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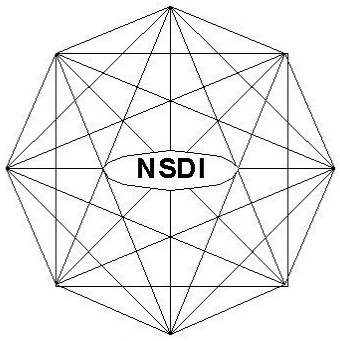

National Spatial Data Infrastructure

Geospatial Positioning Accuracy Standards
Part 5: Standards for Nautical Charting Hydrographic Surveys

Subcommittee on Marine and Coastal Spatial Data
Federal Geographic Data Committee

Federal Geographic Data Committee
Department of Agriculture ? Department of Commerce ? Department of Defense ? Department of Energy
Department of Housing and Urban Development ? Department of the Interior ? Department of State
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Federal Geographic Data Committee

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5.1 Introduction

5.1.1 Objective

This document provides minimum standards for the horizontal and vertical accuracy of features associated with hydrographic surveys that support nautical charting. Such features include, but are not limited to, water depths, objects on the seafloor, navigational aids, and shoreline.

5.1.2 Scope

For the purposes of this Standard, hydrographic surveys are defined as those surveys conducted to determine the configuration of the bottom of water bodies and to identify and locate all features, natural and man-made, that may affect navigation. Nautical charts are compilations of data from numerous sources, principally hydrographic surveys, designed specifically to meet the requirements of marine navigation. The scope of these standards includes the coastal waters of the U.S. and its territories.

5.1.3 Applicability

These standards are intended to be used by federal agencies and their contractors for conducting hydrographic surveys that will be used for updating nautical charts. They do not apply to hydrographic surveys for river and harbor navigation projects or surveys for project construction which are covered by Part 4 of the FGDC Geospatial Positioning Accuracy Standards. Local authorities may also prescribe these standards for high quality surveys for other purposes.

5.1.4 Related Standards

These standards may be used in conjunction with, or independent of, other Parts of the overall Geospatial Positioning Accuracy Standard. Part 1 (Reporting Methodology) applies directly to this part with the exception that vertical coordinate values should be referenced to the applicable chart datum and not one of the geodetic vertical datums (NAVD 88 or NGVD 29). See section 5.3.

There may be occasions where geodetic control points need to be established to support hydrographic surveys. In such instances, the specifications in Part 2 (Standards for Geodetic Networks) should be referenced. The accuracy testing described in Part 3 (National Standard for Spatial Data Accuracy) is generally inapplicable to this Part 5 since the referenced features are not repeatedly measured. Part 4 (Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management) provide accuracy standards for other categories of hydrographic surveys (Contract Payment, Project Condition and Reconnaissance) that are not explicitly conducted to support nautical charts.

5.1.5 Standards Development Procedures

This standard was developed by the FGDC Bathymetric Subcommittee during 1998 and generally follows the Standards for Hydrographic Surveys adopted by the International Hydrographic Organization in April 1998.

5.1.6 Maintenance

The U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Coast Survey, is responsible for developing and maintaining Standards for Nautical Charting Hydrographic Surveys for the FGDC Subcommittee on Marine and Coastal Spatial Data. Address questions concerning the standards to: Director, Office of Coast Survey, NOAA, N/CS, 1315 East-West Highway, Silver Spring, Maryland 20910.

5.2 Spatial Accuracy

As defined in Part 1, horizontal spatial accuracy is the two-dimensional circular error of a data set?s horizontal coordinates at the 95% confidence level. Vertical spatial accuracy is defined by the one-dimensional linear error of depths at the 95% confidence level.

5.3 Reference Datums

The horizontal reference datum should be the North American Datum of 1983 (NAD 83). If other datums or coordinate systems are used, their relationship to NAD 83 should be documented. Vertical coordinate values should be referenced to the applicable chart datum and not one of the geodetic vertical datums (NAVD 88 or NGVD 29). The Mean Lower Low Water (MLLW) datum is used for Atlantic, Pacific and Gulf coast charts. The nautical chart vertical datum for each of the Great Lakes is referenced to the International Great Lakes Datum (1985). Other water level-based datums are used on lakes and rivers.

5.4 Classification of Surveys

To accommodate in a systematic manner different accuracy requirements for areas to be surveyed, four orders of survey are defined. These are described below, with specific details provided in Table 1.

5.4.1 Special Order

Special Order hydrographic surveys approach engineering standards and their use is intended to be restricted to specific critical areas with minimum underkeel clearance and where bottom characteristics are potentially hazardous to vessels. These areas must be explicitly designated by the agency responsible for survey quality. Examples are harbors, berthing areas, and associated critical channels. All error sources must be minimized. Special Order requires the use of closely spaced lines in 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 1 meter 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. Side scan sonar should not be used for depth determination but to define areas requiring more detailed and accurate investigation.

5.4.2 Order 1

Order 1 hydrographic surveys are intended for harbors, harbor approach channels, recommended tracks, inland navigation channels, and coastal areas of high commercial traffic density where underkeel clearance is less critical and the geophysical properties of the seafloor are less hazardous to vessels (e.g. soft silt or sand 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. In some areas the detection of 1-meter cubic features may be specified.

5.4.3 Order 2

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.

5.4.4 Order 3

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.

TABLE 1
Summary of Minimum Standards for Hydrographic Surveys

ORDER	Special	1	2	3
Examples of Typical Areas	Harbors, berthing areas, and associated critical channels with minimum underkeel clearances	Harbors, harbor 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
Depth Accuracy for Reduced Depths (95% Confidence Level) [1] [2]	a = 0.25 m b = 0.0075	a = 0.5 m b = 0.013	a = 1.0 m b = 0.023	Same as Order 2
100% Bottom Search [3]	Compulsory	Required in selected areas	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	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 should be introduced into:

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

where:
a is a constant depth error, i.e. the sum of all constant errors, b*d is the depth dependent error, i.e. the sum of all depth dependent errors where b is a factor of depth dependent error, and d is depth.

[2] The confidence level percentage is the probability that an error will not exceed the specified maximum value.
[3] A method of exploring the seabed which attempts to provide complete coverage of an area for the purpose of detecting all features addressed in this publication.
[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 either (1) spacing of sounding lines for single beam sounders or (2) distance between the outer limits of swaths for swath sounding systems

5.5 Positioning

The horizontal accuracy, as specified in Table 1, is the accuracy of the position of soundings, dangers, and all other significant submerged features with respect to a geodetic reference frame, specifically NAD 83. The exception to this are Order 2 and Order 3 surveys using single-beam echo sounders where it is the positional accuracy of the sounding system sensor. In such cases, the agency responsible for the survey quality should determine the accuracy of the positions of soundings on the seafloor.

If the accuracy of a position is affected by different parameters, the contributions of all parameters to the total position error should be accounted for. A statistical method, combining different error sources, for determining positioning accuracy should be adopted. The position error, at 95% confidence level, should be recorded together with the survey data. Although this should preferably be done for each individual sounding, the error estimate may also be derived for a number of soundings or even for an area, provided differences between error estimates can be safely expected to be negligible.

It is strongly recommended that whenever positions are determined by terrestrial systems, redundant lines of position should be observed. Standard calibration techniques should be completed prior to and after the acquisition of data. Satellite systems should be capable of tracking at least five satellites simultaneously; integrity monitoring for Special Order and Order 1 surveys is recommended.

Primary shore control points should be located by ground survey methods to a relative accuracy of 1 part in 100,000. When geodetic satellite positioning methods are used to establish such points, the error should not exceed 10 cm at 95% confidence level. Secondary stations for local positioning, which will not be used for extending the control, should be located such that the error does not exceed 1 part in 10,000 for ground survey techniques or 50 cm using geodetic satellite positioning.

The horizontal positions of navigation aids and other important features should be determined to the accuracy stated in Table 2, at 95% confidence level.

Table 2

Summary of Minimum Standards for Positioning of Navigation Aids and Important Features

	Special Order surveys	Order 1 surveys	Order 2 and 3 surveys
Fixed aids to navigation and features significant to navigation	2 m	2 m	5 m
Natural Coastline	10 m	20 m	20 m
Mean position of floating aids to navigation	10 m	10 m	20 m
Topographical features	10 m	20 m	20 m

5.6 Depths

The navigation of commercial vessels requires increasingly accurate and reliable knowledge of the water depth in order to exploit safely the maximum cargo capabilities. It is imperative that depth accuracy standards in critical areas, particularly in areas of marginal underkeel clearance and where the possibility of obstructions exists, be more stringent than those established in the past and that the issue of adequate bottom coverage be addressed.

In determining the depth accuracy of the reduced depths, the sources of individual errors should be quantified and combined to obtain a Total Propagated Error (TPE) at the 95% confidence level. Among others these errors include:

a) measurement system and sound velocity errors

b) tidal measurement and modeling errors, and

c) data processing errors.

A statistical method for determining depth accuracy by combining all known errors should be adopted and checked. Recognizing that both constant and depth dependent errors affect the accuracy of depths, the formula under Table 1 is to be used to compute the allowable depth errors at 95% confidence level by using the values from row 3 for a and b. As an additional check on data quality, an analysis of redundant depths observed at crossline intersections should be made.

For wrecks and obstructions which may have less than 40 m clearance above them and may be dangerous to normal surface navigation, the least depth over them should be determined either by

high definition sonar examination or physical examination (diving). Mechanical sweeping may be used when guaranteeing a minimum safe clearance depth.

All anomalous features previously reported in the survey area and those detected during the survey should be examined in greater detail and, if confirmed, their least depth should be determined. The agency responsible for survey quality may define a depth limit beyond which a detailed seafloor investigation, and thus an examination of anomalous features, is not required.

Measured depths should be reduced to chart or survey datum, by the application of tidal or water level height. Tidal reductions should not be applied to depths greater than 200 m, except when tides contribute significantly to the TPE.

5.7 Sounding Density

In planning the density of soundings, both the nature of the seabed in the area and the requirements of the users have to be taken into account to ensure adequate bottom coverage. It should be noted that no method, not even 100% search, guarantees by itself the reliability of a survey nor can it disprove with certainty the existence of hazards to navigation, such as isolated natural hazards or man made objects such as wrecks, between survey lines.

Line spacing for the various orders of hydrographic surveys is proposed in Table 1. The results of a survey should be assessed using procedures developed by the agency responsible for the survey quality. Based on these procedures the adequacy of the sounding density should be determined and the line spacing reduced if warranted.

5.8 Bottom Sampling

The nature of the seabed should be determined by sampling or may be inferred from other sensors (e.g. single beam echo sounders, side scan sonar, sub-bottom profiler, video, etc.) up to the depth required by local anchoring or trawling conditions. Under normal circumstances sampling is not required in depths greater than 200 meters. Samples should be spaced according to the seabed geology, but should normally be 10 times that of the main scheme line spacing. In areas intended for anchorages, density of sampling should be increased. Any inference technique should be substantiated by physical sampling.

5.9 Tidal Observations

Tidal height observations should be made throughout the course of a survey for the purpose of providing tidal reductions for soundings, and providing data for tidal analysis and subsequent prediction. Observations should extend over the longest possible period, and if possible, for not less than 29 days. Tidal heights should be observed so that the total measurement error at the tide gauge, including timing error, does not exceed +/- 5 cm at 95% for Special Order surveys. For other surveys +/- 10 cm should not be exceeded.

5.10 Metadata

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 information describing the data is called metadata. Examples of metadata include overall quality, data set title, source, positional accuracy and copyright. Metadata is data implicitly attached to a collection of data.

Metadata should comprise at least the following information:

- the survey in general (e.g. date, area, equipment used, name of survey platform)
- the horizontal and vertical datum
- calibration procedures and results
- sound velocity for corrections to echo soundings
- tidal datum and reduction procedures
- accuracies achieved and the respective confidence levels.

Metadata should preferably be in digital form in compliance with the FGDC-endorsed Content Standard for Digital Geospatial Metadata (version 2.0), FGDC-STD-001-1998, and an integral part of the survey record. Shoreline metadata should comply with the Metadata Profile for Shoreline Data. If this is not feasible, similar information should be included in the documentation of a survey. It is recommended that agencies responsible for the survey quality systematically develop and document a list of metadata used for their survey data.

It is understood that each sensor (i.e. positioning, depth, heave, pitch, roll, heading, seabed characteristic sensors, water column parameter sensors, tidal reduction sensor, data reduction models etc.) possesses unique error characteristics. Each survey system should be uniquely analyzed to determine appropriate procedure(s) to obtain the required spatial statistics. These analysis procedure(s) should be documented or referenced in the survey record.

5.11 Elimination of Doubtful Data

To improve the safety of navigation it is desirable to eliminate doubtful data, i.e. data which are usually denoted on charts by PA (Position Approximate), PD (Position Doubtful), ED (Existence Doubtful), SD (Sounding Doubtful) or as "reported danger". To confirm or disprove the existence of such data it is necessary to carefully define the area to be searched and subsequently survey that area according to the standards outlined in this publication.

No empirical formula for defining the search area can suit all situations. For this reason, it is recommended that the search radius should be 3 times the estimated position error of the reported hazard at the 95% confidence level as determined by a thorough investigation of the report on the doubtful data by a qualified hydrographic surveyor. If such report is incomplete or does not exist at all, the position error must be estimated by other means as, for example, a more general

assessment of positioning and depth measurement errors during the era when the data in question was collected.

The methodology for conducting the search should be based on the area in which the doubtful data is reported and the estimated danger of the hazard to navigation. Once this has been established, the search procedure should be that of conducting a hydrographic survey of the extent defined in the preceding paragraph, to the standards established in this publication. If not detected, the agency responsible for the survey quality shall decide whether to retain the hazard as charted or to expunge it.

5.12 Quality Control

To ensure that the required accuracies are achieved it is necessary to check and monitor performance. Establishing quality control procedures which ensure that data or products meet certain standards and specifications should be a high priority for hydrographic authorities. This section provides guidelines for the implementation of such procedures.

Quality control for positioning ideally involves observing redundant lines of position and/or monitor stations which are then analyzed to obtain a position error estimate. If the positioning system offers no redundancy or other means of monitoring system performance, rigorous and frequent calibration is the only means of ensuring quality.

A standard quality control procedure should be to check the validity of soundings by conducting additional depth measurements. Differences should be statistically tested to ensure compliance of the survey with the standards given in Table 1. Anomalous differences should be further examined with a systematic analysis of contributing error sources. All discrepancies should be resolved, either by analysis or re-survey during progression of the survey task.

Crosslines intersecting the principal sounding lines should always be run to confirm the accuracy of positioning, sounding, and tidal reductions. Crosslines should be spaced so that an efficient and comprehensive control of the principal sounding lines can be effected. As a guide it may be assumed that the interval between crosslines should normally be no more than 15 times that of the selected sounding lines.

The proposed line spacing from Table 1 may be altered depending on the configuration of the seafloor and the likelihood of dangers to navigation. In addition, if side scan sonar is used in conjunction with single beam or multibeam sonar systems, the specified line spacing may be increased.

Multibeam sonar systems have great potential for accurate seafloor coverage if used with proper survey and calibration procedures. An appropriate assessment of the accuracy of measurements with each beam is necessary for use in areas surveyed to Special Order and Order 1 standards. If any of the outer beams have unacceptable errors, the related data may be used for reconnaissance but the depths should be otherwise excluded from the final data set. All swaths should be

intersected, at least once, by a crossline to confirm the accuracy of positioning, depth measurements and depth reductions.

References

International Hydrographic Organization, April 1998, IHO Standards for Hydrographic Surveys, Special Publication No. 44, 4th Edition, 23p.