CREATING A GIS FROM NOAA ELECTRONIC NAVIGATIONAL CHARTS
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ABSTRACT
NOAA's Electronic Navigational Charts (NOAA ENC®s) have been developed to support the marine transportation infrastructure and coastal management. The NOAA ENCs are in S-57, a data standard developed by the International Hydrographic Organization (IHO) to be used for the exchange of digital hydrographic data. NOAA ENCs can be incorporated into Geographic Information Systems (GIS) extending NOAA ENCs use and accessibility. However, many GIS's, cannot read an ENC's native S-57 format. To address this problem, "NOAA's ENC Direct to GIS" (ENC Direct) web portal provides comprehensive access to all available large scale NOAA ENC data in a variety of GIS/CAD formats for non-navigational purposes using Internet mapping service technology. Nautical chart features contained within an NOAA ENC provide a detailed representation of the U.S. coastal and marine environment. This data includes coastal topography, bathymetry, landmarks, geographic place names and marine boundaries. Features in an NOAA ENC are limited in that they only represent the geographic region that is depicted in that particular NOAA ENC. By aggregating nautical features from NOAA ENCs in the creation of GIS data, a contiguous depiction of the U.S coastal and marine environment is achieved. In the Internet mapping service, marine and coastal features are represented as layers organized into categorical groups. Using the Internet mapping service's GIS tools, ENC Direct layers can be explored. Because the data is not certified for navigation, symbolization of ENC Direct data can be generalized. Geographic place name labels also provide orientation. ENC Direct allows users to specify output format, coordinate system and the spatial extent of the data they wish to download through query and selection tools.

INTRODUCTION
A Nautical Chart is a graphic portrayal of the marine environment showing the nature and form of the coast, the general configuration of the sea bottom including water depths, locations of dangers to navigation, locations and characteristics of man-made aids to navigation, rise and fall of the tides, and the characteristics of the Earth's magnetism. In addition to its basic elements, a chart is a working document used by the mariner both as a "road map" and worksheet and is essential for safe navigation. In conjunction with supplemental navigational aids, it is used to map out a ship's course for the shortest and most economically safe route.
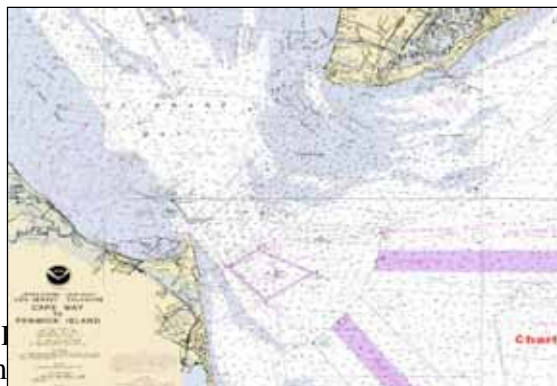
NOAA NAUTICAL CHARTS
The United States claims [...] a 200 nautical mile fisheries jurisdiction and Exclusive Economic Zone (EEZ) for the exploration and management of both living and nonliving marine resources. This vast area covers approximately 3.4 million nautical square miles. The United States National Ocean Service's Office of Coast Survey produces and maintains a suite of nearly 1000 nautical

charts to support the safety and efficiency of marine transportation, offshore engineering projects, naval operations, and recreational activities. This includes coastal and adjacent ocean areas of the United States, including the Great Lakes, Puerto Rico, US Virgin Islands, US Trust Territories, and other islands in the Atlantic and Pacific Oceans. Data sources for NOAA Nautical Charts include: bathymetric data from NOAA hydrographic surveys, topography from photogrammetric surveys, other federal agencies, (U.S. Coast Guard, U.S. Army Corps of Engineers), state and local government and the private sector). The NOAA Nautical Chart production system is a complicated process with an update cycle as often as every 6 months, or as infrequently as 12 years for remote areas. Revisions of individual nautical charts are published on an average interval of every 2 years.
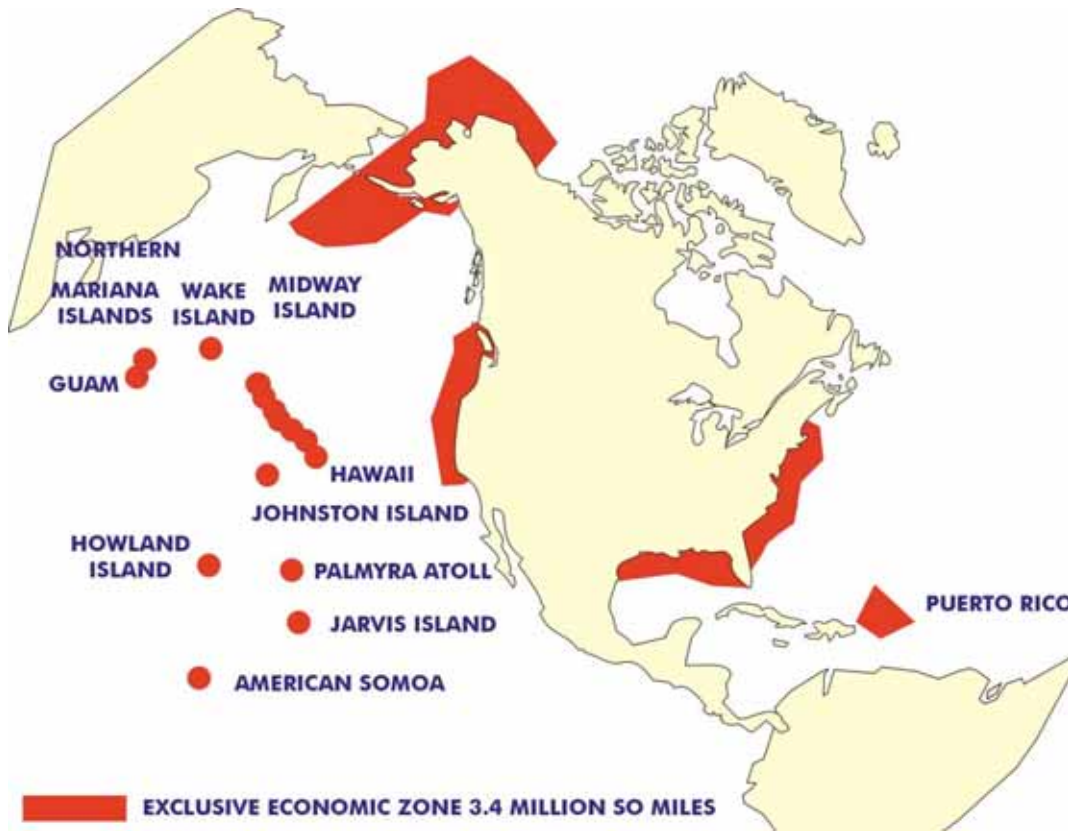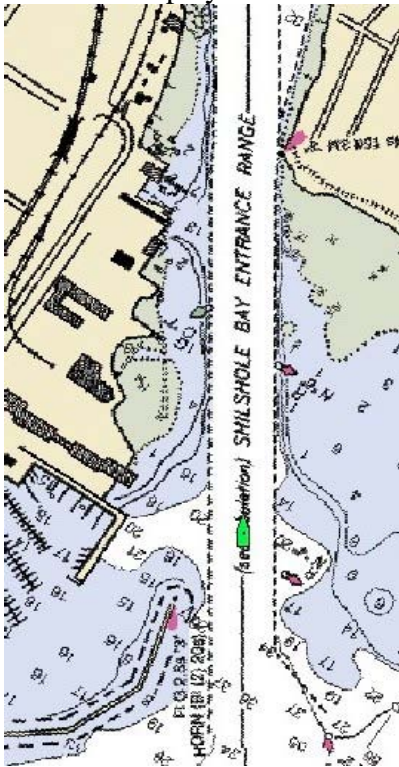

DIGITAL TECHNOLOGY IMPROVES NAUTICAL CHARTS
Advances in digital technology have expanded the accuracy and completeness of marine geographic information portrayed on nautical charts. Spatial data is information about the location and attributes of geographic features.
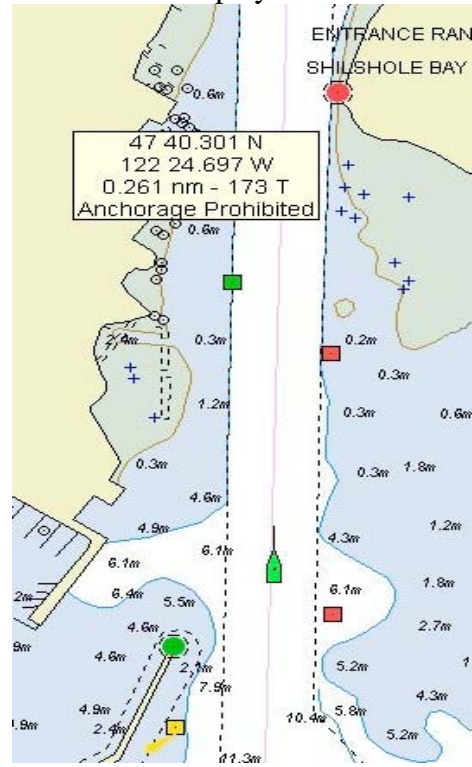
There are two main classes of spatial data:
- raster
- vector

Raster Display: NOAA RNC   Vector Display: NOAA ENC

Raster data is characterized by pixel values. A raster nautical chart is an electronic picture of a paper chart. The raster file tells the computer what color to draw at each pixel. Each pixel in a grid has exactly one value. Thus, the computer "knows" what color is there, but cannot distinguish a black pixel that is part of a sounding from a black pixel that is part of a dangerous wreck.

An electronic navigational chart (ENC) is a vector-based digital file containing marine features suitable for marine navigation. Vector data creation is a system of recording features based on the interaction between arcs and nodes, represented by points, lines, and polygons. A point is a single node, a line is two nodes with an arc between them, and a polygon is a closed group of three or more arcs. For raster files the display is static. For vector files the display is dynamic and can be customized to support multiple users. In an ENC, raster images and text files are supported for pictorial and text descriptions of certain charted features. The content of the ENC is comparable to the published paper chart with more recent updates added directly to the ENC dataset.

S-57 is a standard developed by the International Hydrographic Organization (IHO) that the ENC product specification is based upon. This standard allows hydrographic offices throughout the world to share and exchange digital chart data. Features encoded in an ENC are known as S-57 objects, have spatial components describing where they are and feature components describing what they are. Feature objects may be points, lines or areas.
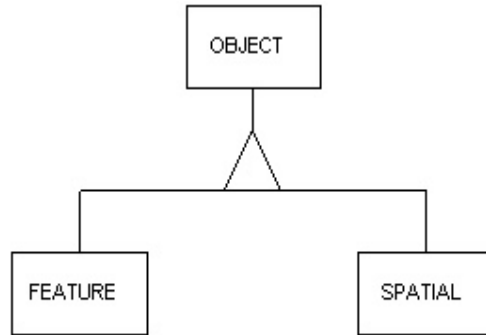
Figure 1. Simplified S57 object diagram

Each real-world entity is described by an object, which belongs to a certain class. Each object has a set of associated attributes with it. As shown in Figure 1, there are two kinds of objects: feature objects and spatial objects. The feature object is used to describe a real-world phenomenon like a ship wreck, coastal town, restricted fishing area, a harbor, and so on. A spatial object is used to represent a location on the Earth's surface such as a point (which is called an isolated node in the S-57 standard) with its latitude and longitude coordinates. A feature object will use a spatial object to indicate its location. Both kinds of objects have attributes associated with them. For example, a buoy object will have attributes like color; a spatial object, say an isolated node, will have attributes such as positional accuracy. These two kinds of objects are the conceptual building blocks of a dataset (which is called a cell in the S-57 standard). Currently there are four types of spatial objects (Figure 2): isolated nodes, connected nodes, edges and faces. (Faces are not supported in ENCs) Detailed definitions of these spatial objects can be found in the S-57 standard.
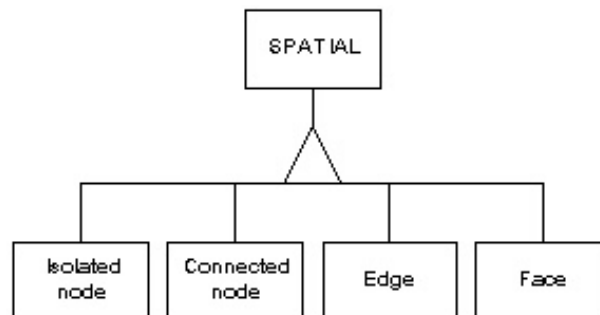

Figure 2. S57 spatial objects

THE S-57 OBJECT CATALOG
The S-57 standard provides a standard object catalog that specifies classes of objects. Data encoders can use the catalog to depict hydrographic data. In version 3.1 of the S-57 standard, 181 object classes are defined. Each class has a set of associated attributes. The object catalog provides attribute definitions including attribute data types and valid value domains.
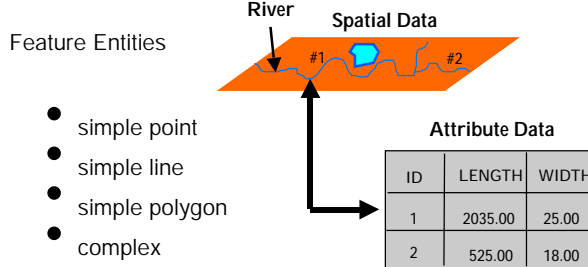
GEOGRAPHIC INFORMATION SYSTEM (GIS)
A GIS is created by the interaction between tabular and spatial data, where the tables contain information related to map features. Tabular data consists of attribute tables that define the parameters of the map features. There is really no limit to the types of data (Boolean, text, numeric) contained in the attribute tables. For example, a Boolean entry in a wreck table may define whether or not each wreck is dangerous or not. A text entry

may have the wreck's name, or the wreck's history. A numeric entry could have the wreck's depth or lat/long coordinates. An advantage of a GIS's relationship between its spatial and tabular data is that the data can be sorted and selectively displayed as map information.

GIS FEATURES

- A Feature logically consists of both the spatial data linked with its attributes in a feature table.

Feature Entities

- simple point
- simple line
- simple polygon
- complex

Spatial Data

River

#1   #2

Attribute Data

ID	LENGTH	WIDTH
1	2035.00	25.00
2	525.00	18.00

TRANSLATING FROM S-57 TO GIS

The S-57 standard is object based. Each object class has mandatory and non-mandatory attributes that describe it. Non-mandatory attributes that were not populated are not visible in database. When the ENC is translated to GIS, a table is created that includes all attributes for that object class, both mandatory and non-mandatory. This results in null record values in the table, where non-mandatory attributes have not been populated for feature objects. While this may appear as data missing from the table, it is a fundamental difference between the relational database model and the S-57 standard.

Converting an ENC to GIS results in exposing the S-57 object classes contained in the S-57 dataset as individual entities that are composed of as both a spatial and feature components. Each object class feature attributes are stored in a relational table.

CHART SCALE AND ENC FEATURE COLLECTION

A Chart's scale is a ratio that relates a unit of measure on a chart to some number of the same units of measure on the earth's surface. It is also an expression of how much the area represented has been reduced on the map. A larger representative fraction indicates a smaller chart scale. Small-scale charts cover a larger spatial extent than large scale charts but have less detail. A wreck may appear to be a point on a small-scale chart. On a larger scale chart the outline of the wreck may be collected as an area. Features on large-scale charts are more like to be collected at a greater detail and be collected as an S-57 area feature.

The Overview, General and Coastal ENCs are smaller scale then the Approach and Harbor ENCs.

ENC Scale Bands:

1   Overview to 1:1,500,001

2   General 1:1,500,000 to 1:600,001

3   Coastal 1:600,000 to 1:150,001

4   Approach   1:150,000 to 1:50,001

5   Harbor   1:50,000 or larger

6   Berthing   very large (not included in NOAA ENCs)

The NOAA ENC Scale is encoded in the third character of ENC dataset name.

Example: US5GA21M.000 is a Harbor ENC
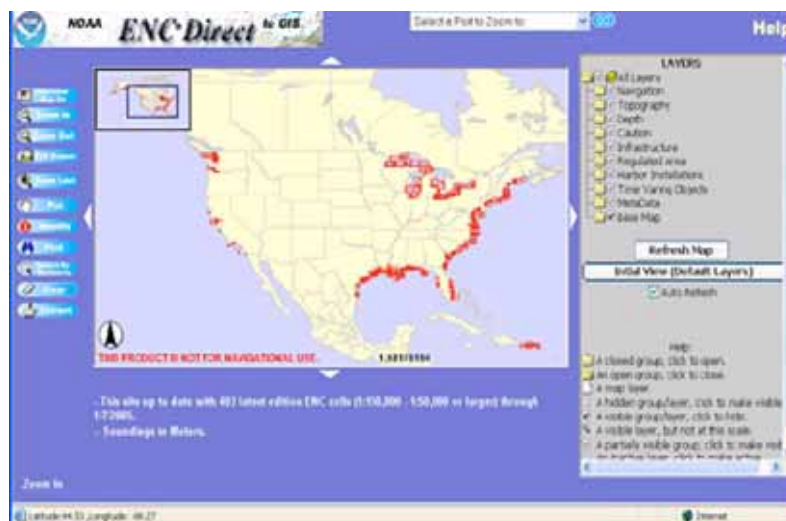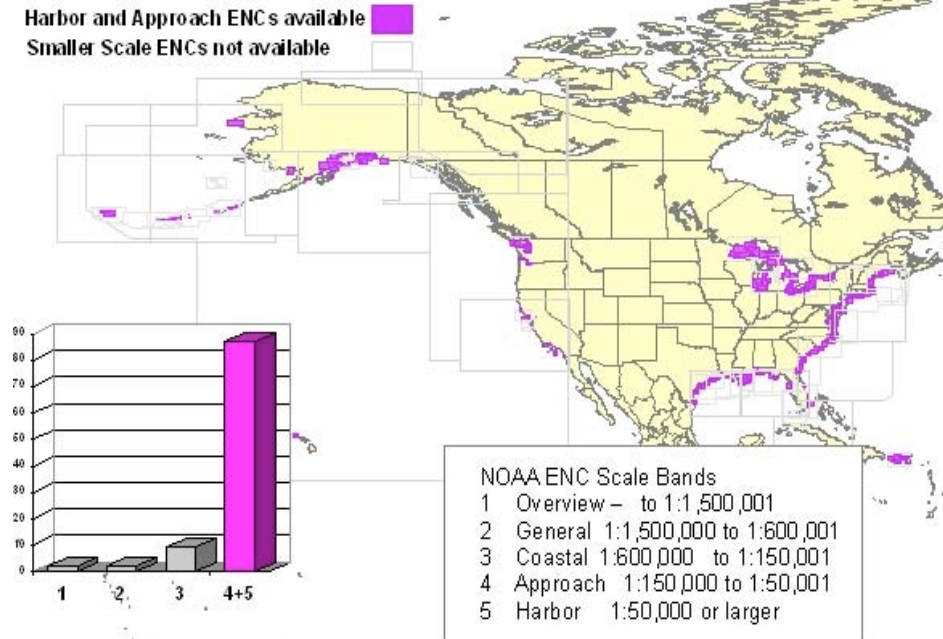
ENC DIRECT DATA CREATION

The ENC Direct layers are created by merging each S-57 object class in all large scale ENCs. (i.e., Approach and Harbor) Each ENC Direct layer comprises the complete ENC coverage of the object class for the scale band that it represents. For example, the soundings layer in ENC Direct contains the S-57 object class SOUNDG that has been merged with the SOUNDG object class from all Approach and Harbor ENCs. SOUNDG may contain only a few thousand soundings in single ENC, while the Soundings GIS layer contains close to a million soundings. The spatial and descriptive information for the nation's charted soundings that exist in the Approach and Harbor ENCs can now be accessed from a single GIS layer. Wrecks, Buoys and all of the other marine features that exist in the large scale ENCs are now accessible as GIS layers. Currently there are over 400 Approach and Harbor ENCs. This coverage extent includes the nation's harbors in ports. Other areas of coverage from smaller scale ENCs are not available in ENC Direct because merging this data would cause data at different chart scales to overlap. Merging together the Coastline object class (COALNE) from all ENC scale bands would result in multiple-scaled shoreline to overlap over certain areas. Data overlap between charts of different scale involves unresolved inconsistencies. However, Harbor and Approach ENCs can be merged together without causing data overlap.

FEATURE MANIPULATION ENGINE

The industry leading data interability software FME, (Feature Manipulation Engine) is used to translate the NOAA ENCs to GIS. The data is converted to ESRI Shapefile format. S-57 object classes that have multiple geometry types are output by geometry type. The translation results in over 200 shapefiles. The soundings layer is too large for the shapefile format and is stored in ArcSDE for Oracle.

## NOAA ENC Direct to GIS includes 90% of all NOAA ENCs

Harbor and Approach ENCs available
Smaller Scale ENCs not available

NOAA ENC Scale Bands
1 Overview – to 1:1,500,001
2 General 1:1,500,000 to 1:600,001
3 Coastal 1:600,000 to 1:150,001
4 Approach 1:150,000 to 1:50,001
5 Harbor 1:50,000 or larger

ENC Direct

ENC DIRECT INTERNET MAPPING SERVICE

ENC Direct to uses ESRI ArcIMS to display and serve the data stored in the ENC Geodatabase and in ESRI shapefile format using Internet mapping technology. Each S-57 object class is represented as a layer in the Internet mapping service. The S-57 object classes have been organized into meaningful groups based on category and geometry type in a layer list. ENC Direct layers can be explored using the Internet mapping service's GIS tools. Symbolization of ENC Direct Data is generalized being that the data is not for navigation. Geographic place names map labels are produced from object class attribute fields for orientation. Each layer has a map scale dependency. Map scale dependency means that features for a layer are only visible at a particular scale. This is necessary to

keep the service running at a functional level and to keep the map view from being cluttered. Most layers are visible when zoomed into at least 1:150,000 map scale.
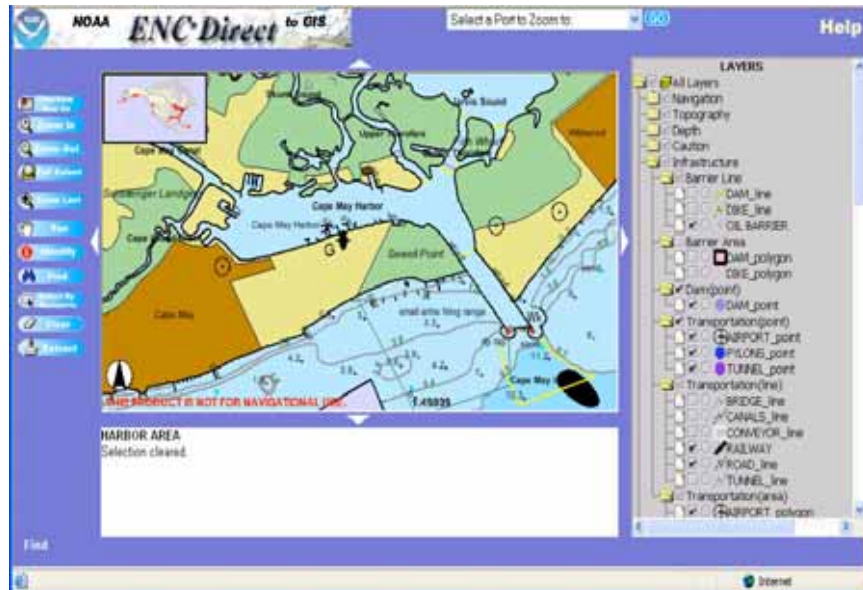
ENC Direct displaying Cape May Harbor New Jersey

Aquaculture displayed in Long Island, New York

DATA DELIVERY

All layers in the internet mapping service that are visible in the view of the mapping service, can extracted and downloaded in multiple GIS/CAD formats and coordinate systems. If the extent of the feature is outside of the view, then the exported feature that is exported is clipped to reflect the display view. The request for extracting data desired can be customized to extend the geographic limits specified latitude and longitude coordinates data extraction.

Data is selected for download

Download format, coordinate system and spatial extent is determined

Data is clipped, zipped and shipped

CONCLUSION

ENC Direct expands the usefulness of NOAA ENCs through the creation of web-accessible
GIS. Spatial and descriptive information about the nation's charted shoreline,
bathymetry, navigational aids, harbors, piers, and other entities depicting US coastal
waters collected through the marine charting process have become accessible through the
Internet. The ENC suite is scheduled to be complete in 2007. Currently, the main source
for NOAA ENCs are paper charts. ENCs are only as accurate as the source data from
which they are derived. ENCs, being a navigational product focus on marine features

pertaining to navigation by providing multiple marine layers for the navigator. When ENC data are served by ENC Direct the benefits expand to include non-navigational users such as those interested in homeland security, coastal management, environmental conservation and restoration, state and local governments, educators and the news media.

REFERENCES
Nautical Chart Manual Volume One: Polices and Procedures Seventh Addition (1992)
US Department of Commerce Coast and Geodetic Survey
International Hydrographic Organization, IHO TRANSFER STANDAND for DIGITAL HYDROGRAPHIC DATA. Special Publication No. 57. Edition 3.0 Nov. 1996.