDC) introduced the concept of “framework data” as a common-use data layer—the geospatial foundation—upon which an organization can add additional detailed mapping information (FGDC, 1995). Reference frame data, as defined by the committee in this report, are a type of framework data consisting of fundamental geospatial position information (including the necessary geodetic controls).

The primary (nonderivative) properties of the coastal zone are represented by *source data*. Source data, and their associated metadata (data describing the data), include data from aerial and satellite imagery (conventional and digital photography as well as data generated by other imagery sensors), other remote sensors, and direct measurements or sampling. Properties often measured or sampled directly include sediment and soil type, soil moisture and porosity, salinity, temperature, turbidity, nutrient concentrations, and data describing plant and animal communities.

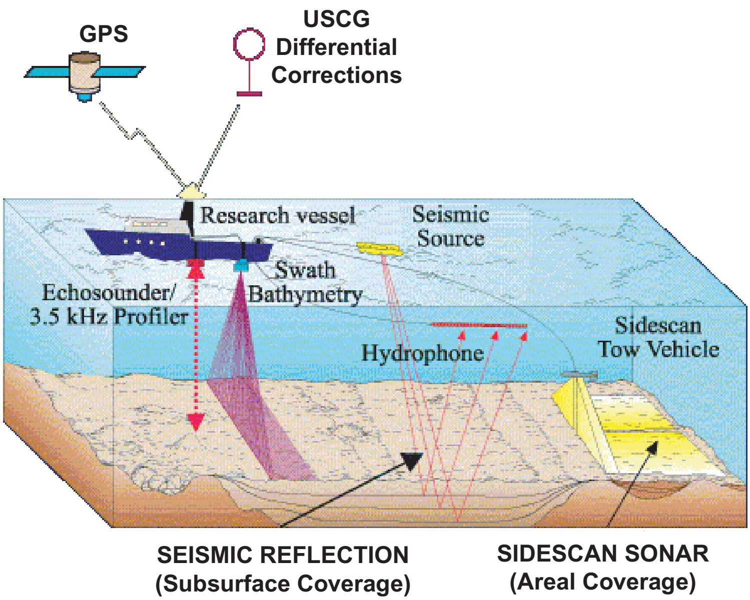
Numerous methods, platforms, and sensors are used to collect the framework and source data needed to produce coastal maps and charts (see Box 2.1). Bathymetry is most frequently collected using acoustic

[2]WAAS (Wide Area Augmentation System) provides correction information from a precisely surveyed ground reference station. See http://gpsinformation.net/exe/waas.html.
[3]See http://www.geod.nrcan.gc.ca/index_e/geodesy_e/gps-13_e.html.

BOX 2.1
Coastal Mapping and Charting Technology

1. REMOTE ACOUSTIC SENSORS

Acoustic sensors include underwater instruments that transmit and receive sound underwater to measure various parameters. The most common acoustic remote sensors are echosounders and sonars.



Overview of common seafloor mapping systems. SOURCE: U.S. Geological Survey (USGS) Coastal and Marine Geology Program.[a]

1.1 Single-Beam Echosounder

The single-beam echosounder has been used extensively to determine water depths from vessels. This simple sounder measures the round trip time of an acoustic pulse emitted from a hull-mounted transducer and reflected, or echoed, from the seafloor back to the ship. Water depth is determined by converting the round-trip travel time into distance. Simple echosounders use an approximate speed of sound in water to make this conversion. More accurate echosounders use a separately measured acoustic velocity. Other factors are also taken into consideration to improve accuracy, including the vessel's instantaneous heave, pitch, roll, squat, tide, and

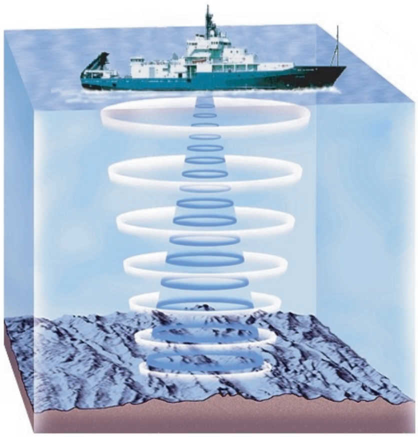
continued

sensors mounted on ships, launches, or autonomous underwater vehicles. Multibeam sonar systems are becoming increasingly important because they can provide complete high resolution coverage of the seafloor as compared to the sparse sampling of single-beam sonars. Acoustic backscatter from multibeam sonar systems and sidescan sonar systems provides bottom characterization information that can be used for habitat mapping and bottom geomorphology. If water clarity permits, airborne Light Detection and Ranging (LIDAR) systems can provide relatively high resolution bathymetry in depths up to 60 meters (although 20 to 30 meters is more typical). When coupled with a topographic LIDAR and the appropriate tidal and geodetic models, LIDAR can provide seamless measurements across the shoreline. Recent years have also seen a remarkable revolution in the spectral and spatial capabilities of airborne and spaceborne imaging sensors as well as the analytical tools available for the data derived from these sensors. Photogrammetric and multispectral imagery obtained from aircraft and spacecraft can now provide a wealth of data on land use, topography, habitat, biological, nutrient, suspended sediment, and shoreline data and in special circumstances can even provide some bathymetric data. Across the board, the capability of sensors and ancillary systems (e.g., positioning systems) is rapidly increasing, and these increases in capability (resolution, accuracy, etc.) will inevitably play an important role in future coastal zone mapping. In particular, the ability to collect coregistered datasets (e.g., sonar data combined with video data) and the development of software that will support data fusion and automated feature extraction will greatly facilitate the subsequent analysis and interpretation of complex coastal datasets.

Derivative or "value-added" products are created from the integration and interpretation of reference frame and source data. Most of these products fall into one or more of the following themes:

- Safety of Navigation
- Legal and Other Boundaries
- Environmental Management and Protection
    - Habitat and sensitive environments
    - Water quality and pollutants
    - Seafloor type and quality
    - Living coastal resources
    - Land-use characterization
- Coastal Hazards
- Minerals and Energy Management
- Coastal Zone Planning and Development
- Cultural Resource Management

BOX 2.1 Continued



Differential Global Positioning System (DGPS) antenna position relative to the transducer. Higher-frequency echosounders provide higher resolution but have less depth range. Narrower transducer beam widths also improve accuracy. A single-beam survey results in a single line of bathymetric data points along the survey vessel's track. Historically, most bathymetric data were collected using lead lines or single-beam echosounders. Because survey track lines were generally far apart, obstructions or seafloor irregularities between track lines could remain undetected.

1.2 Multibeam Echosounder

Over the past decade, multibeam echosounders have increasingly replaced single-beam echosounders as the preferred tool for comprehensive bathymetric surveys. Multibeam systems are capable of measuring a number of high-resolution depths across a wide corridor as the survey vessel transits. For example, some multibeam echosounders can gather more than 250 soundings across a swath up to seven times the water depth (swath bathymetry). If the swaths from adjacent survey lines overlap, the multibeam echosounder can produce full bottom coverage during a bathymetric survey. Because multibeam systems measure an angular sector originating at the transducer on the ship's hull, they are more efficient in deeper water.

The data are corrected for heave, pitch, roll, squat, tide, and DGPS antenna offset relative to the transducer. Acoustic sound velocity profiles

continued

The coastal zone is dynamic. Storms, vegetation and drainage basin changes, development, sea level rise, tides, wave actions, and currents alter the coastal zone over time. Consequently, repeat measurements of reference frame and source data, together with time series of the derived products, are a critical requirement for understanding and managing the coastal zone.

COASTAL ISSUES REQUIRING GEOSPATIAL DATA AND PRODUCTS

Appendix A summarizes, on an agency-by-agency basis, the needs and activities of the agencies involved in coastal zone mapping and charting. This section recasts those needs and activities within a framework of the seven major themes that capture the fundamental raison d'etre for most coastal zone mapping and charting activities. Collectively, these themes encompass most issues involved in coastal zone management and planning:

- Navigation
- Homeland Security
- Coastal Zone Boundaries
- Environmental and Living Resource Management
- Coastal Hazards
- Minerals and Energy Management
- Cultural Resource Management

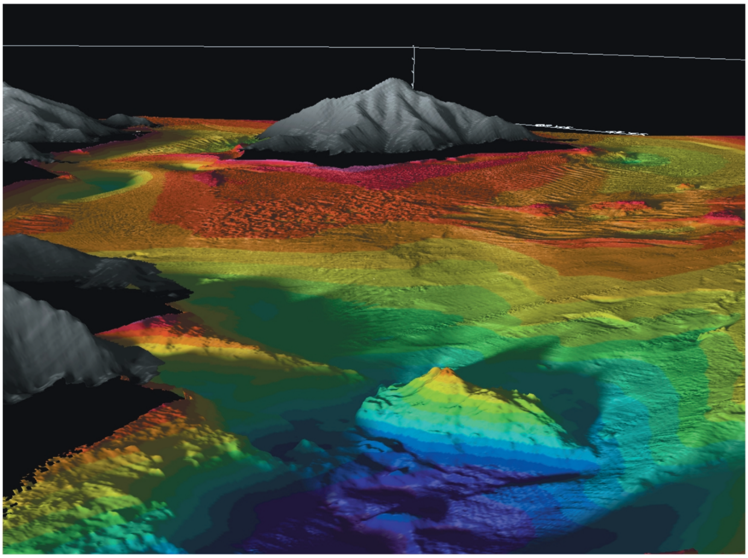
Navigation

Information and products for safe and efficient navigation are fundamental to the maritime interests of any coastal nation. Providing safe and efficient navigation generates a sizeable economic benefit, is a cornerstone for sustainable development, avoids or mitigates environmental catastrophes, and contributes to the quality of life. Because safe and efficient navigation forms the foundation for such a broad range of economic, environmental, and recreational activities, maritime nations have historically undertaken the tasks of collecting, producing, disseminating, and maintaining the necessary navigational data, products, and services within their own waters as a service available to all users at modest cost. In addition, a number of maritime nations with historically global interests have sought to ensure safety of navigation for their merchant and military fleets wherever they may be called on to operate. International organizations and conventions are devoted to furthering safe and efficient navigation

BOX 2.1 Continued

are also measured and integrated into the solution for high-accuracy results. Like single-beam echosounders, higher frequencies have higher resolution but are limited to more shallow water. Lower frequencies can sound, with less accuracy, to full ocean depth.

In addition to bathymetry, many multibeam echosounders can also simultaneously measure the magnitude of the reflected signal, which results in colocated backscatter (or multibeam) imagery. Because hard or rough seabed reflects more energy than soft or smooth seabed, multibeam imagery can be used for habitat and sediment mapping. The combination of multibeam echosounder with GPS produces bathymetry and imagery data that are accurately positioned, so that three-dimensional computer-generated digital terrain models (bathymetry) can be draped with the accompanying imagery to depict seabed morphology as well as the nature of sediments. By combining datasets in this way, features can be more easily detected, such as rock outcrops, channels, and small-scale bedforms.



Multibeam data collected by USGS from San Francisco Bay combined with USGS topographic data. New visualization techniques allow such complex environments to be interactively explored in ways that are both intuitive and quantitative. SOURCE: Image courtesy of the Center for Coastal and Ocean Mapping, University of New Hampshire; used with permission.

continued

through increased geographic coverage and improved quality of service (IHB, 2001).

Economic Importance of Shipping

As noted earlier, over 98 percent of the nation's non-NAFTA trade is carried by ships through the U.S. coastal zone. With access to adequate charts of the coastal zone, ships can ply the optimum routes, which in most cases are the shortest navigable routes. In other cases, an optimum shipping route may be longer but traverse a deep water approach that allows larger, fully loaded ships to proceed to port. By coupling high-resolution hydrographic surveys, accurate tidal monitoring and modeling, and dynamic ship response predictors, the minimum under keel clearance can be actively managed to maximize the loading of large commercial vessels (see Box 2.2). Additionally, accurate and up-to-date charts and navigation services should ultimately reduce insurance premiums, as reduced navigation-related incidents are factored into premium calculations. In sum, the advantages of accurate and complete navigational information yield maximum throughput of cargo at the lowest possible costs.

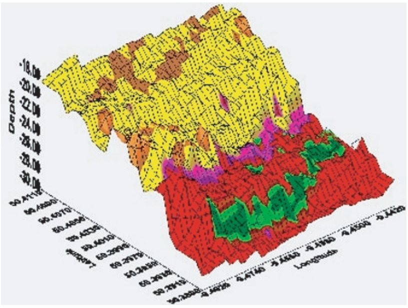
BOX 2.2
Dynamic Under Keel Clearance Management

In most cargo ports the maximum loading of vessels is determined using a conservative consideration of numerous factors, together with the errors associated with the prediction or estimation of these factors. These factors include bathymetry, tides, ocean swell, water density, and the squat, pitch, roll, and heave of a vessel underway in a channel. If greater precision can be achieved in the measurement or prediction of these factors, the cumulative safety allowance can be reduced and vessel loading maximized. Accurate hydrographic surveys are essential for determining bathymetry and the nature of the water bottom, and for improving the dynamic modeling of tides, ocean waves, and the dynamic response of a ship transiting the channel. Several Australian ports actively manage the maximum loading of cargo ships through real-time ocean swell monitoring, accurate tidal modeling, high-resolution hydrographic surveys, and ship response modeling. The economic impact is impressive. For the 1996-1997 fiscal year in Hay Point/Dalrymple Bay, Queensland, 123 vessels loaded nearly an additional 0.75 million tons of coal. The savings in freight cost was $7.5 million, and the increased value of exported earnings was $30 million (O'Brien, 1997).

BOX 2.1 Continued

1.3 Acoustic Seabed Characterization

Single-beam echosounders have been used increasingly over the past decade not only to collect bathymetry but also to determine seabed characteristics. One such system is used by ecologists to characterize habitats in shallow waters (1.4 to 30 meters), where it can work effectively at vessel speeds of 8 to 12 knots. The first and second (multiple) echoes returned to the seabed characterization system's sensor provide indications of the bottom roughness and hardness, respectively. By examining the information from both types of returns, sediment type can be characterized as long as calibration protocols are closely followed. One of the advantages is that the data can be monitored in real time and thus calibrated for a local environment. The disadvantages are that it is not effective in very shallow water (less than 1.4 m) and its narrow coverage may not be suitable for interpolation in areas with patchy distribution of sediment types. These systems typically require local calibration against known bottom types for optimal performance.



1.4 Sidescan Sonars

Sidescan sonars use the acoustic energy returned laterally from the seafloor. There are many types of sidescan sonars, and each has its advantages and disadvantages.

Conventional Sidescan Sonar. Sidescan sonars can be used to make digital acoustic images of the seabed. Although most sidescan units are towed behind a survey vessel, they can also be hard mounted to the vessel for very shallow work. The figure shows a towed sidescan sonar that is "looking" out across the seafloor to either side of the ship. Sidescan sonars typically gather imagery with higher resolution than multibeam echosounders, and over a broader swath width. Because they are towed close to the seabed, sidescan sonars can also better delineate seabed obstructions such as rock outcrops, wrecks, and debris. The seafloor is typically surveyed in swaths 100 to 500 meters wide; digital splicing of adjacent sonar lines can be employed to assemble a sidescan sonar mosaic that provides continuous imaging of a mapping area. Like multibeam imagery, digital

continued

Navigation Safety

A thorough understanding and charting of the nearshore zone contributes to a reduction in maritime accidents and aids in the mitigation of accidents should they occur. It is self-evident that properly navigated ships using accurate charts will avoid groundings, with their associated risk of oil and hazardous cargo spillage and the potential for destruction of sensitive marine habitats. There are several additional services required for safe and efficient navigation that further prevent or mitigate environmental catastrophes. A maritime information system that monitors changes in the maritime environment and provides mariners with reports of conditions that affect their operations is integral to providing safe and efficient navigation. Local Notice to Mariners (LNM) provides frequent updates to navigational products, with information regarding hazardous conditions such as inoperative navigational aids, wrecks, dredging operations, and military exercises. The World Wide Navigational Warning System (WWNWS) provides navigational and meteorological warnings and other urgent safety-related messages via radio and satellite communications. Maintaining the currency of navigational information, broadcasting emergent safety information, and providing a 24-hour network for mariners to report incidents and unsafe conditions all markedly contribute to the avoidance of maritime accidents and to rapid response when they do occur.

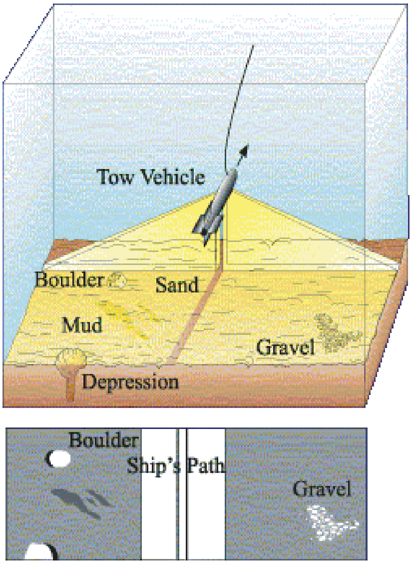
Navigation safety is of concern for recreational boats as well as large vessels. Annual USCG statistics for recreational boating accidents show that there are approximately 500 groundings and 200 additional incidents of "striking submerged objects" each year. Together, these accidents result in more than 300 injuries and deaths annually and millions of dollars in property damage. Because these statistics do not include similar accidents involving nonrecreational vessels such as commercial fishing boats, oilfield supply vessels, and the academic fleet, the true annual cost of property damage is probably substantially greater than that for recreational boats alone. Although some proportion of the costs results from human error, there is undoubtedly a significant proportion that results either directly from inadequate charts or indirectly from reduced situational awareness that could be rectified with modern electronic chart displays.

With the increased availability and decreased cost of GPS receivers, recreational boaters can now receive accurate position data, and many GPS receivers integrate position data with chart data for easy viewing. Unfortunately, the chart data may not be particularly current and therefore may no longer represent the geographic regions accurately. This, together with the enormous variety of areas in which recreational boaters

BOX 2.1 Continued

sidescan sonar mosaic images can be draped over a digital terrain model. NOAA often uses a combination of multibeam echosounders and sidescan sonar for nautical charting surveys.

The intensity of sound received by the sidescan sonar tow vehicle from the seafloor (backscatter) provides information on the general distribution and characteristics of surficial sediment. In the lower schematic, strong reflections (high backscatter) from boulders, gravel, and vertical features facing the sonar transducers are white; weak reflections (low backscatter) from finer sediments or shadows behind positive topographic features are black.



Chirp Sidescan Sonar. A technical advance from the conventional sidescan sonar is the chirp sidescan sonar. While conventional sidescan sonars transmit a single frequency (typically 100 or 500 kHz), chirp sidescan sonars transmit a range of frequencies (e.g., 114 to 126 kHz). Through its ability to transmit more energy into the water and the employment of pulse compression techniques, chirp sidescan provides improved target or feature resolution.

High-Speed Sidescan Sonar. Sidescan sonars are generally towed at speeds ranging from 2 to 5 knots. Faster tow speeds result in sonar image blurring because consecutive sonar image lines are too far apart. This effect would be similar to a television that displays only a fraction of the usual number of lines on the screen. However, a new high-speed sidescan can be towed at speeds up to 10 knots, because multiple image lines are recorded in a single transmission. These higher-speed sonars have significantly improved the productivity of surveys in less than 100 meters of water.

Synthetic Aperture Sonar. Another technical advance for sidescan sonars is the newly available synthetic aperture sonar. Synthetic aperture sonar allows consecutive overlapping sonar images to be intelligently stacked

continued

travel, has increased the demand for more current and accurate navigational charts (in both paper and electronic formats).

The International Maritime Organization (IMO), a specialized body of the United Nations of which the United States is a signatory Contracting Government, explicitly described the governmental obligation to provide for safe and efficient navigation in the Safety of Life at Sea (SOLAS) Convention (see Box 2.3).

The Marine Navigation Safety Coalition is a marine industry stakeholder group that includes more than 60 organizations, including port authorities, port associations, shipping associations, pilot associations, cruise lines, insurance companies, marine exchanges, and other private corporations. For each of the past several years, the coalition has encouraged NOAA and Congress to more aggressively address the survey back-

BOX 2.3
Regulation 9 of Chapter V of the Safety of Life at Sea (SOLAS) Convention

1. Contracting Governments undertake to arrange for the collection and compilation of hydrographic data and the publication, dissemination, and keeping up to date of all nautical information necessary for safe navigation.
2. In particular, Contracting Governments undertake to co-operate in carrying out, as far as possible, the following nautical and hydrographic services, in the manner most suitable for the purpose of aiding navigation:

2.1 To ensure that hydrographic surveying is carried out, as far as possible, adequate to the requirements of safe navigation;
2.2 To prepare and issue official nautical charts, sailing directions, lists of lights, tide tables and other official nautical publications, where applicable, satisfying the needs of safe navigation;
2.3 To promulgate notices to mariners in order to keep official nautical charts and publications, as far as possible, up to date;
2.4 To provide data management arrangements to support these services.

3. Contracting Governments undertake to ensure the greatest uniformity in charts and nautical publications and to take into account, whenever possible, the relevant international resolutions and recommendations.
4. Contracting Governments undertake to co-ordinate their activities to the greatest possible degree in order to ensure that hydrographic and nautical information is made available on a worldwide scale as timely, reliably and unambiguously as possible.

BOX 2.1 Continued

(added together), thereby minimizing random noise while enhancing the image. This technology will allow a 10-fold increase in sidescan sonar resolution, from 1-meter pixel size to 5 centimeters or better across the full sonar swath. This also means that the volume of collected data will increase by more than 100-fold.

Interferometric Sonar. Interferometric sonars are designed to gather both sidescan imagery and swath bathymetry. Interferometric techniques have been tried for many decades with varying degrees of success. In general, they provide excellent sonar imagery but reduced quality of bathymetry, although new developments in sonar design and signal processing are improving the quality of interferometric bathymetric data. These improved versions are of particular interest for coastal mapping work because of their ability to achieve very wide swaths in relatively shallow water.

1.5 Subbottom Profiler

Subbottom profilers use reflected sound (similar to the way an ultrasound provides images of internal organs) to provide acoustic (seismic) profiles, or cross sections, of features below the ocean floor. Subbottom systems operate at lower frequencies than echosounders and imaging sonars. High-resolution subbottom profilers operate at the high end of the frequency range (e.g., 3.5 kHz) but do not penetrate very far into the seafloor. Midrange systems (boomers, etc.) collect geophysical information to depths of 80 to 100 meters beneath the ocean floor but provide less detail. Very low frequency seismic systems (air and water guns) are used to profile much deeper into the subsurface (with a further loss of resolution); these are the standard hydrocarbon exploration tool. Subbottom profilers often achieve limited penetration in hard-bottom areas (sand, rocks, etc.) and areas where shallow methane gas has accumulated.

2. OTHER UNDERWATER SENSORS

Other underwater sensors include magnetic systems and light-based systems (e.g., cameras and lasers). Some of these have been in use for many

continued

log (estimated in 2000 to be 43,000 square nautical miles for "critical" areas and 491,000 square nautical miles for "significant" areas; DeBow et al., 2000) and associated tidal monitoring programs. This group maintains that such programs are critical for safety of life and the protection of property and the environment as well as for improving the efficiency and competitiveness of the U.S. marine transportation system.

Collection and Processing of Source Data for Navigation

For U.S. waters the Office of Coast Survey (OCS), an office of NOAA's National Ocean Service (NOS), collects and processes the vast majority of data necessary for navigation. OCS vessels, or private industry ships contracted by OCS, collect hydrographic data that include bathymetry, tides, water column properties, and bottom composition. Nearly 50 percent of the data compiled by OCS are obtained through contract to private industry. Aids to Navigation (AtNs) are initially fixed during these surveys; however, USCG normally maintains these aids and provides updated status and position to OCS as conditions warrant.

The National Geodetic Survey (NGS) provides delineation of the nation's shoreline using numerous techniques, including airborne photogrammetry, satellite altimetry, LIDAR, and land-based survey. Data collection performed at low tide may also be useful for detecting shallow-water hazards.

The U.S. Army Corps of Engineers (USACE) is tasked to monitor and maintain the navigability of numerous harbors and inland waterways. Additionally, the USACE undertakes beach replenishment projects, requiring an understanding of sediment transport processes and the identification of sediment sources. Each of these activities requires the collection of bathymetry, bottom composition, and coastal topography, although in some instances the data collection may not meet international standards for nautical charts.

The U.S. Navy collects and processes hydrographic data outside the nation's territorial waters. These data are provided to the National Geospatial-Intelligence Agency (NGA; formerly the National Imagery and Mapping Agency) for compilation into the nautical charts and products that are used for U.S. and allied military operations. Since September 11, 2001, the U.S. Naval Oceanographic Office has collaborated with OCS in the collection of bathymetric and sidescan sonar data in strategic U.S. harbors (see Homeland Security section below).

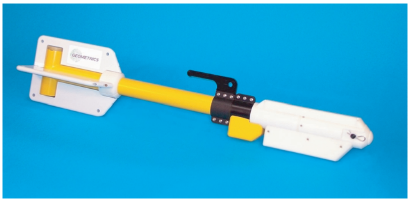
The USCG installs and maintains AtNs throughout U.S. waters, and the precise positions of these AtNs are provided to NOS and NGA for inclusion in nautical charts and publications. Changes in the status or characteristics of AtNs and the existence of hazardous conditions are

BOX 2.1 Continued

years, while others are more recent developments; all of these technologies, however, are experiencing continual improvements in hardware, software, and data presentation.

2.1 Magnetometer

The marine magnetometer measures the earth's magnetic field and is normally towed from a vessel in a manner similar to the sidescan sonar. Ferrous objects, such as pipelines, sunken vessels, and metal debris, will affect the ambient magnetic field measured by the magnetometer. These effects, or anomalies, provide indications of the presence of features that are not apparent from data provided by acoustic sensors. The magnetometer is particularly useful for locating buried or subtle ferrous objects.

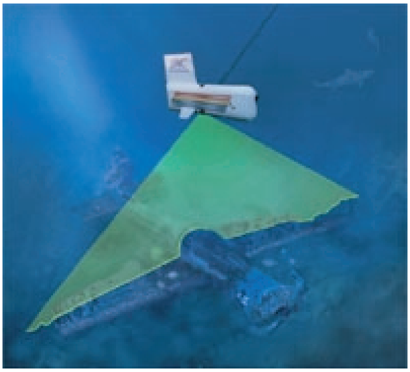


2.2 Gradiometer

Gradiometers are actually comprised of two magnetometers, whose solutions are combined to reduce the effects of ambient ferrous, or magnetic, noise. They are of particular value when trying to identify small ferrous objects that are within the magnetic field of larger ferrous objects. An example would be locating individual items within a debris field.

2.3 Laser Line Scan

Laser line scanning systems are towed or mounted on a sled and moved in a slow constant fashion at a stable height over the seafloor. As the sled moves forward, a narrow laser beam incrementally scans a portion of the seafloor. Individual scans are combined to create very detailed images with a quality that approaches that of a conventional photograph. Accurate positioning determinations are critical for assembling continuous mosaic coverage of a mapped area. One advantage of this laser technique is the ability to obtain



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monitored by the USCG and reported through LNMs and provided to NGA for worldwide distribution. Recreational boaters, through the activities of the U.S. Power Squadron and the USCG Auxiliary, provide a valuable quality assurance function and source of input for LNMs.

NGA does not generally collect source data, relying on the U.S. Navy and exchange agreements with other nations; however, the agency partnered with the National Aeronautics and Space Administration (NASA) on the Shuttle Radar Topography Mission (SRTM) that collected high-resolution radar altimetry data for over 80 percent of the earth's land topography. These data are sufficiently accurate to position a non-tidally corrected coastline. Additionally, NGA accesses commercial and intelligence satellites capable of providing topography and land-use information; however, the collection of this information is generally restricted to foreign land, and the resulting products are frequently classified.

NGA, NOAA-OCS, USACE, and the Navy access satellite imagery operated by other government agencies (NOAA's National Environmental Satellite, Data, and Information Service [NESDIS], National Reconnaissance Office) or commercial activities (IKONOS, LANDSAT, SPOT, etc.). Historical information regarding coastal processes is accessed through archives held by state and local governments and academia.

Tools and Applications for Using Navigation Data

The various agencies use different tools and applications to process, disseminate, and display their hydrographic data. NOAA's CSC Web site[4] offers access to GIS tools for accessing rasterized navigation charts, and NOAA's National Geophysical Data Center (NGDC) Geophysical Data System (GEODAS) software offers access to point data in a more basic form. NGA and the Navy developed the Hydrographic Source and Assessment Systems (HYSAS) protocol for the transfer, assessment, and manipulation of data between these two agencies, and other agencies have similar programs tailored to their individual needs. USACE's Scanning Hydrographic Operational Airborne LIDAR Survey (SHOALS) ToolBox provides applications for the manipulation of geospatial data and engineering calculations. A wide range of private-sector electronic chart products (some supported by officially sanctioned databases) offering both raster and vector products exist (e.g., Electronic Chart Display and Information Systems [ECDIS], Ward et al., 2000).

[4]See http://www.csc.noaa.gov/bins/tools.html.

BOX 2.1 Continued

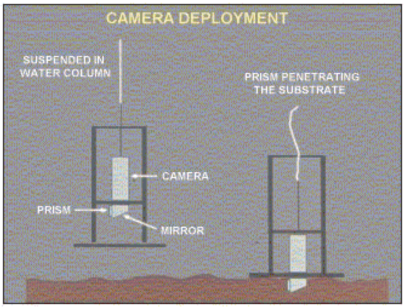
a relatively clear image at three times the range of an underwater camera. However, because of their cost and complexity, laser line scan systems are in limited use.

2.4 Photography/Videography

Underwater video and photography can be effective methods for obtaining marine data. Photographs and video stills can be used in conjunction with image analysis software to determine the coverage and character of submerged vegetation or bottom sediments and the density and health of epibenthic (seafloor surface-dwelling organisms) species. Like other visual techniques, the quality of video or photo data is negatively affected by turbid water, and ranges are typically quite limited.

2.5 Sediment Profiling Imagery

Sediment profiling systems are specially designed cameras and frames with a wedge-shaped prism mounted to penetrate the seafloor. The weight of the whole apparatus drives the prism into the sediment and the rate of descent is controlled by oil-filled pistons. One side of the wedge is plexiglass, and the whole prism is filled with distilled water. Turbidity of the water does not interfere with the image quality because the plexiglass is directly in contact with the sediment. A mirror on the back of the prism reflects the sediment profile up to a camera that is mounted above the prism. The prism penetrates up to 20 centimeters of sediment, and the image has a resolution of approximately 0.06 millimeters.



One disadvantage of the sediment profile system is that a rough characterization of the bottom type is required before deployment to avoid rocky areas. Like other point sampling techniques, many samples may be required to characterize a habitat using a sediment profile imagery system, especially if there is high variability on a small spatial scale. However, when combined with other technology such as a multibeam echosounder or sidescan sonar, this equipment can produce highly detailed habitat characterization.

continued

Navigation Products

Numerous safety-of-navigation products are compiled directly from source data. The purest examples are databases accessible in hard copy or digitally through the Internet, such as LNMs, Lists of Lights, AtNs, and Radio Navigation Aids. These products are produced locally by USCG and on a worldwide basis by NGA. More complex products are produced through the combination of several data sources. The World Vector Shoreline produced by NGA is an example of a database populated from a variety of sources. On the extreme end of complexity, a nautical chart is the depiction of numerous datasets, such as bathymetry, AtNs, bottom composition, and water column properties. As noted above, nautical charts are produced by OCS for U.S. waters and globally by NGA. Similarly, USACE produces several products based on source data collected for the waterway projects for which the agency is responsible. Typical USACE products include inland waterway charts, both hard-copy and electronic, navigation channel condition reports, and engineering drawings of waterway projects. The fact that the above products flow directly from source data does not imply an automated process. Since these products are directly related to safety of navigation, there are extensive quality control, validation, and verification components associated with their generation.

The combination of disparate datasets, modeled parameters, and rule-based assumptions is the basis for *derived* map products for the navigator, such as NGA's Sailing Directions, Pilot Charts, and Port Directories, as well as general navigation reference documents such as *The American Practical Navigator*, sight reduction tables, and nautical almanacs.

Homeland Security

The physical security of U.S. ports is a mission of the USCG in general and the U.S. Navy for selected ports. Following the terrorist attacks of September 11, 2001, homeland security has become a priority national concern, with port security being a significant focus. Coastal mapping and charting are integral elements of several components of homeland security. In particular, the mining of a port, the intrusion into the port by swimmers or underwater vehicles, or the release of chemical or biological agents into the water are all potential threats. An adequate knowledge of the nation's ports and surrounding coastal areas is a necessary requirement for defending against or responding to such terrorist attacks.

Counter Mine Warfare (CMW) requires high resolution bathymetry and backscatter data for entire ports and shipping sortie routes out to deep water in advance of any threat. These data are used to identify and precisely fix all objects on the bottom that may appear mine-like. In the

BOX 2.1 Continued

3. REMOTE SENSING FROM AIR AND SPACE

Concomitant with the rapid evolution of sonar technology have been revolutionary changes in the spatial and spectral capabilities of imagery collected from air or space. Remote sensing from the air offers the distinct advantage of high productivity through large areal coverage. On the other hand, it is often constrained by weather, visibility, and sun angle. Optical remote sensing techniques rarely penetrate through the water column but can provide extremely valuable data to describe the terrestrial component of the coastal zone, as well as water quality conditions, sediment transport, surface water temperature, and organic productivity.

3.1 Aerial and Satellite Imagery

Photography from aircraft can be accomplished with conventional film or digital technology. Digital images have the advantage of being viewable in the field, allowing immediate verification of image quality. Positional information is generally recorded concurrently using GPS and Inertial Measurement Unit (IMU) instruments. Disadvantages of aerial photography include difficulties in the timing of flights to coincide with low tide, vegetative cover, and acceptable weather conditions. With adequate ground truthing, aerial photography can be orthographically rectified (or orthorectified), so that the image (an "orthoimage") can be scaled in both directions. If the aerial imagery has adequate overlap, three-dimensional data can be generated.

Satellite imaging systems such as Landsat and the Advanced Very High Resolution Radiometer (AVHRR) provide even wider coverage, with multispectral information useful for sensing objects in the onshore and very shallowest offshore components of the coastal zone. Although the resolution of these sensors has been limited to tens of meters up to a few kilometers, recent improvements in high-resolution satellite imaging (e.g., IKONOS and QuickBird) have created the potential for employing satellite images in coastal zone applications that previously have been supported only by aerial photographs. Satellite imagery has the advantage of systematic coverage, periodic observations for both short- and long-term change detection, and potentially better cost effectiveness. The committee anticipates increased use of satellite images in coastal applications in the future. Unfortunately, satellite-based imaging capabilities degrade rapidly as water depth increases. Although the bathymetry of deep-ocean basins may be considerably improved using satellite-based radar altimetry (Sandwell et al., 2002), the limited resolution available using this technique in shallow coastal waters offers little potential for replacing acoustic bathymetric measurements.

continued

event that a harbor is mined, change detection algorithms are used to discriminate between the previously mapped mine-like objects and new objects detected by post-mining surveys. Bottom characterization using acoustic methods and grab or core samples is necessary to determine the likelihood of mine burial, and accurate current and circulation models are necessary to predict the trajectory of floating mines. Additionally, description of the local magnetic field variability is required to defend against magnetic influence mines. CMW efforts typically produce "Q-Route" charts[5] that lay out predetermined sortie routes, which can be easily cleared of mines because they have few existing mine-like objects and have bottom characteristics that would ease the detection and removal of mines. The various factors affecting CMW are assembled in classified Mine Pilot Publications for each port of interest.

Visual detection and acoustic detection are the primary methods used to counter the intrusion of swimmers or underwater vehicles. Acoustic detection in shallow water is difficult, but is more easily accomplished with a combination of high resolution bathymetry and bottom and water column characterization that relates to sound propagation. High-resolution bathymetry is pivotal to improved tidal and current models that are important components in understanding waterborne intrusion routes. In the event of a release of chemical or biological agents into the water, high-resolution bathymetry, bottom characterization, and tidal and current modeling are critical for understanding the propagation of these agents and their interaction with bottom sediment.

The U.S. Navy has collected data necessary for port security and Q-Route determination for certain strategic naval ports. Post-9/11 activities in support of homeland security demonstrate several examples of improved communication and cooperation between agencies. With the need to expeditiously collect data, NOAA, Navy, USCG, and USACE have routinely met and assigned data collection responsibilities against a prioritized list of requirements. This list typically includes 100 percent coverage of designated port areas for a range of data—high-resolution bathymetry, acoustic bottom backscatter, sea bottom characterization, fixing of mine-like objects, tides, currents, physical properties of the water column, and magnetic variability.

Coastal Zone Boundaries

Boundaries in the coastal zone are linear features defined for a range of purposes, including the establishment of national, international, and

[5]The U.S. Navy refers to shipping lanes in mined or potentially mined waters as "Q-routes" (see NRC, 2003c).

BOX 2.1 Continued

Hyperspectral imaging instruments can collect spectral reflectance data in shallow water or over land. The sensors are mounted on small aircraft and detect reflectance up to 288 narrowband wavelengths in the visible and infrared spectrum. The user can specify which spectral bands are measured and the bandwidths that are used. GPS coordinates and altitude are recorded along with the reflectance data. The data produced by hyperspectral imaging achieve very high resolution but require special image-processing software for importation into GIS. Like all aircraft-mounted technologies, hyperspectral sensors require clear, calm, shallow water to obtain high-quality data offshore. Variable water chemistry and tidal or solar conditions can alter the spectral signal of particular bottom features, and therefore a highly trained observer is required to interpret the data.

The Compact Airborne Spectrographic Imager (CASI) was the first commercially available hyperspectral sensor. The information gathered by CASI systems can be used for mapping bathymetry and habitat in shallow water. CASI can also be used to assess some water quality parameters such as the presence of algae that are associated with Harmful Algal Blooms (HABs; e.g., red tides).

3.2 Topographic LIDAR

This equipment measures the distance between the ground and an aircraft using laser light. LIDAR sends a short laser pulse, and the elapsed time for the signal to be reflected from the ground to the airborne receiver is recorded. Because the laser scans across track, topographic data are collected across a wide corridor as the survey proceeds. Highly accurate topographic maps (up to 20 centimeters vertical resolution) can be made using LIDAR in sandy areas, but this technology is not as effective in rocky habitats. The strength of the return signal provides additional information about the target.

In contrast to bathymetric LIDAR, where federal agencies are providing the substantial investment needed for initial technology development, topographic LIDAR is a relatively mature technology that is now dominated by the private sector, with numerous companies offering commercial LIDAR services.[b]

3.5 Bathymetric LIDAR

Bathymetric LIDAR works like a multibeam echosounder but using light instead of sound. It can determine depths across a swath width of 220 meters when flown at an altitude of 400 meters. Data densities of 2 meters × 2 meters have been achieved, with a depth resolution to 15 centimeters. In clear water, bathymetric LIDAR is far more productive than ship-based

continued

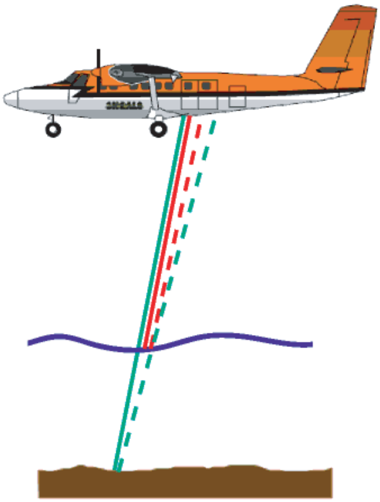
local jurisdictions (territorial claims and property lines), hazard studies, and long-term environmental management. In many cases, coastal zone boundaries represent the convergence of law and spatial mapping. Both marine and onshore boundaries share the concept of "cadastre" in that they have components of adjudication, survey, and owner rights but differ in that the common land-based process of demarcation is not usually applied to marine boundaries. Instead marine boundaries are typically delimited mathematically, with no physical evidence like monuments or pins present (Fowler and Treml, 2001). Marine boundaries often define the initial starting points for many critical legal issues and process studies, but because of the dynamic nature of the coastal environment, these boundaries may change over time. Timely and routine mapping and updating of these boundaries are thus extremely important for safe navigation, resource management (e.g., Thormahlen, 1999), environmental monitoring, coastal development, and many other applications.

The Shoreline

Many coastal zone boundaries are described relative to the dynamic shoreline. Because the shoreline is not static and its location at any point in time is affected by tides, a discussion of shoreline mapping (and most other marine boundary mapping) cannot be separated from discussion of tidal datums. A tidal datum is a base elevation used as a reference from which to measure heights or depths that are defined with respect to a certain phase of the tide (Hicks et al., 2000). A number of tidal datums are used in chart making—in the United States, the common datums are Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Low Water (MLW), Mean Lower Low Water (MLLW), and Mean Sea Level (MSL). To establish an official tidal datum, tide measurements are made over a period of 19 years—the National Tidal Data Epoch (NTDE). The datum used—for example, MLW—is thus the average of all of the MLWs over a 19-year period. The 19-year average is used because it represents the Metonic cycle that accounts for the full range of distances between the earth, the sun, and the moon. The NTDE is reviewed annually for revision and must be reconsidered every 25 years (Hicks et al., 2000). Depending on which datum is used, the position of the "shoreline" or land-water interface on a map will be different, with significant impact on the determination of maritime boundaries (see Figure 2.1).

Figure 2.1 illustrates the multiple definitions of the shoreline and submerged lands that are used by different federal, state, and local authorities. Twenty-one states define the state submerged land boundaries based on the tide-coordinated shorelines (MHW and MLLW), and the Exclusive Economic Zone (EEZ) boundary is determined based on the MLLW shore-

BOX 2.1 Continued



multibeam echosounders. Bathymetric LIDAR uses red and green lasers to determine water depth. Both signals are transmitted simultaneously, but the red is reflected at the water surface while the green laser is reflected from the ocean bottom. The time difference between the two returned signals is used to determine the depths. Bathymetric LIDAR is limited to three times secchi depth (about three times the visibility range), resulting in a typical maximum depth capability of 20 to 30 meters, and bathymetric LIDAR can never achieve the spatial resolution of multibeam echosounders because the laser beam spreads to approximately one-half the water depth upon entering the water. Nonetheless, bathymetric LIDAR and ship-based multibeam echosounders are complementary; clear, very shallow water is best surveyed with LIDAR, whereas more turbid waters are best surveyed with multibeam echosounders.

4. DIRECT SAMPLING

Remotely sensed data, such as sidescan imagery, require a certain amount of direct sampling verification to ensure their interpretation is valid. A range of seafloor sampling devices are available for this purpose; two of the more common ones are grab samplers and piston corers.

4.1 Grab Sampler

Grab samplers are often used to ground truth data from remote sensing instruments. A variety of designs are used to obtain sediment samples from the ocean bottom. Generally, grab samplers consist of a clamshell "jaw" that is locked open and lowered to the bottom by a cable. When the grab sampler impacts the bottom, a trigger mechanism allows the jaw to close and take a "bite" out of the bottom. The type of information that can be obtained includes sediment type, sediment quality, organic content, and the density and identification of infauna.

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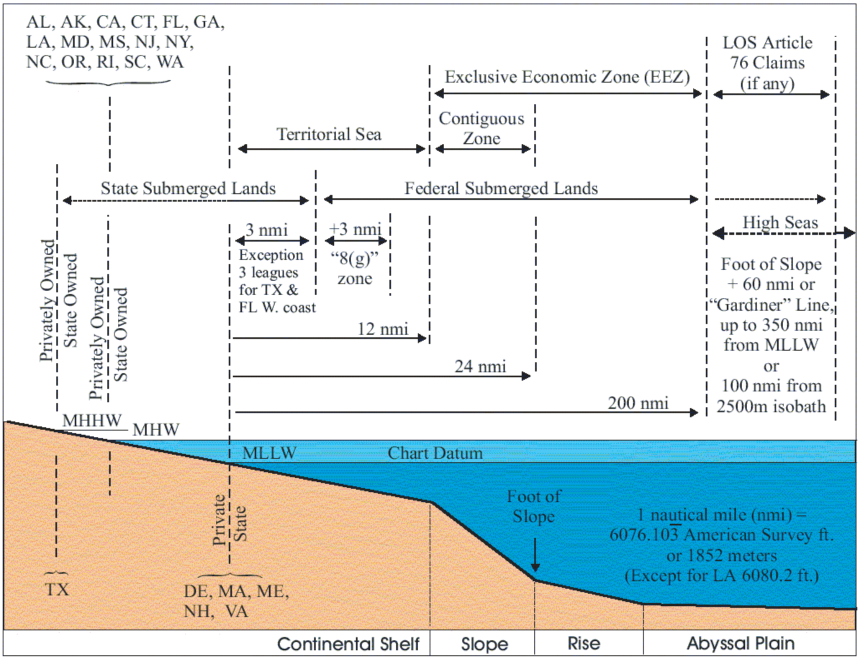


FIGURE 2.1 Definitions of shorelines by federal and state agencies. Figure courtesy of the Minerals Management Service.

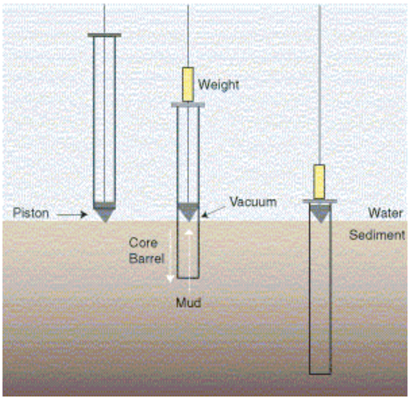
line. Shoreline locations are important to all levels of government operations, coastal policy making, and judicial applications. Private land owners use parcel boundaries for their land ownership. The Federal Emergency Management Agency (FEMA) and insurance companies determine premiums and damage estimates using private land boundaries and shorelines. Any private land lost due to erosion or other reasons becomes state submerged land in many states. Underwater dumping sites and oil and gas lease boundaries are on federal or state submerged lands, which in turn are determined based on the tide-coordinated shoreline.

Compounding the problem of shoreline delineation is the spatial and temporal variability of tides as well as the influence of local winds and weather. The United States maintains a network of only about 140 permanent tidal stations around the coastline. The information from these long-term discrete tidal measurement points (as well as data from shorter-term supplemental tidal stations) is used to build predictive models that allow tidal datums to be determined in the absence of long-term records and

BOX 2.1 Continued

4.2 Piston Corer

Like grab sampling, piston core sampling is generally effective only in soft sediment. Under the right seafloor conditions, typical piston corers can provide a few meters of ocean bottom sediment samples. Larger "jumbo" piston coring systems can produce samples up to 30 meters long, and there is one giant piston corer that can penetrate to 60 meters. The coring apparatus is lowered to the bottom and triggered. A weight pushes the core barrel into the seafloor while a piston seal in the barrel causes suction, helping to recover the sediment sample. The piston core technique results in minimal stratigraphic disturbance.



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[a]See http://woodshole.er.usgs.gov/operations/sfmapping/dataacq.htm.
[b]See http://www.airbornelasermapping.com/ALMIndex.html for a national and international listing.

SOURCES: 1.1–single-beam echosounder, image courtesy of the Woods Hole Oceanographic Institution; 1.2–multibeam echosounder, image courtesy of Kongsberg Simrad; 1.3–acoustic seafloor map, image courtesy of Stenmar Sonavision Limited; 1.4–sidescan sonar, image courtesy of USGS Coastal and Marine Geology Program; 1.5–EdgeTech subbottom profiler, image courtesy of EdgeTech Sonar Products; 2.1–Geometrics G-882 magnetometer, image courtesy of Geometrics; 2.3–laser line scan, image courtesy of NOAA Office of Ocean Exploration; 2.5–sediment profile camera deployment, image courtesy of NOAA Coastal Services Center; 3.5–bathymetric LIDAR, image courtesy of Optech, Inc.; 4.2–piston corer, image courtesy of USGS Coastal and Marine Geology Program.

instantaneous tidal levels to be predicted at locations where tide gauges are not present. Unfortunately, these predictions are often very coarse and inaccurate and are complicated by local topography, wind, and waves. Finally, the process of making bathymetric measurements close to the shoreline is often difficult. As noted above, acoustic techniques for measuring depth are often inaccurate and inefficient in very shallow water, and optical techniques (e.g., LIDAR) are often foiled by poor visibility in the surf zone.

The ubiquitous need for defining the shoreline as a critical reference point for a range of jurisdictional, scientific, and management purposes has led to the collection of shoreline data by many agencies using a variety of techniques. Not all techniques take into consideration the effect of tides. For example, the shoreline delineated on USGS topographic maps is derived from stereo aerial photographs without reference to tidal (MHW or MLLW) datums. This results in the establishment of an instantaneous and static shoreline representing the time the aerial photograph was taken. Some states use similar methods but may delineate a shoreline using only a single aerial photograph without rectification. The shoreline on maps developed by the Bureau of Land Management (BLM) is delineated by the approximate seaward limit of land vegetation, as determined by observation and surveying. The shorelines depicted on NOAA nautical charts are defined as the shorelines generated by the intersections between the land and water surfaces of the MHW and MLLW datums. In practice, the shorelines are derived from stereo aerial photographs taken at times when the water level reaches the estimated MHW and MLLW from long-term tide gauge station observations. The NOAA shoreline is the official boundary line recognized by international agencies. EEZ boundaries are defined as boundaries 200 nautical miles from the MLLW shoreline as depicted on NOAA nautical charts.

Ecological and Land-Use Boundaries

Ecological and/or land-use descriptions and boundaries are necessary for effective resource management and coastal planning. At federal and regional levels, land-use boundaries and ecological boundaries in the coastal zone—such as coral reef, wetland, and land-cover (vegetation type) boundaries—are generally derived from LANDSAT satellite images with resolutions of 15 to 30 meters, or from aerial photographs. Similarly, wetland and Submerged Aquatic Vegetation (SAV) boundaries are derived from satellite and aerial photographs. Watershed boundaries on maps produced by FEMA are created from aerial photographs and terrain models. State and local jurisdictions often employ more precise mapping with field verification.

Administrative and Legal Boundaries

Administrative boundaries such as forest and park boundaries, refuge and preserve boundaries, marine sanctuary and marine protected area boundaries, and oil and gas lease boundaries are often established based on geographic coordinates. Such boundaries are determined based on a variety of fragmented and complex laws, regulations, programs, and special jurisdictions and by a variety of means. Cadastral boundaries are surveyed using both old (surveying) and new technologies (GPS) with different accuracies and often using different coordinate systems.

Often, different boundary definitions of maritime regions are required for different applications. For instance, the MHW shoreline is important for FEMA, where catastrophic flooding is of concern, while the MLLW shoreline is required for producing charts that will ensure safe navigation. In other cases the different definitions have no rationale other than historical precedent.

The problems described above in delineating the shoreline and other coastal boundaries are ubiquitous to all those who need spatial information in the coastal zone—it is a region that is difficult to map, and reference lines, reference frames, and reference points must be established that can be easily updated and transferred among a range of users. Consequently, the user community needs improved means to collect data in the region of the shoreline as well as the means to seamlessly integrate and transform data from disparate sources collected for different purposes.

Environmental and Living Resource Management

Human impacts on coastal ecosystems have expanded faster than the rate of population growth. Increased stress resulting from development, waste disposal, and the lack of adequate planning and controls have all contributed to the degradation, loss, and pollution of coastal wetlands, beaches, dunes, nearshore waters, and estuarine habitats. Information and management tools for stressed coastal areas are needed for wise stewardship and sustainable development. A fundamental requirement is an understanding of coastal habitats and ecosystems, their geographic extents, and the manner in which these habitats are changing through both natural and anthropogenic processes. The key to obtaining this understanding is the collection of appropriate combinations of one-time "snapshots" and routine time-series measurements of a number of geospatial parameters.

Living Resources and Coastal/Marine Habitats

Geospatial information is required for the management and sustainable use of a broad range of economically important living resources that provide:

- Income from the harvesting of living resources (fisheries/aquaculture);
- Habitats that support onshore and nearshore food webs;
- Opportunities for recreational activities;
- Biogeochemical functions such as buffering and recycling discharges from land (mud flats, barrier islands, and salt marshes); and
- Physical protection from storms (e.g., mangroves, coral reefs).

Maps showing the locations and extent of submerged and emergent habitats are an essential requirement for coastal zone planning activities, so that resources can be properly allocated and development planned to minimize negative ecological impact. Habitat mapping—the description of the physical and biological characteristics of an area—is an essential first step toward development of effective protection strategies for endangered and threatened species. The need for coordinated, comprehensive habitat mapping encompasses environments from the terrestrial to the deep ocean:

- Terrestrial habitats (riparian areas, wetlands, and coastal uplands);
- Shoreline and emergent habitats (beaches, dunes, marshes, and mangroves);
- Intertidal habitats, including areas of shellfish concentrations, sand and mud flats, and wash zones;
- Shallow marine and estuarine habitats requiring significant light levels (shellfish beds, submerged aquatic vegetation, cold water corals, and coral reefs);
- Identification of essential fish habitat as required by the Magnuson-Stevens Fishery Conservation and Management Act; and
- Deep-water marine shelf habitats (hard-bottom substrates, deeper-water alga and corals, sand and mud deposits).

The basic source data required to characterize this range of habitats include bathymetry and topography, submerged and emergent geology (including depositional environments and bottom characterization), currents and tidal range, and the submerged and emergent ecology (including the types and distributions of organisms, biological diversity and health, and community structure). The synthesis, display, and utilization of such diverse information components require basemaps that encompass offshore and onshore regions and are continuous across local, state, or other jurisdictional boundaries.

Since the coastal zone can be subject to rapid changes, time-series data collection at appropriate intervals is necessary. Datasets collected at intervals must be comparable and capable of being geographically coregistered. The specific habitat mapping requirements identified by those agencies charged with assessing and mapping habitats and sensitive areas and by science and coastal manager users, as identified in the NOAA-CSC *Coastal Resource Management Customer Survey*, are listed in Appendix A.

An ultimate goal would be the establishment of a uniform habitat classification system that could provide the basis for mapping living resources in the coastal zone. The call for a national habitat classification system is one of the recommendations of another NRC report (NRC, 2002), which noted that logical and consistent habitat classification would provide the basis for evaluating the extent and significance of habitat disturbance. While the complex issues of defining a uniform national habitat classification scheme are beyond the scope of this report, collection of the framework and source geospatial data essential for such a system are not.

Sediments

Sediment movement in the coastal zone is often responsible for changes in shoreline position (accretion or erosion), habitat distribution and quality, and bathymetry (deposition and erosion). Such changes are relevant to human occupation of the coastal zone because they alter ports and navigation channels, change the patterns of hazardous coastal flooding, and impact the physical and biological character of coastal areas. Mapping sediment type and tracking sediment movement along the coastal zone—including the mapping of shoals that impact economic commerce—are important responsibilities of the federal government and state governments. Sediment management for the purpose of keeping shipping lanes open is a major task of the USACE.

Sediments also play a critical role with respect to living resources. Sediments moving across and through coastal ecosystems have the potential to benefit or harm living communities. Most ecosystems in the coastal zone rely, to some degree, on a natural substrate. Many species experience substrate-dependent life stages, and their location and settlement on particular substrates are key to their reaching maturity and achieving reproductive success. Other species rely on substrate-specific food sources. As depositional environments and sediment quality change, substrate characteristics are altered, potentially forcing changes in associated ecosystems.

Certain coastal environments such as beaches, dunes, flats, and wetlands are sediment dependent. For instance, tidal lagoon substrates are populated by sessile filter feeding communities that depend on material flux as a food source. The same communities are vulnerable to excess sediment influx from upland land use related to agriculture or development. Conversely, coastal marshes need sediment input to keep up with sea level rise. Too much upland sediment control and damming of rivers can starve these vital resources of the sediment necessary for their survival. Thorough knowledge of the role that sediments play in supporting various coastal plant and animal communities is crucial to management agencies responsible for regulating sediment flux across the coastal zone from upland sources.

An enormous volume of sediment-related geospatial data is spread throughout government agencies, academic research programs, and the private sector. Much of this information is in the form of benthic surveys that were collected at a variety of scales, using different datums and covering an assortment of areal extents. Additionally, few of these data span the intertidal zone, so that they can be linked to terrestrial geospatial data. Other data were collected for a single purpose and now lie unused and unknown to others.

The dynamic nature of coastal processes and the shifting pathways of coastal sediments require that effective coastal resource agencies and permitting authorities have ready access to timely and accurate sediment flux and distribution information that spans the land-water interface. This information must be easily manipulated, accurately tied to a widely used and recognized datum, and rectified at the submeter scale in three dimensions (cf., NRC, 1990; 1995a).

Water Quality and Pollutants

Healthy habitats and ecosystems have their own strict requirements for water quality. Human usage of coastal areas for food production, recreation, and other activities has water quality implications and requirements. The protection of estuarine and marine water quality from pollutants is a priority of local, state, and federal agencies as well as industry and the public (EPA, 2001). Nutrient enrichment from wastewater treatment plants and runoff leading to eutrophication are growing problems in almost all estuarine systems in the United States (NRC, 2000). Some embayments, and even some open-ocean areas (e.g., portions of the Gulf of Mexico near the outflow of the Mississippi River), are experiencing extreme hypoxia leading to recurring fish kills and habitat loss (e.g., sea grasses, coral reefs). In some areas (e.g., offshore Florida), the degradation of onshore aquifers causes coastal zone pollution when the aquifers discharge from offshore freshwater springs. Also of concern to coastal resource managers are the impacts of heavy metals (still discharged in small quantities) on water quality, coastal zone habitats, and benthic and pelagic species.

Resource managers, regulators, and researchers monitor water quality to assess the baseline condition of water bodies, identify impacts of coastal discharges and developments, determine temporal and spatial variability of estuarine and open-ocean systems, and discover violations of water quality standards. From baseline and time-series data, researchers also develop models that can aid in predicting the potential impacts of continued development or the effectiveness of proposed management measures.

In the interest of public health, many states (often with assistance from local governments, beach associations, and environmental groups) monitor the water quality of swimming beaches during the swimming season and make the results available to the public. However, when it comes to a more comprehensive understanding of the status of their coastal waters, relatively few states have the resources to develop long-term comprehensive marine monitoring programs beyond what is required for the protection of public health, National Pollutant Discharge Elimination System (NPDES) permits, or Environmental Protection Agency (EPA) 301 (3)(b) reporting requirements. EPA's National Coastal Assessment Program is supporting state efforts to develop a national marine monitoring system that meets state-specific needs. This five-year program provides an opportunity for states to design programs and synthesize data for public outreach.

The development of ocean-observing arrays and in-situ buoys is expanding our ability to access real-time water quality data in addition to other oceanographic parameters (e.g., Gulf of Maine Ocean Observing System[6]). Managers are increasingly looking for ways to spatially depict water quality data, both as management tools and to provide greater public access to the data (EPA, 2001). The multidimensional nature of water quality data complicates the mapping of such data. Water quality data (e.g., dissolved oxygen, total suspended solids, fecal coliform, chlorophyll content) are typically plotted as a function of position and depth. An even greater challenge is to depict water quality data as a function of time (i.e., time-series plots). Because of the continuum of processes—from land-based sources to offshore sinks—water quality maps need to be continuous across the land-sea interface. Intuitive and standardized tools are needed to integrate and display rich thematic water quality datasets. Once water quality data are digitized and tools are developed, managers can

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[6]See http://www.gomoos.org/.

overlay pollutant source data with habitat and other relevant source data layers on a consistent mapping framework.

Coastal Hazards

Coasts are by nature dynamic, complex regions where a multitude of natural and man-made forces converge to produce change. To mitigate the impacts of detrimental change and enhance the efficacy of beneficial change, managers need to be able to understand the causes of such changes so that predictive tools and management strategies can be developed. This section focuses on the impact of coastal hazards—occurrences of detrimental natural change that threaten life, property, and human activities along the coast. A recent report (Heinz Center, 2002) noted that the rapid population growth and resulting increase in development along the coast during the past 50 years have resulted in greatly increased natural hazard risk to 160 million Americans and more than $3 trillion in coastal property.

The importance of shoreline and coastal hazard issues to the user community is clearly expressed in recent recommendations, made by the CSO to the U.S. Commission on Ocean Policy, that the USACE together with NOAA, FEMA, USGS, and other appropriate agencies should be tasked to "identify, compile, integrate and make available to the states data and information on shoreline change and processes, and work in conjunction with states and other local project sponsors to identify further information and data collection processes needed to fill the gaps in understanding a comprehensive approach to littoral system management" (CSO, 2002; pp. 19-20). The CSO also recommended that the Commission on Ocean Policy should "request that Congress appropriate additional funds authorized in section 215(c) of WRDA 99 for the National Shoreline Study [and] delineate erosion risks on flood insurance rate maps and incorporate erosion risk into the rate structure of the National Flood Insurance Program" (CSO, 2002; p. 20).

Among the more important coastal hazards are coastal flooding, tsunamis, sea level rise, shoreline erosion and accretion, and other geologic agents such as earthquakes and landslides:

Coastal Flooding

Coastal flooding is the greatest hazard faced by U.S. coastal communities in terms of natural threats to life and property. Flooding may occur as a result of storm rainfall and runoff or by inundation from the sea as a result of storm surge. In low-lying areas and along vulnerable coasts, storm-induced flooding may be exacerbated by high waves that accelerate shoreline erosion and increase structural damage. Although the federal government, through FEMA's flood hazard program, helps reduce the costs of such flooding to individual homeowners, anecdotal evidence suggests that U.S. insurance companies are beginning to examine the efficacy of continuing to issue policies in coastal areas after paying out huge sums of money in the aftermath of recent hurricanes.

Tsunamis

Although relatively quiescent during the past century, historical records suggest that very large tsunamis, generated by seafloor seismic activity or submarine landslides, have had tremendous impact on coastal communities. A magnitude 7.8 earthquake in Alaska's Aleutian Island Chain in 1946 generated a 35-meter tsunami that destroyed the USCG Scotch Cap lighthouse on Unimak Island and killed all five of its occupants. The tsunami reached the Hawaiian Islands 5 hours later, completely obliterating Hilo's waterfront on the island of Hawaii and killing 159 people. Damage was estimated at $26 million (in 1946 dollars). As a result of this event, the Pacific Tsunami Warning Center was established in Hawaii. Alaska was struck again by a tsunami in 1964, in this case generated by the largest northern hemisphere earthquake of the 20th century. This magnitude 8.4 earthquake affected an area that was almost 1600 km long and more than 300 kilometers wide, elevating some areas by as much as 15 meters. The tsunami generated by this earthquake was very destructive in southeastern Alaska, in Vancouver Island (British Columbia), and in Washington, California, and Hawaii. The tsunami killed more than 120 people and caused more than $106 million in damages, making it the costliest ever to strike the western United States and Canada.[7]

Sea Level Rise

Historically, sea level variations have produced significant changes in shoreline position, with shorelines with gentle gradients being most affected. The current rate of sea level rise averages about 35 centimeters per century (Douglas, 1995), which is sufficient to increase the hazard posed by waves and storm surge and eventually inundate low-lying areas; exacerbate shoreline erosion and wetland loss, particularly in settings with low sedimentation rates; and exacerbate problems with saltwater intrusion into coastal aquifers.

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[7]See http://www.prh.noaa.gov/itic/library/about_tsu/faqs.html#1964.

Shoreline Erosion and Accretion

Shoreline erosion is estimated to be occurring along 80 percent of the U.S. coastline, and retreating shorelines threaten vital habitats and coastal infrastructure (Heinz Center, 2000a; 2000b). Storm surge and local wave and current activity are the typical agents, but human activities such as armoring the shoreline or construction of jetties often exacerbate the problem. Erosion rates are often highest in areas where natural or human-induced subsidence is occurring. USGS and NOAA have recognized the need to adequately quantify future threats from shoreline erosion and are supporting federal and state efforts to quantify erosion rates and to map erosion hazards. Coastal hazards (e.g., offshore bars and shoals) can also be caused by shoreline accretion resulting from increased sediment input from cleared watersheds and/or by natural longshore drift.

Geologic Forces

Earthquakes, volcanoes and lava flows, and landslides may produce large and very rapid changes in coastal landforms. Yet compared to storm surges, waves, and other ocean processes, they do not readily lend themselves to quantitative prediction or forecasts. Therefore, geologic hazard reduction strategies usually incorporate a blend of statistical probabilities describing the threat, combined with laws and policies to regulate site and building requirements for coastal development.

Coastal Hazard Risk Reduction

Numerous tactics have been developed to reduce the risks associated with coastal hazards. A common approach involves preventing direct exposure to the threat by enacting laws prohibiting construction or activities in hazard-prone areas. Another is to provide early warnings when threats are perceived, such as sirens or radio alerts to warn the public of impending potentially catastrophic events (e.g., tsunami, storm surge). Construction practices can be modified to reduce—but not necessarily eliminate—the risk (e.g., elevating oceanfront homes above the estimated storm surge height or burying offshore cables and pipelines). In many areas, protective works reduce the threat of extreme weather and ocean hazards.

Regardless of the tactics used to reduce risk, long-term success has been achieved only when the nature of the threat has been understood and protective measures and/or practices have been designed accordingly. Table 2.1 provides some generic examples of the importance of coastal mapping and charting products to coastal hazards reduction, illustrating the dependence of design information for coastal hazards risk

TABLE 2.1 Mapping/Charting Contributions to Coastal Hazard Risk Reduction

Hazard	Process, Model, and/or Product Type	Map or Chart Requirements
Coastal Flooding		
Runoff and rainfall	Flood hazard maps, flood warnings, flood models	Topographic maps, DEMs
Storm surge	Flood hazard maps, surge models	Blended bathymetric/topographic maps and DEMs/DDMs
Sea level Rise	Inundation maps, risk assessments	Blended bathymetric/topographic maps and DEMs/DDMs
Waves		
Wind waves	Wave contributions to storm surge, wave runup and wave setup	Blended nearshore bathymetric/ topographic maps and DEMs/DDMs
	Extreme wave vulnerability assessment	Blended nearshore bathymetric/ topographic maps and DEMs/DDMs
Tsunami	Tsunami wave propagation, inundation maps, vulnerability assessment	Blended offshore/nearshore/ onshore bathymetric/topographic maps and geological maps
Shoreline Erosion and Accretion		
Chronic	Sea/lake-level rise impacts on shoreline erosion and accretion, coastal change models	Repeated mapping to quantify rate and distribution of change
	Sea/lake-level rise vulnerability assessment	Blended nearshore bathymetric/ topographic maps and DEM/DDMs, habitat maps
Short-term	Hurricane- and storm-induced erosion and accretion	Pre- and post-storm mapping to quantify change
	Storm vulnerability assessment	Blended nearshore bathymetric/ topographic maps and DEMs/DDMs; habitat maps
Winds	Topographic effects on extreme winds, wind models, wind vulnerability assessments	High-resolution DEMs
Landslides	Landslide vulnerability assessments	Blended bathymetric/topographic maps and DEMs/DDMs
Volcanic Activity	Volcano/lava vulnerability assessments	Onshore/offshore volcanic activity distribution maps
Earthquakes	Seismic vulnerability assessments	Onshore/offshore fault and seismic activity maps

reduction on several types of coastal mapping and charting products. Of particular note is the common need for seamless earth surface depictions across the land-water interface (i.e., blended bathymetric/topographic digital elevation models and digital depth models—DEMs/DDMs). The specific mapping/charting needs identified by those agencies charged with assessing and/or reducing the risks and threats posed by coastal hazards are presented in Appendix A.

Minerals and Energy Management

The coastal zone is the repository of vast quantities of mineral, oil, and gas resources. In addition to the onshore fields located in the coastal zone, a significant percentage of the oil and natural gas produced in the United States (18 and 27 percent respectively; NOAA, 1998) comes from the federally controlled "Outer Continental Shelf"—that part of the continental margin adjacent to the United States that is not under control of the coastal state. Typically this is the area beyond 3 nautical miles from the shoreline but within the definition of the coastal zone used for this study. The percentage of oil and gas recovered from the offshore is expected to rise significantly over the next few years and with it the revenue collected by the federal government from oil and gas leases (NOAA, 1998). These revenues were between $3 billion and $4 billion in 1998, distributed to the general treasury, the Land and Water Conservation Fund, and the National Heritage Fund. In addition to the revenue generated for the federal government and the income generated by the private sector, the offshore oil and gas industry provides approximately 170,000 jobs in the United States (NOAA, 1998).

More than 20,000 offshore oil and gas wells have been drilled in the United States, a number that is expected to increase in the coming years as the offshore contains 15 and 19 percent of the nation's proven oil and gas reserves, respectively, and is thought to contain more than 50 percent of the nation's remaining undiscovered oil and gas reserves (NOAA, 1998). Although there are questions concerning economic viability, the coastal zone also has the potential for providing non-hydrocarbon energy sources such as tidal, wave, and wind power; several wind power projects are currently under regulatory review along the northeast to mid-Atlantic coast.

The coastal zone also contains vast deposits of sand and gravel, phosphorites, heavy minerals, and other valuable resources such as gold, titanium, and diamonds. These deposits are typically transported to the coastal zone by rivers and glaciers and then sorted by wave action. Sand and gravel together represent the largest mineral resource extracted from the coastal zone. They are used for beach replenishment, barrier island restoration, building materials (construction aggregates), and capping contaminated sediments. Technical innovations in dredging technology, including high-capacity underwater pumps and multiple-booster pumps, are rapidly increasing the efficiency of the extraction of sand, gravel, and other aggregate materials in the coastal zone (NOAA, 1998).

With the growing demands for reliable energy sources and the rapid growth of construction and road building in coastal regions, the demands for increased extraction of oil, gas, and aggregate minerals are putting tremendous pressure on those charged with managing and protecting the coastal zone. Within 3 miles of the shoreline—or three marine leagues for Texas and the Gulf Coast of Florida—the coastal state has jurisdiction in accordance with the Submerged Lands Act of 1953; beyond this limit, the federal government is the responsible body. The Minerals Management Service (MMS) is the federal agency charged with managing exploration and development of mineral and energy resources on the outer continental shelf as well as ensuring environmental protection and impact mitigation.

Specific MMS duties include:

- Assessment of oil, natural gas, and mineral reserves;
- Assessment of drilling hazards;
- Siting of oil and natural gas facilities;
- Selection and survey of oil pipeline routes;
- Minerals production siting;
- Offshore sand and gravel management (e.g., for coastal erosion mitigation, construction of berms for coastal protection);
- Development and implementation of leasing programs;
- Regulation of exploration and development; and
- Provision of information needed to predict, assess, and manage environmental impacts from offshore gas and oil and marine mineral exploration, development, and production activities on human, marine, and coastal environments.

Those wishing to explore for and exploit energy and mineral resources, as well as those charged with managing and protecting those resources, will continue to require a wide range of mapping and charting products to meet their objectives. For those resources that extend across the land-water interface, these products will need to seamlessly extend across the shoreline. A fundamental requirement for these maps will be establishment of the geospatial framework for all subsequent studies—the reference frame provided by high-resolution bathymetry and topography. Beyond the reference frame data, a suite of source data products (acoustic imagery, optical imagery, offshore video and photography, direct sampling, etc.)

will provide the basic context needed to understand the distribution and viability of resources as well as the engineering constraints needed for the siting of platforms, pipelines, and other structures.

In concert with studies aimed at identifying mineral and energy resources, baseline studies of local habitats will be required to understand the impact of any potential resource extraction. Habitat studies have their own set of mapping requirements (see above). Much work must also be done in the areas of risk assessment and mitigation. Plans must be in place to minimize and mitigate potential disruption of seafloor habitat and benthic communities resulting from the discharge of chemicals, drilling muds and cuttings, hydrocarbon emissions, and spills. Each of these requires detailed maps that depict reference frame, source, and derivative data.

Many resources are located below the seabed, and in these cases subbottom seismic profiling and other geophysical techniques (gravity, magnetics, resistivity, and heat flow) are used to better understand and map the structure and distribution of subsurface features. These datasets will also need to be integrated into the basic geospatial framework, adding a three-dimensional mapping component.

Given the breadth of needs associated with oil, gas, and mineral resource extraction in the coastal zone, the range of mapping products required for exploration, exploitation, management, regulation, protection, and mitigation involves almost every conceivable type and form of map or chart. The key to the successful balance of exploitation and environmental protection will be the availability for coastal managers of easily accessible and easily manageable data that can be seamlessly integrated and fused. Ensuring that such datasets are readily available is a fundamental focus of this study.

Cultural Resources Management

Cultural resources along the nation's coasts and offshore areas include coastal and maritime parks, maritime preservation sites, underwater and coastal archeological sites (including Native American middens, rock art sites, excavation sites), maritime national historic landmarks, and national monuments (including lighthouses, life-saving stations, vessels, forts, submerged and coastal shipwrecks, and submerged historic docks and launches). Each of these is a valuable time capsule with the potential for revealing important aspects of the nation's past.

In order to better understand and preserve this aspect of the nation's heritage, coastal zone managers require detailed maps and documentation of cultural artifacts. Such documentation typically includes:

- Development of GIS-based, integrated cultural and natural resource data to be used for survey, identification, inventory, evaluation, protection, and preservation of cultural resources;
- Development of management plans for preservation and recreational use of coastal cultural resources; and
- Coordination among agencies and entities (e.g., state agencies, tribal nations, NOAA National Marine Sanctuary System, U.S. Navy, USCG, National Geographic Society) regarding submerged and coastal cultural resources throughout U.S. territories.

Many federal and state agencies have responsibilities for the management and protection of coastal cultural resources. Examples from among the federal agencies include the National Park Service, the National Marine Sanctuaries Program established by NOAA to protect important submerged cultural resources and which publishes a shipwreck database, and the Federal Energy Regulatory Commission and USACE which require offshore archeological surveys for pipeline and cable crossings and consideration of the impact of dredging projects on cultural resources. At the state level, archeological investigations commonly occur in connection with permitting activities as well as under the general purview of historical commissions and state archeological offices. Whether on land or underwater, such investigations are often a two-tiered approach involving a reconnaissance-level survey to determine the potential for significant finds, together with follow-up work, as necessary, to document the site. While increased availability of coastal mapping products expands our knowledge of underwater cultural resources, this availability also increases the risk that archeological sites could be tampered with by sport divers and treasure hunters. Data security related to cultural assets is a major concern.

The important source data needed for the management and protection of cultural resources in the coastal zone include:

- High-resolution bathymetry (both reconnaissance and site-specific DDMs);
- Coastal topography (high resolution DEMs);
- Coastal configuration, including man-made historical infrastructure (location and identification of wrecks, submerged docks, launches, etc.);
- Remote sensing data, including acoustic imagery (seismic profiling and sidescan sonar at both reconnaissance and site-specific scales) and magnetometer surveys;
- Physical sampling (grabs, cores, etc.);
- Underwater photographic and video imagery (site-specific) and diver surveys;

- Aerial and satellite imaging;
- Shoreline delineation and reconstruction of old shorelines;
- Soil and bottom sediment characteristics;
- Marine boundaries to resolve jurisdictional issues; and
- Written historical and descriptive data and original field notes.

From the above source data, products such as bathymetric and topographic maps and charts, underwater and aerial photographs and mosaics, and archeological site and artifact illustrations can be produced and used for the identification, assessment, monitoring, and protection of coastal cultural resources.

MAPPING NEEDS BEYOND THE COASTAL ZONE

The focus of this study has been the coastal zone, defined by the committee and the FGDC to extend to the limits of the U.S. territorial sea (12 nautical miles). This, of course, is an arbitrary and artificial mapping limit, as coastal and oceanographic processes are continuous offshore, and an emerging need for mapping well beyond the limit of the territorial sea should be acknowledged. One impetus is the need to document the geospatial framework for the wealth of living and nonliving resources within our nation's EEZ (presently defined as 200 nautical miles from our territorial baseline—the official shoreline defined on NOAA charts). With fishing as well as hydrocarbon and mineral exploration moving to deeper and deeper waters, we find a pressing need (some of it legislated for example, by the Magnuson-Stevens Fishery Conservation Act) to better understand deep-water processes and environments. It is also of critical importance to establish baselines so that we may better understand and control the impacts of resource exploration and exploitation.

Contributing to this critical need for mapping is Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS). Under this article, coastal states may claim jurisdiction over "submerged extensions of their continental margin beyond the recognized 200 nautical mile limit of their EEZ" (UN, 1983). The circumstances that define whether a coastal state can extend its jurisdiction are based on a complex set of rules that require an analysis of the depth and shape of the seafloor in areas of interest as well as an understanding of the thickness of underlying sediment. Consequently, full implementation of Article 76 requires the collection, assembly, and analysis of a body of relevant bathymetric, geologic, and geophysical data. The United States has not yet acceded to the UNCLOS, but growing recognition that implementation of Article 76 could confer jurisdiction and management authority over large (and potentially resource-rich) areas of the seabed beyond our current 200 nautical mile limit has renewed interest in the potential for a U.S. claim. In this context, there has been congressionally mandated activity to evaluate the content and completeness of the nation's bathymetric and geophysical data holdings in areas surrounding the nation's EEZ, with emphasis on ensuring their usefulness for substantiating the extension of resource or other national jurisdictions beyond the present 200 nautical mile limit (Mayer et al., 2002; Jakobsson et al., 2003). Congress has also recently funded the first year of data collection programs in support of a potential claim under Article 76.

It is the belief of this committee that the strategies and mechanisms established for coastal zone mapping, particularly in terms of survey registration, database development, data standards, and data distribution (see below), will be equally applicable to deeper-water mapping efforts. Applying these mechanisms and protocols to EEZ mapping will ensure that the deeper-water datasets will seamlessly merge with those collected in the nearshore region.

SUMMARY

There is an immense and substantiated need for geospatial data in the coastal zone to fulfill a wide variety of uses and applications. At least 15 federal agencies, state and local governments, the private sector, academia, and the general public are actively involved in the collection, processing, or dissemination of coastal zone data and/or products. The challenge facing the committee has been to evaluate the large volume of information provided and to determine whether there are gaps between the needs for geospatial data and the activities of those acquiring and processing data in the coastal zone (i.e., "unfulfilled needs"); to determine whether there are redundancies in effort, and to establish where and how efficiencies may be gained so that unfulfilled needs can be more effectively addressed.

Appendix A, and the expanded description presented in the committee's interim report, formed the basis for the analysis presented in this chapter by summarizing federal agency needs and activities on an agency-by-agency basis. As Appendix A illustrates, the scope of the identified needs and activities is extremely complex and far-reaching; however, the committee's review of users' needs and the available information describing activities has revealed several cross-cutting issues related to unfulfilled needs. These issues reflect broad-based requirements for better data acquisition (both quality and quantity of data) and for a better and more efficient infrastructure to support and encourage cooperative collection, compilation, integration, processing, and dissemination of information. These cross-cutting issues highlight the following needs for:

- A consistent spatial framework for coastal data that allows a seamless transition from onshore to offshore, including clarification of offshore boundary definitions, a consistent geodetic framework for shoreline definitions, and easy transformation between various horizontal and vertical datums;
- More and better (timely and accurate) primary source data, including high-resolution topography and shallow-water bathymetry; tide and current information; comprehensive imagery coverage; systematic and standardized bottom and habitat characterization; and human-use, land-cover, land-use, and coastal change data;
- Consistent data, metadata, and mapping standards as well as a means to evaluate the accuracy of geospatial data;
- Timely and straightforward access to the existing body of coastal data;
- Increased inter- and intra-agency communication, cooperation, and coordination; and
- Enhanced ability to interpret and apply spatial data and tools for decision making.

The review of agency activities also indicated apparent overlaps in the collection and processing of coastal zone geospatial data. In some cases these proved to be only "apparent" overlaps, in that some agencies had similar titles for activities that on the surface appeared to be the same but in actuality are not (e.g., the NOAA-CSC *Community Vulnerability Assessment Tool* used by FEMA and EPA's *Vulnerability Self Assessment Tool*, which despite their similar names have completely different functions). In other cases, overlaps clearly do exist and must be addressed (e.g., redundancies of effort involving the acquisition of shoreline and habitat mapping data).

As the committee explored the intersection of needs and activities, the emphasis remained focused on efficiently establishing the fundamental information and tools necessary to fulfill the nation's appropriate role in coastal zone mapping and charting. In the following chapter, the present inability to seamlessly combine onshore and offshore data, compare differently defined shorelines, and integrate and exchange existing and new coastal zone maps are described. The quantity and quality of coastal data are addressed in Chapter 4, with particular emphasis on the reference frame data (bathymetry and topography) that establish the fundamental geospatial framework for all other measurements. Chapter 5 addresses issues of timely and efficient access to these data. Chapter 6 identifies several areas where efficiencies can be gained by better coordination and collaboration and offers specific suggestions for improving interagency communication and collaboration. The strategies and recommendations associated with these issues collectively define our approach to fulfilling the vision outlined in Chapter 1.

3

A Common Coastal Zone Reference Frame: The Seamless Coastal Map and Consistent Shoreline

Working in the coastal zone presents a special challenge, as coastal processes are dynamic and often continuous across the land-sea interface, whereas the maps and charts that are used have historically been collected in either one realm or the other. Differences among agency missions and onshore versus offshore topographic and bathymetric mapping techniques, different vertical reference frames used for each of these products, and the inherent difficulty of collecting source data in the surf and intertidal zones have combined to produce a fundamental incompatibility between onshore maps and offshore charts. Yet as seen in the preceding chapter, seamless geospatial datasets across the land-water interface are needed by almost all users wrestling with issues of navigation, resource management, planning, hazard delineation and mitigation, environmental studies, and regulation issues. Often under contractual pressure, the problem of creating a seamless product is frequently solved by ignoring—through data blending and large-scale spatial averaging—datum transformation issues and the unmapped intertidal region. In so doing, what had originally been carefully positioned geospatial data becomes geospatially error-ridden in the interest of product delivery. An additionally troublesome feature of this approach is that no true database is generated—the product is one of a kind and cannot serve as an accurate base for additional studies. Furthermore, the geospatially compromised product is often exported to downstream users without their awareness of the inherent geospatial errors and uncertainties.

These error-ridden products may go on to be applied in inappropriate ways. For instance, modeling studies of marine hazards such as tsunami inundation, high-wave flooding, and storm surge flooding rely on integrated depth and elevation data. Such modeling exercises are often based on geospatial data that have positional uncertainties of tens of meters, in addition to the model prediction uncertainties of tens of meters. The final product, with its partially undetected errors as well as uncertainties of many tens of meters in horizontal space and several meters in vertical space, may be used by authorities for hazard management and mitigation (e.g., the identification of evacuation routes). There is enormous potential for catastrophe if vehicles are directed to use a flood-prone evacuation route that was selected because of faulty elevation data input to a storm surge model.

As discussed in Chapter 2, an additional critical information element for a wide variety of public and private entities is the shoreline position. Although depicted as a fixed line on maps and charts, shorelines are dynamic features that present unique challenges to coastal managers. The diminishing amount of land area available for development and the overwhelming importance of shorelines as economic, cultural, environmental, and recreational resources place a premium on understanding shoreline dynamics and mapping the characteristics of shoreline change.

Few state, local, or private organizations make their own maps and charts and thus must extract shoreline information from either U.S. Geological Survey (USGS) topographic maps or National Oceanic and Atmospheric Administration (NOAA) nautical charts. In a great many cases the jurisdictional needs of state and local agencies are not represented by the boundaries provided on these federal maps, and the maps themselves leave the zone between Mean Sea Level (MSL; as delineated by the USGS shoreline) and Mean High Water (MHW) or Mean Lower Low Water (MLLW; as delineated by the NOAA shoreline) unmapped because of the gap between USGS maps and NOAA charts. As a result, state and local needs are often left unfulfilled. Even worse, errors are frequently promulgated through imprecise attempts to rectify this situation. The problem of consistent shoreline definition applies equally to the Great Lakes coastline. In a funding environment where coastal zone management funds are allocated on the basis of shoreline length, equity among the states requires that a consistent set of definitions and procedures be applied.

The lack of accurate maps and charts that seamlessly cross the land-sea interface creates a serious obstacle for the coastal zone managers of our nation. These managers need precise, accurate, and timely data and products that are easily accessible and usable for a wide variety of applications. A remedy for this situation, and the committee's vision for the future, is the development of a seamless transformation framework that is available through a single digital portal that offers data, maps and charts, and tools as well as the ability to translate rapidly from one jurisdictional shoreline to another. Such a portal would be constantly updated with timely datasets and would offer transformations to all major international, federal, state, and local shoreline needs coupled with tailored map production. In the following sections the impediments to fulfilling this vision of a seamless coastal geospatial product and possible strategies to overcome these impediments are described in more detail.

THE NEED FOR A COMMON FRAMEWORK

The most critical technical barrier to completing the vision of a seamless coastal map is the lack of a common reference framework that would allow cartographers and coastal zone data managers to weave together topographic datasets (e.g., USGS Digital Elevation Models [DEMs]) and bathymetric datasets (e.g., NOAA's hydrographic survey data) in a way that is faithful to cadastral, geodetic, and cartographic standards. This deficiency arises for a number of reasons primarily related to differences in the projections, scale, and horizontal and vertical datums. While problems with horizontal datums, scales, and projections can be resolved with well-documented digital data and existing tools, resolving vertical datum discrepancies is a much more difficult task.

All geospatial datasets must be referenced to some kind of a vertical datum. Unfortunately, there is no consistent level that is used for this reference. This is due to both historical technical limitations (inaccuracies in locating points in a pre-global positioning system [GPS] world) and also because of the different protocols and datums used to produce onshore maps and offshore charts. For instance, USGS DEMs are horizontally referenced to the North American Datum 1983 (NAD83) and vertically referenced to an orthometric datum that approximates MSL (defined by the North American Vertical Datum 1988—NAVD88). Older USGS map products used an earlier vertical reference—NAVD29. However, the shoreline depicted on USGS map products does not represent the position where these datums intersect the earth's surface but instead is the opportunistic instantaneous waterline captured in aerial photographs used in making the map. NOAA nautical charts are also horizontally referenced to NAD83, but all soundings are referenced to contemporaneous local MLLW—the average of the lower low water height of each tidal day taken over the National Tidal Data Epoch. NOAA charts depict both MHW and MLLW as two shorelines located using tide-controlled aerial photography. Neither of these shorelines corresponds to the MSL shoreline of the land-based USGS topographic maps.

A map producer will encounter additional inconsistencies in datum delineation when integrating modern and historical data for the purpose of delineating environmental and cultural changes through time. For instance, the USGS National Shoreline Assessment project (as well as several state-sponsored projects) attempts to incorporate historical NOAA topographic maps ("T-sheets") with modern orthorectified aerial photographs, as well as topographic and bathymetric Light Detection and Ranging (LIDAR) data. Historical T-sheets from the pre-World War II era were referenced by surveyors of the time to the local high-water mark, as delimited by debris and other indicators along the shoreline. There are substantial uncertainties associated with how these historical local levels correlate to modern MHW, given the influence of subsequent sea-level changes, land-level changes, seasonal wave conditions, and thermal changes in water level since the time of these past surveys, together with changes in shoreline position due to sediment flux. It is widely misunderstood that the older historical T-sheets present MHW when in fact they simply present a high-water mark on the shoreline. Further, modern NOAA nautical charts present a line that is identified as the position of MHW. In reality the line is the drafted waterline from aerial photography flown at the approximate time of MHW (as predicted by a model). This line differs from the true position of MHW due to the influence of wind and wave set-up (or set-down), which is capable of changing sea-level position by a meter or more. Finally, the position of any given water level (e.g., MLLW) constantly moves along the shoreline in response to the migration of the tide wave as it responds to gravity and friction. A cartographer tasked with integrating bathymetric data with topographic data must know the instantaneous position of that wave (the water level) at closely spaced positions along the mapped area to properly correct geospatial data. This requires a numerical model that predicts the position of the tide level through the highly crenulated bays and promontories of the U.S. shoreline.

The problem of vertical datums is confounded by the fact that multiple agencies at many levels of government (federal, state, and local), researchers, and the private sector also use different horizontal datums, different scales, and different projections. If only paper products are produced, there is little opportunity to transform and thus seamlessly integrate these individual products. However, if data are digital and well documented, tools currently exist to correct and transform differences in resolution, horizontal datum, scale, and projection (e.g., Figure 3.1). Unfortunately, we do not yet have the infrastructure in place to ensure that data are collected in such a form. Thus, along with the difficulties in producing mapping products that are continuous *across* the shoreline, there are also inconsistencies in producing mapping products that are continuous *along* the shoreline, particularly where such products cross jurisdictional boundaries.

With these unresolved differences or discrepancies in vertical datums associated with onshore versus offshore data, it is not possible to generate

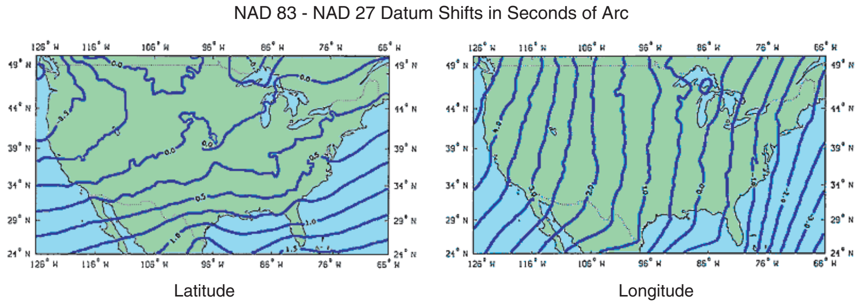


FIGURE 3.1 Maps showing datum shifts (in seconds of arc) between NAD 83 and NAD 27 datums, output from NADCON software, the federal standard for NAD 27 to NAD 83 datum transformation produced by NOAA-National Geodetic Survey (NGS). Similar tools are available for projection conversions, but the data must be digital and well documented. Image courtesy NOAA-NGS.

an accurate map that seamlessly crosses the land-water interface. Although very useful generalized products that ignore these discrepancies by averaging over large spatial area (e.g., the National Geophysical Data Center's Coastal Relief Model with 90-meter spatial resolution) can be produced, these products will be of little or no use for detailed study of any process that needs to be accurately mapped across the land-water interface (e.g., mapping for flood hazard mitigation).

STRATEGIES FOR DEVELOPING A COMMON FRAMEWORK

The first step toward developing a truly useful coastal mapping product is to produce a seamless bathymetric/topographic model across the land-water interface. To accomplish this, it is necessary to reference all data (land-based elevations and offshore depths) to a common, continuous, and universal datum. Fortunately, modern GPS measurements provide the opportunity to use just such a common datum—the ellipsoid. GPS measurements are made using a three-dimensional coordinate system that is converted to an ellipsoidal coordinate system. The ellipsoid provides a geometric model that approximates the shape of the earth's surface (without the topography). The GPS ellipsoidal coordinates combined with gravity (geoid) data provide elevations compatible with the orthometric heights (approximating MSL) used on USGS topographic maps. Therefore, both elevation and bathymetric data collected with GPS can be referenced to this continuous (albeit mathematically projected) ellipsoidal surface.

While elevations and depths can both be referenced to the ellipsoid datum, there will always be a need to present data with respect to the more traditional tidal or orthometric datums. Nautical charts, for example, must always be referenced to a tidal datum to ensure that a mariner will know the depth of water with respect to the real water level (and thus avoid running aground). To assist safe navigation, NOAA uses MLLW because it is a very conservative estimate of the water level. Topographic maps are typically referenced to an orthometric datum because it approximates MSL. The key to producing a seamless dataset across the coastal zone, however, is to understand the differences between the reference surfaces used to make the measurements (i.e., the differences between the ellipsoid and real terrain, between the ellipsoid and the geoid, between the ellipsoid and MLLW, etc.). These differences are expressed as "separation" or "difference" models, and with detailed knowledge of these models, conversions can be made among the various reference frames to produce a seamless dataset—a Coastal Terrain Model (CTM) across the coastal zone (see Figure 3.2).

Vertical information collected on land is measured from fixed platforms or from airborne or spaceborne platforms whose elevations can be very precisely determined in a fixed reference system. Bathymetric data, on the other hand, present a more difficult problem because they have historically been collected shipboard on a surface that constantly changes with the tide. True vertical reference frames for bathymetric data exist only at a few discrete points where water-level gauges have precisely defined a datum like MLLW (and thus where a difference or separation model exists). In order to extend (spatially integrate) the vertical reference frame established at the discrete points where MLLW has been accurately measured by tide gauges, sophisticated hydrodynamic models are needed.

Development of the CTM thus requires vertical datum integration, supported by appropriate tide gauge stations and meteorological observations, together with tools for hydrodynamic modeling. Since the depths are defined based on the MLLW level, long-term observations of water gauge stations are needed to determine the MLLW, and GPS surveys are then required to transform the MLLW to the orthometric datum. Consequently, the depth information can be referenced to the orthometric datum, and the topographic and bathymetric data can be integrated into one unique CTM. Once a continuous CTM is available, the hydrodynamic model can be used as a tool to produce water datum surfaces of MHW, MLLW, or any other mean water levels required by the various users. The intersection of the CTM and a water datum surface will generate a digital shoreline defined to that water datum. Thus, in order to generate a shoreline of a particular definition (e.g., MHW), the MHW surface needs to be output by the model and the MHW shoreline can then be produced as the

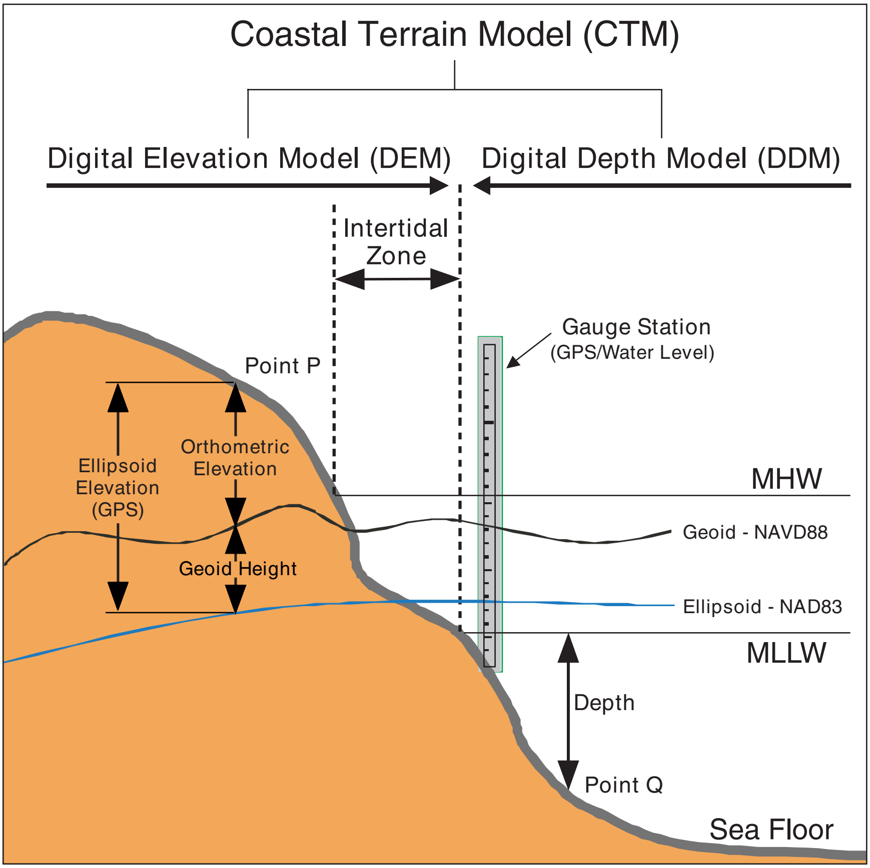


FIGURE 3.2 Coastal reference systems and observations, illustrating the components of onshore elevation (e.g., Point P) and offshore bathymetric (e.g., Point Q) data. Based on Li et al. (2003).

intersection line of the CTM and the MHW surface. Therefore, this approach provides a means to digitally produce any datum-defined shoreline and to transform between shorelines with differing definitions.

The development of a hydrodynamic tidal model also allows the transformation of historical datasets to a common ellipsoidal datum. NOAA, USGS, and other partners have undertaken a pilot project in Tampa Bay, Florida, that has demonstrated both the complexity and the feasibility of generating a seamless bathymetric/topographic dataset (see

Box 3.1). This project required the establishment of a fully calibrated hydrodynamic model for Tampa Bay and the development of a vertical datum transformation tool (Vdatum) that allows the easy transformation of elevations among as many as 26 orthometric, three-dimensional, or tidal datums. This pilot project has proven very successful and provides a clear indication of an optimum mechanism for producing seamless coastal charting products.

IMPLEMENTATION OF A COMMON NATIONAL FRAMEWORK

The Tampa Bay Bathy/Topo/Shoreline Demonstration Project demonstrated that, although complex, it is possible to establish a seamless coastal framework. The project has also demonstrated the value of interagency collaboration. The next step is to establish a national framework that provides a seamless bathymetric/topographic dataset for all U.S. coastal regions. Although horizontal datum issues can be readily resolved with existing transformation tools, vertical datum issues present the most serious challenge to this effort. To resolve the vertical datum issues, a project to apply Vdatum tools on a national scale is needed, involving the collection of real-time tide data and the development of more sophisticated hydrodynamic models for the entire U.S. coast, as well as the establishment of protocols and tools for merging bathymetric and topographic datasets. The resulting dataset must be documented and disseminated in such a way that it can become the basemap for a wide range of applications, including the definition of local, regional, or national shorelines.

Based on presentations and information provided by NOAA-NGS, a national Vdatum project would require an initial five-year effort to expand the current tidal modeling efforts to include all geographic areas of the U.S. coast. This would involve the development of numerical tidal models[1] that in some areas would require the installation of additional tide gauges. Modeling results would be available to users on an area-specific basis through a Web-accessible database. This database could be linked to the single Web-based coastal geospatial data portal described below (see Chapter 5).

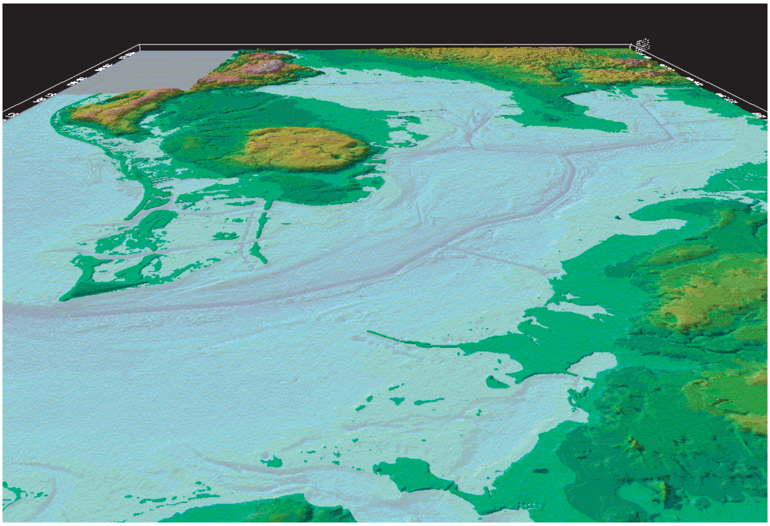
A national Vdatum Web site, linked to a national coastal zone mapping portal, would ensure that the full suite of Vdatum (and other) transformation tools would be easily available to the user community as well as ensure that data standards and acquisition details would be fully

[1]The estimated cost would be approximately $2 million for the first year and $1.5 million for years 2 to 5. After the fifth year, the system could be maintained and updated for an annual cost of less than $1 million.

BOX 3.1
NOAA-USGS Tampa Bay Bathy/Topo/Shoreline Demonstration Project

In this joint demonstration project for the Tampa Bay region, NOAA's National Ocean Service (NOS) and the USGS's Geography Discipline (formerly the National Mapping Division) blended their bathymetric and topographic datasets into a DEM with all data initially referenced to the ellipsoid. A fully calibrated hydrodynamic model of Tampa Bay was used to determine the geographic distribution of tidal datums, and the Vdatum tool was used to transform all bathymetric data from the MLLW datum to the ellipsoid (Parker et al., 2001). Recent high-resolution third-party bathymetric and topographic data are being incorporated into the DEM. An up-to-date high-resolution shoreline is being developed using data from various airborne and satellite remote sensing sources. The DEM, shoreline, and additional data layers will ultimately be available from a Web-accessible database and on CD-ROM. The Web-accessible bathy/topo DEM and accompanying shorelines will not only solve the problem of inconsistency between NOAA and USGS products that has caused difficulty for coastal managers but will also provide a standard DEM (or framework) on to which others can append their bathymetric, topographic, or other data and will allow detailed modeling of storm-surge or sea-level rise effects. This is the first step toward the development of a mutually agreed upon "national shoreline." It is also an excellent example of interagency collaboration and cooperation and a clear indicator of a viable approach to addressing the issue of a seamless vertical datum for the coastal zone. For NOAA and USGS it represents the beginning of a new way of doing business with each other that will reduce duplication of effort and better meet the needs of state and local agencies.

described with metadata. Once established, the national framework would need to be maintained and regularly updated. Again, a Web portal is the key to the dissemination and timeliness of information. In addition to the modeling efforts associated with a national framework for seamless coastal data integration, there would be the need to collect additional coastal zone framework data (topography, bathymetry, and tidal information), particularly in the very shallow region at the land-water interface. Such an expanded mapping effort is discussed in Chapter 4.



Three-dimensional model of seamless dataset produced by Tampa Bay Bathy/Topo/Shoreline Demonstration Project with high stand of sea level superimposed. Image courtesy of the Center for Coastal and Ocean Mapping, University of New Hampshire.

WHERE AND WHAT IS THE SHORELINE— IS A NATIONAL SHORELINE NEEDED?

Inextricably linked to the establishment of a national framework for seamless coastal mapping products is the issue of a national shoreline. As the fundamental boundary for so many applications and studies, the lack of a consistently defined shoreline has frustrated coastal zone managers, planners, and scientists for many years. Since shoreline definitions typically relate to a water level, the shoreline is dynamic, changing over various temporal and spatial scales. As noted earlier, the shoreline is not a deterministic physical line but rather a conceptual line defined on a statistical basis over a finite time. The long-term accuracy and consistency of shoreline maps cannot be assured, in part because they are subject to ceaseless natural and man-made processes that continually alter the shoreline's shape and character. Modernization of the nation's definition and depiction of the shoreline through development and application of state-of-the-art geospatial mapping techniques is urgently needed to address a wide variety of management, policy, and legal issues on local, national, and international scales.

Although a public law passed by Congress in 1998 provides explicit authority for NOAA to promulgate national standards for all information acquired for nautical charting purposes, including shoreline delineation, several different shoreline definitions are in use by various federal, state, and local authorities to meet non-navigational needs. A single nationally accepted and consistent U.S. shoreline does not exist, and the use of inconsistent shoreline definitions between maps, charts, GIS outputs, and other products leads to user confusion and ill-informed decision making. Another reason for this lack of consistency appears to be the significant overlap in federal efforts to acquire coastal shoreline data and in the subsequent generation of derived products, such as shoreline erosion and accretion maps. This issue is important enough that it will be discussed separately in Chapter 6.

As discussed in Chapter 2 and illustrated in Figure 2.1, the U.S. coastal zone encompasses a bewildering array of shoreline designations and definitions. The management and regulatory environment includes the different concepts of the USGS topographic maps and NOAA charts with a MHW shoreline that is actually a waterline photographed at high tide, leading to the situation where the boundary between private lands and state jurisdiction is defined as Mean Higher High Water (or a proxy) in some cases, MHW in others, and MLLW in still others. And as noted earlier, the Bureau of Land Management (BLM) defines the shoreline as the approximate seaward limit of land vegetation. The use of inconsistent shoreline definitions between maps, charts, GISs, and other sources leaves all but the most knowledgeable scratching their collective heads.

Such differences in definitions and boundaries not only result in confusing map products (with different agencies producing maps with different positions of the shoreline) but also can have serious legal and financial ramifications. A striking example of this is *The Dinkum Sands Case* (Reed, 2000), where the state of Alaska claimed that a sand body off the northern coast of Alaska was an island and thus constituted a baseline from which to calculate a 3-mile state boundary. This baseline extended the area under which the state was allowed to grant oil and gas leases under the Submerged Lands Act. The federal government claimed that the sand body was not an island and that consequently the area was under federal jurisdiction. After 17 years of litigation the U.S. Supreme Court ruled in favor of the federal government, denying Alaska the rights to approximately $1.6 billion in oil and gas revenues.

Differences in shoreline definition can also lead to unnecessary duplication of data acquisition efforts (typically the most expensive aspect of coastal mapping), with individual agencies collecting independent datasets in accordance with their own definitions of the shoreline. In the course of presentations to the committee, it became apparent that some agencies maintain their own crews and collect their own shoreline data (e.g., BLM collects its own data to define the vegetation line as the basis for its shoreline). In contrast, other agencies accept shoreline definitions provided by NOAA (e.g., the Minerals Management Service [MMS] uses NOAA's MLLW shoreline definition). A consistent definition of the shoreline would thus not only reduce legal and jurisdictional confusion but also would undoubtedly lead to increased data acquisition efficiency (see Chapter 6).

While a call for a nationally consistent shoreline is laudable (and practical for some applications), we cannot escape the fact that embedded in local, state, and federal laws are an array of legislative definitions of the shoreline that will not be easily changed. With this in mind, it seems impractical to recommend adoption of a single national shoreline. However, an alternative is the consistent geodetic framework—the CTM—described above. With the CTM and appropriate difference or tidal models, different agencies can adopt common and consistent horizontal and vertical reference frames and have the ability to transform and integrate shoreline definitions within this common framework. National consistency can be achieved when all parties define their shorelines in terms of a tidal datum, so that vertical shifts can be easily calculated between and among the various datum-based shoreline definitions. This approach has the advantage of allowing agencies and users to maintain their existing legal shoreline definitions if required. Accordingly, the Vdatum tool kit and associated Web sites are critical for establishing internally consistent shorelines between and among disparate surveys and studies. In those situations where legislation or application does not preclude adoption of a national shoreline, the internationally recognized shoreline as defined by NOAA-NGS should be adopted.

4

Improving the Quantity and Quality of Coastal Reference Frame Data

The costs associated with the acquisition of data (in particular reference frame data) dominate mapping and charting activities. The presentations and submissions received by the committee repeatedly indicated that the present mapping and charting database is inadequate for applications ranging from safety of navigation to coastal resource management. While the nation will benefit from the collection of additional coastal zone data of many types, the need for more fundamental reference frame data—topography and particularly bathymetry—was consistently cited as having the highest priority. In 1999 the Coastal Services Center (CSC) surveyed 270 offices representing state resource and environmental protection agencies, coastal zone management programs, Sea Grant programs, National Estuarine Research Reserves, National Estuary Programs, and National Marine Sanctuaries (CSC, 1999). The issues represented by these coastal zone groups included public access to the coast, dredging and port issues, land use and land-use changes, coastal erosion and accretion, planning and response for oil and other hazardous material spills, point and nonpoint source pollution, habitat mapping, fish and shellfish stocks, and watershed management. The survey concluded that, out of 29 possible priority datasets, nearshore bathymetry ranked second highest, after high-resolution aerial photography. Although the 2002 CSC survey results were not published prior to completion of this report, the draft report indicated that 83 percent of the respondents require nearshore bathymetry, and of 37 possible priority datasets, bathymetry (when combining estuarine, nearshore, and offshore) ranked number one in use and demand (CSC, 2002). These conclusions are neither unexpected nor novel—earlier assessments have consistently reached the same conclusions:

"The greatest information needs of the users in the states, industry, and academia are for bathymetry, imagery, and seabed characterization" (NRC, 1992; p. 2).

"The nation has a large and growing backlog of requests for new surveys and charts. At the present level of effort, the backlog cannot be reduced" (NRC, 1994a; p. 66).

"NOAA should accelerate the current timetable of approximately 15 to 20 years to reduce the current survey backlog. The backlog prevents NOAA from making progress on surveys and charts for the rest of the exclusive economic zone (EEZ)" (USDOT, 1999; p. 103).

Nearly half the depths published on current charts were measured using lead line techniques over a sparse grid prior to 1940, and one-third of the national shoreline has yet to be mapped. Given limited resources, the National Oceanic and Atmospheric Administration (NOAA) must allocate priority for survey to "critical areas." These areas include only primary coastal shipping lanes and approaches to major U.S. ports and largely exclude the extensive nearshore areas used by fishing fleets, oilfield service vessels, and other commercial, government, academic, and recreational vessels. Also excluded from these surveys are most of the vast coastal areas managed by the nation's primary coastal zone managers, as well as many of the areas containing "essential fish habitat" that require mandatory mapping under the Magnuson-Stevens Fishery Conservation and Management Act. The public cost for inadequate bathymetric data becomes staggering when all factors are included (see Box 4.1).

SHALLOW BATHYMETRY—THE MOST CRITICAL GAP

There is a clear need for an expanded effort in bathymetric data acquisition in the coastal zone. In deeper waters (greater than about 10 meters) the technology to collect these data is available and relatively efficient (see Chapter 2). Accordingly, if a national commitment to accomplishing this deeper mapping exists, it should be straightforward to establish an overarching structure to ensure that it is done efficiently and effectively. The committee is confident that the approaches outlined here could form the basis for effective national planning as well as cost savings that could be directed to additional data collection. The real challenge and

BOX 4.1
Public Costs of Inadequate Bathymetry

- *Groundings.* Of the more than 500 groundings per year in the United States, many result directly or indirectly from poor charts. The cost includes hundreds of injuries and fatalities, millions of dollars in vessel and other property damage, and the potential for billions of dollars in environmental damage. Groundings account for nearly 25 percent of all tanker accidents. Between 1993 and 1996, tankers alone were involved in 174 groundings, 14 collisions, and 12 deaths (NOAA, 1999).
- *Striking submerged objects.* The likelihood of striking submerged objects will decrease as charts become more up to date and electronic chart display becomes more widespread. Like groundings, collisions with submerged objects result in hundreds of injuries and deaths, millions of dollars in property damage, and the potential for many millions of dollars in environmental damage.
- *Damage to submerged infrastructure.* In addition to damage sustained by vessels, their occupants, and the environment, submerged infrastructure can also be damaged. Examples include subsea pipelines, power cables, fiber optic cables, and subsea oil and gas production facilities. The cost of repairing such installations can easily exceed $500,000 per occurrence.
- *Poor spill predictions.* One of the best ways to mitigate the effects of oil spills is to quickly deploy recovery equipment ahead of the spill movement. To generate accurate water current predictions, accurate bathymetry is needed. Inadequate bathymetry can exacerbate potentially catastrophic environmental damage.
- *Longer vessel transits.* Because many charts do not contain accurate or comprehensive bathymetric data, vessel operators must take extra precautions that include transiting further out to sea before following the coast.

impediment, however, is the acquisition of high-quality bathymetry in the shallowest regions—the surf zone, the intertidal zone between low water and Mean Sea Level (MSL), and over bars and shoals at river mouths and tidal inlets. Although the U.S. Geological Survey (USGS) and NOAA datasets function essentially as national cartographic industry standards and, with tens of millions of users, are the two most widely used map/chart series available in the United States, it is clear that it is not possible to create a single, seamless database combining the two without considerable effort. One very important reason for this is that the surface area between Mean Lower Low Water (MLLW) and MSL is not routinely mapped by either agency. Along shorelines of low relief (the most common

In areas where water deepens gradually, precautionary measures can add 12 or more hours to a single transit for some ships. Thousands of ships, transiting dozens of times along the U.S. coast each year, can result in thousands of unnecessary transit days per year.

- *Unused freighter draft.* Container ships might reap $8,000 to as much as $50,000 for each inch of additional draft. To maximize draft and maintain safety, very accurate depths and tidal information need to be acquired. A single percent improvement in the overall efficiency of America's marine transportation system would translate into more than $2 billion in savings across the economy within a decade (AAPA, 2003).
- *Loss of potential EEZ resources.* The United Nations Commission on the Law of the Sea gives coastal nations the opportunity to extend their EEZ under certain conditions. The United States can potentially increase the size of its EEZ significantly. To stake its claim, the United States is required to perform a range of specified bathymetric and seismic surveys in and around the country's EEZ.
- *Excess dredging to overcome inadequate charts and tidal data.* Hundred of millions of dollars is spent annually on dredging. However, the related investment in our charting infrastructure has not been made. This means that new post-dredge data that are so important for navigation safety and import/export cargo tonnage are not available to mariners quickly enough.
- *Seabed damage.* Excess damage to the seabed will continue due to attempted scallop harvest in areas with little or no scallops. It has been demonstrated that multibeam bathymetry can dramatically improve fishing efficiency and significantly reduce unnecessary seabed damage.

case) this gap may extend horizontally for many meters (and in extreme cases can extend for hundreds or thousands of meters) and may extend vertically for a meter or more.

The problem is not just one of mandate, but rather the real technological and logistical difficulty of collecting high-quality data in very shallow water regions. The most comprehensive modern bathymetric data being collected in shallow water are currently acquired with multibeam sonar from a survey launch. Standard multibeam sonar acoustic techniques for collecting high-resolution bathymetric data map a swath of seafloor over a fixed angle (typically 120° to 150° or 3.4 to 7.4 times the water depth). The deeper the water, the greater the area covered. As the water shoals, the seafloor area sampled by the echo sounder decreases, making surveying with multibeam sonar an inherently inefficient process in very shallow water (in 2 meters of water the swath from a 150° multibeam sonar would be less than 15 meters wide—using typical survey protocols, a multibeam survey in this water depth would cover a swath only about 6 meters wide on each survey line). Survey launches are small (typically 7 to 10 meters long), manned, and generally constrained to daylight hours and good sea conditions. As a result, the actual productive survey time for a survey launch is generally less than 10 hours in a 24-hour period, and such surveys often progress very slowly in shallow waters where navigational hazards may be present.

In some areas, problems of survey efficiency and the dangers of operating a vessel in very shallow waters can be overcome through the use of airborne Light Detection and Ranging (LIDAR) systems. While current bathymetric LIDAR systems do not achieve the same data density or level of resolution as multibeam acoustic systems in similar water depths, they can rapidly provide a relatively complete and accurate picture of seafloor bathymetry. They can record data in up to 50 to 60 meters of water where water clarity permits, with a swath width that is unchanged by water depth (typically about 200 meters). Water clarity is the critical limiting factor in the applicability of bathymetric LIDAR, and high water turbidity precludes the efficient use of bathymetric LIDAR in many regions of the coastal United States.

Thus, acoustic systems are difficult to operate in the very shallowest regions of the coast, and bathymetric LIDAR systems, which can be operated safely from the air, may have difficulty in regions with high turbidity. Faced with this dilemma, the committee explored what technologies may aid in mapping the "shallowest of the shallow."

STRATEGIES FOR PROVIDING SHALLOW BATHYMETRY

To respond to the need for comprehensive and accurate data in shallow nearshore waters and along beaches, new and improved mapping and data acquisition technologies are being developed. Although research activities are attempting to increase the resolution and range of acoustic systems, in shallow water the physics of sound transmission in water is a fundamental limitation. Sweep systems that use an array of vertical-incidence transducers rigged on large booms to either side of the survey vessel may also be efficient in shallow water but need very calm conditions to be effective. Incremental advances in swath width may be gained by new interferometric and synthetic aperture sonars. These sonars provide excellent sidescan sonar data, but with some compromise of the fundamental framework bathymetric data. Nonetheless, these systems have proven to be a useful means of efficient geologic mapping in some shallow coastal areas (Denny and Danforth, 2002). Since these systems are also deployed from small vessels, they are subject to the same operational dangers that multibeam systems face in the surf zone.

The following is a discussion of other technologies and approaches that may help address the serious problem of collecting bathymetric and topographic data in the very shallow coastal zone. These technologies and approaches include the deployment of sonar systems on new platforms being developed to operate more safely and efficiently in shallow water (Autonomous Underwater Vehicles [AUVs] and Unmanned Underwater Vehicles [UUVs]), a new generation of LIDAR systems, innovative vehicles that drive through the surf zone, and the collection of "opportunistic" data with the help of the general public.

AUV-Deployed Sonars

An alternative to launches in turbid waters where bathymetric LIDAR is impossible is the use of AUV technology as the platform for sonar and imagery sensors. With the right type of AUVs, enhanced endurance and the ability to operate in a higher sea state can dramatically improve the productive survey time. Autonomous semi-submersible vehicles (e.g., Figure 4.1) have shown impressive productivity improvements during demonstrations. These systems operate just below the water surface to substantially increase the operational weather window but have a mast and antennas that remain above the water surface.

Smaller and more economical vehicles of this type would theoretically be able to operate for up to 72 hours at four knots before refueling. Further, multiple units can be operated simultaneously from the same mother ship, thus substantially increasing productivity. Each would be able to collect multibeam bathymetry, co-located imagery, and sidescan sonar data. Use of an Automatic Identification System (AIS) would allow the autonomous vessels to be plotted in real time on an Electronic Chart Display and Information System (ECDIS) with a radar overlay to assist in collision avoidance. Another AUV technology that may contribute to future survey efforts is the Solar Autonomous Underwater Vehicle (SAUV). The top of the SAUV hull is a solar panel that generates power for both sensors and propulsion (see Figure 4.2). Several SAUVs have been constructed, and they have demonstrated the ability to operate for more than a month at a time. Improvements in AUV technology will undoubtedly provide additional opportunities for their application to coastal zone surveying, where they may prove to be an effective and efficient means of collecting data without exposing field personnel to dangerous launch operations.

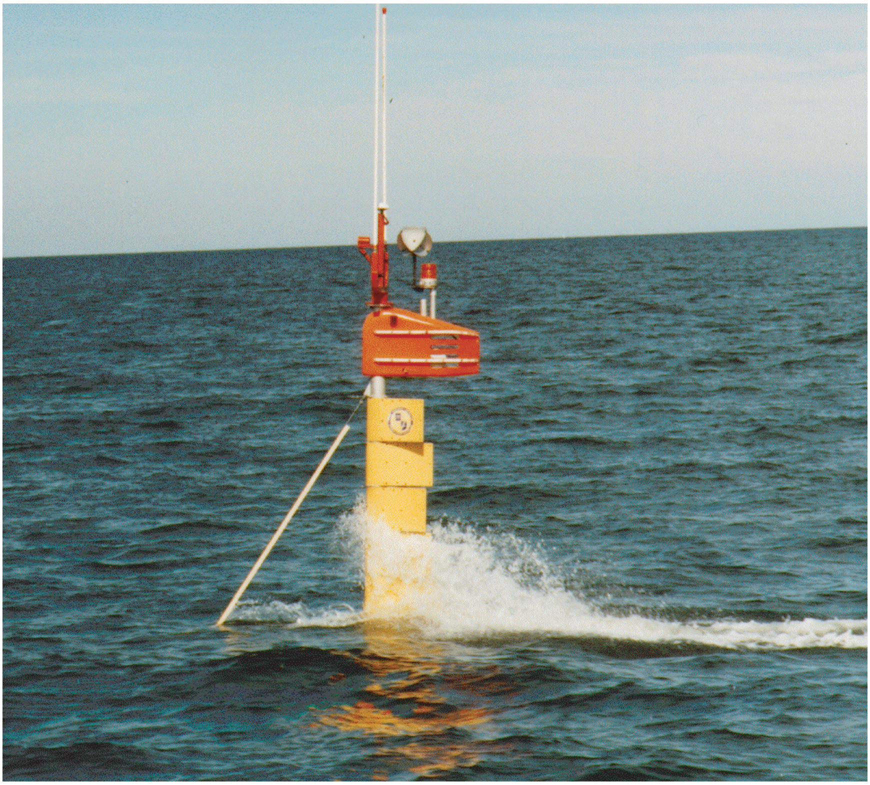


FIGURE 4.1 Mast of ORCA AUV underway while surveying. The ORCA is diesel powered, with a surface mast that allows precise positioning using differential Global Positioning System (GPS) information. Image courtesy of C&C Technologies.

New-Generation LIDARs

Airborne bathymetric LIDAR will always be limited by water clarity. However, new developments in integrated airborne/terrestrial LIDAR offer hope for providing datasets that will greatly facilitate the integration of onshore and offshore data. These new systems will simultaneously collect data from airborne bathymetric LIDAR, airborne topographic LIDAR, digital imaging systems, and perhaps even a hyperspectral scanner. All systems will be navigated using the same satellite-based system to provide a common vertical and horizontal reference frame. In one version of these new generations of LIDAR systems, the U.S. Army Corps of Engineers (USACE) Compact Hydrographic Airborne Raid Total Survey

FIGURE 4.2 Solar-powered AUV. Image courtesy of the Autonomous Undersea Systems Institute.

(CHARTS) system, the bathymetric LIDAR component operates at a rate of 1,000 Hz, while the topographic LIDAR component operates at 10,000 Hz. The system is compact and easily fits onto most photogrammetric aircraft of opportunity. When linked with the Vdatum tools described earlier, these new systems will provide data that are ideally suited to address the "data gap" at the land-sea interface (see Figure 4.3). Finally, while water clarity will always be an issue with bathymetric LIDARs, the careful planning of surveys with respect to season and tidal state may help mitigate this problem. Again, with a national structure that allows coordination of efforts, it should be possible to maximize LIDAR coverage.

Innovative Surf Zone Vehicles

Difficulties in using acoustic and other remote sensing technologies in very turbid water and in the surf zone have led investigators to develop a variety of bottom-following devices that are tracked by instruments to provide instantaneous measurements of bottom elevation. Early devices included a variety of sea sleds that were towed from the shoreline to outside the surf zone. Typically, these measured the elevation of the sled

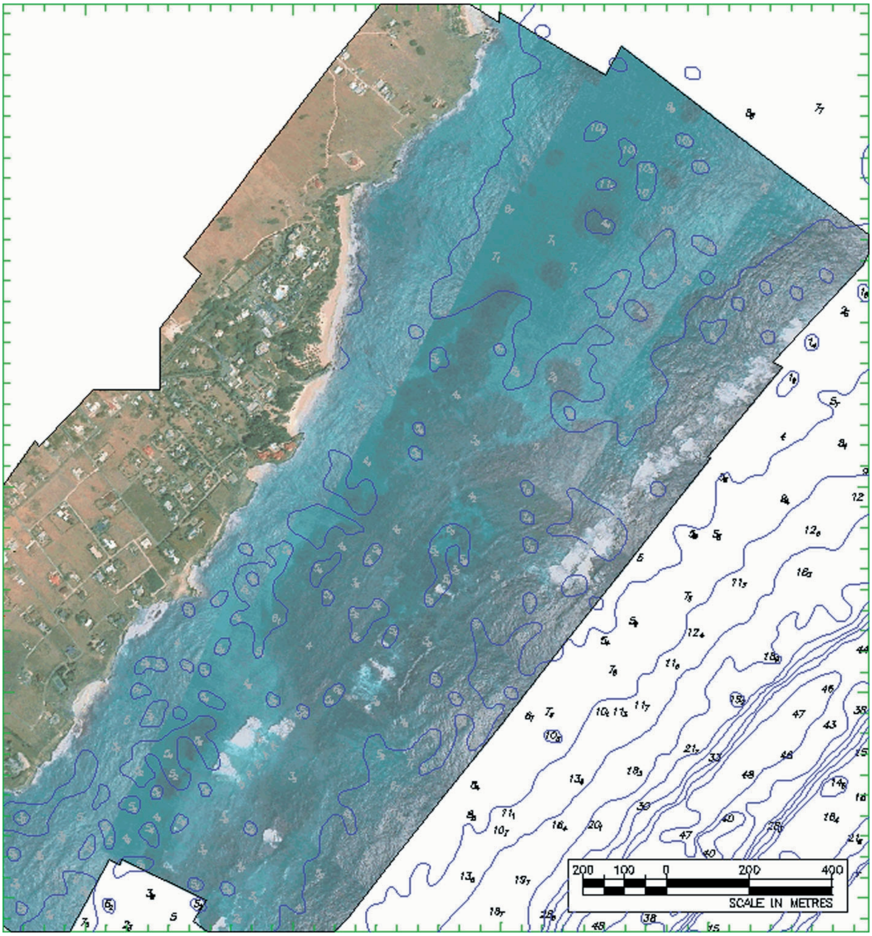


FIGURE 4.3 Airborne LIDAR bathymetry registered with rectified digital imagery. SOURCE: Quinn (2000).

base using a surveyor's level and a corresponding rod on a mast, while determining the sled's horizontal position using either a measured cable or triangulation. With the advent of total surveying stations, all that is needed is a reflecting prism mounted on the top of the mast to obtain its spatial coordinates.

Self-propelled vehicles to eliminate the need for towing were developed in the 1970s (Birkemeier and Mason, 1984), and with the advent of high-resolution Differential Global Positioning System (DGPS), continuous movement of the vehicle significantly reduced the cost and time of nearshore surveys. These types of vehicles have been used extensively for repetitive surveys along the North Carolina coast and also for a few preproject surveys (particularly for sand budget projects of the USACE).

Opportunistic Mapping

Historically, government agencies charged with the collection of data and the generation of mapping and charting products have been very reluctant to accept data from external sources, with government liability for the accuracy of navigation information often cited as the greatest obstacle to accepting third-party information. Incorporating data from sources other than well-qualified private industry partners remains problematic for nearshore hydrographic data. There are, however, numerous examples where public activities provide valuable feedback and, in some cases, data collection. The U.S. Power Squadron and the U.S. Coast Guard (USCG) Auxiliary provide quality assurance of charts and aids to navigation by noting discrepancies in charted versus observed nautical information. Commercial mariners routinely provide weather observations and, through NOAA's Voluntary Observing Ship Program, commercial ships are equipped to take bathythermograph observations. The members of the International Seakeepers Society equip their yachts with sophisticated observation modules capable of measuring several meteorological and near-surface water column parameters.

A potentially viable means for collecting high-quality bathymetric and other data may be by using a certified "black box" approach, where a sealed and calibrated data collection system is installed onboard vessels of opportunity. These systems record the parameters of interest (e.g., depth) together with DGPS-based position information. The recorded data are then downloaded to a central repository for quality control and processing.

TERRESTRIAL SATELLITE IMAGING

The coastal zone has a large and important terrestrial component. While mapping challenges for the "dry" regions of the coastal zone are less severe than those for water-covered areas, new developments in remote sensing techniques are rapidly improving the ability to document this important region. The recent introduction of high resolution commercial satellite imaging systems such as IKONOS (1-meter and 4-meter resolution, depending on channels used) and QuickBird (0.6-meter resolution) provide an important new data source for coastal mapping. In addition to offering high resolution and multispectral data, these systems provide a short revisit time (around 3 days) and have stereo mapping capability. In particular, stereo pairs can be formed in near real time due to a very flexible pointing mechanism. These characteristics make these new high-resolution satellite imagery systems very attractive for monitoring and change detection as well as coastal mapping.

If ground control is used, IKONOS images are capable of producing mapping products with meter position accuracy for general land features and submeter accuracy for objects that can be measured at subpixel level (Di et al., 2003). Although the sensor model is not provided to the users, so-called rational function coefficients are supplied along with stereo imagery to allow generation of Digital Elevation Models (DEMs), ortho-images, and other features. Recent results of tests and experiments to use IKONOS images for coastal mapping have demonstrated the potential to produce shorelines with about 1-meter horizontal and 2-meter vertical accuracy (Li et al., 2002). Since a satellite system has a prescribed orbit, it is impractical to require that the satellite images be taken at the time of a local MLLW or Mean High Water (MHW) level. Shorelines extracted from IKONOS images are therefore always instantaneous shorelines. In conjunction with an accurate Vdatum model, however, instantaneous shorelines can be converted to more traditional tidal datum-based or orthometric shorelines. Accordingly, high-resolution satellite imagery appears to have considerable potential for augmenting or replacing aerial photogrammetry in coastal mapping. There are numerous online resources already available that provide access to aerial- or space-derived imagery. These include the USACE Topographic Engineering Center's Commercial and Civil Imagery Office,[1] the USGS Global Land Information System,[2] and the Microsoft TerraServer web site.[3]

[1]See http://www.tec.army.mil/tio/.
[2]See http://earthexplorer.usgs.gov/.
[3]See http://www.terraserver.com.

5

Access to Coastal Geospatial Data

The fundamental product of the multiplicity of federal, state, and local agencies, private companies, academic researchers, and others who collect or process coastal zone mapping products is data. These data are their raison d'etre and as such need to be accessible, accurate, timely, and useful. The application of information technology has allowed the development of tools and techniques that have greatly enhanced our ability to deal with data of all kinds. Almost all data to populate existing and future coastal geospatial databases will be digital and amenable to the application of modern tools for managing, manipulating, and processing data. Although there will undoubtedly continue to be efforts to rescue or transform older data, our emphasis in addressing data issues will substantially focus on digitally collected data.

It is often difficult to find coastal geospatial data and/or derived products. Once located, it is often difficult to judge the quality of the data or to understand the limitations that apply to their use. With differences in scales, datums, projections, formats, or resolution, the data are often difficult to handle and even more difficult to integrate. As well as the paucity of tools for analysis and manipulation of coastal zone data, there are often concerns about data currency because of the short-term temporal scales of many coastal zone processes.

This does not diminish the importance of the wide range of useful Web sites providing coastal zone geospatial data, together with tool kits to manipulate the data. Examples of such sites are those provided by the National Geophysical Data Center (NGDC) Geophysical Data System

(GEODAS), the U.S. Geological Survey (USGS) Coastal and Marine Program, the Naval Research Laboratory's (NRL) Geospatial Information Database (GIDB) Portal Web Client, and the sites supported by the Coastal Services Center (CSC; e.g., the Ocean Planning Information System [OPIS]). Although each of these groups provides valuable access to data and tools, they still represent only a small percentage of data collected in the coastal zone, and there is an urgent need for a substantial effort to expand on the examples set by these organizations.

NATIONAL STANDARDS AND PROTOCOLS

As the committee evaluated the current status of data access and availability, the path ahead was clear. There is a need for the establishment of national (and perhaps even international) standards and protocols for data collection, metadata creation, and tools for data transformation and integration. With these, the user community would be able to evaluate the accuracy and timeliness of data, change scales and projections, and seamlessly merge disparate datasets. Most importantly, database and data integration tools must be easily accessible to all users, public and private, from a single digital portal accessible through the Internet.

In exploring strategies for implementing this vision, the committee was often reminded that a mechanism already exists that should have made much of this vision a reality. This mechanism—Office of Management and Budget (OMB) Circular A-16 (a directive describing federal agency roles and responsibilities with respect to geospatial data) and the Federal Geographic Data Committee (FGDC) it established—demands many of the processes that the committee has recommended. The FGDC is a federal interagency committee, operating under the auspices of the OMB, with responsibility for facilitating and coordinating federal activities related to geospatial data (see Box 5.1). Recognizing the national importance of geospatial data, the lack of generally accepted standards, and the potential for duplication and inefficiencies in spatial data collection and distribution, the FGDC formally defined the National Spatial Data Infrastructure (NSDI) in 1994. A series of National Research Council reports (NRC, 1993; 1994b; 1995b; 2001) advocated creation of the NSDI and recommended activities and initiatives that the FGDC could undertake to increase awareness, involvement, and usefulness of the NSDI. The OMB recently reissued Circular A-16 to bring it up to date for the 21st century (OMB, 2002). Many of the concerns brought up by the coastal zone user community and noted by the committee are directly addressed by Circular A-16, including the establishment of national standards, interchange formats, and metadata standards for geospatial data; the assurance of compatibility and interchangeability of datasets; the coordination of

BOX 5.1
The FGDC and the National Spatial Data Infrastructure

The FGDC is a federal interagency committee, operating under the auspices of the OMB, responsible for facilitating and coordinating the activities of the NSDI. The NSDI encompasses policies, standards, and procedures for organizations to cooperatively produce and share geographic data. The 19 federal agencies that make up the FGDC are developing the NSDI in cooperation with organizations from state, local, and tribal governments, the academic community, and the private sector. The NSDI is relevant to any agency that collects, produces, acquires, maintains, distributes, uses, or preserves analog or digital spatial data, including all Geographic Information System (GIS) activities, that are financed directly or indirectly, in whole or in part, by federal funds.

Different federal agencies have lead responsibilities for the various spatial data themes. For example, the USGS is responsible for all geologic mapping information and related geoscience spatial data; the National Oceanic and Atmospheric Administration (NOAA) is responsible for offshore bathymetry and shoreline delineation. Lead agencies are required to populate each data theme, principally by developing partnership programs with states, tribes, academia, the private sector, and other federal agencies, and also by facilitating the development and implementation of FGDC standards for each theme.

In order to build and support the NSDI, any agencies that collect, use, or disseminate geographic information and/or carry out related spatial data activities are required, both internally and through their activities involving partners, grants, and contracts, to:

- Develop a strategy for advancing geographic information and related spatial data activities appropriate to their mission.
- Collect, maintain, disseminate, and preserve spatial information such that the resulting data, information, or products can be readily shared with other federal agencies and non-federal users.
- Allocate agency resources to fulfill the responsibilities of effective spatial data collection, production, and stewardship.
- Use FGDC data standards, FGDC Content Standards for Digital Geospatial Metadata, and other appropriate standards; document spatial data with the relevant metadata; and make metadata available online through a registered NSDI-compatible clearinghouse node.
- Coordinate and work in partnership with federal, state, tribal, and local government agencies, academia, and the private sector to efficiently and cost effectively collect, integrate, maintain, disseminate, and preserve spatial data, building on local data wherever possible.
- Support emergency response activities requiring spatial data in accordance with provisions of the Stafford Act and other governing legislation.
- Search all sources, including the NSDI National Clearinghouse, to determine whether existing federal, state, local, or private data meet agency needs before expending funds for data collection.

data collection, data maintenance, and data dissemination; and the establishment of a national clearinghouse for geospatial data.

The NSDI National Clearinghouse concept has been incorporated into an OMB E-government[1] initiative called "Geospatial One-Stop," to provide a single national focal point for FGDC-compliant geospatial data. Geospatial One-Stop was established to provide standards and models for geospatial framework data, an interactive index to geospatial data holdings at federal and non-federal levels, interaction among federal, state, and local authorities about existing and planned spatial data collections, and a single on-line access point to geospatial data. It is the intention that tools will be provided to allow the migration of current non-compliant data to FGDC standards (FGDC, 2002).

The NSDI concept and the Geospatial One-Stop initiative are admirable and, in principle, go a long way toward addressing the frustrations expressed by the coastal zone user community. However, implementation of the NSDI appears to have been, and continues to be, problematic for this community. Although there is a broad awareness of the principles of the NSDI among federal agencies, there seems to be highly variable commitment to concurring with its requirements by different agencies and a lack of incentive to fully implement its principles. This is most readily apparent for the issue of standards, where there are concerns that a single set of standards may not be able to serve all applications and that those developing the standards may at times be too far removed from the user community, and/or that standards sometimes appear too complex for easy implementation and users are unaware of existing tools to simplify the implementation.

For example, rather than follow the FGDC's Content Standard for Digital Geospatial Metadata, agencies and research groups often create their own, less complex internal standards or in some cases do not write metadata at all, citing higher priorities and/or lack of resources and time. This defeats the purpose of Geospatial One-Stop, since those agencies or groups not writing FGDC-compliant metadata are unable to participate in NSDI clearinghouses, which require compliance with the FGDC standard.

Perhaps a more reasonable approach would be to seek stronger involvement from the private sector by contracting key aspects of standards development—and the tools to facilitate adoption of standards (see Box 5.2)—to the private sector and to allow agency procurement processes

[1]"E-government"—an abbreviation for "Expanding Electronic Government"—is the initiative overseen by OMB to expand electronic transactions, reduce paperwork, and make government services available using the Internet; see http://www.whitehouse.gov/omb/egov/2003egov_strat.pdf.

BOX 5.2
Vendors and Geospatial Standards—A Match Made in Heaven?

Various geospatial data standards have been developed to effectively implement the NSDI. Among them are:

- FGDC's standards for digital geospatial metadata (including a metadata profile for shoreline data);
- geospatial positioning accuracy standards (including a U.S. standard for Nautical Charting Hydrographic Surveys that is currently under review);
- spatial data transfer standards and spatial data content standards for hydrographic data in coastal and inland waterways (under review);
- remote sensing swath data standards; and
- classification standards for wetland and deep-water habitats.

Vendors do not create these standards or profiles, but do greatly speed their adoption by incorporating them into their software products. For example, ESRI's flagship GIS product—ArcGIS—embraces several current standards that are pervasive throughout the information technology arena, including the FGDC metadata standard and the Spatial Data Transfer Standard, as well as Web standards such as Extensible Markup Language (XML) and the Unified Modeling Language (UML, the standard notation for the modeling of real-world objects for object-oriented databases and GIS applications). In terms of metadata, if the user is already using ArcGIS for most data display, analysis, and map creation, the metadata documentation tool already in ArcCatalog will allow an FGDC-compliant metadata record to be written on the spot.

The ArcSDE application within ArcGIS for dealing with large spatial databases operates with commercial database management systems and supports a variety of formats, including those from standards bodies such as the OpenGIS Consortium (OGC) and the International Organization for Standardization (ISO), and de facto standard industry formats such as Oracle Spatial, Informix Spatial DataBlade, and IBM Spatial Extender.

This is also true of CARIS and its line of hydrographic production database and GIS software, which also fully supports the International Hydrographic Office's S-57 Transfer Standard for Digital Hydrographic Data, the S-52 Specifications for Chart Content and Display, and the production of S-57 Electronic Nautical Charts (ENCs). CARIS Spatial Data Fusion provides Web filters that help users access data from various clearinghouses without needing to know anything about the specific standards or formats of the data in those clearinghouses.

to continually encourage the private sector to deliver needed products in a timely fashion. As an example, the FGDC and the FGDC Marine and Coastal Spatial Data Subcommittee Web sites do not yet have links to the international S-57 Transfer Standard for Digital Hydrographic Data, critical to successful U.S. nautical charting. However, this standard is already fully supported in several private-sector GIS products, including very effective tools for converting non-standard data into compliant forms.

As noted earlier, there are a number of excellent Web sites that are currently distributing geospatial data nationwide with FGDC-compliant metadata.[2] However, these are too distributed and limited in their content. The committee strongly supports the development of a single portal specifically for all coastal mapping and charting data and derived products within the framework of Geospatial One-Stop. This concept does not require a single site that contains all coastal data but rather a single focal point that can link to distributed databases that all support FGDC-compliant data and to tools that can convert non-compliant data into compliant data. This site would represent the one place where users, particularly new users, can consistently and reliably begin their searches for data and derived products. A single access point should also promote easy and timely data entry.

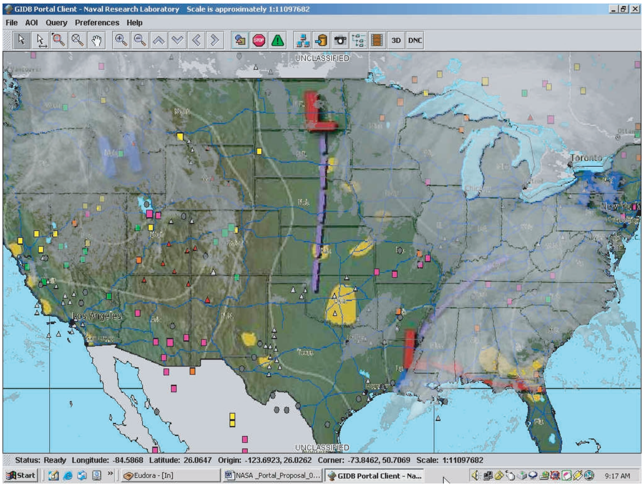
An excellent example of this approach is NRL's Geospatial Information Database (GIDB) Web Portal Client (Harris et al., 2003; see Box 5.3). The U.S. National Guard Counter Drug Program is currently using a version of the GIDB Portal System technology as the basis for its Digital Mapping Server (DMS) portal in support of drug enforcement agents and agencies. This technology is also in use at NGA's Gateway SIPRNET site, allowing dissemination of local file system information at the NGA Gateway as well as integrating that information with multiple other non-NGA sources. In 2004 the GIDB technology will be implemented as the oceanographic, meteorological, and environmental data delivery system for the U.S. Navy.

Effectively sharing data means more than just the ability to download a file. Many valuable datasets and excellent analytical tools available on the Internet are underused and thus do not fulfill their potential. This may be due to the fact that the existence and/or purpose of the data may not be well known by the user community. It also may be due to a lack of understanding by users either of how to access and use the datasets or of data limitations. Therefore, in addition to metadata, information is needed

[2]For example, several coastal/ocean examples are cataloged at http://buccaneer.geo.orst.edu/links/.

BOX 5.3
Naval Research Laboratory's GIDB Portal System

The NRLs Geospatial Information Database (GIDB) Portal System is a standards-based portal for geospatial information discovery, access, and mapping over the Internet (Harris et al., 2003). The system gathers heterogeneous environmental data from disparate databases distributed across the Internet, and this information can then be displayed in a "GIS-like" fashion for data overlay and comparison using NRLs or other popular viewers. Data can be exported in several formats for use in analysis packages.



A sample GIDB Portal System thick-client display showing integrated cloud cover, meteorological information, mineral locations, and other sources. Image courtesy of the NRL.

The portal system was developed in Java for platform portability, to allow data of any origin to be distributed and displayed on mainframe, personal computer, and Personal Data Assistant (PDA) clients. An open source, Java database management system is also available for deployments requiring custom data storage. The GIDB Portal System presently connects the user to 128 servers, including over 800 services across the United States, and the system is government owned and requires no licensing. This portal system technology, accessible at http://dmap.nrlssc.navy.mil, has been under development at NRL for many years with support from multiple sponsors, including the Office of Naval Research (ONR), NRL, National Geospatial-Intelligence Agency (NGA), and the Navy's Space and Naval Warfare Systems Command (SPAWAR).

to describe the appropriate use and limitations of data and derived products. Again, many of these issues are addressed under the NSDI and Geospatial One-Stop, so the fundamental issue becomes a question of identifying ways to make the NSDI and Geospatial One-Stop concepts nationally accepted. A recent report (NRC, 2001) concluded that although the FGDC was successful both in improving access to data through the National Clearinghouse and in beginning to establish content standards for geospatial metadata, little evidence could be found for reduced redundancy and diminished costs associated with data creation or maintenance, for improved accuracy of data, or for any removal of the significant institutional barriers inhibiting the development and maintenance of geospatial data.

In an assessment of the significance of coastal and marine data in the context of the NSDI, Lockwood and Fowler (2000) noted that, although there is an Executive Order to prescribe federal compliance with the NSDI, there are neither any real means of enforcement nor a process to monitor compliance. They also point out that the federal agencies are given some leeway in determining which data might contribute to the NSDI, with OMB Circular A-16 using terms like "most expeditious," "with available resources," and "practical and economical to do so." They cite the need for individual agencies to understand the broader context and the potential benefits that sharing geospatial data can bring in support of their individual mandates, as well as the lack of resources for participation in the NSDI, as further impediments to its success.

The FGDC has recognized problems with implementation of a national strategy for geospatial data. In an effort to improve federal coordination of geospatial data, the FGDC commissioned a design study team to evaluate actions and priorities that the FGDC must address (FGDC, 2000). Based on discussions and interviews with many people within the member agencies of FGDC, the team recognized that there were problems of lack of support and appreciation of the NSDI by senior officials in most of the agencies involved and that there were still problems with interagency coordination and development of NSDI framework layers. To address these issues the team recommended:

- Raising geospatial data awareness to the policy level, to ensure that a clear vision of the NSDI must be presented that is understood by policy makers;
- Identification of full-time coordinators in each agency, with a commitment by senior agency officials to support the goals of Circular A-16;
- Greater pressure from OMB;
- Clarification of individual responsibilities for national data stewardship;

- Restructuring of the FGDC to have it report to the Director of USGS, evaluate and modify the current subcommittee structure and responsibilities, and focus FGDC staff on interagency non-partisan brokering with federal agencies;
- Establishing management and oversight accountability that must involve OMB.

The committee is fully supportive of these recommendations, but disappointed that—as a consequence of its mandate—the design team could not focus on the role that the private sector potentially could play in furthering the goals of the NSDI.

MORE THAN JUST A WEB PORTAL

The establishment of a single portal for coastal geospatial data, together with a series of support tools for data transformation, processing, and integration, will go a long way toward addressing many of the concerns of this committee and the user community. Such tools and databases must also be supported by education and training, so that the user community understands and appreciates the limitations of the various datasets and their appropriate application. Documentation describing the data collection methods and processing tools used (beyond the brief descriptions provided by metadata) must be made available to the community. For example, the USGS Seafloor Mapping Group Web site[3] provides excellent background information on the various acoustic methods used to collect mapping data offshore. The new Oregon Coastal Atlas[4] has similar information about data collection and processing, in addition to providing data.

Training courses and workshops for users are also essential, and agency efforts should be expanded to provide users of their information with the knowledge and tools necessary for intelligent application of the data. The CSC has paved the way in providing these services to users, and these services should either be utilized more effectively by other agencies or be used as a model for other agencies to emulate in transforming their data into useful information.

[3]See http://woodshole.er.usgs.gov/operations/sfmapping.
[4]See http://www.coastalatlas.net.

6

Increasing Coastal Mapping and Charting Efficiency

As with any activity that involves multiple federal, state, and local agencies, academic researchers, and the private sector, there is tremendous potential in coastal zone mapping and charting activities for redundancy and overlap of effort. This becomes particularly important when the activity involves very expensive platforms and sensors. With the large number of agencies involved, their differing histories, the breadth of their mandates, and the complexity of the issues (see Appendix A), there are many instances of both real and "apparent" redundancies ("apparent" refers to situations where an activity appears similar to activities of other programs, either within the same agency or in another agency, but that in reality serves an important separate purpose). The committee attempted to distinguish between real and apparent redundancies in coastal mapping and charting activities within and between agencies based on the information provided directly or through presentations at committee meetings (and summarized in Appendix A). When the titles or brief descriptions of activities indicated apparent redundancy with activities performed by another agency or another office within the same agency, the activities were investigated further to determine whether the apparent redundancy was real. In many cases it was determined that the activities described were not redundant (and there is certainly a lesson to be learned about taking great care in naming and describing an activity). In other cases, however, the committee found that efficiencies could be gained through better coordination of activities, and these are the examples presented here.

It is important to note that the committee did find examples where communication, collaboration, and cooperation were clearly leading to enhanced efficiency and the avoidance of redundant activities (e.g., see Box 6.1). Examples include collaboration by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) in the Bathy/Topo/Shoreline Demonstration Project, efforts by NOAA's Office of Coast Survey (OCS) and USGS to maximize survey

BOX 6.1
Examples of Successful Collaboration

Long Island, New York

In Long Island Sound, there is a 23-year history of cooperative State of Connecticut/USGS/Minerals Management Service/NOAA data collection involving seismic and sidescan sonar surveys; bottom grabs and coring; and bottom reconnaissance using divers, Remotely Operated Vehicles (ROVs), and submersibles. Nine potential study areas have been established by producing continuous sidescan sonar mosaics. Most of the data that have been collected as part of this effort are available on the Internet.[a]

Several derivative products from this effort have also been published and are available on the Internet.[b] There are very few requests for the data used to produce these products or for the background related to the sidescan mosaic areas, but there is extensive and growing use of the derivative maps for permitting, resource management, and resource protection applications.

Stellwagen Bank, Jeffreys Ledge, Massachusetts and New Hampshire

NOAA-OCS, NOAA Fisheries (formerly the National Marine Fisheries Service), the Sanctuaries Program, USGS, and state and local authorities all have great interest in the region from north of Cape Cod seaward to an area known as Jeffreys Ledge. This region includes the approaches to Boston and Portsmouth harbors, Stellwagen National Marine Sanctuary, and many rich fishing grounds, including several regions that have been closed to fishing by NOAA Fisheries. Each of these organizations was planning independent mapping programs, but now, as a result of a series of meetings and conference calls, all of the mapping efforts (including contract surveys to the private sector) are being coordinated so that there will be minimal overlap (except where desired for repeat of comparison surveys) and maximum efficiency.

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[a] See http://woodshole.er.usgs.gov/project-pages/longislandsound/index.htm.
[b] See http://woodshole.er.usgs.gov/project-pages/longislandsound/Pubs.htm.

value by collecting data relevant to both organizations on a single cruise, USGS-National Park Service (NPS) collaborative mapping programs, Environmental Protection Agency (EPA) collaboration with NOAA, USGS, Fish and Wildlife Service (FWS), and a number of state agencies to determine national water quality conditions, and the numerous Coastal Services Center (CSC) efforts to organize states and others with respect to standards and data distribution.

DATA COLLECTION OVERLAP AND REDUNDANCY—TOPOGRAPHY AND BATHYMETRY

Those charged with acquiring or working with coastal zone mapping data and/or derived products do not have an efficient means of determining whether an area of interest has been previously mapped or is planned to be mapped. Even when a user is aware that a mapping effort has been completed, it is often difficult to acquire the data in useful forms. The agencies undertaking mapping programs use various methods to distribute their products, increasingly making digital data available on the Internet, often free of cost. There are numerous examples of excellent Web sites that attempt to offer the user easy access to both primary data and derived products (e.g., the National Geophysical Data Center's Geophysical Data System [GEODAS] and Coastal Relief Model, OCS's Mapfinder, CSC's Ocean Planning Information System [OPIS], and many others), but such efforts are distributed and managed by individual labs, divisions, or agencies and are often difficult to locate. Currently, individuals seeking spatial data must search many Web sites, contact agency staff, and generally learn through trial and error what data exist and how to obtain them. In addition, the usefulness of coastal data often outlasts the work or even the careers of the people who generated the data, and it is essential that future generations have access to such data despite changes in the mandates of agencies and their staff.

As with most situations where redundancy and overlap exists, the problem lies mostly in a lack of communication among agencies (and sometimes within agencies), and between agencies and end-users. During presentations to the committee, there were several occasions where representatives from agencies that were planning mapping or charting programs were made aware of nearly identical programs that existed in, or were planned by, other agencies. While the redundancies identified involve the full range of data collection, analysis, and product development activities, it is redundancy in data collection that is of most concern as this is by far the most expensive of these activities. Noted below are specific examples of activities that can benefit from better communication and coordination, followed by suggestions for strategies that may alleviate some of the potential for duplication of effort and thus produce more effective and efficient coastal zone mapping and charting.

Aerial Imagery

The Cooperative Topographic Mapping Program of the USGS's Geography Discipline archives and disseminates maps and digital spatial data products. The program is developing national digital coverage as a component of "The National Map" initiative, based on participation with federal, state, local, and tribal governments; non-profit organizations; and the private sector. This effort requires coastal topographic data above Mean High Water (MHW) or perhaps Mean Sea Level (MSL). The USGS national mapping program uses stereo aerial images for its production of topographic quadrangles, including digital line graphs, Digital Elevation Models (DEMs), and digital orthophoto quadrangles. Additional aerial photographs are required periodically to update the mapping products. A significant portion of the aerial photographs required by USGS are in coastal areas where NOAA's national shoreline mapping program collects high-quality, tide-coordinated, stereo aerial photographs. Except for the additional requirement for tide-coordinated timing, such aerial photographs are also appropriate for topographic mapping by USGS. A coordinated effort between the two agencies in coastal areas would allow both agencies to benefit from their collective efforts and eliminate redundancy or overlap.

LIDAR Data

Individual agency and state efforts to collect Light Detection and Ranging (LIDAR) data appear to suffer from a significant lack of coordination and cooperation. NOAA-CSC conducts the Topographic Change Mapping project, which supports private-sector LIDAR mapping to help CSC address coastal management needs. There is also an ongoing National Aeronautics and Space Administration (NASA) and USGS research effort to provide LIDAR coverage of the entire U.S. coastline to support improved assessment of coastal change hazards. These two programs closely parallel each other, and there is considerable likelihood of duplication in some regions. In fact, a few years ago the two agencies had worked together—with NASA—to develop the foundation of the Airborne LIDAR Assessment of Coastal Erosion (ALACE), a partnership between CSC, NASA, and the USGS to collect LIDAR data along the sandy beaches of the United States. Unfortunately, this collaboration no longer exists, and as a result there is considerable potential for duplication and lack of coordination.

The U.S. Army Corps of Engineers (USACE) collects bathymetric, topographic, and photogrammetric information in inland waterways and ports for a range of purposes. Additionally, environmental conditions are measured and monitored using spectral and field sampling techniques to determine the impacts of engineering projects. The USACE uses its Scanning Hydrographic Operational Airborne LIDAR Survey (SHOALS) bathymetric LIDAR system, which is also capable of being equipped with multispectral imagers and topographic LIDAR, for mapping and monitoring of the coastal area. This technology is especially useful in waters too shallow or hazardous for efficient employment of survey launches. However, the extent to which USACE project-specific mapping using SHOALS technology could benefit from, or contribute to, the ongoing efforts of NOAA and the USGS is unclear. The process by which the USACE prioritizes its coastal mapping activities and coordinates these activities among its own regional offices is also unclear. Lack of coordination of shallow bathymetric LIDAR surveys was cited as a problem by one state representative who reported that, while the state was conducting a LIDAR mapping program, he discovered "by happenstance" that the USACE was planning LIDAR flights over the same area of coast. In the present situation, where many individual states are seeking to obtain extensive or statewide LIDAR coverage of onshore areas, it is imperative that effective coordination between federal agencies and coastal states be implemented for maximum efficiency and cost savings.

Shoreline Mapping

Nowhere is the problem of agency overlap more evident than in the mapping of the nation's shorelines. The committee identified several technical reasons for the difficulty in defining, locating, and mapping a consistent shoreline, but none of these reasons justify the degree of overlap and lack of coordination evident with respect to shoreline mapping. The following summary of federal shoreline mapping and shoreline change activities illustrates the nature of this problem. Recommendations for reducing these overlaps and improving interagency coordination in the nation's shoreline mapping efforts are presented later in this chapter.

National Oceanic and Atmospheric Administration (NOAA)

NOAA's mission includes the requirement to survey coastal regions and navigable shoreline water areas to provide an official and accurate delineation of what the agency and many international bodies define as "The National Shoreline." These surveys consist of the collection and analysis of aerial photogrammetric shoreline data by NOAA's National

Geodetic Survey (NGS) for nautical chart production and the accurate geographical references needed for managing coastal resources. NOAA-OCS uses the shoreline data collected by NGS to prepare nautical charts and other products for navigation. Recently, these data have been produced in digital form from scanned raster (paper) copies of archived coastal surveys originally used in the production of nautical charts. Most of these efforts are managed by the NOAA-CSC, which is making the data available via the Internet and on CD-ROMs for each U.S. coastal state and territory. For some states, shoreline data digitization is also being accomplished through partnerships with local coastal zone management programs.

Minerals Management Service (MMS)

MMS derives state and federal baselines based on the definition agreed to in the United Nations Convention on the Law of the Sea: ". . . [T]he normal baseline for measuring the breadth of the territorial sea is the low water line along the coast, as marked on large scale charts officially recognized by the coastal state." MMS uses the NOAA-collected and -derived Mean Lower Low Water (MLLW) for baseline point development. Although MMS does not directly perform any coastal mapping or charting, it does support efforts by NOAA's National Ocean Service (NOS) to collect new information where data gaps exist. The NOAA-OCS coordinates development and dissemination of the base cadastre and marine boundaries with the MMS Mapping and Boundary Branch. This coordination between NOAA and the MMS is an example of the type of collaboration that maximizes efficiency.

U.S. Geological Survey

The USGS Geology Discipline supports scientific investigations of shoreline change including the National Assessment of Shoreline Change. Primarily using a NASA airborne topographic LIDAR to map the U.S. coastline, the principal purpose of this program is to develop a repeatable coastal surveying method for periodic measurements of the shoreline. Although it appears that these data could by used by NOAA—and the data is made available to NOAA—this program is not designed to establish legal boundaries but instead is intended to:

- Establish an objective shoreline for the sandy beaches of the continental United States and Hawaii for the development of consistent estimates of coastal change. The committee notes the apparent redundancy with NOAA's efforts to provide "an official and accurate delineation of 'The National Shoreline.'"

- Develop and implement improved uniform methods of assessing and monitoring shoreline change. The committee notes that the Federal Emergency Management Agency (FEMA), USACE, and NOAA also conduct shoreline change assessments.
- Provide data and information to other federal and state agencies through partnerships.

Federal Emergency Management Agency (FEMA)

FEMA is the principal agency tasked with identification and mitigation of the nation's coastal hazard threat. Through the use of grant monies allocated to state agencies and published standards, FEMA oversees the production of Flood Insurance Rate Maps (FIRMS). FIRMS delineate the location and intensity of flooding hazards in the coastal zone related to hurricane storm surge and tsunami occurrence, based on historical frequency and site-specific physical parameters.

Almost all of the current FEMA coastal hazard enterprise has been focused on water-level inundation and has not considered other types of coastal hazards, such as coastal erosion or sea level rise, which can only be effectively evaluated using geospatial tools. Congress has recognized this deficiency and drafted legislation that would allow FEMA to engage in coastal erosion mapping, with a significant amount of funding ($150 million in 2003 and $200 million in 2004 for map modernization) potentially appropriated toward this effort.

Traditionally, FEMA has used a state-by-state approach to collect the geospatial data necessary for delineating the erosion hazard zone, rather than working with other federal agencies in a cooperative effort. The state-by-state approach suffers from parochial definitions and lack of standards for data collection and analysis methods and is unlikely to result in the nationally consistent geospatial dataset envisioned by this committee and urgently required by coastal managers, scientists, and policy makers.

U.S. Army Corps of Engineers (USACE)

In 2001, USACE received funding from the Congress to initiate a National Shoreline Management Study,[1] which directs that a report be prepared for Congress describing the state of the shores of the United States. This study will examine the extent and causes of shoreline erosion and accretion and discuss the economic and environmental impacts of these processes. The intent is to provide the information needed for

[1]See http://www.iwr.usace.army.mil/NSMS/.

developing recommendations on levels of federal/non-federal participation in shore protection and to outline systematic approaches to sand management and coastal management decision making. The scope of this study, particularly investigating the causes of shoreline erosion, appears to duplicate the efforts of USGS's science-based National Assessment of Shoreline Change, and it was unclear to the committee whether or how this apparent duplication would be addressed by the respective agencies.

DATA COLLECTION OVERLAP AND REDUNDANCY—HABITAT MAPPING

In the context of coastal mapping, habitat is necessarily a derived thematic layer constructed on a variety of primary data sources. Habitat mapping can encompass almost all other primary information sources, including the framework information of topography and bathymetry, and source data elements, including water movement; the quality, character, and distribution of bottom materials; sediment dynamics; and other biological and chemical components of the ecosystem. The measurement and compilation of any and all physical, chemical, and biological coastal information can be considered "habitat mapping." With such broad information needs and high socioeconomic value, it is not surprising that many agencies express a need for habitat information and/or have active efforts to map habitat.

With so many agencies involved in habitat mapping, there is a high potential for duplication and overlap. However, there are a number of difficulties in assessing potential overlaps and gaps and in recommending steps to address the problem. Many individual habitat mapping initiatives occur on regional or local scales to address specific needs (e.g., activities of coastal states to address their permitting and management requirements). A recent report noted that "in general, habitat maps have been compiled only on an ad hoc basis for small areas . . . due partly to the lack of an accepted classification scheme for seafloor habitats in the United States" (NRC, 2002; p. 31). Different efforts often address different species, biogeographic regions, or research questions. Nevertheless, considerable benefits and cost savings are likely to result from a national approach to mapping coastal habitats. As with all thematic layers, the basic geospatial data (topography and bathymetry) are an essential component of habitat mapping, providing the framework upon which habitat data are displayed and referenced. At the next level, information describing substrate type and distribution and sedimentary processes are components of habitat characterization (e.g., Kostylev et al., 2001). Consequently, sidescan sonar imagery, multibeam backscatter, aerial and satellite imagery, seafloor photography, and other techniques for determining the nature of seafloor substrate are an important additional layer for mapping habitat. In addition, more ephemeral and difficult to measure parameters like salinity, currents, water temperature and range, nutrient levels, and associated species are all components of a final determination of habitat. Although the complexity of the issues involved with habitat mapping may justify involvement of numerous agencies in the collection of habitat data, it is likely that better coordination of effort and broader access to data would lead to increased efficiency.

An additional requirement to support consistency of habitat mapping among agencies and other users is a nationally—if not internationally—accepted marine habitat classification system. Such a system would ensure that a map developed in one region is comparable to that from another area in terms of nomenclature, quality assurance, and other standards. This will allow appropriate understanding, planning, and action to address threats to the important species, biodiversity, and habitats that extend beyond state or national borders.

STRATEGIES FOR ADDRESSING REDUNDANCY AND OVERLAP

The Federal Budget Process—the Problem Behind the Problem

The lack of coordination and communication within and between federal agencies, as well as between state and federal entities, has resulted in overlap and redundancy, not only in terms of agency operations but also in terms of agency missions related to coastal mapping and charting. This probably comes as no surprise to most federal managers, for in a very real sense the budgetary and programmatic decision making processes of the federal government favor those who set themselves apart by promoting their own agendas, rather than those who would support coordinated partnerships between agencies. In large measure, the federal budget process discourages partnership planning and funding.

Each federal fiscal year's budget cycle begins with the development of an agency-level budget proposal. For example, the component bureaus (USGS, NPS, FWS, MMS, etc.) of the Department of the Interior all develop separate proposals. The bureaus set priorities and goals for the myriad of individual efforts to be continued or initiated by their offices during the coming fiscal year. Bureau proposals are then submitted to the department for review, where they are subject to departmental priorities reflecting a host of policy, legislative, regulatory, procurement, and management needs that are usually more closely tied to the administration's priorities than those at the bureau level.

Although these two steps probably offer the highest potential for rewarding internal or internal/external partnerships under the existing budget system (perhaps because the benefits are clearer to the interested parties), such partnerships face strong competition from internal forces seeking to preserve, sustain, and, most often, expand internal funding and capabilities. Requests for funding to support partnerships with other agencies may be denied because of a perceived risk that if one agency partner fails to receive funding, the project may not be viable; alternatively, it may be denied because if a single project is listed in more than one agency's budget, it may appear to be a duplication when in reality it is actually cost sharing.

The next step is submission of departmental budgets to the Office of Management and Budget (OMB), where individual examiners, assigned to particular departments and bureaus, review the proposals. Among the objectives of such reviews is the reduction or elimination of any requests for funding that do not fall within the administration's priorities, as well as identification of potential redundancies. There is potential for OMB examiners to perceive funding for the same project in two or more agencies' budgets as a duplication of effort and to eliminate funding to one or more of the partnering agencies.

After OMB makes its decisions, the departmental budget requests are compiled into the president's request to Congress. In both the House and the Senate, separate committees dealing with the individual "bins" of the federal budget review, deliberate, and ultimately arrive at a "mark" for each of the line items in the administration's request. Agencies with coastal mapping and charting responsibilities and needs are distributed across a number of congressional committees that authorize and appropriate funds. The "stovepipe" nature of the committee system, combined with the location of agencies with coastal mapping and charting responsibilities in different "pipes," limits opportunities for promoting or establishing interagency partnerships.

Occasionally, legislation is passed that directs specific agencies to work in partnership to address a critical national need. However, funds may not have been appropriated for the new directive, which means that funding must come from existing agency budgets. Occasionally a program will generate support across several levels of the government. One of these was the U.S. Global Climate Change Research Program, which developed a strong rationale for centralized funding to address this critical national concern. As a result, OMB strongly supported interagency requests for additional funds.

It is with this in mind that the committee encourages OMB management and agency/bureau representatives to the Federal Geographic Data Committee (FGDC) to recognize that no single agency has the resources, or the mission, to collect the data and develop the models necessary to support the comprehensive geospatial products that will meet all of the nation's coastal user needs. Only through intensive and extensive partnerships between and within agencies can significant progress be made toward the community vision of an integrated and continuous coastal zone mapping and charting product.

Enhancing Inter- and Intra-agency Cooperation and Collaboration

The committee recognizes a pressing need for establishing and improving formal and informal mechanisms for collaboration in planning, funding, and implementing the nation's coastal mapping and charting efforts. We appreciate that success will ultimately depend on support at many levels of government, from agency offices, to OMB examiners, to Congress. Our overarching concern is that without such mechanisms, the nation's capability to map and chart its coastal areas will be seriously degraded by duplicative and unnecessarily costly field efforts, lack of standardized approaches for enhancing the utility of the data and derived products, and serious gaps in capability and data coverage. In the following paragraphs we present specific mechanisms that could be used to further such collaborations.

Mandatory registration of all federally funded coastal mapping and charting activities in a central, publicly available database.

As noted above, in the process of the committee's meetings we observed several occasions where representatives from agencies that were planning mapping or charting programs were made aware of nearly identical programs that existed in, or were planned by, other agencies. If this happened several times in the course of only four committee meetings, there is clearly a serious problem. As a first—and enforceable—step in ensuring that information be readily available, the committee recommends that all agencies receiving federal funds for coastal mapping or charting activities be required to register these activities in a publicly available, easily accessible database. This database would contain critical information on the spatial extent of the survey, the equipment used, the parameters measured, and so forth. The database would track surveys completed but, most importantly, would list surveys being planned. In this way, other organizations could identify the extent and parameters for planned surveys. While registration cannot be made mandatory for states and those funded by sources other than federal funds, they should be encouraged to register their planned and completed activities. In addition, these organizations would have a single place to search to find what federally funded surveys have already been done and, more importantly, what surveys are planned in their regions. There could also be a portion of the database reserved for a "surveys needed" section, where all agencies or organizations (including non-federal organizations) could list areas that are in need of mapping as well as the type of data required.

Aspects of this recommendation are already covered under the newly revised OMB Circular A-16 (OMB, 2002):

> . . . [A]ll agencies that collect, use, or disseminate geographic information and/or carry out related spatial data activities will, both internally and through their activities involving partners, grants, and contracts:
>
> Prepare, maintain, publish, and implement a strategy for advancing geographic information and related spatial data activities appropriate to their mission, in support of the NSDI Strategy. Annually report to OMB on your achievements relative to your strategies, and include spatial data assets within Exhibit 300 submissions (see OMB Circular A-11, sec. 300) . . . [and] . . . before the obligation of funds, ensure that all expenditures for spatial data and related systems activities financed directly or indirectly, in whole or in part, by federal funds are compliant with the standards and provisions of the FGDC. All Information Technology systems which process spatial data should identify planned investments for spatial data and compliance with FGDC standards within the Exhibit 300 capital asset and business plan and submission (see OMB Circular A-11, sec. 300).

While this directive requires some degree of registration for all geospatial data collection activities, the committee calls for a much more focused database to encompass coastal zone-specific activities, linked to the proposed single coastal zone Web portal.

Through a system based on the centralized registration of coastal survey work and a centralized coordination office, the specifications for proposed work could be viewed by all interested parties. If an agency notes that survey work is being planned by others in an area of interest to it, the agency can assess the proposed data types and specifications and then may choose to fund any incremental costs necessary to bring the survey specifications into line with its own needs. Thus, the registry not only would serve to reduce redundancy and overlap but would also have the potential to greatly enhance efficiency by facilitating "incremental" surveys, that is, when one agency plans a survey for a particular purpose (e.g., bathymetry for safety of navigation) and another agency requires a different type of data in the same area (e.g., backscatter for habitat mapping), the "piggyback" agency can provide the incremental funding required to collect the additional data rather than conducting a very expensive independent survey (see Box 6.2). The database would be served by the single Web portal dedicated to coastal zone mapping (described in Chapter 5).

In 2001 the USGS Geography Discipline proposed that it should develop "The National Map"—a database of continuously maintained

BOX 6.2
Incremental Surveys—A Scenario

A magnitude 6.5 earthquake is reported in the Seattle area. The epicenter is determined to be offshore, and there is concern that the earthquake has created seafloor instability with the potential to trigger underwater landslides. The USGS Coastal and Marine Program, which has responsibility for offshore geologic mapping, makes plans to map the area and registers the upcoming survey in the national coastal mapping survey database. The personnel assigned to the centralized coordinating office for coastal mapping activities receive notification of the planned USGS survey and review the registered "survey needs" list of other agencies. They find that NOAA-OCS has listed the area offshore from Seattle on their list of desired survey areas. The coordinating office personnel then contact NOAA and suggest that the agency contact the appropriate authority at the USGS. NOAA is informed that the USGS intends to contract the survey to a qualified contractor and collect multibeam sonar bathymetry and backscatter to "geologic standards." NOAA determines that for a 10 percent additional cost the data could be collected to "hydrographic standards." NOAA authorizes the additional funding, and data suitable for the needs of both USGS and NOAA are collected at a small fraction of the cost of two separate surveys. One year later, NOAA Fisheries determines that it needs to map Essential Fish Habitat off the same area of the coast. The coastal survey database is searched and shows that the USGS has already mapped the region, collecting bathymetry to hydrographic standards and backscatter in support of geologic interpretation. This is more than suitable for NOAA Fisheries needs, and so it is only necessary to schedule a "ground-truth" cruise to collect video and other imagery. The cost of another mapping survey is saved.

base geographic information for the United States and its territories designed to serve as the nation's topographic map for the 21st century (USGS, 2001). This database would include orthorectified imagery, elevation data (including bathymetry), cultural features and boundaries, geographic names, and land-cover data. The strategy proposed for assembly of this database is to use a combination of existing data together with data provided through partnerships with federal, state, and local agencies; the private sector; academia; libraries; and the public. A major incentive for this proposal was the need to update the aging USGS paper map coverage. In many ways the USGS concept for the National Map has much in common with this committee's vision for easy access to data derived from multiple sources and available from a single Web site. A recent review of the USGS plans for the National Map (NRC 2003b) applauded the National Map vision, describing it as ambitious, challenging, and worthwhile, but also noted that there was little new in the USGS proposal and that the biggest challenges that will need to be overcome are not scientific or technical, but rather institutional and cultural. This committee considers that incorporating offshore geospatial data will present additional challenges related to the technical issues involved with including bathymetric elevation data (as described in detail above), and to the significant institutional challenges involved with assuming some degree of responsibility for the completeness, consistency, and accuracy of data elements that are the mandated responsibility of other federal agencies. The acknowledgment in the National Map implementation plan of the importance of partnerships is a gratifying recognition of the need for extensive interagency collaboration among all agencies involved.

Formal coordination of geospatial data collection and analysis efforts

Coordination of coastal zone mapping activities among all the primary agencies involved in coastal zone mapping must be through a mechanism that has the means to monitor and ensure compliance. Structurally, the FGDC seems to be the appropriate body to oversee such coordination, although this committee has concerns about the effectiveness of current FGDC initiatives (see below). Either a restructured and empowered FGDC Marine and Coastal Spatial Data Subcommittee or a subcontract to an independent third party (e.g., the National Ocean Partnership Program [NOPP]) could serve in this role. Irrespective of whether the FGDC subcommittee or a third party plays this role, there will be the need for a dedicated staff member to locate and mine databases and reports, and to establish a Web-based focal point for agency activities.

Joint Offices for Thematic Coordination

In the 1980s and 1990s, NOAA and USGS supported a joint office for Exclusive Economic Zone (EEZ) mapping to coordinate the activities of the two agencies and reduce inefficiencies and overlap in costly ocean mapping activities. Using the same rationale, this committee recommends that similar office(s) be established that would house one (Full-time Equivalent) FTE from each of the representative agencies. The mission of such office(s) would be to reduce programmatic, budgetary, and operational overlap by identifying potential or existing areas of duplication as well as opportunities for joint ventures, and then to coordinate the development of joint plans, schedules, and budget initiatives. Existing needs for such coordination in coastal mapping and charting thematic areas would include federal activities in:

- Source data collection: topographic and bathymetric data acquisition (USGS, NOAA, USACE);
- National blended topographic/bathymetric Digital Elevation Models/Digital Depth Models (National Geospatial-Intelligence Agency, NOAA, USGS);
- Derived products for shoreline mapping and coastal erosion hazards (USGS, NOAA, FEMA, USACE).

Specific Target Areas

It is clear from the above examples that significant synergy and cost effectiveness could be achieved if multiple agencies shared resources, data, and tools for endeavors that are similar or, in some cases, even identical. We have suggested mechanisms to help ensure high levels of collaboration and cooperation—we now suggest specific target areas where enhanced cooperation and collaboration are essential:

- *Data acquisition.* There should be an initial focus on coordinating data collection efforts at the land-water interface. Efforts should be made to maximize the types of data acquired using at least topographic LIDAR at low tide and, if possible, bathymetric LIDAR for shallow nearshore waters. Consideration should also be given to collecting multispectral and hyperspectral data and aerial and satellite imagery, to maximize the area of geographic coverage. In addition, planning should begin for a coordinated, interagency, high-resolution shoreline mapping program to establish a baseline condition for periodic resurveys in order to quantify shoreline change rates. These activities should involve FEMA, NASA, NOAA, USACE, and USGS.
- *Derived products.* A number of assessment efforts are underway that could benefit greatly from new or closer coordination through both formal and informal mechanisms involving *at least* the agencies indicated in the following points.
  —Shoreline change maps, to involve the Bureau of Land Management, FEMA, NOAA, USACE, and USGS.
  —Habitat change maps, to involve EPA, FWS, NOAA Fisheries, NOAA-NOS, and USGS.
  —Hazard vulnerability assessments, to involve FEMA, NOAA, and USGS.

—Modeling of coastal inundation, to involve FEMA, NOAA, USACE, and USGS.

• *Improved data exchange and transfer between federal, state, and local agencies,* including improved dissemination of shoreline data via the Internet. FGDC should take a stronger role in supporting these community-based efforts (see Chapter 5).

• *Research and development to investigate new technologies for shoreline mapping,* (e.g., by using LIDAR). Here, NASA's continued support for development of remote sensing and an increased emphasis by the National Science Foundation (NSF) and NOPP on coastal needs would go a long way toward improving the nation's nearshore and coastal mapping capabilities. The private sector has also been a leader in innovation in this area.

Finally, we cannot ignore the fact that the extraordinarily large population base that depends on the coastal zone can also be a powerful political force. User-driven requests to Congress and to individual agencies from the Coastal States Organization, the Coastal Zone Management Program, and other state and local entities that would benefit from more efficient and standardized federal efforts are an important element of any successful mapping and charting support and coordination strategy. Expanded educational efforts stressing the value and utility of partnered federal and federal/state efforts could be an effective way for the agencies to sensitize Congress and users to the need for additional resources.

7

Conclusions and Recommendations

This report describes the major coastal zone spatial information requirements of federal agencies and the user groups they support, identifies high-priority needs, evaluates the potential for meeting those needs, and suggests steps to increase collaboration and ensure that the need for spatial information in the coastal zone is met in an efficient and timely manner. Information was gathered through a review of relevant literature and through interviews, presentations, and written submissions from a broad range of agency personnel, user groups, and other individuals working in the coastal zone. Due to the huge scope of coastal mapping activities throughout the nation, it is possible that some issues have been overlooked. Nonetheless, we are confident that the major needs and activities of those involved in coastal mapping and charting in the United States are included, making it possible to identify gaps, overlaps, and major issues. The consistency and commonality of the needs expressed and issues raised allowed the committee to develop a vision for the future of U.S. coastal zone mapping and charting, and to make targeted recommendations for achieving that vision.

COMMON NEEDS

While the range of coastal zone mapping and charting applications is as varied and diverse as the user community, there is a striking commonality to certain elements of the community's needs, encompassing:

- A consistent spatial framework for coastal data that allows a seamless transition from onshore to offshore, including clarification of offshore boundary definitions and a framework to allow consistent shoreline definitions;

- Increased collection and availability of primary reference frame and thematic data, including shallow-water bathymetry, acoustic and satellite imagery of the seafloor, bottom type, habitat distribution and classification standards, land use, land cover, and coastal change data.
- Easy access to up-to-date digital, geospatial data, imagery, and mapping products;
- Compatibility among data formats, or standards and transformation protocols that allow easy data exchange, and a means to evaluate the accuracy of geospatial data; and
- Increased inter- and intra-agency communication, cooperation, and coordination.

Addressing these critical issues, which are described in more detail below, will provide the basic reference frame, source data, and tools necessary to create the wide range of derivative products needed to efficiently and effectively manage the coastal zone.

A Consistent Spatial Framework

Any discussion of the coastal zone must acknowledge the unique aspects of this dynamic region. Coastal zone data collection and mapping present a special challenge because most coastal processes are both continuous across the land-sea interface and are subject to constant natural and anthropogenic change. The historical divisions between topographic mapping techniques onshore and bathymetric charting approaches offshore, and the fundamentally different vertical reference frames used, have resulted in a serious incompatibility between existing maps and charts. In particular, offshore features must be measured with respect to the constantly changing tide level, adding considerable complexity to coastal zone mapping and creating enormous difficulties in seamlessly merging onshore and offshore data. A multiplicity of tidal datums, and their dynamic nature, has produced ambiguity in the definition of the shoreline, creating considerable confusion and difficulty in integrating coastal zone studies and management. Additionally, the ever-shifting land-water interface poses significant logistical challenges for mapping. Shallow water, waves, turbidity, and longshore currents all contribute to the difficulty of operating vessels and equipment accurately and safely. These issues are all reflected in the unified call from the user community for a consistent spatial framework that allows a seamless transition from onshore to offshore.

Primary Reference Frame and Thematic Data

A strong common thread was also found in the specific types of data needed. By far the greatest demand is for bathymetric data, to provide the fundamental geospatial framework to which all other offshore data can be linked. Bathymetric data in the shallowest regions of the coastal zone, where logistical challenges make data collection more difficult, are essential to provide the "missing link" between onshore topographic data and more easily collected deeper bathymetric data. Derivative needs that were highlighted by the community include bottom type, human-use, land-cover, and time-series data describing coastal change. Acoustic and satellite imagery of the seafloor and onshore coastal zone would be particularly useful for understanding bottom types and habitat. The value of each of these derivative datasets would be greatly enhanced if referenced to a continuous, seamless, onshore/offshore geospatial framework.

Access to Data and Products

The second most common need expressed by the user community was the desire for easy access to up-to-date, digital coastal geospatial data, images, and maps. The range of data collection activities related to coastal geospatial data collection is staggering. Although some of these data remain buried within the organizations that collected them, much is becoming accessible through Web sites that allow public access to some or all of the data. There is not yet, however, a single Web portal to access coastal zone data. A search for all available data from a given region can be a costly, frustrating, or even an impossible task. Whatever mechanism is established for better data distribution, the dynamic nature of coastal processes requires that the data be updated regularly and made available in a very timely manner.

Data Compatibility and Accuracy

In order for the accessed data to be most useful, data collected by different organizations at different times and using different sensors must be in forms that allow easy exchange and integration. The user community must also have a way to evaluate the accuracy of the data it accesses. This means that standards must be established, metadata provided, and tools developed for data transformation and data fusion.

Agency Communication, Cooperation, and Coordination

There is widespread demand by the user community for increased inter- and intra-agency communication, cooperation, and coordination of coastal mapping activities. Particularly in the area of data acquisition, which is the most costly aspect of mapping in the coastal zone, redundancy and lack of communication appear to exist. Of particular concern were the large number of shoreline and habitat mapping efforts being undertaken by different agencies and by different offices within agencies. Some overlap might be expected, given the large number of organizations involved, the varied histories and mandates of these organizations, the complex definitions of shoreline and habitat, and the many other difficult issues facing those working in the coastal zone. Although not surprising, it is unquestionably inefficient and often counterproductive. In contrast, there are also a number of examples where laudable cooperation and collaboration among agencies have been achieved. Examples of such collaborative efforts include the National Oceanic and Atmospheric Administration (NOAA) and U.S. Geological Survey (USGS) Bathy/Topo/Shoreline Demonstration Project, NOAA-Office of Coast Survey (OCS)/USGS efforts to maximize survey value by collecting data relevant to both organizations on a single cruise, USGS/National Park Service (NPS) collaborative mapping programs, the Environmental Protection Agency's (EPA) collaboration with NOAA, USGS, Fish and Wildlife Service (FWS), and a number of state agencies to determine national water quality conditions, and numerous NOAA-Coastal Services Center (CSC) initiatives with respect to standards and data distribution. These positive examples are often the result of fortuitous information exchanges between the right people at the right moment. To build on these successes, mechanisms are required to promote full information exchange and make collaboration and cooperation the rule rather than the exception.

A VISION FOR THE FUTURE

The commonality of the issues raised and the needs expressed forms the basis for a vision for the future of coastal zone mapping and charting. This vision requires the development of an integrated and coordinated coastal mapping strategy for the nation, based on a foundation—a reference frame—on which all data collection, analyses, and products can be built. To establish this foundation, there must be a national effort to collect the information and develop the tools necessary to seamlessly blend topographic (onshore) and bathymetric (offshore) data. These data and tools will permit the establishment of a nationally coordinated digital database across the land-sea interface consisting of seamless elevation and depth data that can be referenced or transformed to common vertical and horizontal datums.

This database will provide the basic geospatial framework for all subsequent data products, much like the USGS topographic sheet basemaps have formed the foundation for a multitude of subsequent studies. Unlike the USGS topographic sheets, however, a coastal zone database must take account of tidal variation and be able to reconcile the differences between land and offshore datums.

The committee's vision for the future of coastal zone mapping and charting also includes mechanisms to ensure communication among all agencies and entities involved in order to minimize redundancy of efforts and maximize operational efficiencies. There will be national—and perhaps international—standards and protocols for data collection and metadata creation and readily available tools for data transformation and integration. With these tools the user community will be able to evaluate the accuracy and timeliness of data, change scales and projections, and seamlessly merge disparate datasets. The database and data integration tools will be easily accessible to all users, public and private, from a single digital portal accessible through the Internet.

This is a bold vision but at the same time an obvious one. Who would argue with a system that is efficient and produces easily accessible, fully interchangeable, accurate, and timely data? The vision may be simple to define, but its implementation will be anything but simple. The recommendations that follow are intended to address the root causes of the existing problems, help overcome the barriers to their solution, and begin to turn this vision into reality.

RECOMMENDATIONS

A Seamless Bathymetric/Topographic Dataset for All U.S. Coastal Regions

One of the most serious impediments to coastal zone management is the inability to produce accurate maps and charts so that objects and processes can be seamlessly tracked across the land-water interface. Differences between agency missions, onshore topographic versus offshore bathymetric mapping techniques, differing vertical reference frames, and the inherent difficulty of collecting source data in the surf and intertidal zones have combined to produce this fundamental incompatibility. It will be impossible to properly understand processes, undertake planning, and establish boundaries in the coastal zone while two sets of disparate and non-convergent maps and charts are being separately maintained.

The barrier to the production of continuous integrated mapping products across the land-sea interface is the inherent difference in the horizontal and vertical reference surfaces (datums) and projections used for maps and charts. Horizontal datum and projection issues can be readily resolved with existing transformation tools, although these tools must be made more readily available to the user community. However, vertical datum issues present a serious challenge. In order to seamlessly combine offshore and onshore data, vertical datum transformation models must be developed. These models depend on the establishment and maintenance of a series of real-time tidal measuring stations, the development of hydrodynamic models for coastal areas around the nation, and the development of protocols and tools for merging bathymetric and topographic datasets.

The Tampa Bay Bathy/Topo/Shoreline Demonstration Project, a collaborative effort between NOAA and the USGS, has developed a suite of such tools (called Vdatum) and has demonstrated the feasibility of generating a seamless bathymetric/topographic dataset for the Tampa Bay area. This project has also demonstrated both the inherent complexity of such an undertaking and the substantial benefits that arise from interagency collaboration and coordination.

Recommendation 1: In order to combine onshore and offshore data in a seamless geodetic framework, a national project to apply Vdatum tools should be initiated. This will involve the collection of real-time tide data and the development of more sophisticated hydrodynamic models for the entire U.S. coastline, as well as the establishment of protocols and tools for merging bathymetric and topographic datasets.

This dataset must be documented and disseminated in such a way that it can become the base for a wide range of applications, including the definition of local, regional, or national shorelines. As a result of this effort, it will be possible to merge data collected either on land or offshore into a common geodetic reference frame, while at the same time allowing application-specific maps and charts to be generated that maintain traditional tidal-based datums (e.g., for navigational charts) or orthometrically based datums (e.g., for topographical maps).

Shoreline Definition Protocols

Numerous agencies have identified the lack of a consistently defined national shoreline as a major barrier to informed decision making in the coastal zone. While a consistent shoreline is certainly desirable, many different definitions of the shoreline remain embedded in local, state, and federal laws, making it impractical to call for a single "National Shoreline." Rather, the key to achieving a consistent shoreline is the seamless geodetic framework referred to in Recommendation 1. With a seamless bathymetric/topographic dataset across the land-water interface, appropriate difference or tidal models, and consistent horizontal and vertical reference frames, any shoreline definition can be transformed and integrated within the common framework. The Vdatum tool kit and associated Web sites will be the key to establishing internally consistent shorelines between and among disparate surveys and studies.

Recommendation 2: To achieve national consistency, all parties should define their shorelines in terms of a tidal datum, allowing vertical shifts to be calculated between and among the various shoreline definitions, while at the same time permitting different agencies and users to maintain their existing legal shoreline definitions. In situations where legislation or usage does not preclude it, the committee recommends that the internationally recognized shoreline established by NOAA's National Geodetic Survey be adopted.

The committee encourages the Federal Geographic Data Committee's (FGDC) Marine and Coastal Spatial Data Subcommittee to pursue implementation of this recommendation.

Easy Access to Timely Data

Easy access to timely data is an essential component of effective coastal zone management. Many agencies have created Web sites that offer access to data in a variety of forms as well as data manipulation tools. However, these sites still represent only a small percentage of existing coastal zone data.

Recommendation 3: A single Web portal should be established to facilitate access to all coastal mapping and charting data and derived products. The site should be well advertised within federal and state agencies, state and local governments, academic institutions, nongovernmental organizations and conservation groups, and to other potential users. The portal should work well with all Web browsers and on all computer platforms, to make it easily accessible to all users.

The single portal is not intended to host all coastal data. Rather, it should serve as a focal point that links to many distributed databases maintained by individual agencies or organizations. This site would represent the one place where users, particularly new users, could begin their search for coastal data and derived products. A single, easily accessible data portal with appropriate data manipulation tools should also promote the timely entry and retrieval of data. Coordination of such a site logically falls under the purview of the FGDC, and is fully consistent with the Geospatial One-Stop concept.

Data Integration, Interchangeability, and Accuracy

Providing easy access to data through a single Web portal is a critical starting point for addressing the needs of the coastal zone community. However, users must also be able to combine and integrate data collected by different agencies using a range of sensors and often based on different datums or projections. Users must also be able to assess the attributes and accuracy of the data provided. Integration of data and assessment of data quality are made possible by the establishment of data and metadata standards and the application of tools for data transformation.

Recommendation 4: All thematic data and other value-added products should adhere to predetermined standards to make them universally accessible and transferable through a central Web portal. All sources should supply digital data accompanied by appropriate metadata.

The FGDC is in the process of establishing a series of standards for the National Spatial Data Infrastructure (NSDI) that will be applicable to all coastal zone data. Unfortunately, implementation of the NSDI continues to be problematic for the coastal/marine community due to highly variable levels of commitment by different agencies and insufficient incentives to fully implement its principles. This may, in part, be due to the structural and budgetary barriers discussed in Chapter 6, the inability of a single set of standards to serve all applications, and disconnects between those developing the standards and the user community. One approach to addressing this issue is for additional involvement by the private sector.

Recommendation 5: The private sector should be more involved in developing and applying data standards and products. Agency procurement requirements can be used to encourage the private sector to deliver needed products in a timely fashion.

The committee is aware of numerous examples where private-sector initiatives established well-accepted and easily used data protocols—in effect de facto standards—that significantly enhance the effectiveness of data products. The private sector is often capable of greater speed and efficiency in the adoption of standards and tools than its government agency counterparts. Access to data, metadata, and data standards must be complemented by readily available tools to easily convert between and among different data formats, scales, and projections.

Recommendation 6: Government agencies and the private sector should continue to develop tool kits for coastal data transformation and integration. This will facilitate data analyses and the production of a range of value-added products. The tools should be accessible through the Web portal.

Documentation of the tools and techniques used to process data must also be provided to help the user community understand the limitations and appropriate uses of various datasets. A variety of training courses and workshops will be essential to provide end-users with the knowledge and tools necessary for intelligent application of the available data.

Improved Coordination and Collaboration

Any activity that involves multiple federal, state, and local agencies, academic researchers, and the private sector has the potential for redundancy and overlap of effort. This is amplified when the activity requires expensive platforms, technologies, and sensors. In the area of coastal zone mapping and charting, the large number of agencies involved, their differing histories, the breadth of their mandates, and the complexity of the task offer ample opportunities for redundancy and inefficiency. Because data acquisition is unquestionably the most expensive aspect of coastal zone mapping, elimination of redundancy and overlap in this area is likely to yield large savings. Ensuring that all relevant agencies are aware of one another's activities will be an important first step toward improved coordination.

Recommendation 7: All federally funded coastal zone mapping and charting activities should be registered at a common, publicly available Web site. This combined registry should be accessible through the single Web portal for coastal zone information.

Each entry in the registry should include a description of the mapping activity, its location and purpose, the agency collecting the data, the tools to be used, the scales at which data will be collected, and other relevant details. Non-federally funded agencies conducting coastal mapping activities should be encouraged to register their activities at the same site. A section of the registry should be dedicated to descriptions of planned but unfunded coastal mapping activities, as well as a prioritized compilation of coastal areas where surveying would be particularly helpful to state or local agencies. Technically, components of such registration may already be required under Office of Management and Budget (OMB) Exhibit 300, but Recommendation 7 suggests a considerably expanded effort focused on making all federally funded coastal zone mapping efforts more widely known.

Once implemented, this registry could serve as the focal point for national coordination of geospatial data collection and analysis efforts. Individual agencies would continue to set their own priorities, but through the registry process any overlapping efforts could be quickly identified and avoided. The registry would also facilitate increased efficiency by highlighting opportunities for "incremental" surveys, where one agency takes advantage of the mapping activities of another agency in a region of common interest by providing a small amount of additional funding to achieve an additional objective. Such "piggyback" collaborative efforts would allow additional agencies to acquire data that meet their needs at minimal incremental cost.

Recommendation 8: To be effective, coordination should be carried out among all the primary agencies involved in coastal zone mapping; it should be mediated by a body that has the authority and means to monitor and ensure compliance; and it should involve people who are knowledgeable enough to identify the most critical issues.

Structurally, the FGDC appears to be an appropriate body to oversee such coordination, but many concerns remain about its effectiveness. Some restructuring of FGDC, and perhaps an empowered Marine and Coastal Spatial Data Subcommittee, will be required to allay these concerns. In this light the committee endorses the recommendations of a recent design study team that calls for major structural and management changes for the FGDC (FGDC, 2000). A less appealing alternative might be either a new government office or an extra-governmental body charged with establishing oversight of all national coastal mapping and charting activities.

Recommendation 9: Whichever body is charged to carry out the needed coordination activities, dedicated staff personnel should be assigned to maintain the Web portal (Recommendation 3), the activities registry (Recommendation 7), and associated Web sites, and to proactively search for areas where efforts can be coordinated, supplemented, or combined to increase efficiency.

Specific areas where better coordination among federal agencies is urgently needed (with the agencies likely to be involved listed in parentheses) include the following:

- High-resolution topographic and bathymetric data acquisition at the land-water interface, including aerial and satellite imagery, Light Detection and Ranging (LIDAR) surveys, and bathymetric surveys (Federal Emergency Management Agency [FEMA], National Aeronautics and Space Administration [NASA], NOAA, U.S. Army Corps of Engineers [USACE], and USGS).
- National seamless topographic/bathymetric Digital Elevation Models/Digital Depth Models (National Geospatial-Intelligence Agency [NGA], NOAA, and USGS).
- Derived products for mapping *shoreline change* (Bureau of Land Management [BLM], FEMA, NOAA, USACE, and USGS), *habitat change* (EPA, FWS, NOAA Fisheries, NOAA-National Ocean Service, and USGS), *hazard vulnerability* (FEMA, NOAA, and USGS), and *coastal inundation and erosion hazards* (FEMA, NOAA, USACE, and USGS).

Increased Data Collection

There is a widespread need for more and better data to be collected in the coastal zone. Growing pressure from a variety of constituencies (e.g., fisheries, shipping and navigation, Law of the Sea implementers, resource managers) will lead to ever-greater demands for useful information. The single most consistently cited need among the agencies and the user community is for enhanced bathymetric data, particularly in very shallow coastal waters. These data provide the basic geospatial framework for almost all other studies and are a key component for derived products such as offshore habitat maps.

> **Recommendation 10: The fundamental reference frame data for the entire coastal zone should be collected, processed, and made available. The dynamic nature of the coastal zone requires that there should be specific plans for repeat surveys over time. The important role of qualified private survey contractors in coastal zone mapping and charting should also be acknowledged. Much of the work done by this sector is contracted by government agencies, and accordingly the prioritization and tracking of surveys can be coordinated by the body called for in Recommendation 8.**

Given the number of agencies and private-sector companies involved in coastal mapping, and their disparate missions and budget directives, it is unrealistic to expect agreement on a single, unified and prioritized national mapping initiative. While each agency has responsibility for its own mapping priorities, a strong and enforceable mechanism for tracking and coordinating existing, ongoing, and planned mapping efforts (as outlined in Recommendation 7) would increase efficiency to the point where considerably more survey work could be carried out for each dollar spent. Inconsistencies in scale and resolution for new data collection efforts could be resolved by the coastal zone coordinating body called for in Recommendation 8. After surveying agency needs, the coordinating body could determine whether the incremental value of collecting data over a larger area or in a slightly different form (e.g., at higher resolution) warrants modification of a planned surveying effort.

Severe challenges remain for those attempting to map the coastal zone. As well as the fundamental conceptual problem of reconciling terrestrial and tidal datums, there are also a number of logistical challenges, including shallow depths, waves, turbid waters, and longshore currents, that make it difficult to operate survey vessels and other equipment safely, accurately, and efficiently.

Recommendation 11: New remote sensing and in situ technologies and techniques should be developed to help fill critical data gaps at the land-water interface.

There are a number of promising new technologies and techniques:

- Integrated bathymetric/topographic LIDAR, multispectral, hyperspectral, and photographic imaging systems;
- Sensors deployed on autonomous underwater vehicles;
- "Opportunistic" mapping using volunteer recreational boats equipped with specialized mapping sensors approved by issuing agencies;
- Autonomous bottom-crawling vehicles;
- Improved satellite imaging capabilities; and
- Data fusion capabilities.

Continued support from funding agencies for development of coastal remote sensing tools, combined with an increased emphasis on coastal needs, will greatly accelerate the development and implementation of these critically needed technologies. The private sector can play a major role in addressing this recommendation.

Underestimation of the importance of the coastal zone threatens the well-being of the nation, and those charged with management and maintenance of this critical environment carry tremendous demands and responsibilities. In order to understand and address the effects of complex natural and anthropogenic forces in the coastal zone, a holistic multidisciplinary framework must be developed to account for the interconnectivity of processes within the system. At the base of this framework is accurate geospatial information about the locations of important features and processes, both onshore and offshore. The recommendations and strategies outlined above call for the establishment of a consistent geospatial framework and the application of innovative new acquisition, integration, and data management technologies that should allow coastal zone scientists, engineers, and managers to efficiently produce easily accessible, fully interchangeable, accurate, timely, and useful geospatial data and mapping products that seamlessly extend across the coastal zone. The recommendations also suggest simple mechanisms to enhance collaboration and cooperation among those charged with acquiring data in this complex region. These mechanisms should facilitate efficiency gains that will allow most of the nation's coastal zone to be mapped in a timely manner. While simple in concept, implementation of the suggested strategies will require a focused effort on the part of the coastal zone community. If implemented, however, the committee believes that a major step will have been taken toward assuring the long-term well-being of the coastal zone.

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APPENDIXES

Appendix A

Agency Needs and Activities

Summary of the unfulfilled needs and activities identified by those agencies and entities charged with assessment and mapping of coastal areas, and/or the production of coastal mapping data and products.

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Department of Commerce National Oceanic and Atmospheric Administration National Environmental Satellite, Data and Information Service (NESDIS)		
NESDIS	• Nationally consistent ` shoreline definition	• Data from environmental buoys • Wetland characterization • Harmful Algal Bloom (HAB) Observing System • Satellite-based environmental remote sensing systems for environmental data • Coastal Relief Model • Bathymetric and geophysical datasets • Real-time meteorological data • Oceanographic data • Tsunami data

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
NESDIS National Coastal Data Development Center	• Access to restricted data and widely distributed coastal data sources • Adequate metadata • Consistent boundary definitions • Consistent data and mapping standards	• Development of data transformation tools to facilitate generation of value-added products • Provides archive of, and access to, long-term coastal datasets
Department of Commerce National Oceanic and Atmospheric Administration NOAA Fisheries (formerly National Marine Fisheries Service)		
NOAA Fisheries	• Definition of habitat classifications • Species use of habitat	• Habitat maps for managing Essential Fish Habitat (e.g., coral reefs, hard bottom, Submerged Aquatic Vegetation [SAV]) • Collection of multibeam bathymetric data
Department of Commerce National Oceanic and Atmospheric Administration Office of Ocean and Atmospheric Research (OAR)		
OAR Ocean Exploration Program	• Maps of the nation's entire Exclusive Economic Zone (EEZ), encompassing physical, biological, chemical, archeological, and geological characteristics	• Maps of more than 3,200 square miles of largely offshore areas of the EEZ using high-resolution multibeam technology
OAR National Undersea Research Program	• Continuous-coverage seafloor topographic and backscatter map products at regional and local spatial scales • Multibeam and sidescan sonar mosaic capabilities for small spatial scale (e.g., 1-km × 1-km) mapping to assess dynamics of seafloor features • A standard hierarchical descriptive matrix for classification of sedimentological and biological attributes of seafloor habitats	• A geo-referenced database of underwater imagery for seafloor characterization • Time-series observations of seafloor attributes at sites with ocean-observing system installations

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Department of Commerce **National Oceanic and Atmospheric Administration** **National Ocean Service (NOS)**		
NOS Center for Operational Oceanographic Products and Services	• Improved VDatum transformation tools and use of kinematic global positioning systems (GPSs) in all operations • Expanded network of tidal stations	• Collects and distributes tide and water-level predictions, observations, reference datums, and tidal zoning to support nautical charting and shoreline mapping
NOS Coastal Services Center (CSC)	• Shorelines and elevations that are nationally consistent • Uniform standards for coastal mapping • Access to restricted data • Timely data delivery in readily accessible formats • Consistent metadata and standards for coastal information and maps • Seamless bathy/topo coverage • Environmental Sensitivity Index mapping nationwide • Essential Fish Habitat mapping	• Coastal remote sensing • Coastal change analysis • Land-cover mapping • HAB forecasting • Geospatial data and application development • Environmental characterizations • Watershed modeling • Fish and vulnerability assessments of coastal hazards • High-accuracy coastal topography • Digital shoreline • Geospatial training courses • Coastal metadata tools and training • Data and information access tools • NOS Enterprise GIS Initiative
NOS National Centers for Coastal Ocean Science	• Data available on Internet • Consistent standards and data interchange • Access to non-federal databases • Consistent horizontal datums • Consistent collection and display standards and protocols for land-sea data • Ship time in remote areas	• Shallow-water benthic habitat mapping • Estimating bathymetry in clear shallow water using satellite imagery • Coral reef habitat maps • Models of habitat/species associations

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
NOS National Geodetic Survey	• Web-based shoreline data dissemination • Improved data exchange between federal/state/local agencies • Updated shorelines for 1,200 nautical charts • New technologies for shoreline mapping • Improved hydrodynamic models and tidal zoning	• National Spatial Reference System • Seamless digital database of the national shoreline • Tidal datums • Aerial photographs • Geodetic Tool Kit
NOS National Marine Sanctuary Program	• Detailed high-resolution bathymetry in marine sanctuaries • Biogeographic information for key areas • Adequate jurisdictional boundary definitions • Seamless bathy/topo integration	• Ensure that each National Marine Sanctuary is accurately characterized (benthic habitat, bathymetry, shoreline, etc.) • Publication of a shipwreck database • Accurate delineation of sanctuary and adjacent park boundaries
NOS Office of Coast Survey	• Nationally consistent shoreline definition • Efficient techniques for shallow-water bathymetry • Seamless vertical datum	• Nautical charts • Water depth, bottom characteristics, historical data of bathymetry and shoreline • Blended bathymetry/ topography, including digital elevation models and consistent "shorelines" for coastal managers
NOS Office of Ocean and Coastal Resource Management	• Standardized blended high-resolution bathymetric-topographic digital elevation models and maps • Within New England Estuarine Research Society single-habitat classification scheme for coastal zone	• Administers National Estuarine Research Reserves and state Coastal Zone Management Programs • Hydrodynamic analyses, shoreline erosion, nearshore habitat characterization maps • Risk analyses for sea level rise
NOS Office of Response and Restoration	• Reconnaissance aerial photography • Bathymetry • TopoLIDAR	• Environmental Sensitivity Maps • Identification and inventory of abandoned and submerged vessels and their environmental consequences • Assist resource managers in understanding the extent and nature of the threats posed by abandoned vessels

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
NOS Special Products Office	• Nationally consistent standards for metadata, data content, and models • National synoptic coastal mapping capability • Datasets for a foundation (bathymetry, topography) and core socioeconomic information (demographics, land use) for national and regional-scale assessments of coastal change	• NOS Mapfinder Web site • NOAA Enterprise GIS • Inventory of marine managed areas • Coastal Assessment Framework • Digital Atlas of West Coast Living Marine Resources
Department of Defense **U.S. Army Corps of Engineers (USACE)**		
USACE	• Nationally consistent shoreline definition • Better access to time-sensitive data • Lower cost for data acquisition • Standard formats for GIS • Consistent standards for content, metadata, transfer, collection, accuracy, improved data use, models, and tools • Blended bathymetric/topographic maps • Engineering products from remotely sensed data	• Topographic Light Detection and Ranging (LIDAR) and multispectral imagers • LIDAR bathymetric systems—SHOALS • National Shoreline Management Study to determine extent and causes of shoreline change • Regional sediment management GIS • Wave and surge modeling • Harbor and waterways projects, including hydrographic surveys and dredging

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Department of Defense **National Geospatial-Intelligence Agency (NGA) (formerly National Imagery and Mapping Agency)**		
NGA	• Legal resolution to allow distribution of worldwide Digital Nautical Chart • Free exchange of coastal geospatial information • International standards • Consistent boundary definitions • Global real-time tidal observations • Hydrodynamic models • Vertical datum and transformations • Long-term and seasonal changes in shoreline • More accurate data on tides and tidal currents • Accurate definition of coastal geoid	• Charts non-U.S. waters, including Digital Nautical Charts
Department of Defense **Oceanographer of the Navy**		
Oceanographer of the Navy	• Locational definition of the EEZ • Surveys of ports • Charts for the coastal Artic • Ocean observations • Integrated bathy/topo data • Consistent international standards	• Outside U.S. waters, collects bathymetry from acoustic and LIDAR, ocean temperature, color, currents, tide heights • Maps of integrated hydrographic and oceanographic parameters
Department of Defense **Office of Naval Research (ONR)**		
ONR	• Consistent international standards in data management • Ocean observations	• Improvements in data collection, processing, and display • Improvements in understanding of coastal processes (tides, waves, sedimentation, water properties)

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Department of the Interior Bureau of Land Management (BLM)		
BLM	• Nationally consistent shoreline definition • Resurvey using modern equipment	• Primarily onshore databases • Waterfowl, shorebirds, and fisheries management
Department of the Interior U.S. Fish and Wildlife Service (FWS)		
FWS	• Habitat maps for coastal ecosystems	• Maps of Coastal Barrier Resources System • Species Information System
Department of the Interior Minerals Management Service (MMS)		
MMS	• Nationally consistent interpretation of shoreline • Consistent baseline for states • Nationally consistent mapping products • Consistent standards and formats	• Offshore cadastral maps • Marine boundary maps • OCS leasing maps primarily in oil and gas leasing areas

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Department of the Interior National Park Service (NPS)		
NPS	• Nationally consistent shoreline definition • Benthic habitat characterization (coral reefs, SAV) • Shoreline change rates • Threats to natural and cultural resources • Estuaries/wetlands mapping • Anthropogenic alterations • Seamless topo/bathy maps • Sediment pathways and transport • Shoreline change rates • Island mapping and geologic framework • Forecast and hindcast shoreline configuration • Anthropogenic alterations • Climate change impacts • Vulnerability indices • Base mapping (bathymetry, backscatter) • Subsidence modeling (e.g., USS *Arizona* settling) • Critical mapping units identified for submerged, anthropogenic, coastal-riverine, intertidal, subtidal	• Baseline geologic data for parks • Submerged resources center for archeological projects • Shoreline change monitoring • Vulnerability maps for parks • Survey, identification, inventory, evaluation, protection, and preservation of cultural resources
Department of the Interior U.S. Geological Survey (USGS)		
USGS Biology Discipline	• Better benthic habitat characterization of natural and artificial reefs • Mapping of risks to resources in hazard-prone areas	• Coral reef maps • Benthic habitat maps • Physical habitat maps • Nursery and coastal foraging habitat of fishes, birds, and mammals • Coastal erosion GIS • Storm, coastal erosion, and sea level rise impacts on living resources • Modeling of ecosystem response to coastal disturbance

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
USGS Geology Discipline	• Nationally consistent shoreline definition • Nationwide compilation of reliable shoreline data • Standardized methods for tracking shoreline position over time • Consistent vertical datum • Consistent GIS data standards	• Nearshore and terrestrial geologic maps • National Assessment of Shoreline Change • Bathymetric and coastal hydrodynamics maps • Surficial geology/benthic habitat maps • SHOALS LIDAR mapping • Coral reef mapping • Surficial and sub-bottom geologic mapping for hazards and resource assessments • National and regional coastal hazards vulnerability assessments
USGS Geography Discipline	• Higher resolution of basic geographic information • Consistent scales, update cycles, data classifications, data models, data formats, metadata • Online access to geospatial data and products	• "The National Map," including surface elevation data, bathymetry, hydrology, land cover • Coastal erosion GIS
USGS Water Discipline	• Accessible archive of remote sensing data and products • Time-sensitive storm surges and floods data	• Bathymetry of estuaries • Submerged aquatic vegetation • Remotely sensed water quality data • Real-time and retrospective coastal flooding data and flood hazard assessment, including flood modeling
Department of State		
Office of Ocean Affairs	• Boundary definition of continental shelf • Continental shelf bathymetry and sediment data, especially in the Arctic • Consistent shoreline definition	• *Limits of the Seas* series, reporting on national ocean claims

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Department of Homeland Security Federal Emergency Management Agency (FEMA)		
FEMA	• Nationally consistent shoreline definition • Blended bathymetric/ topographic maps • Wave and flood models • Comprehensive climate and storm data	• Storm surge models, including bathymetry, topography • Environmentally sensitive areas • Coastal erosion maps • Earthquake, flood, and wind hazard maps • Coastal community vulnerability assessments
Department of Homeland Security U.S. Coast Guard (USCG)		
USCG	• High-resolution imagery and bathymetry to support homeland security • Coastal circulation models	• Positions of Aids to Navigation • Updates of navigation charts • Aids to Navigation Information System
U.S. Environmental Protection Agency (EPA)		
EPA Office of Water, Office of Research and Development, Office of Air and Radiation	• Location accuracy of data points from various sources • Timely access to data sources (water quality, sediment chemistry) from other agencies or academic sources • Compatibility between data formats (scale, projections) • Adequate storage and hardware • National consistency for airshed and watershed maps	• Monitoring and assessment activities to support water quality, safe drinking water, marine debris, watershed modeling, HAB mapping • Environmapper for Water • National Environmental Information Exchange Network
National Aeronautics and Space Administration (NASA)		
NASA	• Long-term geodetically controlled tide gauge system • Ability to separate different components of sea level change	• Coral reef mapping • Geodetic imaging, digital data online • Global maps of water quality parameters • Technology development for coastal hazards development

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
National Science Foundation (NSF)		
NSF	• Centralized online metadata catalog • Quality control of data • User-friendly Web-based tools for searching and accessing data • Standard digital forms for reporting data	• Marine environmental data collected by principal investigators must be deposited in a designated national data center no later than 2 years after being collected
Office of Management and Budget Federal Geographic Data Committee (FGDC)		
FGDC	• Improved interagency coordination • Improved collaboration and minimization of duplication between agencies • Increased progress on FGDC Framework • Increased acceptance of FGDC standards and protocols • Quicker approval of spatial data collection and mapping standards • Increased private-sector involvement • Improved data access	• Development of the National Spatial Data Infrastructure (NSDI) • Support and publicize Geospatial One-Stop • Promulgation of standards • Support for NSDI Communications Toolkit
States, Tribes, and Territories		
Resource Managers, as identified by response to CSC (1999)	• Enhanced ability to interpret and apply spatial data and imagery for decision making • Access to information from other entities • Enhanced interagency coordination • Habitat and human-use maps and data • Nearshore and estuary bathymetry • Fish distribution • Wetland function • Land-use change maps	• Varies widely by entity

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Coastal Resource Management Departments	• Consistent scale and format for coastal and marine data • Consistent shoreline definition • Consistent protocols for data collection, mapping, storage, and reporting • More detailed bathymetry, elevation, hydrography • Better information about land-sea interface (0 to 50 ft depth) • More detailed need for improved spatial data to address hazards • Elevation, hydrography seismic profiling, sidescan sonar, coring, diver surveys, paleo reconstructions, etc.	• Varies widely by entity
Environmental Protection Departments	• Data and mapping to support water quality permitting, construction/dredging permits • Groundwater issues (such as saltwater intrusion) • Habitat restoration, urbanization issues	• Varies widely by entity
Natural Resource Departments	• Data and mapping to support assessments of coastal hazards, coastal erosion, fisheries management, rare and endangered species	• Varies widely by entity
Emergency Management Departments	• Data and mapping to support assessment of flooding and other hazards	• Varies widely by entity
Geological/ Biological Surveys	• Data and mapping to support assessment of living and non-living resources, rare and endangered species, biodiversity, basemaps, coastal change	• Varies widely by entity

Agency or Entity	Identified Unfulfilled Needs for Coastal Mapping and Charting	Activities Related to Coastal Mapping Data and Products
Archeology/ Cultural Heritage	• Data and information in support of locating and documenting cultural/ archeological resources	• Varies widely by entity

SOURCES: Communications and presentations by agency personnel and other interested individuals, Appendix A in NRC (2003a), and NOAA-CSC Coastal Resource Management Customer Surveys (CSC, 1999; 2002).

Appendix B

Committee and Staff Biographies

Larry A. Mayer (Chair), University of New Hampshire. Larry Mayer earned his Ph.D. at the Scripps Institution of Oceanography. He is currently director of the Center for Coastal and Ocean Mapping and co-director of the Joint Hydrographic Center at the University of New Hampshire. Dr. Mayer's research interests include sonar imaging, remote classification of the seafloor, and applications of visualization techniques to problems of ocean mapping. He has participated in more than 45 cruises during the past 20 years and has been chief or co-chief scientist of numerous expeditions, including two legs of the Ocean Drilling Program. He is a recent recipient of the Keen Medal in Marine Geology, was a member of the President's Panel on Ocean Exploration, and was recently awarded an honorary doctorate from the University of Stockholm.

Rear Admiral Kenneth E. Barbor, International Hydrographic Bureau. Rear Admiral Kenneth Barbor earned his M.S. in meteorology and oceanography at the Naval Postgraduate School. He currently serves as director of the International Hydrographic Bureau. RDML Barbor was the inaugural director of the Hydrographic Science Research Center at the University of Southern Mississippi, a part of the Department of Marine Science located at the Stennis Space Center. He retired from the U.S. Navy after a 28-year career that included assignments as commander of the Naval Meteorology and Oceanography Command, directing the Navy's operational hydrography, oceanography, and meteorology activities; commanding officer of a hydrographic survey unit and two meteorology and oceanography forecast units; and headquarter staff tours with the

Oceanographer of the Navy and Naval Meteorology and Oceanography Command.

Paul R. Boudreau, Bedford Institute of Oceanography. Paul Boudreau received his M.S. in ecology from Dalhousie University. He is currently manager of the Habitat Management Division of the Canadian Department of Fisheries and Oceans. Mr. Boudreau's research interests include habitat and population production in freshwater, estuarine, and marine ecosystems and environmental impact assessment, which includes development, application, and analysis associated with mapping marine benthic habitats. He holds numerous committee positions, including membership on the International Council for the Exploration of the Sea Working Group on Marine Habitat Mapping.

Thomas S. Chance, C&C Technologies. Thomas Chance received his M.S. degrees in geodesy and industrial administration from Purdue University. He is founder and president of C&C Technologies, a hydrographic and land-surveying company headquartered in Lafayette, Louisiana. Mr. Chance is a member of the Hydrographic Society, the Institute of Navigation, the Society of American Military Engineers, and the Marine Technology Society. His expertise includes surveying for the submarine telecommunications industry, the offshore oil industry, and the U.S. government (including NOAA and the USGS). Mr. Chance served on the President's Panel for Ocean Exploration. He also participated in the Global Ocean-floor Mapping Project workshop.

Charles H. Fletcher, University of Hawaii. Charles Fletcher received his Ph.D. in geology, with a concentration in coastal sedimentology and Pleistocene-Holocene sea level change, from the University of Delaware. Dr. Fletcher is currently a professor of geology and geophysics in the School of Ocean and Earth Science and Technology (SOEST) at the University of Hawaii. His research interests include coastal sedimentary geology, which focuses on sediment budgets, sea-level history, erosion and accretion patterns, hazards, shelf sedimentation, and coastal zone management. Dr. Fletcher also has an interest in carbonate reefs, reef history, remote sensing, and habitat mapping. In 2001, Dr. Fletcher received the Robert W. Clopton Award for Outstanding Service to the Community.

Holly Greening, Tampa Bay Estuary Program. Holly Greening received her M.S. from Florida State University. She has been a senior scientist at the Tampa Bay National Estuary Program since 1991. Ms. Greening's responsibilities include coordinating state, federal, and university researchers and resource managers investigating impacts to the natural resources of Tampa Bay. Her research interests include freshwater inflow, atmospheric deposition, and watershed management. Ms. Greening recently served on the NRC Committee on Causes and Management of Coastal Eutrophication and serves on the Governing Board of the Estuarine Research Federation.

Rongxing Li, Ohio State University. Rongxing Li received his Ph.D. in photogrammetry and remote sensing from the Technical University of Berlin. He is currently a professor of geoinformation and geodetic science at Ohio State University. His research interests include Geographic Information Systems, Land Information Systems, photogrammetry, remote sensing, and applications involving coastal mapping, environmental monitoring and transportation. Dr. Li is a certified photogrammist and a member of the American Society for Photogrammetry and Remote Sensing. He is also a member of the American Society of Civil Engineers and the American Geophysical Union.

Curt Mason, Private Consultant. Curt Mason received his B.S. from Oregon State University and his M.S. in physical oceanography from Texas A&M University. From 1997 until his retirement in 2001, Mr. Mason served as a senior coastal oceanographer for NOAA. His primary areas of expertise include beach erosion, coastal storm impacts, and tidal inlet hydrodynamic and sedimentary processes. During his 36 years as a coastal oceanographer for the federal government, he led a major Corps of Engineers research program on tidal inlets, in addition to establishing and directing the Corps of Engineers Field Research Facility. Mr. Mason served as a program director in the NOAA National Sea Grant Program and Coastal Ocean Program offices; led the establishment of and served as deputy director for the NOAA Coastal Services Center, coordinated major budget initiatives within NOAA and the Department of Commerce on national disaster reduction (for which he received the department's Bronze Medal in 1998), and served as the NOAA/USGS liaison for science interactions and budget initiatives. He recently served on the National Academies Committee to Review the USGS Coastal and Marine Geology Program.

Susan Snow-Cotter, Massachusetts Office of Coastal Zone Management. Susan Snow-Cotter received her M.A. in marine affairs from the University of Washington. She holds a B.A. in political science with an emphasis in environmental politics from the University of Massachusetts/Amherst. Ms. Snow-Cotter is currently the assistant director at the Executive Office of Environmental Affairs for Massachusetts Office of Coastal Zone Management. She has 15 years of experience with ocean resource management including aquaculture, habitat mitigation, regulatory review of coastal and ocean development, and exotic species planning and management. Ms. Snow-Cotter represents Massachusetts on several regional and national programs including the Gulf of Maine Council on the Marine Environment, the Minerals Management Service's Outer Continental Shelf Policy Committee and the Northeast Aquatic Nuisance Species Panel.

Dawn J. Wright, Oregon State University. Dawn Wright received her Ph.D. in physical geography and marine geology from the University of California, Santa Barbara, in 1994. She is currently a professor of geography and oceanography at Oregon State University. Dr. Wright's research interests include geographic information science, marine geography, tectonics of mid-ocean ridges, and the processing and interpretation of high-resolution bathymetric, video, and underwater photographic images. She has completed oceanographic fieldwork in some of the most geologically active regions of the planet, including the East Pacific Rise, the Mid-Atlantic Ridge, the Juan de Fuca Ridge, the Tonga Trench, volcanoes under the Japan Sea and the Indian Ocean, and has dived three times in the Alvin submersible. Dr. Wright serves on the board of directors of the University Consortium for Geographic Information Science, and has recently edited the books *Marine and Coastal Geographical Information Systems* (Taylor & Francis, 2000) and *Undersea with GIS* (ESRI Press, 2002).

Staff

David A. Feary has been a senior program officer with the Board on Earth Sciences and Resources since 1999, where he also has responsibility for the Committee on Seismology and Geodynamics. He earned his Ph.D. at the Australian National University before a 15-year period as a research scientist with the marine program at the Australian Geological Survey Organisation. During this time he participated in numerous research cruises—many as chief or co-chief scientist—and most recently was co-chief scientist for Ocean Drilling Program Leg 182. His research activities have focused on the role of climate as a primary control on carbonate reef formation.

Terry Schaefer was a program officer with the Ocean Studies Board from August 2001 until October 2003. Terry received his Ph.D. in oceanography and coastal sciences from Louisiana State University in 2001 and a master's degree in biology/coastal zone studies from the University of West Florida in 1996. In 1998, Terry served as a John A. Knauss Marine Policy fellow in the Office of the Chief Scientist, National Oceanic and Atmospheric Administration. During his time with the Ocean Studies Board he directed the study *Science and its Role in the National Marine Fisheries Service*

(2002). Previously, Terry worked for the U.S. Environmental Protection Agency, National Park Service, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and the U.S. Forest Service. Dr. Schaefer's interests include recruitment dynamics of marine populations, experimental statistics, coastal zone management, and marine policy.

Yvonne Forsbergh was a research assistant for the Board on Earth Science and Resources. Previously, she was a program analyst for the Office of Grants and Special Programs at Howard Hughes Medical Institute for both the Precollege Science Education Program and the Graduate Science Education Program. She has also held a position with the Board on Science and Technology for International Development as consultant and program administrator. She holds a B.S. from the University of Tennessee in microbiology and education, and she is currently a M.Ed. candidate at George Mason University in instructional technology.

Byron Mason is a senior project assistant for the Division on Earth and Life Studies. He received a B.A. in anthropology from the University of Florida. During his time at the NRC he has assisted with the completion of two reports: *Implementing Climate and Global Change Research* (2004) and *A Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting* (2004).

Alison Schrum was a project assistant with the Ocean Studies Board through much of 2002, where she was primarily involved with organizational aspects of the *National Needs for Coastal Mapping and Charting* study.

Appendix C

Acronyms

AIS	Automatic Identification System
ALACE	Airborne LIDAR Assessment of Coastal Erosion
AtN	Aids to Navigation
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BLM	Bureau of Land Management
CASI	Compact Airborne Spectrographic Imager
CHARTS	Compact Hydrographic Airborne Raid Total Survey
CMW	Counter Mine Warfare
CSC	Coastal Services Center
CSO	Coastal States Organization
CTM	Coastal Terrain Model
DDM	Digital Depth Model
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DMS	Digital Mapping Server
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive Economic Zone
ENC	Electronic Nautical Chart
EPA	U.S. Environmental Protection Agency

FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FIRMS	Flood Insurance Rate Maps
FTE	Full-time Equivalent
FWS	U.S. Fish and Wildlife Service
GEODAS	Geophysical Data System
GIDB	Geospatial Information Database
GIS	Geographic Information System(s)
GPS	Global Positioning System
HAB	Harmful Algal Bloom
HYSAS	Hydrographic Source and Assessment System
IMO	International Maritime Organization
IMU	Inertial Measurement Unit
ISO	International Organization for Standardization
LIDAR	Light Detection and Ranging
LNM	Local Notice to Mariners
MHHW	Mean Higher High Water
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MMS	Minerals Management Service
MSL	Mean Sea Level
NAD	North American Datum
NAFTA	North American Free Trade Agreement
NASA	National Aeronautics and Space Administration
NAVD	North American Vertical Datum
NESDIS	National Environmental Satellite, Data, and Information Service
NGA	National Geospatial-Intelligence Agency (formerly National Imagery and Mapping Agency)
NGDC	National Geophysical Data Center
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Ocean Partnership Program
NOS	National Ocean Service
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRC	National Research Council

NRL	Naval Research Laboratory
NSDI	National Spatial Data Infrastructure
NSF	National Science Foundation
NTDE	National Tidal Data Epoch
OAR	Office of Ocean and Atmospheric Research
OCS	Office of Coast Survey
OGC	Open GIS Consortium
OMB	Office of Management and Budget
ONR	Office of Naval Research
OPIS	Ocean Planning Information System
ORCA	Oceanographic Remotely Controlled Automaton
ROV	Remotely Operated Vehicle
SAUV	Solar Autonomous Underwater Vehicle
SAV	Submerged Aquatic Vegetation
SHOALS	Scanning Hydrographic Operational Airborne LIDAR Survey
SOLAS	Safety of Life at Sea
SPAWAR	Space and Naval Warfare Systems Command
SRTM	Shuttle Radar Topography Mission
UML	Unified Modeling Language
UNCLOS	United Nations Convention on the Law of the Sea
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
UUV	Unmanned Underwater Vehicle
WAAS	Wide Area Augmentation System
WWNWS	World Wide Navigational Warning System
XML	Extensible Markup Language