

INTERNATIONAL HYDROGRAPHIC ORGANIZATION



MANUAL ON HYDROGRAPHY

Publication M-13

**1st Edition
May 2005**

**PUBLISHED BY THE
INTERNATIONAL HYDROGRAPHIC BUREAU**

MONACO

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PREFACE

The IHO Manual on Hydrography general objective is to provide knowledge on the concepts involved in hydrography as well as guidance to plan and execute hydrographic surveys. The Manual is considered to be a professional guide for hydrographic surveyors and a tool for teachers and students involved in hydrographic courses or programs.

The preparation of this Manual started after the majority of IHO Member States (MS) responded in favour of proceeding with a project that could result in a Hydrographic Manual (1999). The IHB proposed then the establishment of a Working Group that met for the first time at the IHB premises, 20-22 June 2001, where the Table of Contents was agreed; Team Leaders were identified to deal with specific subjects, being responsible for the compilation of experts' contributions, and a work program was defined. In 2004 a second meeting took place to review the result obtained and decide on a draft version of the Manual. After collecting comments from MS, the final version was prepared and the IHO Manual on Hydrography was published.

The Manual is considered to be a worthy product that contributes to the mission of the IHO, whose objectives are:

- The co-ordination of the activities of national hydrographic offices;
- The greatest possible uniformity in nautical charts and documents;
- The adoption of reliable and efficient methods of carrying out and exploiting hydrographic surveys;
- The development of the sciences in the field of hydrography and the techniques employed in descriptive oceanography.

It has to be acknowledged that several Hydrographic Offices (HO) have made great efforts in preparing and keeping up to date their version of a Hydrographic Manual, almost since their establishment, but the resources, both, in time and manpower required for this activity have precluded several HOs from continuing this practice, thus agreeing in the need to co-operate and co-ordinate the efforts for the preparation of an IHO Hydrographic Manual. A Manual that could be useful to everybody, containing specific aspects on hydrography and other matter only in general terms, as they are much more thoroughly covered in existing textbooks which refer to them in considerably greater detail.

The content of this Manual is divided into seven chapters:

- Chapter 1 refers to the principles of hydrographic surveying, including its specifications;
- Chapter 2 refers to positioning;
- Chapter 3 refers to depth determination, including both the principles and techniques used;
- Chapter 4 provides information on sea floor classification and object detection;
- Chapter 5 refers in particular to water levels and flow;
- Chapter 6 is devoted to topographic surveying applied to hydrography;
- Chapter 7 provides, in a structured way, complete details on hydrographic practice;
- Annexes with Acronyms, Bibliography and other relevant information.

It is the IHB responsibility to keep this Manual up dated, following inputs from MS and other organisations who are encouraged to provide the IHB with relevant information in this regard. If needed, the IHB will request the advice of the FIG/IHO/ICA International Advisory Board on Standards of Competence for Hydrographic Surveyors and Nautical Cartographers, on the best way to include new material and/or organise the relevant chapter(s).

The IHB will keep the digital version of this Manual on the IHO web page and will print hard copies on demand. With the assistance of readers and of Member States, the IHB will aim to maintain this publication on a regular basis..

The IHB is particularly grateful to Admiral Ritchie of the United Kingdom for his encouragement and support in writing the Introduction to this Manual.

The IHB would like to thank the following principal authors for their efforts in preparing the final text, whilst acknowledging that they were ably assisted by many others who remain unnamed:

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INTRODUCTION

BRIEF HISTORY OF HYDROGRAPHY

The oldest navigational chart known today is the Carte Pisane, so named as it was bought in 1829 from a Pisan family by the Bibliothèque Nationale in Paris. It was drawn on an animal skin towards the end of the 13thC, probably in Genoa where a school of marine cartography had been established; there was a similar school in Venice, while a third school was developed on the isle of Majorca. Known as 'portolans' the charts produced by each of these schools were similar in style and content. The most striking feature was networks of interconnecting rhumb lines emanating from compass roses representing 32 winds directions, each one of which could be used with dividers to set a ship's course. The entire Mediterranean coastline was depicted, the coastal names shown on the land leaving the sea area clear for track plotting. There were a few symbols including the cross for submerged rock but no depth soundings.

By the 15thC Portuguese and Spanish portolans enabled Mediterranean seamen to sail to southern England and Flanders to load wool.

For generations the northern seamen had navigated from one headline to another using written directions and soundings handed down from their forebears, a method of pilotage known as 'caping the ship'. With the development of printing Pierre Garcie of Rouen was the first to publish caping information in his 'Routier de la Mer', which he illustrated with simple woodcut coastal views.

Cornelius Anthonisz, a draughtsman of Amsterdam realised that woodcut blocks could be used to print charts on paper, his first being his 'Karte van Ostland' of the Baltic and North Seas. Whilst adopting rhumb lines and other portolan features, he used Ptolomy's projection which had recently been rediscovered in Constantinople.

Anthonisz had shown the way but it was Lucas Janszoon Waghenauer of Enkhuizen in Holland who, forty years on, printed paper charts from copper plate engravings. For many years he had travelled widely as a sea pilot gathering hydrographic information and when he came ashore at the age of 49 he enlisted fellow mariners to supply him with such material for compiling his charts. In 1584 Waghenauer published his great atlas 'Spiegel der Zeevaerdt' (Mirror of the Sea) containing 45 charts covering the European coasts from Norway to the Strait of Gibraltar. He introduced many new features such as coastal recognition profiles behind the coastlines; reducing the distances between harbours so that their approaches could be shown on a larger scale; the introduction of symbols for buoys, beacons, church spires etc. and soundings reduced to their depth at half tide.

Waghenauer had made the great breakthrough in producing a paper chart designed by a seaman for seamen. He had a number of Dutch followers so that, for over 100 years, Dutch charts were widely available, even of British waters; eventually King Charles decided that the whole of Britain's coasts and harbours should be surveyed.

For this massive task he selected a naval officer named Greenville Collins, granted him the title 'Hydrographer to the King' and provided him with the yacht Merlin. The work began in 1681 and took eleven years.

There was no general topographic map of the Kingdom to which Collins could relate his charts, nor did he have any method of finding his longitude and only the quadrant to assess his latitude; his soundings reduced to low water were fixed by compass bearings of shore marks which in turn were fixed by compass and measuring chain. In 1693 the resulting charts were published in an atlas entitled 'Great Britain's Coasting Pilot', which contained 47 charts and 30 pages of tide tables, sailing directions and coastal views. Precisely engraved, the charts included soundings and leading lines for harbour entry etc. The Pilot appealed to British seamen, a further twenty editions being published during the next hundred years.

During the 16thC a school of hydrography was formed in Dieppe by the many sea pilots who sailed to distant shores. In 1661 Jean Baptiste Colbert became Chief Minister to Louis XIV and among his many tasks was that of revitalising the French Navy. He not only took over the Dieppe school but established similar hydrographic centres in a number of other French ports. This enabled him to have surveys made of the whole French coastline, every chart being directly connected to the national triangulation established by the Cassini dynasty.

Colbert's cadre of hydrographers were working in New France and the mass of material coming from Quebec led to the establishment in Paris of the 'Dépôt Général des Cartes et Plans', now recognised as the first national Hydrographic Office. Denmark was the next nation to establish a Hydrographic Office, followed closely by the British in 1795; a further twenty or so countries established such offices in 19thC.

About 1775 two British surveyors, Murdoch Mackenzie and his nephew of the same name were largely responsible for the invention of the station pointers, a device with which a vessel's position could be precisely plotted by the observation of two horizontal angles between three fixed marks onshore. This was a major technical advance which revolutionised sea surveying throughout the 19thC during which the demands for navigational charts both for war and peace increased dramatically.

Even before World War I a number of national Hydrographers were considering how international co-operation could lead to the exchange of and the standardisation in chart design. With the end of the War the British and French Hydrographers jointly called for an international Conference at which delegates from 22 countries gathered in London in June 1919. Many Resolutions were adopted by the Conference concerning chart standardisation and finally a Resolution to form an International Hydrographic Office with three Directors.

H.S.H. Prince Albert I of Monaco, who had been kept in touch with the Proceedings of the Conference, generously agreed to provide a building in the Principality to house the Bureau where it remains.

The history of hydrography during the 20thC, during which there have been many technical developments, can be followed in the 75th Anniversary Commemorative Issue of the International Hydrographic Review dated March 1997.

IMPORTANCE OF HYDROGRAPHY

Firstly it is necessary to consider the IHO definition of Hydrography, which stands as follows:

That branch of applied sciences which deals with the measurement and description of the features of the seas and coastal areas for the primary purpose of navigation and all other marine purposes and activities, including –inter alia- offshore activities, research, protection of the environment, and prediction services. (IHO Pub. S-32)

Therefore, the development of a National Maritime Policy requires a well developed capability to conduct all these activities which will allow the obtaining of basic knowledge of the geographical, geological and geophysical features of the seabed and coast, as well the currents, tides and certain physical properties of the sea water; all of this data must then be properly processed so that the nature of the sea bottom, its geographical relationship with the land and the characteristics and dynamics of the ocean can be accurately depicted in all zones of national shipping. In brief, Hydrography, as defined, is the key to progress on all maritime activities, normally of great national economic importance.

To adequately address areas of safe and efficient operation of maritime traffic control; coastal zone management; exploration and exploitation of marine resources; environmental protection and maritime defence, it is necessary to create a Hydrographic Service. The Hydrographic Service, through systematic data collection carried out on the coast and at sea, produces and disseminates information in support of maritime navigation safety and marine environment preservation, defence and exploitation.

To adequately address areas such as:

- Safe and efficient operation of maritime traffic control;
- Coastal Zone Management;
- Exploration and Exploitation of Marine Resources;
- Environmental Protection;
- Maritime Defence.

It is necessary to create a Hydrographic Service. The Hydrographic Service, through systematic data collection carried out on the coast and at sea, produces and disseminates information in support of maritime navigation safety and marine environment preservation, defence and exploitation.

FIELDS OF COMPETENCE ASSOCIATED WITH HYDROGRAPHY

Maritime Transport

More than 80% of international trade in the world is carried by sea. Maritime commerce is a basic element for a nation's economy. Many areas and ports in the world do not have accurate nor adequate nautical chart coverage. Modern nautical charts are required for safe navigation through a country's waters and along coasts and to enter its ports. A lack of adequate nautical charts prevents the development of maritime trade in the waters and ports of the concerned nations.

The shipping industry needs efficiency and safety. Poorly charted areas and the lack of information can cause voyages to be longer than necessary, and may prevent the optimum loading of ships, thus increasing costs. The saving of time and money resulting from the use of shorter and deeper routes and the possibility to use larger ships or load ships more deeply may produce important economies for national industry and commerce. It is also very important to note that the SOLAS Convention Chapter V considers a ship unseaworthy if it does not carry up-to-date charts necessary for the intended voyage.

A solution to these problems would not be possible without the quality maps and charts produced and continually updated and distributed by a Hydrographic Service. These charts, produced by means of modern hydrographic surveys, are required to enable the larger ships of today to navigate through national waters and enter ports the access to which was formerly insecure and therefore are essential tools for the creation of coastal nations' incomes.

Modern charts also provide information required to create the routing systems established by international conventions and to meet the economic interests of the coastal state.

Coastal Zone Management

Adequate coastal zone management includes items such as construction of new ports and the maintenance and development of existing ones; dredging operations for the maintenance of charted depths and for the establishment, monitoring and improvement of channels; control of coastal erosion; land reclamation from the sea; establishment and monitoring of dumping grounds for industrial waste; extraction of mineral deposits; aquacultural activities; transportation and public works projects including construction of near shore infrastructure.

Precise large-scale surveys provide the primary data essential for projects involving all items mentioned above. Due to the rapid changes to which shorelines are subject, these surveys must be updated with the frequency dictated by the monitoring and analysis process. The information collected by Hydrographic Offices about the coastal zone provides essential input to coastal zone GIS (Geographic Information Systems) which are increasingly being used for better overall management and decision-making with regard to conflicting uses within the coastal region. The users of hydrographic information go beyond the traditional user group, mariners, to include government agencies, coastal managers, engineers, and scientists.

Exploration and exploitation of marine resources

Although intended primarily to support safety of navigation, the extensive data-bases amassed over the years by Hydrographic Offices, together with their various products and services, are of considerable economic value in assisting the management and exploitation of natural marine resources. In recent years, it has become more evident that inadequate hydrographic services not only restrict the growth of maritime trade but also lead to costly delays in resource exploration.

Coastal and offshore sedimentary areas may contain mineral deposits, in particular hydrocarbons, which require adequate surveys in order to be identified. If the existence of these hydrocarbons is confirmed, this will lead to the coastal nation's undertaking development of hydrocarbon production which implies interpretation of the sea floor morphology; navigation safety for the transportation of these hazardous cargoes; safety of offshore platforms and related sea floor transmission systems and the placement of production wells and the laying of pipelines. Bathymetric, tidal and meteorological data provided by a Hydrographic Service is a fundamental element in the development of a hydrocarbon industry.

The fishing industry is also a source of national wealth. Fishermen need marine information not only for the safe navigation of their vessels but also for safe deployment of their fishing gear, which will prevent costly losses. In addition, oceanographic charts, compiled and produced by Hydrographic Offices, are now being extensively used by the fishing industry.

Fishery activities need detailed charts in order to:

- avoid loss of fishing gear and fishing vessels on undetected or poorly charted obstructions;
- identify fishing areas;
- locate areas where fishing is limited or prohibited.

This kind of information is subject to frequent changes and therefore needs constant updating. Hydrographic surveying is essential to obtain timely and up-to-date information and should be periodically repeated.

The trend of modern fishery science is orientated towards habitat management; bathymetry and other ocean data will provide important input for proper species management and development.

Environment Protection and Management

An essential factor for the protection of the environment is safe and accurate navigation. Pollution caused by wrecks and oil spills are a major damage factor, the economic consequences of which are more devastating than is commonly imagined, but which, in some cases, have been estimated at US \$ 3 billion for a single incident.

The value of navigation services for the protection of the marine environment has been internationally recognized. In this respect, it should be noted that Chapter 17 of Agenda 21 of the United Nations Conference on the Environment and Development (UNCED), held in 1992, recognized that **"Hydrographic charting is vitally important to navigational safety"**

Marine Science

Marine science depends largely on bathymetric information. Global tide and circulation models, local and regional models for a wide variety of scientific studies, marine geology/geophysics, the deployment/placement of scientific instrumentation and many other aspects of marine science depend on bathymetry provided by Hydrographic Services.

National Spatial Data Infrastructure

In the information age it is realised by governments that good quality and well managed spatial data are an essential ingredient to economic and commercial development, and to environmental protection. For this reason many nations are establishing national spatial data infrastructures, bringing together the services and data sets of major national spatial data providers, for example topography, geodesy, geophysics, meteorology, and bathymetry. The Hydrographic Service is an important part of the national spatial data infrastructure.

Maritime Boundary Delimitation

Good hydrographic data is essential to proper delimitation of the maritime boundaries as detailed in the United Nations Convention on the Law of the Sea.

Maritime Defense

Navies are major users of nautical chart products in that they must be prepared for deployment to many areas in the world and typically must maintain a large set of charts. The unique risks associated with the carriage of munitions and nuclear material make it important for such vessels to have up-to-date information. The marine data and information provided by national Hydrographic Offices support a variety of products used in naval operations. Surface, submarine, anti-submarine, mine-hunting and air-sea naval operations need nautical information products very different one from another. Hydrographic and oceanographic data necessary for the preparation of such products must be available if national investment in defence is to be optimised.

Tourism

Good charts are particularly important to the development of the economically important industry of tourism, especially involving cruise ships. The potential of the cruise ship industry is especially important to developing nations. Yet this important source of revenue cannot be properly developed if safe navigation to remote touristic landscapes is prevented or limited by a lack of adequate charts. Tourism is one of the major growth industries of the 21st Century.

Recreational boating

The recreational boating community represents a large percentage of mariners. It is generally not mandatory for leisure craft to carry charts and recreational mariners often do not update their charts; however, the advent of digital chart information is making it possible for the recreational user to have updated chart information readily available along with many types of value added information such as marina locations, etc. This development is likely to result in the recreational leisure sector becoming a significantly larger user of the hydrographic data as greater numbers of people become able to afford boat ownership. Again income from this sector is increasingly significant to many countries.

As it can be seen, it is extremely difficult to quantify the economic and commercial benefits which flow from a national hydrographic programme, but several studies by IHO Member States have suggested that the cost to benefit ratio is about 1:10 for major maritime nations. It is also true that volumes of maritime trade are growing continuously and, in the future, the exploitation and sustainable development of the national maritime zones will become a major pre-occupation of government and industry.

It should also be noted that, in economic parlance, the national hydrographic programme is regarded as a "Public Good". That is to say the necessary services required in the public interest will not be supplied at optimal levels by market forces alone. In every IHO Member State the provision of hydrographic services is a responsibility of central government, as an essential component of national economic development. This overall and important economic dimension of the work has sometimes been obscured by the emphasis on sector interests served by hydrographic services, and more recently by legislative or regulatory requirements. It is clear that the economic dimension of Hydrography deserves greater attention than it has received in the past.

CHAPTER 1 PRINCIPLES OF HYDROGRAPHIC SURVEYING

1. INTRODUCTION

Hydrographic surveying deals with the configuration of the bottom and adjacent land areas of oceans, lakes, rivers, harbours, and other water forms on Earth. In strict sense, it is defined merely as the surveying of a water area; however, in modern usage it may include a wide variety of other objectives such as measurements of tides, current, gravity, earth magnetism, and determinations of the physical and chemical properties of water. The principal objective of most hydrographic surveys, is to obtain basic data for the compilation of nautical charts with emphasis on the features that may affect safe navigation. Other objectives include acquiring the information necessary for related marine navigational products and for coastal zone management, engineering, and science¹.

The purpose of hydrographic surveying is²:

- To collect, with systematic surveys at sea, along the coast and inland, georeferenced data related to:
 - ◆ Shoreline configuration, including man made infrastructure for maritime navigation i.e. all those features on shore that are of interest to mariners.
 - ◆ Depths in the area of interest (including all potential hazards to navigation and other marine activities).
 - ◆ Sea bottom composition.
 - ◆ Tides and Currents.
 - ◆ Physical properties of the water column.
- To process the information collected in order to create organized databases capable of feeding the production of thematic maps, nautical charts and other types of documentation for the following most common uses :
 - ◆ Maritime navigation and traffic management.
 - ◆ Naval operations.
 - ◆ Coastal zone management.
 - ◆ Marine environment preservation.
 - ◆ Exploitation of marine resources and laying of submarine cables/pipelines.
 - ◆ Maritime boundaries definition (Law of the Sea implementation).
 - ◆ Scientific studies.

Mariners have unquestioning faith in nautical charts and where no dangers are shown, they believe that none exist. Nautical chart is an end product of a hydrographic survey. Its accuracy and adequacy depend on the quality of the data collected during the surveys³. A nautical chart is a graphic portrayal of the

¹ NOAA Hydrographic Manual Part-1, Edition July 4, 1976, P-1-3, www.thsoa.org/pdf/hm1976/part1ch123.pdf

² International Hydrographic Organisation, Monaco, National Maritime Policies and Hydrographic Services (M-2), P-13.

³ NOAA Hydrographic manual Part-1, Edition July 4, 1976, P-1-3, www.thsoa.org/pdf/hm1976/part1ch123.pdf

marine environment; showing the nature and form of the coast, depths of the water and general character and configuration of the sea bottom, locations of dangers to navigation, rise and fall of the tides, cautions of manmade aids to navigation, and the characteristics of the Earth's magnetism. The actual form of a chart may vary from a traditional paper chart to an electronic chart.

An electronic chart is not simply a digital version of a paper chart; it introduces a new navigation methodology with capabilities and limitations very different from paper charts. The electronic chart has become the legal equivalent of the paper chart as approved by the International Maritime Organization. Divergences in purpose have led to the publication of various "new-generation" charts. Bathymetric charts developed from digital data or created from multi-beam sounding data allow the underwater relief to be visualised by means of varying blue tints and isobaths. Similarly, side-scan sonar mosaics have been published in the form of charts or atlases to characterise the large geomorphological structures. Such charts no longer have, as their object, the safety of navigation, but rather, the knowledge of the environment required for submarine navigation, oceanographic research or industrial applications, such as cable laying, seabed mining and oil exploitation.

Hydrographic surveying is undergoing fundamental changes in measurement technology. Multibeam acoustic and airborne laser systems now provide almost total seafloor coverage and measurement as compared to the earlier sampling by bathymetric profiles. The capability to position the data precisely in the horizontal plane has been increased enormously by the availability of satellite positioning systems, particularly when augmented by differential techniques. This advance in technology has been particularly significant since navigators are now able to position themselves with greater accuracy than that of the data on which older charts are based⁴.

2. HYDROGRAPHIC SURVEYING

2.1 Survey Specifications

Requirements for hydrographic surveys arise as the result of policy decisions, product user reports or requests, national defence needs, and other demands. The inception of a specific hydrographic survey project follows an evaluation of all known requirements and the establishment of priorities. Among the many objective and subjective factors that influence the establishment of priorities are national and agency goal, quantitative and qualitative measures of shipping and boating, the adequacy of existing surveys, and the rate of change of the submarine topography in the area⁵.

To accommodate in a systematic manner different accuracy requirements for areas to be surveyed, four orders of survey are defined by IHO in publication S-44 edition 98. These are described in subsequent paragraphs. Tables 1 and 2 summarize the overall, requirements and are in fact the essence of the complete standard⁶.

2.1.1 Special Order hydrographic surveys approach engineering standards and their use is intended to be restricted to specific critical areas with minimum under keel clearance and where bottom characteristics are potentially hazardous to vessels. These areas have to be explicitly designated by the agency responsible for survey quality. Examples are harbours, berthing areas, and associated critical channels. All error sources must be minimized. Special Order requires the use of closely spaced lines in

⁴ International Hydrographic Organisation, Monaco, National Maritime Policies and Hydrographic Services (M-2), P-19.

⁵ NOAA Hydrographic manual Part-1, Edition July 4, 1976, P-2-1, www.thsoa.org/pdf/hm1976/part1ch123.pdf

⁶ International Hydrographic Organisation, Monaco, IHO Standards for Hydrographic Surveys (S-44), P-14-8, fourth edition 1998.

conjunction with side scan sonar, multi-transducer arrays or high resolution multibeam echosounders to obtain 100% bottom search. It must be ensured that cubic features greater than 1m can be discerned by the sounding equipment. The use of side scan sonar in conjunction with a multibeam echosounder may be necessary in areas where thin and dangerous obstacles may be encountered.

2.1.2 Order 1 hydrographic surveys are intended for harbours, harbour approach channels, recommended tracks, inland navigation channels, and coastal areas of high commercial traffic density where under keel clearance is less critical and the geophysical properties of the seafloor are less hazardous to vessels (e.g. soft silt or sandy bottom). Order 1 surveys should be limited to areas with less than 100 m water depth. Although the requirement for seafloor search is less stringent than for Special Order, full bottom search is required in selected areas where the bottom characteristics and the risk of obstructions are potentially hazardous to vessels. For these areas searched, it must be ensured that cubic features greater than 2 m up to 40 m water depth or greater than 10% of the depth in areas deeper than 40 m can be discerned by the sounding equipment.

2.1.3 Order 2 hydrographic surveys are intended for areas with depths less than 200 m not covered by Special Order and Order 1 and where a general description of the bathymetry is sufficient to ensure there are no obstructions on the seafloor that will endanger the type of vessel expected to transit or work the area. It is the criteria for a variety of maritime uses for which higher order hydrographic surveys cannot be justified. Full bottom search may be required in selected areas where the bottom characteristics and the risk of obstructions may be potentially hazardous to vessels.

2.1.4 Order 3 hydrographic surveys are intended for all areas not covered by Special Order, and Orders 1 and 2 in water depths in excess of 200 m.

Notes:

For Special Order and Order 1 surveys the agency responsible for the survey quality may define a depth limit beyond which a detailed investigation of the seafloor is not required for safety of navigation purposes.

Side scan sonar should not be used for depth determination but to define areas requiring more detailed and accurate investigation.

TABLE 1.1
Summary of Minimum Standards for Hydrographic Surveys

ORDER	Special	1	2	3
Examples of Typical Areas	Harbours, berthing areas, and associated critical channels with minimum under keel clearances	Harbours, harbour approach channels, recommended tracks and some coastal areas with depths up to 100 m	Areas not described in Special Order and Order 1, or areas up to 200 m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy (95% Confidence Level)	2 m	5 m + 5% of depth	20 m + 5% of depth	150 m + 5% of depth

ORDER	Special	1	2	3
Depth Accuracy for Reduced Depths (95% Confidence Level) ⁽¹⁾	a = 0.25 m b = 0.0075	a = 0.5 m b = 0.013	a = 0.1.0 m b = 0.023	Same as Order 2
100% Bottom Search	Compulsory ⁽²⁾	Required in selected areas ⁽²⁾	May be required in selected areas	Not applicable
System Detection Capability	Cubic features > 1 m	Cubic features > 2 m in depths up to 40 m; 10% of depth beyond 40 m ⁽³⁾	Same as Order 1	Not applicable
Maximum Line spacing ⁽⁴⁾	Not applicable, as 100% search compulsory	3 x average depth or 25 m, whichever is greater	3-4 x average depth or 200 m, whichever is greater	4 x average depth

- (1) To calculate the error limits for depth accuracy the corresponding values of 'a' and 'b' listed in Table 1 have to be introduced into the formula

$$\pm \sqrt{[a^2 + (b*d)^2]}$$

with

- a constant depth error, i.e. the sum of all constant errors
b*d depth dependent error, i.e. the sum of all depth dependent errors
b factor of depth dependent error
d depth

- (2) For safety of navigation purposes, the use of an accurately specified mechanical sweep to guarantee a minimum safe clearance depth throughout an area may be considered sufficient for Special Order and Order 1 surveys.
- (3) The value of 40 m has been chosen considering the maximum expected draught of vessels.
- (4) The line spacing can be expanded if procedures for ensuring an adequate sounding density are used

The rows of Table 1 are explained as follows:

- Row 1 "Examples of Typical Areas" gives examples of areas to which an order of survey might typically be applied.
- Row 2 "Horizontal Accuracy" lists positioning accuracies to be achieved to meet each order of survey.
- Row 3 "Depth Accuracy" specifies parameters to be used to calculate accuracies of reduced depths to be achieved to meet each order of survey.
- Row 4 "100% Bottom Search" specifies occasions when full bottom search should be conducted.

- Row 5 "System Detection Capability" specifies the detection capabilities of systems used for bottom search.
- Row 6 "Maximum Line Spacing" is to be interpreted as
 - spacing of sounding lines for single beam sounders, and
 - distance between the outer limits of swaths for swath sounding systems.

2.2 Survey Planning

Survey planning covers a wide range of activities from the development of an idea for a survey within the Hydrographic Office and its subsequent issue as Project Instructions / Hydrographic Instructions (HIs), to the detailed planning and organisation of a surveying ship to fulfil a practical task. It covers inter departmental liaison at Government level, diplomatic cooperation and the allocation of numerous expensive resources. It also covers prioritization of resources and day to day running of a survey ship employed on surveying task. Survey planning involves blending of these activities into a coherent pattern aimed at the achievement of a specific task.

A survey begins long before actual data collection starts. Some elements, which must be decided, are⁷:

- Exact area of the survey.
- Type of survey (reconnaissance or standard) and scale to meet standards of chart to be produced.
- Scope of the survey (short or long term).
- Platforms available (ships, launches, aircraft, leased vessels, cooperative agreements).
- Support work required (aerial or satellite photography, geodetics, tides).
- Limiting factors (budget, political or operational constraints, positioning systems limitations, logistics).

Once these issues are decided, all information available in the survey area is reviewed. This includes aerial photography, satellite data, topographic maps, existing nautical charts, geodetic information, tidal information, and anything else affecting the survey. HO will normally undertake this strategic planning of surveys in cooperation with other organisations and, from this, Projects Instructions / Hydrographic Instructions (HIs) will be compiled by the Hydrographer and issued for compliance. Details provided in Project Instructions / HIs will include some or all of the following, depending on the type of survey required⁸:

- Survey limits.
- Data requirement and resolution.
- Method of positional control, together with the accuracy expected.
- Use to be made of sonar.
- How the survey report is to be rendered and target date if appropriate.
- A general, and at times detailed, description of the reason for the survey priorities, methods to be employed, particular observations to be made and other relevant guidance or instruction.

In addition, appendices to HIs will give instruction or guidance on the following:

- Horizontal datum, projection and grid to be used.
- Wrecks in the area.

⁷ Bowditch -The American Practical Navigator, P-411, <http://www.irbs.com/bowditch/>

⁸ Admiralty, General Instructions for Hydrographic Surveys (GIHS), Sixth Edition, 1992, P- 5-3.

- Tidal datum and observations required.
- Particular instructions regarding the collection of data in respect of oceanography, geophysics, sailing directions, air photography etc.

On receipt of Project Instructions/HIs, the survey planners then compile sound velocity information, climatology, water clarity data, any past survey data, and information from lights lists, sailing directions, and notices to mariners. Tidal information is thoroughly reviewed and tide gauge locations chosen. Local vertical control data is reviewed to see if it meets the expected accuracy standards, so the tide gauges can be linked to the vertical datum used for the survey. Horizontal control is reviewed to check for accuracy and discrepancies and to determine sites for local positioning systems to be used in the survey.

Development of a general survey plan and subsequent site specific survey plans will create a more efficient survey. The general survey plan addresses the way that surveys are planned, performed, and processed. This plan must be well thought out and robust to account for as many contingencies as possible. This plan includes training, software, equipment maintenance and upgrades, logistics, all data requirements, schedule, safety, and weather. The site specific survey plan will address local notifications, survey lines, datum, data density, and specific equipment and personnel that will meet the general survey plan requirements. Few are described below:

- Training of surveyors should be catered during a survey operation in order to ensure appropriate competencies are maintained.
- Data logging and processing software are critical in a survey operation. These should be user friendly and personnel employed on these need to be well conversant with its all functions.
- Suitable survey platform and equipment should be selected. Some equipment will lend itself to particular types of surveys and others will be more general in use. It is paramount that a proper selection is made.
- The purpose for the survey will usually dictate the data requirement (density, coverage, and precision). However, if there are no impact to cost and schedule, then as many requirements should be addressed as possible.
- Schedule is often a critical element in a hydrographic survey. The data requirement usually has as a specific deliverable date assigned, such that the survey data collection and processing occur within a very specific time frame. This requires that the personnel and equipment resources be adequate to meet this need. In some cases, if the schedule cannot be met, then the survey simply will not be requested and other sources will be used. Considering this, it is important to plan and analyze all aspects of a general survey plan with the ability to meet schedule as a prime element.
- Safety is the primary consideration. It is incumbent on the person in charge in the field to evaluate every situation for possible hazards. If there is an identified hazard, then it needs to be addressed before continuing with the activity.
- Notifications to the local authorities / harbourmaster office should be made with enough time to allow them to notify the local mariners.
- Survey lines for multibeam surveys should follow the contours of the harbour bottom. This will reduce the changes in bottom coverage created by different water depths. However, when using a single beam survey system, the lines should run perpendicular to contours. This will help in

determining changes in the bottom relief. Multibeam survey lines also need to be spaced so as to achieve the proper amount of overlap or data density to meet the survey standard.

- An integral part of the data of a survey is the reference datum. It is required, by good survey practice, to clearly indicate by note on the published survey the actual vertical and horizontal reference used, and the procedures used to establish the datum for the survey. WGS-84 is being used worldwide.
- Data density will vary based on method of survey, water depth, and need. The method of survey will be determined by equipment available for the survey, the personnel, and survey site conditions. If only a single beam survey system is available, then data density will be less. With a multibeam system, the greater the water depth the less dense the data will be, unless multiple passes are made. The type of survey will dictate the data redundancy or data overlap requirements.
- It is important to standardize the equipment as much as possible to limit training, maintenance and overheads.

2.3 Data Gathering

Data gathering is dependent upon various factors. The survey requirements, the platform and equipment available and the time specified for a particular task will determine the amount of data to be collected. A large amount of data can be collected using latest hydrographic software's and tools like multibeam echo sounders. In particular, the purpose of the survey will usually dictate the data requirement (data density, data coverage, and data precision). However, if there is no impact to cost and schedule, then as many data may be collected as possible during field survey. The data collection be made in methodical manner starting from one side of the area ending on other.

It should be noted that data redundancy and data density are not the same thing. Data density is the number of soundings per unit of area, while data redundancy refers to data overlap or data collected at a different time at the same location. The type of survey defines data redundancy or data overlap requirements. Full coverage surveys deal more with data density insuring that all bottom features/obstructions have been located. These need to be clearly understood by those requesting the survey and those doing the survey to insure compliance with the standards specified by IHO.

2.4 Data Processing

Data processing must be done under strict quality control criteria. Hydrographic data is either collected by automated systems or converted into an automated format. Final data processing and plotting are accomplished using onboard or office-based computer systems. A standard approach for a hydrographic survey is the collect-process-collect methodology⁹. The data collected is processed and subsequently gaps and areas with questionable data re-surveyed. Most of the hydrographic systems are capable of performing "field-finish" operations, wherein survey data is collected, processed, plotted and analyzed in the field. Comprehensive survey planning is required for an integrated approach that generates the base line for all real-time and post processing operation with the system. An example of such a model is given below¹⁰:

⁹ B. Bourgeois, F. Petry, M. Harris & P. Alleman, "A GIS Integration Approach for Dynamically Reconfigurable Surveys", *The Hydrographic Journal*, January 1999, P 3-10.

¹⁰ Pentti Junni & Ralf Lindgren, "The Hydrophic Information System – Co-operation, Concept and Future", *Finish Maritime Administration*, <http://www.esri.com/library/userconf/proc97/proc97/pap619/p619.html>

Data + Process = Job

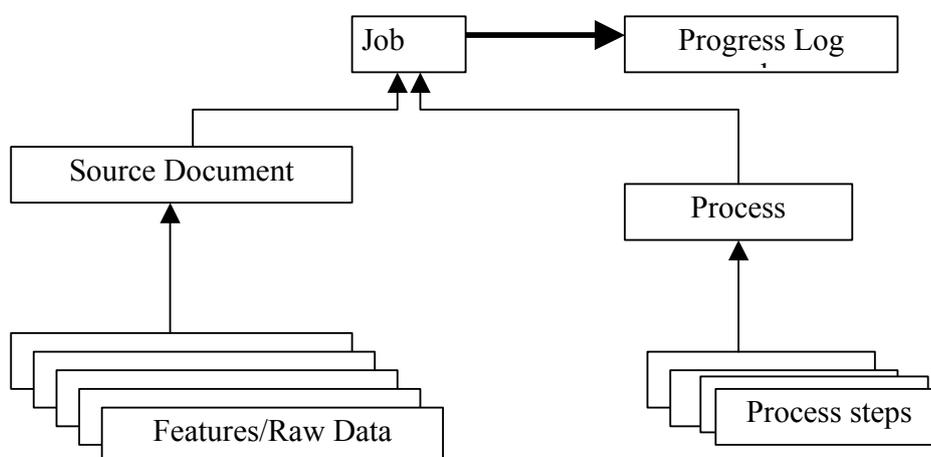


Fig. 1.1 "Data Processing model"

This model describes the different processes that can ideally handle the hydrographic information. The process contains several steps. The comments of each process step along with results, statistics should be recorded in a progress log. Further, the source and general quality information of any new data be described in source document which is stored in the database.

The core requirement of data processing is the generation of valid data; which has been sufficiently processed i.e. undergone through various procedures at various stages or represented so that evaluation can be made. These procedures/processing steps could be applied in real-time or during post processing but have to ensure that the final product meets the standards and specifications defined by IHO.

Care is to be exercised in processing the raw data. It is to be ensured that all errors have been eliminated and necessary corrections e.g. system calibration factors and sensor offsets, or variable values such as sound velocity profiles and tide values for the reduction of soundings, have been applied. The processing should strive to use all available sources of information to confirm the presence of navigationally significant soundings and quality data. Few processing steps outlined below are only to be interpreted as an indication, also with regard to their sequence, and are not necessarily exhaustive¹¹:

- **Position:** Merging of positioning data from different sensors (if necessary), qualifying positioning data, and eliminating position jumps.
- **Depth corrections:** Corrections should be applied for water level changes, measurements of attitude sensors, and changes of the draught of the survey vessel (e. g. squat changing with speed; change over time caused by fuel consumption). It should be possible to re-process data for which corrections were applied in real-time.
- **Attitude corrections:** Attitude data (heading, pitch, roll) should be qualified and data jumps be eliminated.

¹¹ IHO, Monaco, Circular Letter 45/2001, "Guidelines for the Processing of High Volume Bathymetric Data", Para-3.2, dated 5 Oct 01.

- **Sound velocity:** Corrections due to refraction be calculated and applied; If these corrections have already been applied in real-time during the survey, it should be possible to override them by using another sound velocity profile with the advent of MBES, the application of S V has become critical.
- **Merging positions and depths:** The time offset (latency) and the geometric offset between sensors have to be taken into consideration.

2.5 Data Analysis

The accuracy of the results of survey measurement should always be quoted to show how good or reliable they are. Since no equipment is entirely free of errors, therefore, errors are introduced in all observations. In addition, errors are introduced in computations by approximations in formulae or by rounding. Observational techniques are designed to eliminate all but small random errors, which can then be analyzed by rigorous techniques to quantify the accuracy of the observations. Various errors, their sizes and procedures to eliminate are as under:

ERROR	SIZE	ELIMINATION
Blunder	Large	Training, care procedures.
Constant	Usually small, but fixed	Calibration or procedures
Periodic	Usually small, but variable	Procedure (repetition), even for large errors
Random	Usually small	Only reduced, by repetition

Constant, Systematic and Periodic errors are frequently considered together as ‘Systematic Errors’. Constant and Systematic errors are accumulative, and thus cannot be reduced by repetition. Random errors are present in all observations; the result can never be ‘exact’. These errors are as likely to be positive as negative and more likely to be of small size.

It is important that no method of adjustment can obtain an accurate solution from inaccurate observations. All errors other than small random ones must be eliminated prior to the adjustment. However, it may be possible to isolate a ‘systematic’ error by analysis, provided that sufficient data is available. It is clearly desirable to know when Constant and / or Systematic Errors are present in observations. Constant Errors are often difficult to detect, and may only become apparent during computation or in special checks, e.g., an incorrectly calibrated crystal of a Tellurometer can be detected if that Tellurometer is compared with another. Periodic and Random Errors however can often be detected by analyzing a series of observations. The algebraic difference between each observation and the mean of all the observations is called the Residual of that observation. If only random errors are present, then the Residuals will vary randomly in magnitude and sign. If systematic errors are present then the magnitudes and / or the signs of the Residuals will show systematic trends. To assist in data analysis, raw data attributes and metadata should be mentioned for subsequent evaluation.

2.6 Data Quality

Quality is about “fitness for the use”. It has to do with the extent to which a data set, or map output satisfied the needs of the person judging it. Error is the difference between actual and true data. Error is a major issue in quality. It is often used as an umbrella term to describe all the types of the effects that

cause data to depart from what they should be¹². To allow a comprehensive assessment of the quality of survey data, it is necessary to record or document certain information together with the survey data. Such information is important to allow exploitation of survey data by a variety of users with different requirements, especially as requirements may not be known when survey data is collected. The process of documenting the data quality is called data attribution; the information on the data quality is called metadata. Metadata should comprise at least information on¹³:

- The survey in general as e.g. date, area, equipment used, name of survey platform.
- The geodetic reference system used, i.e. horizontal and vertical datum; including ties to WGS 84 if a local datum is used.
- Calibration procedures and results.
- Sound velocity.
- Tidal datum and reduction.
- Accuracies achieved and the respective confidence levels.

Metadata should preferably be in digital form and an integral part of the survey record. If this is not feasible similar information should be included in the documentation of a survey. Data quality can be achieved by effective quality control either by automatic or manual means¹⁴.

- **Automatic (Non-interactive) Quality Control:** In this, the coordinates (i.e. positions and depths) obtained should be controlled automatically by a programme using suitable statistical algorithms which have been documented, tested and demonstrated to produce repeatable and accurate results.
- **Manual (Interactive) Quality Control:** In this, the use of 3-D visualisation tools is strongly recommended. These tools should allow viewing the data using a zoom facility. The interactive processing system should also offer different display modes for visualisation, e.g. depth plot, error plot, single profile, single beam, backscatter imagery etc. and should allow for the visualisation of the survey data in conjunction with other useful information as e.g. shoreline, wrecks, aids to navigation etc; editing of data should be possible in all modes and include an audit trail. If feasible, data displays should be geo-referenced. The flags set during the automatic stage, which correspond to depths shallower than the surrounding area, should require explicit operator action, at least, for Special Order and Order 1 surveys. If the operator overrules flags set during the automatic stage, this should be documented. If a flag is set by the operator, the type of flag used should indicate this.

2.7 Data Quality - Presentation

2.7.1 Chart Reliability Diagrams

Traditionally, the quality of bathymetric data has been a subjective procedure. For a user, the quality of the data which is presented is assessed through the chart reliability diagram. This diagram is displayed as an inset on a chart and indicates the areas surveyed together with some detail, e.g. scale, line spacing, year

¹² Patrick McGlamery, "Issues of Authenticity of Spatial data", University of Connecticut USA, 66th IFLA Council and General Conference, <http://magic.lib.uconn.edu>.

¹³ International Hydrographic Organisation, Monaco, IHO Standards for Hydrographic Surveys (S-44), P-12, fourth edition 1998.

¹⁴ IHO, Monaco, Circular Letter 45/200, "Guidelines for the Processing of High Volume Bathymetric Data", Para-3.3, dated 5 Oct 01.

of survey. Unfortunately, the very nature of the information displayed on a reliability diagram, the ability to qualify data quality is severely limited. For instance, if the chart user is unaware what a pre 1970 sonar swept area means or what might be inferred from a line spacing of “n” metres, then the reliability diagram is of little real use in determining the quality of the depth data shown.

The original concept of the reliability diagram was to classify the quality of survey data and depict the different classifications on a diagram in terms of good, fair or poor quality. The diagram was intended to provide the mariner with the capacity to assess the danger of deviating from the recommended track. However, there has been growing concern over the complexity of the reliability diagram and the increasing difficulty of maintaining it in a form which is simple for the chart user. If they are too complicated; reliability diagrams become difficult to construct as a cartographic activity, prone to error in construction, and its use would be ignored by the mariners.

Reliability diagrams fall well short of achieving the fundamental aim of providing an indication of data quality to the mariner and in a very simple form. Furthermore, given the precise navigation capability which ENC and the ECDIS can facilitate, users require a far more definitive assessment of data quality to be available so that they can use the available information prudently. Thus, an alternative to the existing reliability diagram is required as the final quality indicator.

Source diagrams and similar variants shown on charts are all considered to present similar shortcomings.

2.7.2 Zones of Confidence (ZOC)

The ZOC concept was developed by the IHO to provide a mean of classifying bathymetric data. ZOC provide a simple and logical mean of displaying to the mariner the confidence that the national charting authority places on any particular selection of bathymetric data. It seeks to classify areas for navigation by identifying the various levels of confidence that can be placed in the underlying data using a combination of the following criteria:

- * Depth and position accuracy,
- * Thoroughness of seafloor search, and
- * Conformance to an approved quality plan.

Under this concept six ZOCs were developed and subsequently approved for inclusion as a part of IHO S-57. ZOCs A1, A2, and B are generated from modern and future surveys with, critically, ZOCs A1 and A2 requiring a full area search. ZOCs C and D reflect low accuracy and poor quality data whilst ZOC U represents data which is un-assessed at the time of publication. ZOCs are designed to be depicted on paper charts, as an insert diagram in place of the current reliability diagram, and on electronic displays.

It must be emphasized that ZOCs are a charting standard and are not intended to be used for specifying standards for hydrographic surveys or for the management of data quality. The depth and position accuracy specified for each ZOC refer to the errors of the final depicted soundings and include not only survey errors but also any other errors introduced in the chart production process. The following paragraphs summaries individual ZOC specifications:

2.7.2.1 ZOC A1 – Position and depth data gathered in accordance with procedures and accuracies specified. Surveys conducted using recognized technology with a full area search undertaken with the aim of ensuring that all significant features are detected and depths measured. Typically, the survey would have been undertaken on WGS 84, using DGPS or a minimum three lines of position with multibeam, channel or mechanical sweep system. Due to the intensity of data gathering and the considerable time required to achieve this standard it can be expected that data with a ZOC A1 rating will

most likely indicate critical channels, berthing areas, areas with minimum under keel clearances, navigation channels, recommended tracks, harbours and harbour approaches.

2.7.2.2 ZOC A2 – Position and depth data gathered in accordance with procedures and accuracies specified. Survey conducted using recognized technology with a full area search undertaken with the aim of ensuring that all significant features are detected and depths measured. Typically, the survey would have been conducted using a modern survey echosounder with sonar or mechanical sweep. Although position and depth accuracies not as high as ZOC A1, seafloor coverage is such that the mariner should have a high level of confidence in the quality of data.

2.7.2.3 ZOC B – Position and depth data gathered in accordance with procedures and accuracies specified. However, a full area search has not been achieved and uncharted features, hazardous to surface navigation, although not expected, may exist. This ZOC indicates to the mariner a reasonable level of confidence in the quality of data. ZOC B has the same position and depth accuracies as those required for ZOC A2 and would apply to (e.g.) modern surveys which have not achieved a full seafloor search and feature detection. The prudent mariner would require more under keel clearance in this ZOC than in ZOC A1 or A2.

2.7.2.4 ZOC C – Position and depth accuracy less than that achieved for ZOC B as described. Depth data may originate from sources other than a controlled, systematic hydrographic survey (e.g. passage sounding). A full area search has not been achieved and depth anomalies may be expected. ZOC C indicates that the mariner should navigate with special care and allow, with due regard to the depth of water in which they are navigating, greater safety margins to the charted information.

2.7.2.5 ZOC D – Position and depth data is of a very low quality or cannot be assessed due to a lack of supporting information. A full area search has not been achieved and large depth anomalies may be expected.

2.7.2.6 ZOC U – The quality of bathymetric data has yet to be assessed.

TABLE 1.2

Category of Zones of Confidence in Data – ZOC Table

1	2	3		4	5
ZOC ¹	Position ² Accuracy	Depth Accuracy ³		Seafloor ⁴ Coverage	Typical Survey ⁵ Characteristics
A1	± 5m	= 0.50 + 1%d		Full area search undertaken. All significant seafloor features ⁴ detected have had depths measured.	Controlled, systematic survey ⁶ high position and depth accuracy, achieved using DGPS or a minimum of three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system.
		Depth(m)	Accuracy (m)		
		10	± 0.6		
		30	± 0.8		
		100	± 1.5		
		1000	± 10.5		
ZOC ¹	Position ² Accuracy	Depth Accuracy ³		Seafloor ⁴ Coverage	Typical Survey ⁵ Characteristics
		A2	± 20m		
		Depth(m)	Accuracy (m)		
		10	± 1.2		
		30	± 1.6		
		100	± 3.0		
		1000	± 21.0		
B	± 50m	= 1.00 + 2%d		Full area search not achieved; uncharted features, hazardous to surface navigation, are not expected, but may exist.	Controlled, systematic survey ⁶ achieving similar depth but lesser position accuracies than ZOC A2, using a modern survey echosounder ⁷ but no sonar or mechanical sweep system.
		Depth(m)	Accuracy (m)		
		10	± 1.2		
		30	± 1.6		
		100	± 3.0		
		1000	± 21.0		
C	± 500m	= 2.00 + 5%d		Full AREA SEARCH NOT ACHIEVED; depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as soundings on passage.
		Depth(m)	Accuracy (m)		
		10	± 2.5		
		30	± 3.5		
		100	± 7.0		
		1000	± 52.0		
D	Worse than ZOC C	Worse Than ZOC C			Poor quality or data that cannot be assessed due to lack of information.
U		Un-assessed			

Notes:

To decide on a ZOC category, all conditions outlined in Columns 2 to 4 of the Table must be met, Explanatory note numbers quoted in the table have the following meanings:

1. The allocation of a ZOC indicates that particular data meets minimum criteria for position and depth accuracy and seafloor coverage defined in the Table. ZOC categories reflect a charting standard and not just a hydrographic survey standard. Depth and position accuracies specified for each ZOC category refer to the errors of the final depicted soundings and include not only hydrographic survey errors but also other errors introduced in the chart production process. Data may be further qualified by Object Class “Quality of Data” (M_QUAL) sub-attributes as follows:
 - * Positional Accuracy (POSACC) and Sounding Accuracy (SOUACC) may be used to indicate that a higher position or depth accuracy has been achieved than defined in this Table (e.g. a survey where full seafloor coverage was not achieved could not be classified higher than ZOC B; however, if the position accuracy was, for instance ± 15 metres, the sub-attribute POSACC could be used to indicate this).
 - * Swept areas where the clearance depth is accurately known but the actual seabed depth is not accurately known may be accorded a “higher” ZOC (i.e. A1 or A2) providing position and depth accuracies of the swept depth meets the criteria in this Table. In this instance, Depth Range Value 1 (DRVAL1) may be used to specify the swept depth. The position accuracy criteria apply to the boundaries of swept areas.
 - * SURSTA, SUREND and TECSOU may be used to indicate the start and end dates of the survey and the technique of sounding measurement.
2. Position accuracy criteria at 95% CI (2.45 sigma) with respect to the given datum. It is the cumulative error and includes survey, transformation and digitizing errors etc. Position accuracy need not be rigorously computed for ZOCs B, C and D but may be estimated based on type of equipment, calibration regime, historical accuracy etc.
3. Depth accuracy of depicted soundings for (e.g.) ZOC A1 = 0.50 metres + 1% d at 95% CI (2.00 sigma) where d = depth in metres at the critical depth. Depth accuracy need not be rigorously computed for ZOCs B, C and D but may be estimated based on type of equipment, calibration regime, historical accuracy etc.
4. Significant seafloor features are defined as those rising above depicted depths by more than:

Note: Mariners should have due regard to limitations of sounding equipment when assessing margins of safety to be applied.

<u>Depth</u>	<u>Significant Feature</u>
< 10 metres	> 0.1 x depth
10 to 30 metres	> 1.0 metre
> 30 metres	> (0.1 x depth minus 2.0 metres)

5. Typical Survey Characteristics – These descriptions should be seen as indicative examples only.

6. *Controlled, systematic surveys (ZOCs A1, A2 and B) – surveys comprising planned survey lines, on a geodetic datum that can be transformed to WGS 84.*
7. *Modern survey echosounder – a high precision single beam depth measuring equipment, generally including all survey echosounders designed post 1970.*

2.8 Data Production

The final data production can both be in digital and analog form. Schematic diagram is given below.

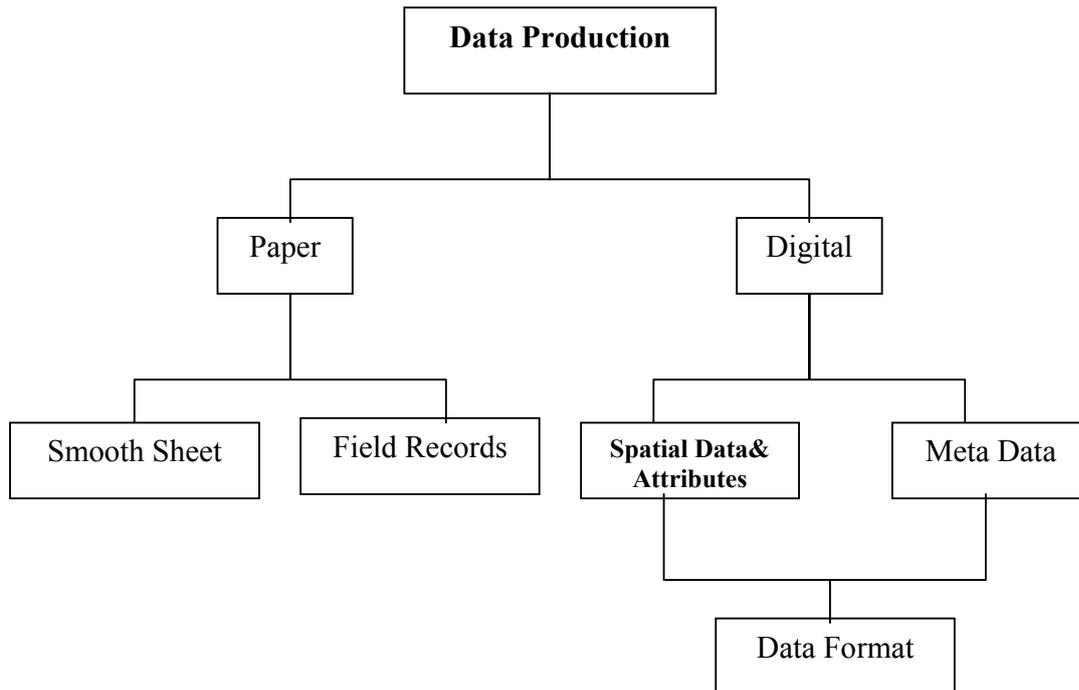


Fig. 1.2 "Digital Production schematic diagram"

Digital data should be in defined format to be directly imported into main database. As each survey typically includes numerous supporting documents and digital data files, deliverables must clearly be labelled in a manner that is both descriptive and intuitive to hydrographic office personnel. Ideally, standard operating procedures agreed by IHO and field units which covers such documents and digital data files, are enforced. **Manual** data should be clear, concise and in legible form which is properly labelled and marked¹⁵.

After the data is collected, processed and plotted in the form of smooth sheets (manuscript in digital form), the inventory of the final deliverables is forwarded to Hydrographic office, the inventory of which should generally include¹⁶:

¹⁵ <http://www.hydro.navy.gov.au/news/htf/htf.pdf>.

¹⁶ Lieutenant Eric J. Sipos and Physical Scientist Castle Parker, "NOAA AHB Quality Assurance Inspections for Contract Hydrographic Surveys", NOAA Hydrographic Survey Division, USA

- Smooth Sheets.
- Digital files of smooth sheet with attributes.
- Raw and processed bathymetric data.
- Tide, sound velocity and vessel configuration files.
- Side scan data files.
- Descriptive report and supplemental reports.
- Field logs and documentation of processing.
- Calibration documentation.

2.9 Nautical Information System (NIS)

Nautical Information system is the combination of skilled persons, spatial and descriptive data, analytic methods and computer software and hardware - all organized to automate, manage and deliver information through presentation i.e. paper and digital charts. Previously, the main use of nautical chart databases was in the production of paper charts. Advances in navigation technology have set new demands on accuracy, reliability and the format of nautical charts. The positional accuracy of the chart should meet the increased accuracy of the positioning systems. To fully benefit from the dynamics of the modern positioning methods, the need of digital chart has arisen in parallel to the traditional printed charts. An international standard for digital hydrographic data has been developed by the International Hydrographic Organization (IHO). The valid version of the standard, S-57 edition 3.1 was adopted as the official IHO standard in November 2000 and is also specified in the International Maritime Organization (IMO) Performance Standards for Electronic Chart Display and Information Systems (ECDIS). S-57 describes the standard to be used for the exchange of digital hydrographic data between national Hydrographic Offices and for the distribution of digital data and products to manufacturers, mariners, and other data users. The most significant digital product being delivered in the S-57 format is the electronic navigational chart (ENC). The rapidly increased need for electronic navigational charts (ENC) has led to a situation for many hydrographic offices where there are two separate production lines for the two products, ENC cells and paper charts. It is essential for the safety of navigation that the products are not in conflict with one another. A typical NIS has four main functional subsystems¹⁷ (Fig 1.3).

- **Data Input.** The data input subsystem allows the user to capture, collect, and transform spatial and thematic data into digital form. The data inputs are usually derived from a combination of hard copy maps, aerial photographs, remotely sensed images, reports, survey documents, etc.
- **Data Base - Storage and Retrieval.** Data storage and retrieval subsystem organizes the data, spatial and attribute, in a form which permits it to be quickly retrieved by the user for analysis, and permits rapid and accurate updates to be made to the database.
- **Data Base - Manipulation and Analysis.** The data manipulation and analysis subsystem allows the user to define and execute spatial and attribute procedures to generate derived information. This subsystem is commonly thought of as the heart of a GIS, and usually distinguishes it from other database information systems and computer-aided drafting (CAD) systems.
- **Data Output.** The data output subsystem allows the user to generate graphic displays, normally maps, and tabular reports representing derived information products.

¹⁷ Dan Sherrill and Asa Carlsson, "The JANUS Solution for Hydrographic Information", T-Kartor AB Sweden- Box 5097 - S-291 05 Kristianstad – Sweden, ds@t-kartor.se & ac@t-kartor.se

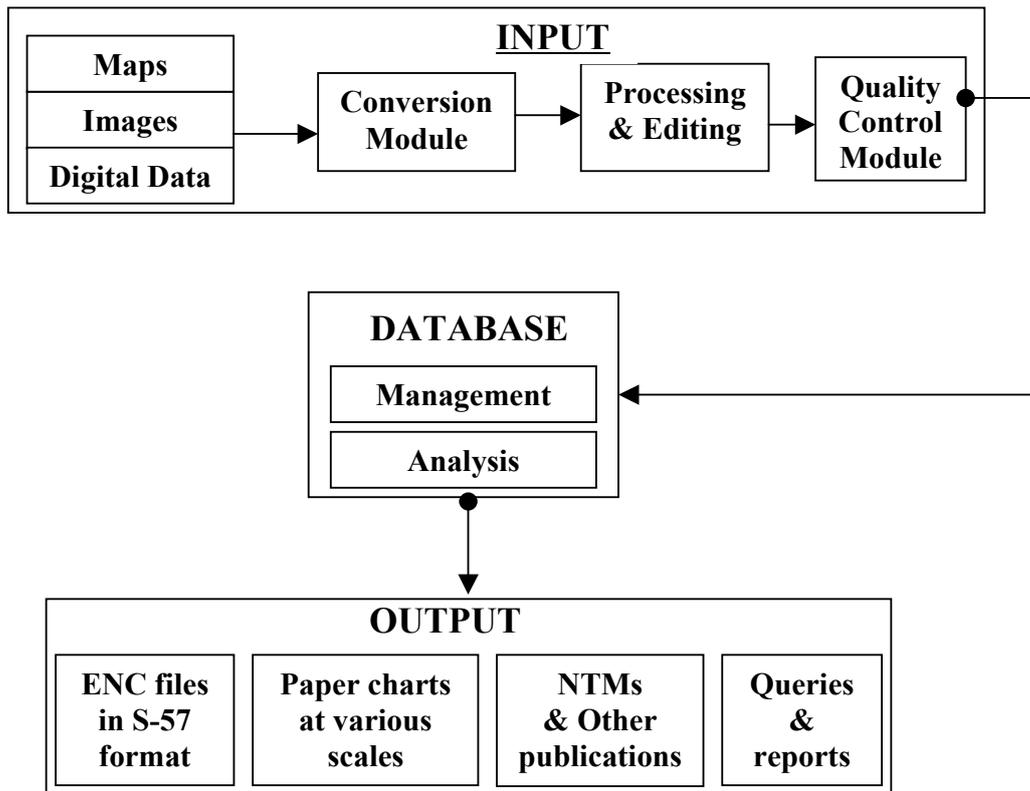


Fig. 1.3 "NIS Functional Subsystems"

There are four components of NIS; data, hardware, software, and users¹⁸. As shown in the Fig 1.4, the components must be integrated; they must be linked together and work in concert to support the management and analysis of spatial or mapped data.

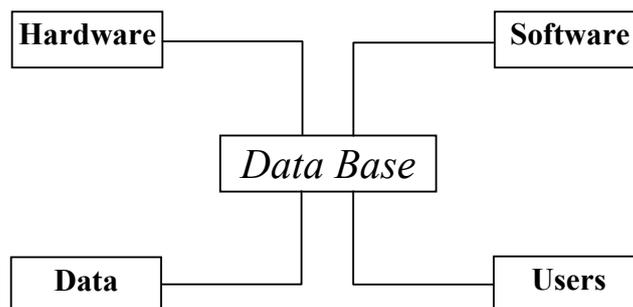


Fig. 1.4 "NIS Components"

¹⁸ Lloyd P. Queen and Charles R. Blinn, "The Basics of geographic Information Systems", lqueen@mercury.forestry.umn.edu and cblinnlqueen@mercury.forestry.umn.edu

- **Data.** All data in a database are either spatial data or attribute data. Spatial data tells us where something occurs. Attribute data tells what occurs; it tells us the nature or characteristics of the spatial data.
- **Hardware.** Computer hardware must be able to support data input, output, storage, retrieval, display, and analysis.
- **Software.** Software used should be dynamic and have wide variety of functional capabilities.
- **Users.** The term "user" may refer to any individual who will use NIS to support project or program goals, or to an entire organization that will employ.

2.9.1 Compilation Process

Data compilation involves assembling all of the spatial and attribute data in NIS. Map data with common projections, scales, and coordinate systems must be pooled together in order to establish the centralized NIS database. Data must also be examined for compatibility in terms of content and time of data collection. Ultimately, the data will be stored in NIS according to the specific format requirements set by both the user and the chosen NIS software/hardware environment.

When all of the common data requirements are set by the user, a "base map" has been established. A base map is a set of standard requirements for data. It provides accurate standards for geographic control, and also defines a model or template that is used to shape all data into a compatible form. A base map is not necessarily a map rather, it is a comprehensive set of standards established and enacted to ensure quality control for the spatial and attribute data contained in the NIS.

Once the data are assembled and base map parameters are set the user must translate manuscript data into computer-compatible form. This process referred to as "conversion" or "digitizing," converts paper maps into numerical digits that can be stored in the computer. Digitizing can be performed using various techniques. Scanning is one technique. Another technique is line digitizing which uses a tablet and a tracing stylus. Digitizing simplifies map data into sets of points, lines, or cells that can be stored in the NIS computer. Each NIS software package will impose a specific form and design on the way that these sets of points, lines, and cells are stored as digital map files.

Following figure shows the various types of compilation processes.

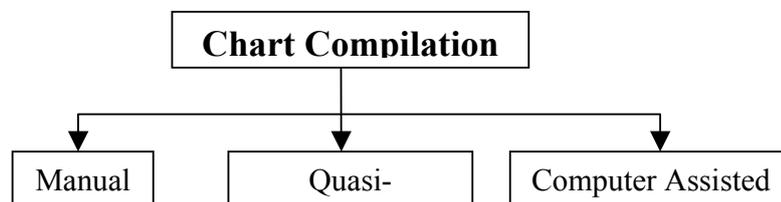


Fig. 1.5 "Chart Compilation Processes"

2.9.1.1 Manual: Traditional cartographic work, is based on colour separation and manual processes. The fair drawing is a manual method of preparing linework, symbols and topology (names) in accordance with the chart specifications. High quality linework is achieved by a process called “scribing” where the image is engraved on a coated film ensuring that cartographic specifications are carefully adhered to. Each colour used on a map is scribed on a separate film colour plate and symbols and names are combined photo-mechanically to produce colour separates for printing. Traditional cartography, defined as the manual techniques used for the production of a paper chart (before the advent of the computer), can be split in six components¹⁹:

- **Compilation Work.** The selection of the information collected for the production of the new edition of the paper chart.
- **Image generation.** The process of assigning symbol type, shape and structure to features on a map.
- **Image registration.** The technique to ensure that individual colour components fit each other in the map.
- **Contact copying at scale.** The operation used to produce same-size line, half-tone and continuous-tone positives and negatives by a direct contact process.
- **Image separation/combination.** The techniques used to produce multicolour maps by the sequential overprinting of a number of separate colour components.
- **Printing.** The charts are printed using offset lithographic process.

Quasi – automatic: Quasi-automatic cartography is the combination of manual and computer assisted techniques used for the production of a paper chart. Although, it contains the steps involved in manual but some of them are done by automatic means e.g. contouring is done by drafting machines instead of hands.

2.9.1.2 Computer Assisted Cartography: To improve services and to meet the growing demands for chart, computer assisted mapping systems are also used. The introduction of computer assisted mapping and geographic information systems have added new dimensions to cartographic techniques and usage of spatial data. The computer assisted cartographic steps are generally divided into the following six steps²⁰:

- **Acquisition and Input.** Digital data is usually obtained from various sources e.g. digital files or scanning of old charts.
- **Verification.** All incoming data is verified for various and checked for formats, scale and feature coding etc.
- **Editing and attributing.** Main tasks involve ensuring features are topologically correct, attributed and symbolized according to Cartographic Digital Standards (CDS). Original manuscripts that were scanned require geo-referencing, and interactive editing and feature coding. All text or annotation on the map is added interactively.

¹⁹ Lt Cdr Luis Pais, “Production and Distribution of ENC – The Portuguese Experience”, Portugal (IHPT), hidrografia@hidrografico.pt, www.thsoa.org/pdf/h01/7_3.pdf.

²⁰ Vic Dohar and Dave Everett, “Geological Map Production for Dummies”, Natural Resources Ottawa, Canada, vdohar@nrcan.gc.ca, <http://pubs.usgs.gov/of/of00-325/dohar.html>.

- **Quality Control.** A filtering process is used to create a report document that checks the project for completeness and correct feature attribution. Quality control officers ensure that the chart meets design specifications and that the digital data conforms to CDS. All maps are reviewed by the cartographers prior to publication.
- **Printing.** A final file is created for printing. Modern offset printing process may be single colour machines or may print multi colours in sequence.

2.9.2 Presentation

The real world is far too complex for a complete description to be practical, therefore a simplified, highly-specific, view of real world must be used. This is achieved by modelling the reality. The presentation of hydrographic information may vary to suit a particular use (e.g. it may be presented either graphically, using symbols or in a textual form). Therefore, the presentation of information should be independent of its storage. The concept of keeping information storage independent of presentation provides greater versatility and flexibility. It allows the same data to be used for many purposes without requiring any change to its structure or content. If the presentation style or medium changes, only the presentation model has to be changed. Therefore, the model described can be linked to many different presentation models. For example, ENC and paper charts present the same basic data in different ways via different presentation models²¹.

2.9.2.1 Paper Charts. A Nautical Chart is a graphic portrayal that shows the nature and form of the coast, the depths of the water and general character and configuration of the sea bottom, locations of dangers to navigation, the rise and fall of the tides, locations of man-made aids to navigation, and the characteristics of the Earth's magnetism²². 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 lay out courses and navigate ships by the shortest and most economical safe route.

Printed charts present all important information such as chart features with appropriate symbology and descriptive cartographic information texts and symbols. The volume of information is limited due to the size of the chart as well as the readability aspects of it. One of the most important aspects of the preparation work of the data to be published on the printed chart is cartographic generalization and cartographic editing of the data. These include e.g. displacement, aggregation, selection, rotation and text width, font and placement.

2.9.2.2 Digital Charts. Digital charts means a standardized database, as to content, structure and format, as shown in Fig 1.6.

²¹ International Hydrographic Organisation, Monaco, Specifications for Chart Content and Display Aspects of ECDIS (S-52).

²² <http://chartmaker.ncd.noaa.gov/ncd/whatis.html>.

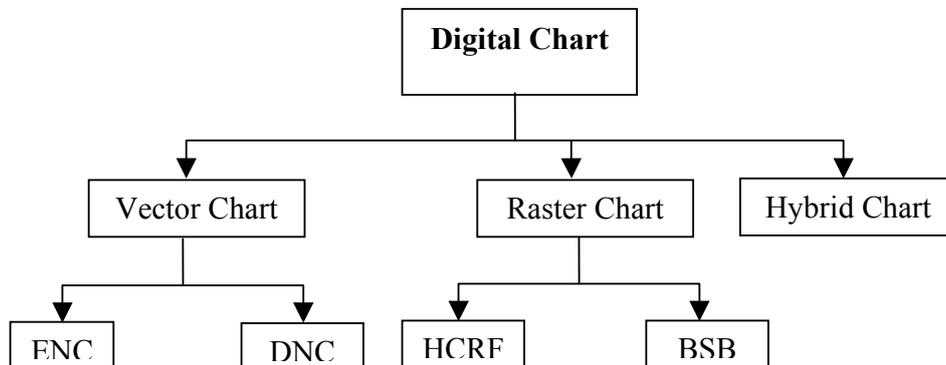


Fig. 1.6 "Digital Chart Types and Formats"

Digital charts²³ are a new navigation aid that can provide significant benefits to maritime navigation, safety, and commerce. More than simply a computer graphics display, digital chart systems combine both geographic and textual data into a readily useful operational tool. As an automated decision aid capable of continuously determining a vessel's position in relation to land, charted objects, aids to navigation, and unseen hazards, ENC are a real-time navigation system that integrates a variety of information that is displayed and interpreted by the Mariner. The most advanced form of digital chart systems represents an entirely new approach to maritime navigation.

2.9.2.3 Vector Charts

ENC: An Electronic Navigational Chart (ENC) is vector data conforming to IHO S-57 ENC product specification in terms of contents, structure and format. Issued for use with ECDIS on the authority of government authorized hydrographic offices, an ENC contains all the chart information necessary for safe navigation and may contain supplementary information in addition to that contained in the paper chart (e.g., sailing directions). In general, an S-57 ENC is an object-oriented, structurally layered data set designed for a range of hydrographic applications. As defined in IHO S-57 Edition 3, the data is comprised of a series of points, lines, features, and objects. The minimum size of a data is a "cell" which is a spherical rectangle (i.e. bordered by meridians and latitude circles). Adjacent cells do not overlap. The scale of the data contained in the cell is dependent upon the navigational purpose (e.g. general, coastal, approach, harbour). Other than a 5 Mb size limit to the amount of digital data contained in an ENC cell, there are no specifications regarding the dimensions of a cell as the smallest packaging.

DNC: The Digital Nautical Chart (DNCTM) is a vector database of selected maritime features that can be used with shipboard integrated navigation systems (e.g. electronic chart systems), or other types of geographic information systems (GIS). Similar to IHO S-57 ENCs, the DNC database consists of points, lines and polygons that contain information regarding hydrography, aid-to-navigation, cultural land marks, land features, depths, obstructions, etc. Each theme (e.g. hydrography) is stored as thematic layer with geo-referenced properties. The DNC product is encapsulated using the Digest Annex C Vector

²³ Lee Alexander, Ph.D., "What is an ENC? It depends who you ask", Offshore Systems Ltd., Vancouver, BC, Canada, http://www.osl.com/Support/what_is_enc.htm.

Relational Form (VRF) of encoding which consists of a set of relational database tables. Further the data is organised into series of “libraries” which are groupings of chart coverage which are commensurate with NIMA’s groupings of paper nautical charts scales (e.g. General, Coastal, Approach, and Harbour). In the ECDIS concept a DNC is a “system” electronic navigational chart (SENC) that contains specified data and display characteristics.

2.9.2.4 Raster Charts

Raster data formats are bitmaps with a geo-reference applied to them. A bitmap is a generic term for a computer image made up of a rectangular grid of very small (254 per inch is one standard) coloured squares or pixels. These bitmaps are usually generated by taking the original chart and scanning them to create a digital picture of the chart. Once this image has been acquired, a geo-reference is applied. This is the process of relating the grid positions of the bitmap pixels to their corresponding latitude and longitudes. In this way, a computer can relate pixel position to latitude and longitude. However, the system has no knowledge of the details of the features and details (such as the coast line) in the raster images it displays. Raster charts are produced by scanning at high resolution the original colour separates, which are used to print the paper charts. The digital files are carefully georeferenced to enable navigation software to map geographic positions to locations in the image. Metadata is added describing the chart, its datum, projection and other information about the chart and the digital file.

Hydrographic Chart Raster Format. (HCRF): This is the format developed by UKHO and used for its Admiralty Raster Chart Service (ARCS) and the Australian HO for its Seafarer Chart Service. Raster charts have the same standards of accuracy and reliability as paper charts. These are used with authorised compatible Electronic Charting Systems (ECS).

BSB Format: The (BSB) format is basically one or more raster images compressed in to an efficient package that is accompanied by the chart details within the package. These chart details include the geo referencing required for determining latitude and longitude as well as other particulars such as, scale, depth units, chart name, etc. The BSB format separates a chart into images depending on the number of compartments a chart contains where a 'compartment' is defined as main chart, chart inset, and chart continuation

2.9.2.5 Hybrid Charts

Ideally the master versions of all discrete digital cartographic product data would be held in vector form. The rise in capacity of computer systems over recent years has opened up the alternative of transferring quickly to digital methods by raster scanning the existing printing separates, and then using hybrid raster/vector techniques during a changeover period. Raster masters are replaced by vector masters in a sequence determined by costs and business priorities.

ANNEX A**ACRONYMS**

ARCS	Admiralty Raster Chart Service
AHO	Australian Hydrographic Office
CAD	Computer aided drafting
CD	Compact Disk
CDS	Cartographic Digital Standards
DNC	Digital Nautical Chart
ECS	Electronic Charting System
ENC	Electronic Navigation Chart
ECDIS	Electronic Chart Display and Information System
GIS	Geographic Information System
HCRF	Hydrographic Chart Raster Format
HTF	Hydrographic Transfer Format
HI	Project Instruction/Hydrographic Instruction
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
NHO	National Hydrographic Office
NIMA	National Imagery and Mapping Agency
NIS	Nautical Information System
NTM	Notices to Mariners
QC	Quality Control
RNC	Raster Nautical Chart
SENC	System Electronic Navigational Chart
UKHO	United Kingdom Hydrographic Office
VRF	Vector Relational Form
WGS	World Geodetic System

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