PREFACE

This fourth edition of IHO Special Publication No. 44 has been prepared by an IHO Working Group set up in accordance with Decision No. 15 of the XIVth International Hydrographic Conference. Terms of Reference and work procedures were established by Circular Letter 20 of 1993. Initially, the Working Group was divided into several sub-groups to address specific topics by correspondence. Subsequently, two meetings were held at the IHB, Monaco, 26-30 September 1994 and 29 September - 3 October 1997, to discuss proposals for and to draft a new edition of the publication.

Thanks are due to the Hydrographic Offices of Australia, Brazil, Canada, France, Italy, Japan, Norway, Portugal, Spain, Sweden, UK, and USA (NOAA & NIMA) for nominating members for this Working Group.

It should be noted that the issue of a new standard does not invalidate charts and nautical publications based on previous standards, but rather sets the standards for future data collection to better respond to user needs. Member States are encouraged to develop estimates of the positional and depth accuracies of hydrographic surveys conducted prior to the implementation of these new standards.

The principal aim of this publication is to specify **minimum** standards for hydrographic surveys in order that hydrographic data collected according to these standards is sufficiently accurate and that the spatial uncertainty of data is adequately quantified to be safely used by mariners (commercial, military or recreational) as primary users of this information.

Previous editions of S-44 concentrated primarily on classifying accuracies for hydrographic surveys for the compilation of nautical charts. It has now been recognized that users of hydrographic data make up a much more diverse group than previously recognized. Hydrographic data is also important for coastal zone management, environment monitoring, resource development (hydrocarbon and mineral exploitation), legal and jurisdictional issues, ocean and meteorological modelling, engineering and construction planning and many other uses. To increase its usefulness, users require data that is more up to date, detailed, reliable, and in digital form. Even if the standard does not always specifically address these additional users' needs, it is felt that the standard provides them with a basis to assess the quality of hydrographic data.

INTRODUCTION

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 increased enormously by the availability of satellite positioning systems, particularly when augmented by differential techniques. This advance in technology has been particularly significant with navigators now able to position themselves with greater accuracy than that of the data on which charts are based. It should be noted, however, that the accuracy and completeness of a hydrographic survey can never reach that of land mapping.

The increased use of satellite positioning systems by the mariner, combined with the cost effectiveness and improved accuracy provided by these systems (over more traditional terrestrial-based precise navigation systems), have encouraged hydrographic agencies to utilise systems that afford positioning accuracy equal to or better than those enjoyed by the mariner for all future surveys conducted in Special Order and Order 1 (see Chapter 1, Table 1).

The required positioning accuracies in previous editions of S-44 were to a large extent based on the practical limitations of draughtsmanship at a given scale. Automated data management allows data to be presented at any scale. Therefore the accuracy requirements for positions in this new edition of S-44 must be a function of the errors contributed by positioning and sounding systems and the likely use of the data.

The state of the art of the depth measurement equipment has been evaluated by the working group as follows:

a) Single beam echo sounders have reached a sub-decimetre accuracy in shallow water. The market offers a variety of equipment with different frequencies, pulse rates etc. and it is possible to satisfy most users' and, in particular, the hydrographers' needs.

b) Side scan sonar equipment technology has also reached a high level of bottom obstacle detection and definition. Although, at present, its use is limited by the low speed (5-6 knots maximum) at which it can be operated, it is widely employed for harbour and navigable channels surveys to ensure obstacle detection between the measured survey lines. Many hydrographic agencies consider its use compulsory in such areas, often prescribing overlaps of 100% or more.

c) Multibeam echosounder technology is developing rapidly and offers great potential for accurate and total seafloor search if used with proper procedures and provided that the resolution of the system is adequate for proper detection of navigational hazards.

d) Airborne laser sounding is a new technology which can offer substantial productivity gains for surveys in shallow, clear water. Airborne laser systems are capable of measuring depths to 50 m or more.

It is likely that many hydrographic surveys will continue to be conducted with single beam echo sounders which only sample discrete profiles of the seafloor, with the 100% bottom search techniques outlined above possibly only employed in critical areas. This assumption led to the decision to retain the concept of line spacing even though it is no longer directly related to survey scale.

When specifying depth accuracies, this revision of S-44 departs from previous editions by specifying different accuracy requirements for different areas according to their importance for the safety of navigation. The most stringent requirements entail higher accuracies than previously specified, but for areas of less critical nature for navigation the requirements have been relaxed. Furthermore, this version of S-44 makes the new requirement, that surveyors strive to attribute all new data with a statistical estimate of its probable error.

Equipment and procedures used to achieve the standards laid down in this publication are left to the discretion of the agency responsible for the survey quality.

The optimum results are achieved when the appropriate procedures and equipment are used in conjunction with the expertise and training of the hydrographic surveyor. The importance of professional judgement cannot be overemphasized.

Chapter 2 of the 3rd edition of S-44 "Classification Criteria for Deep Ocean Soundings" has been retained for historical reasons. It is reproduced **without amendment** at Annex A.

Chapter 1 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 and at Tables 1 and 2 which summarize the overall requirements and are in fact the essence of the complete standard.

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 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 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.

Order 1

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 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.

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.

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.

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

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 underkeel 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 Specia Order, and Orders and 2
Horizontal Accuracy (95% Confidence Level)	2 m	5 m + 5% of depth	20 m + 5% of depth	150 m + 5% of dep
Depth Accuracy for Reduced Depths (95% Confidence Level) (1)	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	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 (see 3.4.2)

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.

Chapter 2 POSITIONING

2.1 Introduction

The accuracy of a position is the accuracy at the position of a feature (e.g. sounding, navaid) to be located within a geodetic reference frame; but see paragraph 2.3.

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 (see also 5.2).

Positions should be referenced to a geocentric reference system, recommended as the World Geodetic System 84 (WGS 84). If, exceptionally, positions are referenced to the local horizontal datum, this local datum should be tied to a geocentric reference system, recommended as the World Geodetic System 84 (WGS 84).

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.

2.2 Horizontal Control

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.

2.3 Positioning of Soundings

The position of soundings, dangers, and all other significant submerged features should be determined such that the horizontal accuracy is as specified in Table 1.

The accuracy of the position of a sounding is the accuracy at the position of the sounding on the bottom located within a geodetic reference frame. The exception to this are Order 2 and Order 3 surveys using single-beam echo sounders where it is the accuracy of the position 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.

2.4 Navigation Aids and Important Features

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

Chapter 3 DEPTHS

3.1 Introduction

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 search be addressed.

3.2 Depth Accuracy

Depth accuracy is to be understood as the accuracy of the reduced depths. In determining the depth accuracy, the sources of individual errors need to be quantified. All error sources should be combined to obtain a Total Propagated Error (TPE). TPE results from the combination of all contributing errors which include among other things:

a) measurement system and sound velocity errors

b) tidal measurement and modelling errors, and

c) data processing errors.

A statistical method for determining depth accuracy by combining all known errors should be adopted and checked (see also Chapter 7).

The TPE, determined statistically at the 95% confidence level, is the value used to describe the depth accuracy achieved. The TPE should be recorded together with the sounding value (see also 5.2).

Recognizing that there are both constant and depth dependent errors that affect the accuracy of depths, the formula under Table 1 in Chapter 1 is to be used to compute, at 95% confidence level, the allowable depth errors by using for a and b the values from row 3 of Table 1.

3.3 Depth Measurement

Determination of the general seabed topography, tidal reduction, and detection, classification and measurement of seabed hazards are fundamental hydrographic surveying tasks. Depths above hazards need to be determined with, at least, a depth accuracy as specified for Order 1 in Table 1.

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 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.

3.4 Sounding Density

3.4.1 Introduction

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 search.

It should be noted that no method, not even 100% search, which is desirable, guarantees by itself the reliability of a survey. Furthermore they cannot disprove the existence of hazards to navigation with certainty; in particular, the existence or not of isolated natural hazards or man made objects such as wrecks, between survey lines.

3.4.2 Line Spacing

An appropriate line spacing for the various orders of survey is proposed in Table 1. The results of a survey have to be assessed using procedures developed by the agency responsible for the survey quality. Based on these procedures it has to be decided whether the extent of bottom search is adequate and whether the line spacing should be reduced or extended.

These procedures may include an appropriate statistical error analysis which should take into consideration interpolation errors, as well as depth and positioning errors of the measured depths (see also Chapter 7).

Chapter 4 VARIOUS MEASUREMENTS

4.1 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 m. Samples have to be spaced according to the seabed geology. Spacing of samples should normally be 10 times that of the selected line spacing. In areas intended for anchorages, density of sampling should be increased. Any inference technique should be ground-truthed by physical sampling.

4.2 Tidal Observations

Tidal height observations should be made throughout the course of a survey for the purpose of:

a) providing tidal reductions for soundings, and

b) providing data for tidal analysis and subsequent prediction, for which purposes the observations should extend over the longest possible period and 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.

In order for the bathymetric data to be fully exploited in the future using advanced satellite observation techniques, tidal observations should be related both to a low water datum (usually LAT) and also to a geocentric reference system, preferably the World Geodetic System 84 (WGS 84) ellipsoid.

4.3 Tidal Stream Observations

The speed and direction of tidal streams which may exceed 0.5 knots should be observed at the entrances to harbours and channels, at any change in direction of a channel, in anchorages and adjacent to wharf areas. It is also desirable to measure coastal and offshore currents when they are of sufficient strength to affect surface navigation.

The tidal stream at each position should be measured at depths between 3 and 10 m below the surface. Simultaneous observations of tidal height and meteorological conditions should be made.

Tidal stream observations should be made using a recording device. The period of observation should not be less than 15 days, at intervals not greater than 1 hour. Whenever possible, the observation period should be extended to 29 days or more. Alternatively, a logship may be deployed over a period of maximum and minimum water flow. The speed and direction of the tidal stream should be measured to 0.1 knot and the nearest 10° respectively, at 95% confidence level.

Where there is reason to believe that seasonal river discharge influences the tidal streams, measurements should be made to cover the entire period of variability.

Chapter 5 DATA ATTRIBUTION

5.1 General

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 on:

- 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.

It is recommended that agencies responsible for the survey quality systematically develop and document a list of metadata used for their survey data.

5.2 Point Data Attribution

All soundings should be attributed with a 95% statistical error estimate for both position and depth. 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.

In the case of positions, they should be qualified by analyzing redundant lines of position (terrestrial systems) or integrity monitoring (satellite systems); in the case of depth observations, they could be qualified by analyzing redundant depths observed at, for example, checkline crossings.

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 analysed to determine appropriate procedure(s) to obtain the required spatial statistics. These analysis procedure(s) should be documented or referenced in the survey record.

Chapter 6 ELIMINATION OF DOUBTFUL DATA

6.1 Introduction

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.

6.2 Extent of Area to be Searched

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.

6.3 Conducting the Search

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 6.2, to the standards established in this publication.

6.4 Presentation of Search Results

Doubtful data shall be replaced with actual data collected during the search whether or not the hazard has been detected. If not detected, the agency responsible for the survey quality shall decide whether to retain the hazard as charted or to expunge it.

Chapter 7 GUIDELINES FOR QUALITY CONTROL

7.1 Introduction

To ensure that the required accuracies are achieved it is necessary to check and monitor performance. Establishing quality control procedures should be a high priority for hydrographic authorities. This chapter provides guidelines for the implementation of such procedures.

7.2 Positioning

Quality control for positioning ideally involves observing redundant lines of position and/or monitor stations which are then to be 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.

7.3 Depths

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.

Checklines crossing the principal sounding lines should always be run to confirm the accuracy of positioning, sounding, and tidal reductions. Checklines 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 checklines should normally be no more than 15 times that of the selected sounding lines.

7.4 Sounding Density

7.4.1 Single-beam Echo Sounders (SBES)

Depending on the characteristics of the seafloor the line spacing from Table 1 may have to be reduced or, if circumstances permit, expanded. Checklines should be run at discrete intervals (see 7.3).

7.4.2 Side scan Sonar (SSS)

Where SSS is being used in conjunction with SBES or MBES, the line spacing from Table 1 may be increased, whilst ensuring adequate coverage of the area directly beneath the towfish.

7.4.3 Multibeam Echosounders (MBES)

MBES have great potential for accurate seafloor coverage if used with proper survey and calibration procedures. An appropriate assessment of the accuracy of measurement with each beam is compulsory for use in areas surveyed to Special Order and Order 1 standards. If any of the outer beams have unacceptable errors, the related data are to be excluded. If not hampered by geographical constraints, all swaths should be crossed, at least once, by a checkline to confirm, by this method, the accuracy of positioning, depth measurement and depth reductions.

7.4.4 Sweep Systems

Sweep (multi-transducer) systems provide one technology for ensuring the accuracy and total seafloor coverage required for Special Order. It is essential that the distance between individual transducers and the acoustic area of ensonification should be matched to the depths being measured to ensure total search across the measurement swath. If not hampered by geographical constraints, all "sweeps" (width of coverage using a multi-transducer system) should be crossed, at least once, by a checkline to confirm, by this method, the accuracy of positioning, depth measurement and depth reductions.

7.4.5 Airborne Laser

Airborne laser systems are capable of measuring depths to 50 m or more provided the water is clear. Hazards to navigation detected by airborne laser should be examined using SBES, MBES or high density airborne laser. All swaths should be crossed, at least once, by a checkline to confirm, by this method, the accuracy of positioning, depth measurement and depth reductions.

7.4.6 Geostatistics

When the seabed has not been totally searched during a survey, the soundings only provide samples of the seabed at discrete points. In such a case, it is necessary to interpolate depths derived from soundings to obtain a bathymetric model which provides an estimate of depth information over the entire seabed surface.

Geostatistical interpolation techniques may be used to estimate the error introduced by interpolation between soundings, taking into consideration the accuracies of reduced depths and positions as well as the spatial distribution of depth measurements.

Using the values for a and b from Table 3 below, the formula under Table 1 is to be used to compute, at 95% confidence level, the allowable errors for the bathymetric model. If these errors are exceeded, the density of soundings should be increased.

Table 3
Bathymetric Model Accuracy

ORDER	Special	1	2	3
Bathymetric Model Accuracy (95% Confidence Level)	Not applicable, as 100% search compulsory	a = 1.0 m b = 0.026	a = 2.0 m b = 0.05	a = 5.0 m b = 0.05

These interpolation techniques, based on an appropriate statistical error analysis that quantifies the roughness of the seabed, should not be used as the only means to assess the quality of a survey, as they may not provide reliable estimates of the accuracy of the bathymetric model in all cases; particularly, if surveys were conducted with excessive line spacing.

7.5 Error Sources and Budget

Although the following text focusses on errors of data acquired with multibeam systems, it should be noted that it is in principle applicable to data acquired with any echosounding system.

With multibeam and multitransducer echosounding systems, the distance between the sounding on the seafloor and the positioning system antenna can be very large, especially in deep water with a wide swath system. Because of this, sounding position accuracy becomes also a function of the gyrocompass heading accuracy, beam angle (or transducer location for sweep systems) and the water depth (swath systems only).

Roll and pitch errors will also contribute to the relative error of the sounding from the transducer. Overall, it may be very difficult to generalize what is achievable as a typical position accuracy for each sounding as a function of depth in some of these modern systems. The errors are a function not only of the echosounder but also the vessel and the location and accuracy of the auxiliary sensors.

The use of non-vertical beams introduces additional errors caused by incorrect knowledge of the ship's orientation at the time of transmission and reception of sonar echoes. Errors associated with the development of the position of an individual beam must include the following:

a) positioning system error,
b) depth measurement error,
c) the uncertainty associated with the ray path model (including the sound speed profile),
d) the accuracy of the vessel heading,
e) the accurate identification of system pointing errors resulting from transducer misalignment,
f) vessel motion sensor, i.e. roll, heave and pitch accuracy, and
g) time latency.

Agencies responsible for the survey quality are encouraged to develop error budgets for their own systems.

Glossary

accuracy. The extent to which a measured or enumerated value agrees with the true value.

bathymetric model. A surface model of the seafloor as determined by interpolating a grid of depths in between the observed depth samples. Also called seabed surface model, seafloor surface model, seafloor model.

bottom search. 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.

confidence level. The probability that an error will not exceed the specified maximum value.

correction. A quantity which applied to an observation or function thereof will diminish or eliminate the effects of errors and give an improved value of the observation or function. The correction corresponding to a given error is of the same magnitude but of opposite sign. (IHO S32 ed.1994, #1079)

error. The difference between an observed or computed value of a quantity and the ideal or true value of that quantity. (IHO S32 ed.1994, #1671)

geostatistics. The field of statistics which deals with estimating the confidence of interpolated values derived from measurements of geo-referenced data.

line of position (LOP). A line indicating a series of possible positions of a craft, determined by observation or measurement. Also called *position line*. (IHO S32 ed.1994, #2848)

metadata. Information describing characteristics of data, e.g. the accuracy of survey data.
ISO definition: Data (describing) about a data set and usage aspect of it. Metadata is data implicitly attached to a collection of data. Examples of metadata include overall quality, data set title, source, positional accuracy and copyright.

precision. A statistical measure of repeatability of a value, usually expressed as variance or standard deviation of repeated measurements.

quality assurance. All those planned and systematic actions necessary to provide adequate confidence that a product or a service will satisfy given requirements for quality.

quality control. All procedures which ensure that the product meets certain standards and specifications (IHO S32 ed.1994, #4115)

ANNEX A
This Annex corresponds to Chapter 2 of the 3rd edition (1987) of S-44 which has been reproduced without modifications

CLASSIFICATION CRITERIA FOR DEEP SEA SOUNDINGS

Introduction

The criteria given in this Chapter are an updated version of those drawn up by the IHO working group established in 1972.

The aim of compiling deep sea soundings is to map the shape of the seabed. The interest is scientific as much as it is navigational, as distinct from the aim of a hydrographic chart, which must emphasize hazards to navigation.

The aim of classifying deep sea soundings is to select the better data where overlapping soundings disagree. It will also be needed should the requirement arise to compile charts on which all data meet a specified minimum standard.

These criteria provide guidance also to surveyors and data collectors so that essential technical details will be recorded with the soundings. Classification should be applied by the ship collecting the soundings and amended, if necessary, by the Hydrographic Office concerned, if it processes the data further before passing it on to the authorities responsible for storing the data and compiling the charts.

"Deep sea soundings" implies depths greater than 200 m.

The classification is made under four headings:

A. Position, with categories:

Track/Systematic Survey,
Position accuracy;

B. Soundings, with categories:

Beamwidth,
Timing accuracy;

C. Fidelity of scaling soundings to reproduce seabed, with categories:

Single/multi-beam Echo-sounder,
Scaling accuracy;

D. Data processing, with categories:

Whether original data supplied,
Method of correcting soundings.

The reason for preferring this over a single code are :

(i) A multiple code where each characteristic is judged separately is easier for the observer to apply than a single, combination code; the number of combinations required to classify all the information required in a single code would make coding a complicated process. A multiple code is also easier to adjust when one characteristic changes during the course of a cruise; this will often happen with positioning accuracy, for example.

(ii) The compiler needs detailed information on some aspects of the classification. Take, for example, the dilemma that positioning is more important than sounding accuracy on a steeply sloping seabed, whereas sounding accuracy is more important over an abyssal plain; the only practical solution appears to be to classify position and sounding accuracy independently, and leave the final decision to the compiler.

The steps between each category have deliberately been made large in order to simplify classification and to discourage exaggerated claims by making them ridiculous.

Each code has a "Z" category for "unspecified" data. This may be old data or current data submitted without accuracy classification. Category A, B and C of each code are left unused in case of future developments.

The Data Processing Code

(i) This code should describe the form of the data when it is finally entered into the data bank.

(ii) The significance of submitting original soundings as observed is that the corrected depth can be refined should improved sound velocity become available after the original work as done.

(iii) Perhaps the most serious weakness in the present-day process of reporting deep sea soundings is that only a very small part of the data collected is preserved; for example, spot sounding at 10 km intervals out of a continuous seabed profile. Codes A, B and C are intended for the day when a continuous profile can be stored (on magnetic tape?) and used to reproduce all the information gathered.

The roughness of the seabed is an important factor in judging the fidelity with which spot soundings can reproduce a continuous profile, but it is a difficult quality of classify. The fidelity of Scaling soundings code gives the limited information that either the bottom roughness has been described by the sounding selection (category D), or it is rougher than the soundings indicate.

PART 2.A - POSITION

2.A.1 - General

In mapping the seabed, a systematic survey of a large area with high relative position accuracy is the equivalent of a series of single tracks of equivalent geographical accuracy. To reflect this, the code consists of a number specifying the type of survey, followed by a letter specifying the positioning accuracy.

2.A.2 - Type Category

a- Sounding is from a single track. In this case the position accuracy code selected must be based on the geographical position accuracy.

b- Sounding is from a systematic survey of a large area. In this case the position accuracy code must be determined by the relative accuracy between positions in the area followed by the geographical accuracy of the survey as a whole, the two code letters being separated by a slant line.

2.A.3 - Accuracy Category

Accuracy of 95% of positions:

D Better than 100 metres
E Better than 500 metres
F Better than 2km (1.0 NM)
G Better than 10km (5.0 NM)
H Worse than 10km (5.0 NM)
Z Position accuracy not specified.

Examples of positioning methods which may meet the above accuracy categories:

D. (i) Radio navigational systems using frequencies of 1 500 kHz or higher,

(ii) Acoustic range on fixed transponder - the absolute accuracy depending upon the accuracy with which the transponders are located.

(iii) G.P.S. (Global positioning system),

(iv) Doppler satellite (dual frequency), with automatic course and speed input from inertial system speed input from inertial system or bottom lock sonar doppler or Rho-Rho navigational system using frequency of 100 kHz with ground wave reception in best conditions.

E. (i) Radio navigational system using frequencies of 100 kHz or higher with groundwave reception in best conditions,

(ii) Radio navigational systems using frequencies of 10 kHz or higher which are monitored by a fixed station within 500 km.,

(iii) Doppler satellite (dual frequency) with automatic course and speed input from an electronic positioning system.

F. (i) Doppler satellite (dual frequency) with manual input of course and speed from D.R. or an electronic positioning system,

(ii) Doppler satellite (single frequency).

G. (i) Radio navigational system using frequencies of 10 kHz or higher,

(ii) Celestial observations.

2.A.4 - Notes on Positions

2.A.4.1 The accuracy refers to the position of the sounding vessel. The position of the soundings, particularly when interpolated between fixes, may be of lower accuracy.

2.A.4.2 If positions are read off a plotting sheet, the scale of the sheet sets and upper limit on the accuracy of the positions.

2.A.4.3 The differences between geodetic datums, and between a local datum and a geocentric satellite navigation datum, may amount to several hundred metres. For geographic accuracies better than 500m (categories 1D, 1E, 2D and 2E) the datum used must be defined, either by a recognized terms (e.g. "Tokyo datum") or by quoting the reference ellipsoid's "a" and "1/f" values and the datum translation components X_o, Y_o,

Z_o that give the coordinates of the centre of the datum relative to the geocentre. (If the Navy Navigation Satellite System is used, its centre can be assumed to be at the geocentre).

2.A.5 - Example

A systematic offshore survey (category 2) using a positioning system employing radio frequency of 100 kHz (category E) but which was not calibrated and so could have geographical position error of up to 3km would be classified as 2 E/G.

PART 2.B - SOUNDINGS

2.B.1 - General

The accuracy with which the sounder can map the seafloor depends on the precision with which it measures the return travel time of the echo, and on the width of the beam, since a wide beam distorts the depicted shape of the seabed. To reflect this, the code consists of a number specifying the beamwidth followed by a letter specifying the time and recording accuracy (which will be matched in a well-designed sounder).

2.B.2 - Type Category

a Very narrow beam; total beamwidth less than 6° to -3db point, or sounder deep-towed or in a submersible such that dimension of area "illuminated" is less than 1/10 of water depth.

b Narrow beam; total beamwidth less than 12° to -3db point, or dimension of area illuminated less than 1/5 of water depth.

c Normal beamwidth 12° or greater to -3db point.

2.B.3. - Accuracy Category

	Timing	Recording
D	High precision better than 0.1% travel time	High precision, stable dry paper, or calibration marks applied by timer to give recording accuracy of + or - 0.1%. Digital recording to be of the same precision.
E	Better than 2% of travel time	Better than 2% of depth
F	Less accurate than 2%	Less accurate than 2%
Z	Sounding accuracy not specified	

2.B.4 - Example

A normal beamwidth sounder, crystal controlled to give better than + or - 0.1% timing accuracy and with time marks on the depth record, would be classified "3D".

PART 2.C - FIDELITY WITH WHICH SCALED SOUNDINGS REPRODUCE SEABED

2.C.1 - General

Ideally, a profile reconstructed from the scaled soundings would reproduce the original echogram exactly; no information would be lost. Unless the seabed is quite smooth, practical problems of man-hours, plotting scales, etc., reduce the "fidelity" of scaling. The classification reflects how closely the ideal has been approached under the existing constraints of seabed roughness and practical considerations. Since the wide swathe sounded by multi-beam array sonar provides a fuller picture of the seabed than a single beam, the "fidelity" classification includes a number to identify data from a multi-beam sounder.

2.C.2 - Type Category

a. Single beam sounder used

b. Multi-beam array sounder used

2.C.3 - Accuracy Category

D Soundings scaled at peaks, deeps and points of change of slope; seabed smooth between soundings. On the depth profile, straight lines between scale soundings agree with the actual seabed within the tolerance established by the sounding accuracy.

E Soundings scaled at peaks, deeps, and points of change of slope; seabed not smooth between soundings. On the deep profile, straight lines drawn between scaled soundings depart from the actual depth by more than the sounding accuracy.

F Soundings scaled at equal intervals along the track, with a maximum of one deep and one peak scaled between each regular sounding; or soundings scaled at a specified contour interval plus all highs and lows.

G Sounding scaled at equal intervals along the track.

H Only spot soundings available.

Z Sounding selection criteria not specified.

2.C.4 - Example

Soundings scaled at peaks, deeps and points of changes of slope. But due either to the seabed being very rough, or to constraints of time available, or a small plotting scale, the difference between the original echogram and a profile reconstructed from the scaled soundings will exceed the timing accuracy of + or - 0.1%. Classification is "E".

PART 2.D - DATA PROCESSING

2.D.1 - General

In compiling large-scale plots of seabed areas of special interest, and in reconciling data from different sources, it is useful to have the source data available and to know just how the depth measurements, which are in fact time measurements, were converted to true depth. This code consists of a number denoting whether or not the source data is supplied, and whether the sounding velocity used in recording depths is specified, followed by a letter giving the method used in correcting the soundings. It is assumed that corrections have been made for the depth of the transducer and, where appropriate (eg. over seamounts), reduced for the height of the tide.

2.D.2 - Type Category

a Original or photocopy of line sounding echogram, or array sonar isobath graphic/digital recording, supplied. Recording velocity specified.

b Original or photocopy of line sounding echogram, or array sonar isobath graphic/digital recording, supplied. Recording velocity not supplied.

c Listing of original, uncorrected soundings supplied. Recording velocity specified.

d Listing of original, uncorrected soundings supplied. Recording velocity not specified.

e Only corrected soundings supplied.

2.D.3 - Accuracy Category

D By sound velocity measurement at the time of the survey, giving a correction of an accuracy that matches the timing accuracy.

E By sound velocity measurement at the time of the survey, giving a correction that is less accurate than the timing measurements itself.

F By local sound velocity tables which are an improvement over "Echo-sounding Correction Tables" 3rd edition N.P. 139, (U.K.).

G By "Echo-sounding Correction Tables" N.P. 139 (U.K.) 2nd edition.

H By reference to Matthews Tables N.P. 139 (U.K.) 2nd edition.

J Soundings are not corrected.

Z Correction not specified.

2.D.4 Example

If a photocopy of the echogram were supplied with the recording velocity specified, and a listing of soundings corrected by N.P. 139 (U.K.) 3rd edition was also supplied, the classification would be "1G".

COLLECTIVE EXAMPLE

A systematic survey in which soundings were positioned to better than + or - 500 metres relative and + or - 2 km (1.0 NM) geographic accuracy; a normal beamwidth crystal controlled sounder was used; soundings were scaled at peaks, deeps and points of change of slope but it was not feasible to reproduce the entire echogram within the + or -0.1% timing accuracy; photocopy of the echogram was supplied, sounding recording velocity specified and soundings corrected by N.P. 139 (U.K.), 3rd edition. The classification would be :

(Position)	(Sounding)	(Fidelity)	(Data)
2E/F	3D	1E	1G