The Work of NOAA's U.S. Coast and Geodetic Survey
THE NATIONAL GEODETIC REFERENCE SYSTEM
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Introduction

One of the primary concerns of government (federal, state, and local) must be to protect the coastal environment while maximizing the use of coastal resources. This is becoming even more important today with increasing population pressure upon the fragile coastal environment. Essential to the protection process are such activities as mapping and charting of the coastal zone; development and use of geographic information systems (GIS) to display, analyze and model the interactions between environmental and cultural parameters; definition of legal boundaries; development of safe and effective means of navigation; and monitoring of changes in the land/sea boundary. All of these activities require accurate horizontal positioning or determination of elevation. Positions or elevations determined and used by different agencies be compatible. The primary mission of the National Geodetic Survey (NGS), a division of the National Oceanic and Atmospheric Administration (NOAA), is to provide a means for everyone performing horizontal, vertical or gravity measurements to use the same coordinate system, thereby making all measurements compatible. We refer to the positional framework that makes this possible as the National Geodetic Reference System (NGRS). This paper describes NGRS, its applications in the coastal zone, and the products and services of NGS.

NGRS

Geodesy is the earth science used to determine the size and shape of the earth; exact positions/elevations of points on its surface; and its gravity field. NGS uses geodetic surveying techniques to develop and maintain NGRS, which is composed primarily of the nation's three geodetic control networks horizontal (270,000 stations), vertical (585,000 stations), and gravity (2,100,000 stations). Points defined by these networks are the basic geographic location and elevation starting positions for land surveys, cartography, engineering, construction, environmental control measures, and earth science studies. The primary value of NGRS is universal compatibility of spatial products. Simply put, this means that data whose geographic positions are determined through reference to NGRS are compatible with all other data whose geographic positions have been determined relative to NGRS—no costly transformations will be required to make the two data sets compatible.

To create NGRS, NGS defined both vertical and horizontal reference systems and provided users with a means to determine positions and elevations relative to these coordinate systems. The reference systems are the North American Vertical Datum of 1988 (NAVD 88) and the North American Datum of 1983 (NAD 83), respectively.

An essential element of NGRS is a large network of monumented points whose horizontal positions and/or elevations are known relative to NAD 83 or NAVD 88. The user can determine the geographic positions or elevations of unknown
points by beginning at one of the monumented points and performing differential measurements to the unknown points. In the past, ground-based measurement techniques required only the position or elevation of the monumented points to differentially determine the position or elevation of new points. Today, techniques that make use of the Global Positioning System (GPS) of satellites are revolutionizing the determination of horizontal and vertical positions. With GPS techniques, differential positioning (Figure 1) between a point of known geographic location and a point whose geographic coordinates are to be determined requires placing one GPS instrument at the known point, another at the unknown point, and making simultaneous observations of radio signals from several GPS satellites. However, GPS positioning technology requires accurate knowledge of the position of the satellites as a function of time, i.e., accurate satellite ephemeris (or orbital) information. Thus, in the GPS era another component of NGRS is the orbits of the GPS satellites.

GPS technology has introduced another component into NGRS. GPS positioning is three-dimensional—it provides not only horizontal position, but also elevation. However, the elevations provided by GPS are relative to a different reference figure than the NAVD 88 elevations obtained by conventional leveling methods. NAVD 88 (or orthometric height) elevations are required by most users. To convert an elevation obtained by GPS (ellipsoidal height) to an NAVD 88 elevation requires knowledge of the geoid height (geoid undulation) at the point (Figure 2). Thus another component of NGRS is a set of geoid heights as a function of position.

**NGRS and Coastal Mapping, Charting and Land Use**

The original reason for establishing a geodetic surveying capability in the United States was to provide horizontal control to support coastal mapping and charting needed for safe navigation of our coastal waters. This continues to be an important application of NGRS today. All hydrographic surveys by NOAA are performed relative to NGRS through positioning of hydrographic vessels based on points with NAD 83 positions.

GPS is changing the way in which ships are navigated and positioned. NOAA is cooperating with the U.S. Coast Guard (USCG) in a USCG program that will allow ships using GPS to navigate and position themselves more accurately. USCG will establish a network of continuously operating land-based reference stations that will broadcast GPS corrector information. Use of these correctors will neutralize the intentional degrading of GPS signals by the Department of Defense for reasons of national security. This approach is expected to be implemented nationwide during the next few years. Use of this technique will reduce the possibility that ships will ground and the subsequent destruction of the environment. It will also increase the efficiency and accuracy of mapping and charting, again contributing to safe navigation and increasing our knowledge of the coastal and near-coastal environment. These continuously operating GPS reference stations will be tied to NGRS to ensure that they are positioned properly to each other and to the nautical charts. NGS has begun to determine the positions of these continuously operating stations along the Atlantic and Gulf coasts.

Aerial photography of coastal areas is used extensively for coastal mapping, in addition to assessment, monitoring, and management of natural
resources. Aerial photography also has been used to define boundaries between states or between a state and the federal government. Proper determination of these boundaries is critical in the management of natural resources. However, aerial photographs are of little value unless they can be related accurately to each other, to other photographic projects, and to known geographic positions. In the past, this relationship was been provided by identifying and marking (with paint or plastic panels, so that they can be seen in the photograph) points on the ground whose NGRS positions were known. This allows all the photographs to be related to a common framework and to each other.

Unfortunately, identifying and marking these points is very expensive. GPS technology is changing this. The aircraft, the photo center, and ground features shown in the photograph can be positioned accurately relative to a GPS reference station located at some distance from the survey area by placing a GPS receiver in the aircraft. If the reference station has been positioned accurately relative to NGRS, then the location of all ground features in the photograph will be positioned accurately relative to NGRS. This method largely eliminates the need to identify and mark points of known horizontal and vertical position, increasing efficiency and accuracy of photogrammetric operations. This method of photogrammetric mapping is of particular importance in coastal areas where it is often difficult and expensive to mark points that can be identified in the photographs.

For ship positioning, aircraft positioning, or positioning of points on the ground, continuously operating GPS base stations will be of increasing importance. These base stations will be positioned relative to the NGRS coordinate system and will themselves become a component of NGRS.

Horizontal and vertical information provided by NGRS is also essential to the control of coastal development. Following the destructive effects of Hurricane Hugo in 1990, NGS was called on to replace NGRS horizontal and vertical reference monuments along the South Carolina coast. This monumentation provides South Carolina with information to control construction along the coast—all new structures must be located to meet specified setback and elevation criteria, as specified by state law, relative to NGRS.

**NGRS and Coastal Vertical Motions**

The location of the shoreline is of fundamental importance in the development of coastal areas. The impact of shoreline movement is substantial. We usually think of shoreline movement in terms of land erosion. However, the cause of some shoreline movement is the vertical motion of the land itself. This vertical motion can have several origins: subsidence due to fluid removal from buried sediments; slow uplift and subsidence due to internal forces associated with removal of ice loads or the collision of the tectonic plates that make up the earth's surface; and large, nearly instantaneous, vertical motions associated with major earthquakes. NGRS network vertical reference stations in coastal areas provide the primary means for detecting and monitoring vertical motions of the land.

Subsidence due to fluid withdrawal has led to flooding problems at a number of locations along the Gulf and Pacific coasts. One of the most seriously effected is the Houston/Galveston area of Texas. Subsidence resulting from groundwater extraction has exceeded 10 feet in some areas. For a number of years
NGS has supported the Harris-Galveston Coastal Subsidence District by establishing and monitoring a dense network of level lines and vertical reference stations.

Based on the information from NGS studies, the subsidence district reduced groundwater extraction in some areas. Further studies by NGS have shown that subsidence has nearly ceased where pumping was reduced (Figure 3) while continuing in those areas where it was not reduced (Figure 4). NGS expects to continue this work using GPS to perform future monitoring.

NGS has also monitored subsidence due to fluid removal in Louisiana. An important question to answer in the Louisiana study is the amount of subsidence due to fluid withdrawal by human activity and the amount due to natural effects.

Not all vertical movements in coastal areas are due to fluid withdrawal. Studies referencing NGRS vertical reference monuments have determined that such movements in Oregon, Washington and British Columbia are caused by horizontal movement of the large tectonic plates that make up the Earth's surface. The Juan de Fuca plate, on which the Pacific Ocean rests, is moving toward the North American plate, on which most of the North American continent lies, and is being forced under it. These vertical motions are of interest, not only because of the information that they give on shoreline migration, but also because they provide information to aid in determination of the potential for major earthquakes due to the collision of tectonic plates.

The Alaskan earthquake of 1964 resulted in significant vertical as well as horizontal displacements. In some areas the vertical movement was as much as 30 feet. Leveling surveys since 1964 have provided important information on the vertical movements since the earthquake. These vertical motions provide important clues for use in determination of the mechanisms associated with earthquakes in southern Alaska.

NGRS and Pilot MPLIS Projects

NGS also participates in the development of Multi-Purpose Land Information Systems (MPLIS) and GIS through a grant procedure. One of NGS' primary interests in such projects is that the GIS be referenced to NGRS to ensure compatibility of spatial information. NGS administers grants appropriated by Congress and provides assistance to the states and technical review and monitoring of the results from the projects. Of particular interest are projects in South Carolina and Louisiana.

The South Carolina Water Resources Commission is conducting a five-year project under an NGS grant to use MPLIS/GIS techniques and public policy procedures to develop a natural resources decision support system. The objectives of this project are to:

- Determine data collection requirements to support decision-making;
- Develop procedures to identify public interest in natural resources;
- Develop procedures to classify and prioritize natural resources and sites by relative value;
Develop procedures to balance compensation to private landowners with the exercise of regulatory police powers;

Establish a GIS to provide products and services to support natural resource management at the parcel level; and

Use GIS technology for cumulative environmental impact assessment.

NGS administers congressionally appropriated grants to three parishes in Louisiana to develop GISs based on accurate parcel mapping relative to NGRS. These systems will be used for land management with particular reference to subsidence problems in Orleans and Jefferson parishes.

NGS also coordinates the Federal Geodetic Control Subcommittee effort to publish *Multi-Purpose Land Information Systems: The Guidebook*. This book focuses on local government's role in developing an MPLIS. It provides technical and policy standards for states, counties, cities and regional planning bodies designing an MPLIS or GIS.

**Technology Transfer**

NGS maintains an active technology transfer program. This technology transfer is not directed solely to the coastal states, but to the entire United States. However, the technology transferred has universal applicability. In addition, members of our technical staff not only answer questions from the general public but work with personnel from other government agencies and provide training through cooperative agreements.

NGS maintains a small field force of approximately 45 highly trained geodetic surveyors who augment and upgrade NGRS through GPS, leveling and calibration baseline surveys. A large percentage of these surveys are conducted under cooperative agreements with other federal, state or local government agencies and provide not only upgrades to NGRS, but also training for local personnel.

Under NOAA's Geodetic Advisor Program, NGS provides geodetic surveyors to provide technical assistance and training to states under a cooperative 50-50 cost-sharing program with individual states. Geodetic advisers assist states with their geodesy and surveying programs, suggest and coordinate NGRS maintenance functions, ensure that surveys performed by the states meet federal standards and specifications, and provide training in the areas of classical and GPS geodetic surveying, GIS, and various other surveying-related topics.

NGS also conducts a series of workshops to provide guidance on the application of new technology to properly use NGRS. These workshops are often co-sponsored by local government agencies or surveying associations.

**A Look to the Future**

The introduction of three-dimensional GPS measurement technology is revolutionizing positioning and navigation and bringing them closer together. NGS is upgrading NGRS to meet the reference system needs of the GPS era. Two
components—accurate satellite orbits and accurate geoid heights—have been added to NGRS.

NGS produces GPS satellite orbital information in conjunction with NOAA's Office of Ocean and Earth Sciences (OES). OES and NGS expect to improve the accuracy of these orbits in the near future as data from additional permanent GPS tracking stations around the world are incorporated into orbit computations. A result of these more accurate orbits will be the increased accuracy of GPS positioning. Also, it will be possible to use continuously operating GPS reference stations at much greater distances than is now possible. Very soon all aircraft performing remote sensing in coastal areas, as well as ships performing hydrographic or research measurements, will probably be positioned relative to a small number of continuously operating GPS reference stations. The positions of these stations, together with the observational data taken by them, will become an integral part of NGRS. NGS is working with other federal agencies, state agencies and local groups to ensure that all relevant continuously operating GPS reference stations have compatible three-dimensional positions relative to the NGRS coordinate system. NGS is also working to ensure that data from a sufficient number of these reference stations are made available to multiple users and archived for future use.

GPS surveying technology is becoming accurate enough to monitor vertical motions in coastal areas. Because of large cost savings, GPS can be expected in many cases to replace conventional leveling for vertical motion monitoring, particularly where long distances or access problems are involved. To provide continuity and a longer time history for vertical motions, it will be necessary to combine conventional leveling determinations of orthometric height with GPS determinations of ellipsoid height. This will require high-accuracy geoid heights. NGS has already produced a high-accuracy geoid height model, designated GEOID90. A campaign is underway to obtain additional gravity and terrain data to produce an improved geoid in 1995. The ultimate aim is to permit ellipsoid height to orthometric height conversion with an accuracy of 1 to 2 cm. This will be a special challenge in coastal areas because of lack of gravity data in shallow water and in inaccessible coastal swamps.

NGS is providing high-accuracy regional upgrades to NAD 83 to allow surveyors and navigators to take full advantage of GPS. These upgrades consist of networks of stations having a spacing of 25 to 100 km and differential horizontal accuracies of 1 to 3 cm. These monumented stations are tied into and used to upgrade the absolute accuracy of the NAD 83 coordinates of existing NGRS horizontal reference monuments. Such networks are already in place in Washington, Oregon, Florida, Tennessee, Wisconsin, Maryland and Delaware. Observations have been completed and networks will be available over the next few months in Alaska, California, Louisiana and Alabama. These upgrades have been conducted as cooperative efforts with the aforementioned states.

NGRS Products

NGS provides the information needed to make use of NGRS through its National Geodetic Information Center (NGIC). This information consists of listings containing the horizontal positions, vertical elevations, and other data about the monumented points of NGRS, in addition to descriptions on how to locate these
monuments. This information is available in print form or on diskette in a variety of geographic ranges.

Weekly GPS ephemeris (orbital) information is available on diskette from either NGIC or by modem from the U.S. Coast Guard Information Center bulletin board. GEOID90, the high-accuracy geoid model for the United States, and its associated vertical deflection model, DEFLEC90, also are available from NGIC on diskette.

NGS provides a range of computer software for solving geodetic surveying problems. These programs are available for mainframe and personal computers, as well as for HP-41CV programmable calculators. Also available from NGS is a series of publications, including the MPLIS Guidebook. For further information on these products contact the National Geodetic Information Center, N/CG174; Rockwall Bldg; Room 26, NOAA, National Geodetic Survey, 11400 Rockville Pike, Rockville, Md. 20852, (301) 443-8631, fax: (301) 881-0390.
Figure 1. Differential positioning.
Figure 2. Geoid-ellipsoid relationships.
Figure 4. Houston-Galveston 1987 subsidence rates, mm/year.
SHORELINE SURVEYS: PAST AND PRESENT
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ABSTRACT

Current shoreline surveys in the Coast and Geodetic Survey (C&GS) result in the production of shoreline maps and associated data. Also included in the survey process is the collection of high-resolution, metric-quality aerial photographs. Shoreline maps (base maps), associated data and photographs are considered by some to be merely byproducts of the nautical charting program. However, they are also complete products in their own right and are available to the public. They should be of particular interest to those who are working in the coastal environment, since modern tide-coordinated surveys provide a starting point for many scientific studies of the coast. In addition, coastline data from the early 19th century to the present offer insight concerning types and rates of change in coastal areas. The purpose of this presentation is to provide information about these products.

INTRODUCTION

A shoreline survey is the process of establishing the location of the shoreline in a selected area. The shoreline shown on C&GS charts and maps represents the line of contact between the land and a selected water elevation. In areas affected by tidal fluctuations, this line of contact is the mean high water line. In confined coastal waters of diminished tidal influence, the mean water line may be represented. In non-tidal waters, the shoreline represented is the land-water interface at the time of the photography. In areas of marsh grass, cypress or other similar marine vegetation, the shoreline is often obscured. In these areas an apparent shoreline is mapped at the point where the line of vegetation is a definite line above the shoreline datum. Because this is the line that appears to a navigator as the shoreline, it is delineated as such and is located in lieu of the actual high water datum line.

SHORELINE MAPS

Shoreline maps result from the shoreline survey process. They are special-use planimetric or topographic maps that usually cover a relatively narrow zone along the shoreline and portray selected features. (Planimetric maps depict the horizontal placement of natural and manmade features; in addition to these features, topographic maps depict form, usually showing relief as contour lines.)

Shoreline maps are graphic representations derived from plane table and photogrammetric surveys. The maps contain data relating to the shoreline, alongshore natural and man-made features, and usually a narrow zone of natural and man-made features inland of the shoreline. This zone may vary, however, from several hundred meters to an area covering the entire map.

When obtainable, shoreline maps depict the low water line within the limits of the survey. The accurate location of the low water line is extremely valuable for charting because it may be used as the base line from which offshore boundaries
are determined and it eliminates the need for the hydrographer to develop the zero depth curve.

Shoreline maps produced by C&GS may be grouped into three approximate eras, each of which has certain common characteristics, the most prominent of which is the data source.

**Early Era Shoreline Maps (1834-1929)**

The framework in the form of triangulation for the first topographic survey began in 1816. After a brief period, congressional action caused a break in operations until 1832 when work was resumed (Shalowitz, 1964). The topographic survey was completed in 1834 and is registered as C&GS's first topographic map. That map and subsequent ones of the era were the graphic recordings of field topographic surveys. The topographic shoreline surveys and the shoreline maps were essentially the same for these early surveys, since the maps consisted entirely of direct survey recordings made primarily with the use of a plane table and alidade. The plane table was considered by C&GS's authority on topographic surveying, O.W. Swainson (1928), to be "one of the best instruments for topographic surveying, as with it the map is actually drawn in the field where and when the features can be seen and where the amount of detail to be mapped and the accuracy required can be judged to best advantage." For most of the earliest shoreline maps, no supplemental information for the interpretation of the topographic maps was prepared apart from the map itself. Later maps in this era were accompanied by descriptive reports that supplemented the maps with interpretive information not readily shown on the maps themselves. Descriptive reports were included as early as 1863 and were officially mandated in 1887 (Shalowitz, 1964).

**Intermediate Era Shoreline Maps (1930-1979)**

Most shoreline maps produced in this period included the combined graphic representation of data that originated from aerial photography and field surveys. These maps were field-checked, had supplemental data applied to them if necessary, and were edited prior to registration to ensure that all critical nearshore hazards were represented and that the features depicted were accurately described and positioned.

**Photogrammetric Surveys.** During this era the application of photogrammetry was recognized by C&GS as a cost-effective method to survey the shoreline. Photogrammetry is the science of determining the physical dimensions of objects from measurements of photograph images. An investigation into the feasibility of using aerial photography in compiling coastal maps was started June 10, 1919 (Smith, 1979). From that time through 1926 experimentation included various aircraft and camera lens configurations. By 1927, the full potential of photogrammetry as an aid to the production of charts and maps was recognized by C&GS (Smith, 1979). In 1930, the director of C&GS stated: "The Coast and Geodetic Survey is convinced that it is time for the airplane to take its proper place and be officially recognized in the Bureau's mapping program" (Smith, 1979). After that, photogrammetric methods were consistently used in support of the coastal mapping program and also in providing surveys of the coast for the establishment of marine boundaries. In 1971,
this capability was officially recognized and its use stipulated for the survey of the coast (DOC Organization Order 25-5B, July 11, 1971). In areas where adequate tidal datums were available, photogrammetric methods were often used to develop the low water line.

**Aerotriangulation.** Ground control for traditional photogrammetric mapping required a network of photo-identifiable points on the ground for which values, referred to horizontal and vertical datums, had been established. Aerotriangulation is a method of increasing the density of photo-control, relative to the specified horizontal and vertical datums, for photogrammetric use. Aerotriangulation is defined as the process for the extension of horizontal and/or vertical control whereby the measurement of angles and/or distances on overlapping aerial photographs are related into a spatial solution using the perspective principles of the photograph (American Society of Photogrammetry, 1980). Specifications for photogrammetric surveys required that the network of photo-control be established relative to geodetic and tidal/water level datums established by the National Ocean Service (NOS). For the majority of projects, this requirement was met using a combination of field surveying and aerotriangulation methods. The typical practice was to establish and premark available reference control stations throughout the project area using ground survey methods and then establish the full complement of photo-control by aerotriangulation methods.

**Aerial Photography.** In coastal surveys, the spectral reflectance characteristics of water, land, and sea or lake bed were considered and used to advantage. Different films are sensitive to particular ranges of the light spectrum. Infrared light, for example, is reflected by dry land and almost completely absorbed by water. For this reason, since about 1970, tide-coordinated black-and-white infra-red photography has been used when distinct definition of the low and high water lines have been required. Light in the visible range will penetrate clear water, so low-altitude color photography has been used for feature investigations and photobathymetry.

**Modern Era Shoreline Maps (1980 to present)**

Since 1980, aerial photographs have been the sole source used for shoreline mapping. Final maps produced now provide the graphic representation of detail interpreted and extracted from the photographs. This method allows the adequate delineation of the shoreline, coastline structures, interior detail, and, when applicable, the low water line. Limiting factors, however, may affect the adequate representation and portrayal of open-water features. Open-water features on these maps represent only photo-identifiable objects that can be located using photogrammetric disciplines.

Although graphic data from field surveys are not used for compiling these maps, field operations provide an important role in support of photogrammetric mapping. Supporting field functions may consist of any or all of the following operations: recovering or establishing ground control, placing targets on control stations prior to aerial photography, observing tides in support of tide-coordinated photography, and conducting feature investigations that use field surveying techniques to supplement or verify photogrammetric data.
With Global Positioning System (GPS) technology, the task of establishing photo-identifiable geodetic control points on the ground has become less labor- and time-intensive than in the past. Prior to the availability of GPS, flight lines and photographic coverage were often compromised to accommodate existing horizontal control. With GPS receivers, geodetic control is placed wherever needed for maximum photographic coverage and mapping accuracy, including areas previously considered too remote for cost-effective ground survey.

RECENT DEVELOPMENTS

Analytical digital compilation has all but replaced conventional analog stereo plotter technology. In addition, photogrammetric operations are benefiting from new technology that includes photogrammetric surveys using kinematic GPS, a modern flight management system, and digital data.

Analytical Digital Compilation

Shoreline map compilation in C&GS has shifted from analog to analytical methods. The type of compilation can be identified by the registration prefix T, TP or DM. All registered maps compiled by analog methods have the prefix T or TP. These maps are stable-base copies of the original compilations. Registered maps with the prefix DM are computer-generated using a validated digital data set resulting from analytical compilation. This type of compilation is performed with the aid of analytical stereoscopic measuring instruments that differ from the traditional analog instruments in several important aspects. In analog instruments, the photographs are oriented to the same physical relationship that existed at the time of exposure. While compiling the map, the operator continually adjusts the mechanical projection system, and images of the shoreline are traced at scale by a pantograph. In analytic instruments, manual adjustment is replaced by a computer with an electro-servo interface. It continually adjusts the optical projection system by solving a system of equations. The imagery appears in stereo at all times as the operator moves the measuring mark throughout the stereo model. Instead of creating a graphic product, the computer displays and stores digital coordinates in the desired geodetic reference system. The shoreline map is created from the digital data, but the digital data are independent of the specific map. They can be used for a variety of final products.

Photogrammetric Surveys Using Kinematic GPS

During photogrammetric surveys using airborne kinematic GPS, the exposure station of the camera, as well as the targeted control, is positioned by GPS methods. Beginning in 1985, the National Oceanic and Atmospheric Administration (NOAA) Charting Research and Development Laboratory (Lucas, 1987) developed an aerotriangulation simulation model that suggested that positioning the aerial camera exposure station to an accuracy of one meter would eliminate the need for geodetic control for coastal mapping without compromising shoreline accuracy (Lapine, 1991a). Subsequently, various practical tests have been conducted by NOAA to confirm these findings. Lapine (1990) demonstrated that ground
control points can be positioned from aerial photography to an accuracy of five centimeters from an altitude of 6,000 feet above the ground at a speed of 200 mph (1990). On Oct. 5, 1990, the Photogrammetry Branch conducted photogrammetric operations over Albemarle Sound, N.C., which demonstrated the practical application of GPS-controlled photogrammetry. The photo mission was flown at 24,000 feet and at speeds reaching 345 mph. Differential phase observations from an onboard GPS receiver significantly reduced the cost of shoreline mapping by eliminating the need for densely spaced and signalized ground control points. An analysis of the subsequent aerotriangulation process showed virtually no difference between the solution using signalized point positions determined by GPS-controlled aerotriangulation and true (surveyed) values within 1.0 meter in horizontal and 2.1 meters in vertical (Lapine, 1991b). This technology is being used to map the Florida Keys National Marine Sanctuary, where conditions preclude the use of extensive ground controlled photography.

Modern Flight Management System

A new flight management system within C&GS is based on very precise near-real-time GPS pseudo-ranging, a CD-ROM digital map file, and modern electronic camera technology. It enables precise navigation of the aircraft over preplanned nearshore and offshore flight lines. This should bring greater efficiency to aerial photograph operations and result in maintaining mapping accuracy of offshore areas.

Digital Data

The new generation analytical photogrammetric systems allow base mapping to be conducted in a totally digital environment. A benefit of this new technology is that a database of high-resolution seamless shoreline data is collected and can be used for multiple purposes by extracting a portion or all as needed. Any digital data set includes information about the integrity of the data it contains.

Recordkeeping and product retrieval are also advancing into the digital arena. The geographic positions of approximately 380,000 aerial photographs contained in the C&GS Photogrammetry Branch's film library have been digitized from photo indexes and correlated with supplemental information. These data are in the correction and testing phase and will soon be available through interactive computer query. Direct additions to this database will be forwarded from the flight management system on digital media.

A shoreline survey inventory database is currently being loaded with the coordinates and supplemental data relative to each registered shoreline map C&GS has produced to date. This will allow a quick categorical search of inventory via interactive computer query. In addition to this, plans are being developed to convert the historic registered maps to digital form. Each shoreline map will be scanned and the data stored in both raster and vector form for comparison, retrieval, and plotting purposes. Associated reports and records will be scanned and stored along with the digital map data. Ultimately private and commercial users should be able to access these data directly via computer modem.
COOPERATIVE SHORELINE MAPPING PROJECTS

There have been a number of cooperative projects in which C&GS has contributed its shoreline surveying expertise. The latest was to obtain high-precision base mapping for the Florida Keys National Marine Sanctuary. It was sponsored jointly by the National Ocean Service Office of Ocean Resources Conservation and Assessment and Office of Ocean and Coastal Resource Management; the National Marine Fisheries Service Southeast Fisheries Laboratory; the State of Florida's Department of Natural Resources; and Monroe County, Fla.

USES OF COASTAL SURVEY DATA

Coastal survey data not only serve as the database of shoreline and topography used in NOS nautical chart production but also provide an accurate geographic framework for management purposes, many published data, and environmental studies. For example, the National Marine Fisheries Service uses shoreline survey data and aerial photographs to classify, inventory, and map submerged aquatic vegetation. Elements of the NOAA Coastal Ocean Program use these data to evaluate the effects of physical impacts to coastline regions and for estuarine habitat studies. Historical data resulting from these surveys are often used in litigation to determine property ownership and to enforce regulatory mandates. Recently, a litigation settlement involving the states of Georgia and South Carolina resulted in the establishment of the states' boundary by using historical NOS coastal survey data as the basis of its determination.

AVAILABILITY

Shoreline Maps

Final shoreline and photobathymetric maps are registered and permanently archived in the NOS vault. A registered map is a stable base copy of the original manuscript. This copy is registered instead of the original because of its superior durability over time. Associated data, identified as descriptive reports or completion reports, are bound in a single volume and are also registered. They consist of all pertinent reports, records, and listings of production data associated with the shoreline survey and individual maps, beginning with register number T-979, archived in 1863. The shoreline maps are available to the public as stable base or bromide (paper) copies. Copies of the maps and reports may be obtained from the Archives of the National Ocean Service by contacting Data Control Section/NCG243, Nation Ocean Service, NOAA, Rockville, Md. 20852, (301) 443-8408.

Digital Shoreline Data

High-resolution seamless shoreline data will be maintained on file in vector form by the Photogrammetry Branch. For updated information, contact the Support Section, Photogrammetry Branch, (301) 443-8801.
Aerial Photographs

C&GS metric-quality photographs consist of natural-color, false-color, black-and-white (panchromatic), and black-and-white infrared photographs. The majority of available photographs range in scales from 1:20,000 to 1:60,000. Copies of these photographs in nominal 23cm x 23cm (9" x 9") contact size are available as prints, and as film negatives or positives. Paper prints are also available as enlargements ranging through 4.44 times the contact size.

To obtain aerial photographs contact Support Section, Photogrammetry Branch N/CG236, Coast and Geodetic Survey, NOS, NOAA, 6001 Executive Blvd., Room 719, Rockville, Md. 20852, (301) 443-8601.

Cooperative Mapping Projects

To obtain information about possible cooperative base mapping projects contact Photogrammetry Branch N/CG23x1; Coast and Geodetic Survey, NOS, NOAA, 6001 Executive Blvd., Rockville, Md. 20852, (301) 443-8006.

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HYDROGRAPHIC SURVEYS OF U.S. COASTAL WATERS
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Introduction

A stated goal of The Coastal Society is to provide an opportunity and forum to promote the exchange of ideas, techniques and experience in the use and management of coastal resources. This paper is intended to provide information pertaining to the availability of copies of National Ocean Service (NOS) hydrographic surveys and thus further the exchange and sharing of research and information.

It is important to note that this paper addresses hydrographic surveys as a product rather than hydrography, which is the professional surveying activity. Hydrography deals with the measurement and description of the physical features of bodies of water and their littoral land areas. In hydrography, emphasis is usually placed on the elements that affect safe navigation and on the publication of such information in a suitable form for use in navigation. The resultant “... information in a suitable form for use...” is the hydrographic survey.

Hydrographic surveys are a principal source of information necessary to the compilation of nautical charts. Perhaps the NOS hydrographic surveys will serve as an invaluable resource for applications in the coastal and marine environments.

Historical Perspective

In the early days of this republic, the conduct of commerce by means of land transportation presented many difficulties. The difficulties of land transport along with the need for foreign trade, predominantly dependent on coastal shipping, fostered reliance on safe maritime commerce. The responsibility for such safe maritime commerce was recognized as an inherently governmental responsibility. On Feb. 10, 1807, this national obligation was formally recognized when Congress, acting on the recommendation of President Jefferson, adopted a resolution for a “Survey of the Coast.” This resolution had its roots in various reports, circa 1795-97, which recognized the lack of accurate coastal surveys and the need for accurate charts of the “Atlantic coast of the United States, including the bays, sounds, harbors, and inlets thereof as have been made from actual observations and surveys. ...”

In implementing the Act of 1807 scientists were invited to propose a plan for carrying out the monumental and precedent setting task of surveying. Respondents included Swiss geodesist and scientist Ferdinand R. Hassler. Hassler's plan was accepted and he was selected to guide the early organization of the survey. His plan called for the division of the task into the three primary branches of geodetic, topographic and hydrographic operations.

The establishment of acceptable field procedures, training of surveying personnel, provision for the preparation of charts and maps, and the design and acquisition of precise survey instruments, as well as the War of 1812, combined to delay survey work until 1816. The first field work, accomplished in 1816, consisted of reconnaissance for the purpose of establishing two geodetic baselines; one in the vicinity of Englewood, N.J. and the second on Long Island, N.Y. However, due to
circumstances familiar to today's administrators, i.e., lack of adequate funding, it was necessary to suspend the fledgling surveying undertaking. In the early 1830s Congress revived the original act and survey efforts resumed. The first topographic and hydrographic surveys were completed in 1834 and covered the area of Great South Bay, Long Island.

For early inshore hydrographic surveys, depths between 10 and 15 feet were measured with a graduated sounding pole; deeper waters, to 15 fathoms, were measured by a handlead and marked line. The development and implementation of echo sounding technology during the 1920s greatly increased the efficiency and accuracy of hydrographic surveying.

**Hydrographic Survey Types**

**Basic Hydrographic Survey.** The principal purpose of the hydrographic survey is safe navigation. A hydrographic survey may include the determination of one or several of the following classes of data: depth of water; configuration and nature of the bottom; velocity of currents; heights and times of tides and water stages; location of aids and dangers for navigation and survey purposes; configuration of marginal land areas; and determination of magnetic declination and anomalies for navigating by magnetic compass. Information on geographic names and harbor facilities is also often documented. Most NOS hydrographic data are now collected by computer-supported systems.

Following field work, hydrographic survey data are forwarded to be processed and plotted on smooth sheets. The smooth sheet is plotted from verified and corrected data and constitutes the final, neatly drafted accurate plot of a hydrographic survey. The hydrographic survey smooth sheet serves as a primary source for data used in compiling a nautical chart (Figure 1).

Hydrographic survey smooth sheets are usually plotted at a scale of 1:10,000. The criteria for scale selection are based on the area to be covered and the amount of hydrographic detail necessary to depict adequately the bottom topography and portray the least depths over critical features. The standard size for hydrographic survey sheets, whether manually or machine plotted, is 91 cm by 136 cm. Accurate vertical control of hydrographic surveys is tied to tidal observation; other pertinent corrections are tied to the raw soundings, according to the type of sounding equipment utilized. Depths on most hydrographic surveys are reduced to true depths below an accepted datum plane, e.g., mean lower low water.

**Wire Drag Survey.** Wire drag denotes a specialized surveying technique using an apparatus for determining the maximum clearance depth over a bottom feature. It is also used for the detection of isolated dangers to navigation that might escape detection by ordinary sounding methods, e.g., rocks, pinnacles, ledges, boulders and coral reefs. It consists of a horizontal bottom wire supported at intervals ranging from 300 to 600 feet (91 to 183 meters) by adjustable upright cables suspended from buoys on the surface and towed at the desired depth by two ships or launches (Figure 2). The uprights can be lengthened or shortened for various required depths. They are kept in a nearly vertical position by means of weights attached to their lower ends. The end weights and buoys are larger than the intermediate weights and buoys and the towing gear is attached to them.
Wire drag surveys are considered to be of limited use for general purposes other than NOS nautical chart compilation due to the complex overlapping plots of the individual drag strips on the smooth sheet and the depiction of only cleared areas shown on the accompanying "area-and-depth" (A&D) sheet. Figures 3 and 4 illustrate a typical wire drag survey smooth sheet and A&D sheet respectively. **Field Examination (FE).** The FE is a special purpose NOS hydrographic, wire drag, or side scan sonar survey of very limited area. A survey is customarily assigned an FE registry number when it addresses the investigation of an individual item or several scattered items. In most cases, each investigation is smooth-plotted on an 8½-by 11-inch sheet that can be inserted in the descriptive report. Each item is subjected to sufficient investigation to resolve the status of the item in question and support a specific recommendation concerning the charting disposition of the item (Figure 5).

**Navigable Area Survey.** This is a basic hydrographic survey with restricted coverage. The coverage is reduced by omitting requirements for development of the zero-foot depth curve and foul, nearshore areas not considered navigable; and a complete field edit of the survey area. Navigable Area Surveys may also be restricted to the main navigable channel or corridor. By restricting the area of coverage while retaining the basic hydrography concept within surveyed waters, a more rapid progression of field work is realized.

**Hydrographic Survey Products Available**

Copies of survey indexes are available on 8½-by 11-inch sheets. For areas where the page-sized indexes are not current, copies of relevant master diagrams may be provided. Such indexes and diagrams will be furnished on request.

Photographic reproductions of surveys are usually made on paper and are rendered as positives (black lines and figures on white background) called "bromides." Photographic reproductions are also available on film-positive, stable base media (SBM) at a slightly higher cost. There is a charge for bromide and SBM film-positive copies. Fee quotes will be furnished upon request.

Negatives are not routinely generated for FE surveys. Accordingly, copies of FE surveys are only available as electronic (photocopy-type) copies of the descriptive report and accompanying page-sized plots of the individual developed survey areas. Charges are made on a per-page plus base fee basis, which depends upon the number of pages and plotted sheets included in the descriptive report.

**Digital Hydrographic Survey Data.** Approximately 4,324 digital hydrographic survey data sets are available. This covers the majority of surveys conducted since approximately 1930. These data sets are of two types, those conducted manually and later digitized and those acquired digitally (Figure 6).

The digitized datasets consist of 3,204 surveys conducted from 1930 to 1965. The digitally acquired hydrographic survey data consist of approximately 1,120 surveys and continue to grow as new surveys are registered.

**Descriptive Reports.** A descriptive report is written for each hydrographic survey conducted by the National Ocean Service. However, descriptive reports are not available for older hydrographic surveys in the Great Lakes conducted by the now-defunct Lake Survey Center.

The descriptive report comprises a narrative document that describes the conditions under which the survey was performed. It addresses important factors
affecting the adequacy and accuracy of the survey to facilitate survey processing and provide additional information for consideration during the compilation of the nautical chart. In most cases, a copy of the hydrographic survey smooth sheet will be sufficient to meet the needs of the general user public, obviating the additional expense associated with obtaining a copy of the descriptive report. Nevertheless, copies of descriptive reports are available subject to a charge based on a per-page plus base fee basis. The cost varies depending on the total number of pages included in the descriptive report.

Automated Wreck and Obstruction Information System (AWOIS). The Automated Wreck and Obstruction Information System (AWOIS) is a personal computer database, using dBASE III Plus software. The AWOIS, developed by the Coast and Geodetic Survey, Nautical Charting Division, Hydrographic Surveys Branch, contains over 8,800 records on wrecks and obstructions reported in U.S. coastal waters. The database was designed primarily as an automated research tool to assist the Coast and Geodetic hydrographic survey program. It also has been useful to marine archaeologists and historians, fisherman, divers, salvage operators and other users in the marine environment.

Each record in the database has a repetitive format that has information on vessel name, position (latitude/longitude), positional accuracy, survey status, large-scale chart number, project number, survey requirements, history, and description.

Submission of Requests for Products

Requests for photographically reproduced copies of hydrographic surveys, topographic surveys, and photocopy-type copies of descriptive reports are processed upon receipt of payment. The request should be addressed to NOAA, National Ocean Service, HSB, Data Control Section, N/CG243, WSC1, Room 404, 6001 Executive Blvd., Rockville, MD 20852. Make checks payable to U.S. Department of Commerce, NOAA, N/CG243.

The AWOIS data base is maintained by the Hydrographic Surveys Branch, Operations Section, N/CG241. AWOIS computer listings and digital data on diskette are available to anyone for a fee. For further information about AWOIS, please contact Mark J. Friese, National Ocean Service, Hydrographic Surveys Branch (N/CG241), 6001 Executive Boulevard, Rockville, Md. 20852, (301) 443-8752.

Digital Hydrographic Survey Data. NOAA's National Geophysical Data Center (NGDC) is the designated distributor of all NOS digital hydrographic survey data. Copies of all NOS digital hydrographic surveys are sent to NGDC where they are archived. From this archival dataset NGDC has created and maintains the National Ocean Service Hydrographic Data Base (NOSHDB). The NOSHDB incorporates over 40 million uniformly formatted, 40-character survey records. The data are stored as one-degree-square area files on magnetic tape.

NGDC has created a second database that grids the NOSHDB depth records into 15-second cells. The depth assigned to the center of each cell is an arithmetic mean of all depths located within the cell, computed without regard to their spatial distribution. This database is used to generate data density plots that show data coverage for each one-degree-square area.
All inquiries regarding NOS digital hydrographic survey data should be directed to National Geophysical Data Center, NOAA, NESDIS, E/GC3, 325 Broadway, Boulder, Colo. 80303-3328, (303) 497-6338.

Conclusion

Requests for copies of hydrographic surveys, field examination surveys, topographic surveys, and descriptive reports have been received from private sector consultants, attorneys, surveyors, various federal, state and local government agencies, universities and various private individuals. Perhaps some of these products will prove useful for your particular research endeavors.

References


Figure 1. Sample hydrographic survey smooth sheet.
Figure 2. Wire drag and weep construction diagram.
Figure 4. Sample wire drag area and depth (A&D) sheet.
Figure 5. Sample hydrographic field examination (FE) smooth plot.
Figure 6. NOS hydrographic data.
NOAA’S PROGRAM TO MAP
THE U.S. EXCLUSIVE ECONOMIC ZONE
AND THE AVAILABILITY OF RESULTING BATHYMETRIC DATA
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Abstract

In response to a 1983 presidential proclamation, NOAA’s Coast and Geodetic Survey began surveying with multibeam sounding techniques the U.S. Exclusive Economic Zone, extending seaward for 200 nautical miles from the coastline. The resulting maps and data are needed in this largely unexplored area for the conservation and management of living and non-living resources as well as for various types of planning. To date, 71 bathymetric maps have been made, each having a scale of 1:100,000 and generally measuring 1° in longitude by 0.5° in latitude. The basic data are in a digital format. These include full-resolution data (all soundings collected which typically number 5-10 million per map area) and two types of grids derived from these full-resolution data. NOAA is making all maps and digital data available to the public. Gridded data for a single map area are disseminated on diskette in ASCII format for use on PC desktop computers. Full-resolution data are disseminated on magnetic tape.

Introduction

In March 1983, President Reagan signed a proclamation establishing the U.S. Exclusive Economic Zone (EEZ). This zone (Figure 1) extends seaward for 200 nautical miles from the coastline of the United States, its overseas territories and possessions, and the commonwealths of Puerto Rico and the Northern Mariana Islands. As a result of this proclamation, the United States has sovereign rights, in accordance with the rules of international law, over all living and non-living resources in the EEZ. The area of the EEZ is about 1.7 times greater than the combined areas of the above-mentioned land masses. Although the undersea topography and mineral resources of only small parts of this enormous area have been surveyed and are relatively well known, systematic mapping of the EEZ, until recently, has not been done. Such surveys of the seafloor, through the resulting maps and digital data, are expected to yield vast amounts of information that can be used for diverse purposes, including interpretation of geologic features, planning of scientific and environmental studies, wise management of living and non-living resources, and education of students at many levels of study.

This paper describes NOAA’s EEZ program and the nature of the resulting data, as well as formats, products, and the availability of both maps and digital data. Numerous publications give technical details on the multibeam systems used by NOAA (Farr, 1980; Renard and Allenou, 1979). A description of how NOAA manages and processes the data, as well as details of how soundings are used to produce maps, is given by Herlihy et al. (1988). A bibliography concerning the policy and science of EEZ mapping has been prepared by NOAA (1989). This bibliography includes numerous references to the complementary GLORIA sidescan data collected by the U.S. Geological Survey in the EEZ. Also, see papers given in the

Because of the wealth of bathymetric detail revealed by NOAA’s EEZ multibeam program, the dissemination of data was stringently controlled by the U.S. Navy prior to the spring of 1989. At that time the Navy removed all restrictions on data dissemination with the exception of two areas: the EEZ in the Pacific, north of 46°N (essentially the entire EEZ off the coast of Washington); and the Atlantic EEZ extending from Cape Romain, S.C. to Fort Pierce, Fla. The data collected in these two areas from NOAA’s EEZ multibeam program (but not from university multibeam research cruises) remain classified.

Thus, it has only been about three years that these data have been advertised and disseminated to the general public. Because of this small time period, the nature and availability of these multibeam data remain unknown to many potential data users.

One measure of the usefulness of the data is shown by scientific publications using the data to interpret geologic features on the seafloor (Greene et al. 1989; Jackson et al., 1990; Bryant et al., 1991).

Map Areas in Depths Less than 150 M.

It is important to understand, especially when NOAA EEZ maps are used in coastal areas, that the sounding data used in making maps in depths less than 150 m have not been collected by the highly accurate multibeam techniques described in this paper. Instead, these shallow soundings have been obtained from single-beam hydrographic surveys, some of which were made as long ago as the early 1930s. Sounding data from such hydrographic surveys are not as dense or as accurate (in positioning or depth) as soundings obtained by the adjacent multibeam surveys, which are generally conducted in water deeper than 150 m.

Status of Map Production

Every year since 1984, NOAA has conducted EEZ mapping operations with multibeam techniques. Five vessels have been involved in data collection. Off the East Coast and in the Gulf of Mexico, the work has been carried out by NOAA ships *Mt. Mitchell* and *Whiting*. Surveying along the West Coast, and in Hawaiian and Alaskan waters has been conducted by NOAA ships *Davidson*, *Surveyor* and *Discoverer*. Seventy-one 1:100,000 EEZ maps are available in either a published, multicolored format or as black-and-white copies of preliminary maps. The numerical breakdown according to geographic region, to date, is as follows: Central and Northern California (13), Oregon (16), Alaska (4), Hawaii (7), East Coast (2), Gulf of Mexico (29). The exact locations of these maps are shown in a series of index maps (periodically updated) provided free to the public at the address given below.

General Characteristics of EEZ Soundings

Much interest has been expressed about the full-resolution multibeam data, which are collected as follows. A multibeam ship collects data from a swath of soundings along the sea floor. This swath is normal to the ship's heading. Typically
15 or 16 soundings are obtained. A depth and a position are determined for each sounding. An example, showing results from a single swath where 15 soundings are collected, is shown in Figure 2. For NOAA's SeaBeam system, in this water depth, the two outermost soundings (1,234 m and 1,301 m) are both about 440 m from the ship in a horizontal direction, thus giving a total swath width of about 880 m. (The boxed-off depth, 1,273 m, directly beneath the ship, is the only depth that would be recorded with a single-beam system).

A second swath of data is collected from the seafloor several seconds later (five or six seconds is typical—the actual time between swaths depends mainly on water depth). This second swath produces a similar group of soundings that are offset from the soundings of the first swath, in a direction along the trackline of the ship. All soundings collected in this manner, for a complete bathymetric survey, make up a full-resolution dataset. The maps and gridded data described in this paper are based on only a small subset (selected soundings) of these full-resolution data.

NOAA uses both deep and intermediate-depth multibeam systems for EEZ mapping. Two types of intermediate-depth water systems have been used. The first, no longer used, is the Bathymetric Swath Survey System (BSSS), which measured depths between 150 and 600 m. Currently HYDROCHART II is used in depths from 150 m to 1,000 m, although depths as shallow as 15 m have been measured. Both systems operate at 36 KHz and generate a swath on the seafloor with a nominal length of about 2.5 times the water depth.

The SeaBeam system is the only deepwater system used by NOAA. (SeaBeam and the two systems cited above are products of SeaBeam Instruments Inc.). The SeaBeam system is used in depths from the deepest parts of the U.S. EEZ to 1,000 m or 600 m, depending on which of the two intermediate depth systems is used in adjacent shallower waters. SeaBeam operates at 12 KHz and generates a swath measuring about 0.7 times water depth.

At present, the only intermediate depth system used in the Pacific has been BSSS, and the only system used in the Atlantic and Gulf has been HYDROCHART II, although it is anticipated that an intermediate-depth system will be used in the Pacific in the future.

In general, multibeam sounding data are not collected in water shallower than 150 m due to the efficiencies of the systems. In order to complete a map containing such shallow water, NOAA hydrographic survey data, of varying quality, are used (Matula, 1991).

Most EEZ map areas measure 1° in longitude by 0.5° in latitude. In Alaskan waters the east-west dimension is 1.5° of longitude. However, there are exceptions to these standard map limits. These may occur when a map area is close to land and it is judged that certain land features should be included in the map (the map limits would be expanded to include these features). It is also possible that in the future, maps that are close to or include the EEZ boundary may not have these standard map limits. In some cases a seafloor feature, judged to be especially important environmentally or geologically, extends outside the U.S. EEZ boundary into international waters. In such cases NOAA will enlarge its survey area to include the feature. This has been done in the Gulf where NOAA has surveyed parts of the Sigsbee Escarpment extending seaward of the EEZ limit.
The coverage of the seafloor using multibeam systems is 100 percent. The prevalent trend of the topography is known before a survey starts and ship tracklines (mainscheme lines) usually run parallel or subparallel to this trend. Swaths from adjacent, parallel mainscheme lines overlap by 10 percent or more. Crosslines, which generate about 5 percent of the total data collected, are run normal to the mainscheme lines and are used to verify soundings collected on the mainscheme lines.

Sound velocity profiles are developed from conductivity, temperature and depth (CTD) data collected prior to surveying. These results are used to apply velocity corrections to the raw sounding data. Daily expendable bathythermograph (XBT) data are used to see if significant temperature changes have occurred in the water column. If so, new CTD data are collected and used to derive a new sound velocity profile, which is applied to the sounding data.

Positions have been determined by satellite systems (e.g., STARFIX of John Chance Inc. and differential GPS) and shore-based systems, such as ARGO and RAYDIST. LORAN-C positioning is not used because of its limited accuracy (about 0.25 nautical miles or 463 m). All surveys are based on the 1983 North American Datum (NAD83).

The accuracy of the depths and positions are judged to be well within the International Hydrographic Organization (IHO) standards of: (1) one percent of actual depth (we believe that in most cases our depths are better than 0.5 percent of true depth); and (2) within 50 m (based on the scale of our 1:100,000 scale maps) of true position.

Preliminary and Published Maps

NOAA disseminates both printed (i.e., published) maps and preliminary maps (black-and-white photocopies of maps not yet published). Both show identical bathymetric contours except for shallow areas (less than 150 m) where, in general, there are no contours on the preliminary maps. The purpose of disseminating preliminary maps is to make the data available to the public before the map is published. Once a map is published, the preliminary map is no longer used.

The 250-m grids and resulting contours for both types of maps are made using commercial software (Radian Corporation's CPS-1 contouring program) running on a DEC minicomputer. CPS-1 is also used to create the physiographic plots described below.

Both types of maps have the following characteristics: the scale is 1:100,000; contours are in corrected meters; the contour interval is 20 m; the projection is Universal Transverse Mercator; and LORAN-C lines (rates) are shown.

The published maps differ from the preliminary maps as follows: the preliminary maps generally do not show contours in water depths less than 150 m, and published maps may also omit contours in such shallow depths when future maps are published if the hydrographic data, from which these shallow contours are derived, are judged inadequate; the published maps show, where available, labeled lease block outlines provided by the Minerals Management Service; the published showing depth ranges; the published maps include at least one relatively small three-dimensional view of the whole map area (this 3D view is derived from the same 250-m grid (described below) used to generate the map contours); the
published maps label both established names of seafloor features and in many cases new names proposed by NOS or others for relatively large and distinctive features (i.e., features newly discovered or precisely defined for the first time as a result of NOAA's EEZ multibeam surveying. All names shown on the published maps have been approved by the U.S. Board on Geographic Names).

Physiographic Maps

A new product is a multicolored physiographic map consisting of a three-dimensional fishnet plot overlain by a generalized contour map with major seafloor features labeled. This type of map will commonly be made by combining the 250-m grids of six adjacent maps (e.g., 2 across and 3 down giving dimensions of 2° of longitude by 1.5° of latitude) into one large grid. To date, NOAA has published two of these physiographic maps: one in the Gulf of Mexico and one off central California. A third, off northern Oregon, is currently in preparation.

Gridded Data

Gridded data for a map area are produced from a small subset of the full-resolution data. Typically, the number of full-resolution soundings for a map area is about 5 million to 10 million (the actual number being a function of water depth). The subset used for gridding purposes is generally about 350,000 to 400,000 soundings with each sounding having an associated latitude and longitude. The subset (generally referenced as "selected soundings") are randomly or almost randomly distributed over the map area. These are used to produce a 250-m grid usually having 80,000 to 100,000 grid points. A typical grid might have 400 columns and 230 rows. This grid is linked to the UTM map projection with coordinates of all X and Y UTM grid points being evenly divisible by 250.

This 250-m UTM grid is used to automatically produce the contours shown on the preliminary and published maps. This grid is also used to produce a geographic grid with a grid spacing of 15' in both latitude and longitude directions. The geographic grid consists of 241 columns and 121 rows for the standard map area. It is more conveniently manipulated by microcomputers since the number of grid points (29,161) is about one-third the number of points in the 250-m grid. For example, we are able to fit an entire geographic grid into SURFER software (Golden Software Inc.), but the 250-m grid for a complete map is too large for SURFER.

Gridded data are disseminated for a single map area on a diskette, each containing both the 250-m grid and the geographic grid and a parameter file for each. The parameter files give information needed to interpret the grid files. In addition a READ.ME file is included. All five files are provided in ASCII format. No software is provided.

Full-Resolution Data

The full-resolution data for a single map area typically total about 5 to 10 million soundings. The actual number is determined mainly from the water depth, but also from the latitude of the map, the average speed of the ship, and several other factors.
These soundings, each of which is defined by a latitude, longitude and depth value, are important because they contain seafloor details, especially in relatively shallow water, that may not be contained in the 250-m grid used for making our maps (as already mentioned, the 250-m grid is derived from only a fraction of the full-resolution data).

Full-resolution data include sounding data judged to meet IHO standards for depth and position. This means that some of the collected data have been rejected because they have been deemed artifacts of the data collection process (de Moustier, 1986) or data collected during a tight turn of the ship. Typically these rejected data amount to no more than one to two percent or less of the total data collected. They are saved in a "cull" file. A number of corrections are applied to the full-resolution data in order to make them as accurate as possible. Several of these are corrections for the velocity of sound in seawater (including refraction of non-vertical beams), the depth of the transducer (draft correction), tidal corrections (for the intermediate depth multibeam systems only), and a correction for the offset of the transducers from the positioning antenna. All corrections applied are listed in an ASCII header file and provided on diskette.

The format of the full-resolution data (NOAA refers to this format as the SBO format) is the same as the University of Rhode Island (URI) format. The data are written in a binary format on a DEC minicomputer running under VMS. The data are not in ASCII format.

Data Dissemination

NOAA's EEZ maps are made available to the public from the National Ocean Service (NOS) in the Washington, D.C., area. Preliminary maps (black-and-white photocopies of maps prior to publication) are available from the NOS Ocean Mapping Section in Rockville, Md. Printed (published) maps are available from the NOS Distribution Division in Riverdale, Md. All maps (preliminary and published) are sent in mailing tubes. Folded maps are not available.

Gridded data on diskette and full-resolution data on magnetic tape are available from NOAA's National Geophysical Data Center in Boulder, Colo.

Additional Information

Additional information on NOAA's program to map the U.S. EEZ, plus map indexes that show locations of maps and how to order them, may be obtained from the Ocean Mapping Section, Code N/CG224, NOAA/NOS, Rockville, Md. 20852, (301) 443-8251.

Digital data may be ordered from the National Geophysical Data Center/NOAA, Code E/GC3, 325 Broadway, Boulder, Colo. 80303, (303) 497-6338.

The use of commercial names and products in this paper does not constitute endorsement of the names or products by NOAA or any other part of the U.S. government.
References


Figure 1. U.S. Exclusive Economic zone (EEZ) is depicted by shading. (After McGregor and Lockwood, 1985)
Figure 2. Soundings from a single swath. Depths in m.