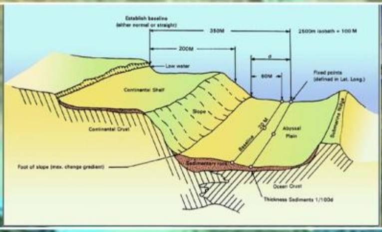
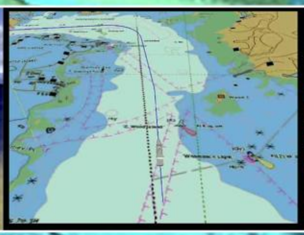
INTERNATIONAL HYDROGRAPHIC ORGANIZATION

IHO Standards for Hydrographic Surveys

5th Edition, February 2008

Special Publication N° 44





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NB: Annexes A and B will be removed from this document when the information contained in them is fully included in IHO Publication M-13 (Manual on Hydrography)

PREFACE

This publication, "Standards for Hydrographic Surveys" (S-44), is one of the series of standards developed by the International Hydrographic Organization (IHO) to help improve the safety of navigation.

Formal discussions on establishing standards for hydrographic surveys began at the VIIth International Hydrographic Conference (IHC) in 1957. Circular Letters to Member States in 1959 and 1962 reported on the views of Member States and the VIIIth IHC in 1962 established a Working Group (WG) comprising 2 members from the USA, 1 from Brazil and 1 from Finland. The WG communicated by mail and held two meetings in conjunction with the IXth IHC in 1967 and prepared the text for Special Publication No S-44.

The 1st Edition of S-44 entitled "Accuracy Standards Recommended for Hydrographic Surveys" was published in January 1968 the Foreword to which stated that "…hydrographic surveys were classed as those conducted for the purpose of compiling nautical charts generally used by ships" and "The study confined itself to determining the density and precision of measurements necessary to portray the sea bottom and other *features* sufficiently accurately for navigational purposes."

Over subsequent years technologies and procedures changed and the IHO established further WGs to update S-44 with the 2nd Edition published in 1982, the 3rd in 1987 and the 4th in 1998. Throughout these revisions the basic objectives of the publication have remained substantially unchanged and this remains so with this 5th Edition.

The Terms of Reference for the WG established to prepare the 5th Edition of S-44 included inter alia: a desire for clearer guidance regarding sea floor *features* and listed a number of concerns including system capabilities for detecting *features* and the characteristics of *features* to be detected. The WG concluded that S-44 sets minimum standards for surveys conducted for the safety of surface navigation. The WG considered it to be the responsibility of each national authority to determine the precise characteristics of *features* to be detected relevant to their organization and to determine the ability of particular systems and their procedures to detect such *features*. The WG further concluded that the design and construction of targets used to demonstrate system detection capabilities is the responsibility of national authorities. The reference to cubic *features* > 1 or 2 metres in size used in these Standards provides a basis for understanding that *features* of at least this size should be detected.

The principal changes made from the 4th Edition are:

The division of Order 1 into 1a where a *full sea floor search* is required and 1b where it is not required. The removal of Order 3 as it was considered that there was no longer a need to differentiate this from Order 2.

The replacement, in most cases, of the words *"accuracy"* and *"error"* by *"uncertainty"*. *Errors* exist and are the differences between the measured value and the true value. Since the true value is never known it follows that the *error* itself cannot be known. *Uncertainty* is a statistical assessment of the likely magnitude of this *error*. This terminology is increasingly being used in measurement: see ISO/IEC 98: 1995 "Guide to the expression of uncertainty in measurement" (due to be updated in 2008) and ISO/IEC 99:2007 "International Vocabulary of Metrology – Basic and general concepts and associated terms (VIM).

The Glossary has been updated and some terms which the WG consider fundamental to the understanding of these Standards are repeated in the Introduction.

The WG considered that information on "How to Survey" was not appropriate to these Standards and this information has been removed from the 5th Edition. However the WG acknowledges the usefulness of this guidance and the information has been retained in two annexes. The WG recommends that this information should be transferred to IHO Publication M-13 (Manual on Hydrography) at which time the annexes should be removed from S-44.

A minimum spot spacing for bathymetric LIDAR has been included in Table 1 for Order 1b surveys where *full sea floor search* is not required.

Finally it was the view of the WG that S-44 provides "Standards for Hydrographic Surveys" and that it is the responsibility of individual Hydrographic Offices / Organizations to prepare "Specifications" based on these Standards. Specifications will be more system specific and as such will be quite dynamic as systems change.

INTRODUCTION

This publication is designed to provide a set of standards for the execution of hydrographic surveys for the collection of data which will primarily be used to compile navigational charts to be used for the safety of surface navigation and the protection of the marine environment.

It must be realised that this publication only provides the **minimum** standards that are to be achieved. Where the bathymetry and expected shipping use requires it, hydrographic offices / organisations wishing to gather data may need to define more stringent standards. Also, this publication does not contain procedures for setting up the necessary equipment, for conducting the survey or for processing the resultant data. These procedures (which are a fundamental part of the complete survey system) must be developed by the hydrographic office/organisation wishing to gather data that is compliant with these Standards. Consideration must be made of the order of survey they wish to achieve, the equipment they have at their disposal and the type of topography that they intend to survey. Annexes A and B provide guidelines for *Quality control* and Data Processing and it is intended that these will be moved to the Manual on Hydrography (IHO Publication M-13) which provides further guidance on how to perform hydrographic surveys.

There is nothing to stop users adopting these Standards for other uses. Indeed, such a broadening of the use of these Standards is welcomed. However, users who wish to adopt these for other means must bear in mind the reason why they were written and therefore accept that not all parts may be suitable for their specific needs.

To be compliant with an S-44 Order a survey must be compliant with ALL specifications for that order included in these Standards.

It is also important to note that the adequacy of a survey is the end product of the entire survey system and processes used during its collection. The *uncertainties* quoted in the following chapters reflect the total propagated *uncertainties* of all parts of the system. Simply using a piece of equipment that is theoretically capable of meeting the required *uncertainty* is not necessarily sufficient to meet the requirements of these Standards. How the equipment is set up, used and how it interacts with the other components in the complete survey system must all be taken into consideration.

All components **and their combination** must be capable of providing data to the required standard. The hydrographic office / organisation needs to satisfy itself that this is so by, for example, conducting appropriate trials with the equipment to be used and by ensuring that adequate calibrations are performed prior to, as well as during and, if appropriate, after the survey being carried out. The surveyor is an essential component of the survey process and must possess sufficient knowledge and experience to be able to operate the system to the required standard. Measuring this can be difficult although surveying qualifications (e.g. having passed an IHO Cat A/B recognised hydrographic surveying course) may be of considerable benefit in making this assessment.

It should be noted that the issue of this new edition to the standard does not invalidate surveys, or the charts and nautical publications based on them, conducted in accordance with previous editions, but rather sets the standards for future data collection to better respond to user needs.

It should also be noted that where the sea floor is dynamic (e.g. sand waves), surveys conducted to any of the Orders in these Standards will quickly become outdated. Such areas need to be resurveyed at regular intervals to ensure that the survey data remains valid. The intervals between these resurveys, which will depend on the local conditions, should be determined by national authorities.

A glossary of terms used in this publication is given after Chapter 6. Terms included in the glossary are shown in the text in italic type and in the electronic version are hyperlinked to their definition. The following "Fundamental Definitions" from the glossary are considered essential to the understanding of these Standards.

FUNDAMENTAL DEFINITIONS

Feature detection: The ability of a system to detect *features* of a defined size. These Standards specify the size of *features* which, for safety of navigation, should be detected during the survey.

Full sea floor search: A systematic method of exploring the sea floor undertaken to detect most of the *features* specified in Table 1; utilising adequate detection systems, procedures and trained personnel. In practice, it is impossible to achieve 100% ensonification / 100% bathymetric coverage (the use of such terms should be discouraged).

Reduced depths: Observed depths including all *corrections* related to the survey and post processing and reduction to the used vertical datum.

Total horizontal uncertainty (THU): The component of *total propagated uncertainty* (TPU) calculated in the horizontal plane. Although THU is quoted as a single figure, THU is a 2 Dimensional quantity. The assumption has been made that the *uncertainty* is isotropic (i.e. there is negligible correlation between *errors* in latitude and longitude). This makes a Normal distribution circularly symmetric allowing a single number to describe the radial distribution of *errors* about the true value.

Total propagated uncertainty (TPU): the result of *uncertainty propagation*, when all contributing measurement *uncertainties*, both random and systematic, have been included in the propagation. *Uncertainty* propagation combines the effects of measurement *uncertainties* from several sources upon the *uncertainties* of derived or calculated parameters.

Total vertical uncertainty (TVU): The component of *total propagated uncertainty* (TPU) calculated in the vertical dimension. TVU is a 1 Dimensional quantity.

CHAPTER 1 – CLASSIFICATION OF SURVEYS

Introduction

This chapter describes the orders of survey that are considered acceptable to allow hydrographic offices / organizations to produce navigational products that will allow the expected shipping to navigate safely across the areas surveyed. Because the requirements vary with water depth and expected shipping types, four different orders of survey are defined; each designed to cater for a range of needs.

The four orders are described below along with an indication of the need that the order is expected to meet. Table 1 specifies the minimum standards for each of these orders and **must** be read in conjunction with the detailed text in the following chapters.

The agency responsible for acquiring surveys should select the order of survey that is most appropriate to the requirements of safe navigation in the area. It should be noted that a single order may not be appropriate for the entire area to be surveyed and, in these cases, the agency responsible for acquiring the survey should explicitly define where the different orders are to be used. It should also be noted that the situation discovered in the field by the surveyor may differ sufficiently enough from what was expected to warrant a change of order. For instance in an area traversed by Very Large Crude Carriers (VLCCs) and expected to be deeper than 40 metres an Order 1a survey may have been specified; however if the surveyor discovers shoals extending to less than 40 metres then it may be more appropriate to survey these shoals to Special Order.

Special Order

This is the most rigorous of the orders and its use is intended only for those areas where under-keel clearance is critical. Because under-keel clearance is critical a *full sea floor search* is required and the size of the *features* to be detected by this search is deliberately kept small. Since under-keel clearance is critical it is considered unlikely that Special Order surveys will be conducted in waters deeper than 40 metres. Examples of areas that may warrant Special Order surveys are: berthing areas, harbours and critical areas of shipping channels.

Order 1a

This order is intended for those areas where the sea is sufficiently shallow to allow natural or man-made *features* on the seabed to be a concern to the type of surface shipping expected to transit the area but where the under-keel clearance is less critical than for Special Order above. Because man-made or natural *features* may exist that are of concern to surface shipping, a *full sea floor search* is required, however the size of the *feature* to be detected is larger than for Special Order. Under-keel clearance becomes less critical as depth increases so the size of the *feature* to be detected by the *full sea floor search* is increased in areas where the water depth is greater than 40 metres. Order 1a surveys may be limited to water shallower than 100 metres.

Order 1b

This order is intended for areas shallower than 100 metres where a general depiction of the seabed is considered adequate for the type of surface shipping expected to transit the area. A *full sea floor search* is not required which means some *features* may be missed although the maximum permissible line spacing will limit the size of the *features* that are likely to remain undetected. This order of survey is only recommended where under-keel clearance is not considered to be an issue. An example would be an area where the seabed characteristics are such that the likelihood of there being a man-made or natural *feature* on the sea floor that will endanger the type of surface vessel expected to navigate the area is low.

Order 2

This is the least stringent order and is intended for those areas where the depth of water is such that a general depiction of the seabed is considered adequate. A *full sea floor search* is not required. It is recommended that Order 2 surveys are limited to areas deeper than 100 metres as once the water depth exceeds 100 metres the existence of man-made or natural *features* that are large enough to impact on surface navigation and yet still remain undetected by an Order 2 survey is considered to be unlikely.

CHAPTER 2 – POSITIONING

2.1 Horizontal Uncertainty

The *uncertainty* of a position is the *uncertainty* at the position of the sounding or *feature* within the geodetic reference frame.

Positions should be referenced to a geocentric reference frame based on the International Terrestrial Reference System (ITRS) e.g. WGS84. If, exceptionally, positions are referenced to the local horizontal datum, this datum should be tied to a geocentric reference frame based on ITRF.

The *uncertainty* of a position is affected by many different parameters; the contributions of all such parameters to the *total horizontal uncertainty* (THU) should be accounted for.

A statistical method, combining all *uncertainty* sources, for determining positioning *uncertainty* should be adopted. The position *uncertainty* at the 95% *confidence level* should be recorded together with the survey data (see also 5.3). The capability of the survey system should be demonstrated by the THU calculation.

The position of soundings, dangers, other significant submerged *features,* navaids (fixed and floating), *features* significant to navigation, the coastline and topographical *features* should be determined such that the horizontal *uncertainty* meets the requirements specified in Table1. This includes all *uncertainty* sources not just those associated with positioning equipment.

CHAPTER 3 – DEPTHS

3.1 Introduction

The navigation of vessels requires accurate knowledge of the water depth in order to exploit safely the maximum cargo carrying capacity, and the maximum available water for safe navigation. Where under-keel clearances are an issue the depth *uncertainties* must be more tightly controlled and better understood. In a similar way, the sizes of *features* that the survey will have or, more importantly, may not have detected, should also be defined and understood.

The measured depths and drying heights shall be referenced to a vertical datum that is compatible with the products to be made or updated from the survey e.g. chart datum. Ideally this *sounding datum* should also be a well defined vertical datum such as, LAT, MSL, a geocentric reference frame based on ITRS or a geodetic reference level.

3.2 Vertical Uncertainty

Vertical *uncertainty* is to be understood as the *uncertainty* of the *reduced depths.* In determining the vertical *uncertainty* the sources of individual *uncertainties* need to be quantified. All *uncertainties* should be combined statistically to obtain a *total vertical uncertainty* (TVU).

The maximum allowable vertical *uncertainty* for *reduced depths* as set out in Table 1 specifies the *uncertainties* to be achieved to meet each order of survey. *Uncertainty* related to the 95% *confidence level* refers to the estimation of *error* from the combined contribution of random *errors* and residuals from the correction of systematic *errors*. The capability of the survey system should be demonstrated by the TVU calculation.

Recognising that there are both depth independent and depth dependent *errors* that affect the *uncertainty* of the depths, the formula below is to be used to compute, at the 95% *confidence level*, the maximum allowable TVU. The parameters "a" and "b" for each order, as given in Table 1, together with the depth "d" have to be introduced into the formula in order to calculate the maximum allowable TVU for a specific depth:

$$\pm\sqrt{a^2 + (b \times d)^2}$$

Where:

a	represents that portion of the *uncertainty* that does not vary with depth
b	is a coefficient which represents that portion of the *uncertainty* that varies with depth
d	is the depth
b x d	represents that portion of the *uncertainty* that varies with depth

The vertical *uncertainty* at the 95% *confidence level* should be recorded together with the survey data (see also 5.3).

3.3 Reductions for Tides / Water-level Observations

Observations sufficient to determine variations in the water level across the entire survey area must be taken for the duration of the survey for the reduction of soundings to the relevant *sounding datum.* These may be determined either by direct measurement of the water level (i.e. by using a gauge) and if necessary carried across the survey area by co-tidal *corrections* or by 3D positioning techniques linked to the required *sounding datum* by a suitable separation model.

Tidal / water-level reductions need not be applied to depths greater than 200 metres if TVU is not significantly impacted by this approximation.

3.4 Depth measurement

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 position and least depth determined. If a previously reported anomalous *feature* is not detected refer to Chapter 6 for disproving requirements. The agency responsible for survey quality may define a depth limit beyond which a detailed sea floor investigation, and thus an examination of anomalous *features,* is not required.

For wrecks and obstructions which may have less than 40 metres clearance above them and may be dangerous to normal surface navigation, their position and the least depth over them should be determined by the best available method while meeting the depth *uncertainty* standard **of the appropriate order** in Table 1.

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

3.5 Feature detection

When a *full sea floor search* is required, the equipment used to conduct the survey must be demonstrably capable of detecting *features* of the dimensions specified in Table 1. Additionally, the equipment must be considered as part of a system (includes survey / processing equipment, procedures and personnel) that will ensure there is a high probability that these *features* will be detected. It is the responsibility of the hydrographic office / organisation that is gathering the data to assess the capability of any proposed system and so satisfy themselves that it is able to detect a sufficiently high proportion of any such *features.*

The Special Order and Order 1a *feature detection* requirements of 1 metre and 2 metre cubes respectively are minimum requirements. *Features* may exist that are smaller than the size mandated for a given order but which are a hazard to navigation. It may therefore be deemed necessary by the hydrographic office / organization to detect smaller *features* in order to minimise the risk of undetected hazards to surface navigation.

It should be noted that even when surveying with a suitable system 100% detection of *features* can never be guaranteed. If there is concern that *features* may exist within an area that may not be detected by the Survey System being used, consideration should be given to the use of an alternative system (e.g. a mechanical sweep) to increase the confidence in the minimum safe clearance depth across the area.

3.6 Sounding Density / Line Spacing

In planning the density of soundings, both the nature of the seabed in the area and the requirements of safe surface navigation have to be taken into account to ensure an adequate *sea floor search.*

For Special Order and Order 1a surveys no recommended maximum line spacing is given as there is an overriding requirement for *full sea floor search.*

Full sea floor search is not required for Orders 1b and 2 and Table 1 recommends maximum line spacing (Orders 1b and 2) and bathymetric LIDAR spot density (Order 1b). The nature of the seabed needs to be assessed as early as possible in a survey in order to decide whether the line spacing / LIDAR spot density from Table 1 should be reduced or extended.

CHAPTER 4 - OTHER MEASUREMENTS

4.1 Introduction

The following observations may not always be necessary but if specified in the survey requirement should meet the following standards.

4.2 Seabed Sampling

The nature of the seabed should be determined in potential anchorage areas; it may be determined by physical sampling or inferred from other sensors (e.g. single beam echo sounders, side scan sonar, sub-bottom profiler, video, etc.). Physical samples should be gathered at a spacing dependent on the seabed geology and as required to ground truth any inference technique.

4.3 Chart and Land Survey Vertical Datums Connection

IHO Technical Resolution A2.5, as set out in IHO Publication M-3, requires that the datum used for tidal predictions should be the same as that used for chart datum. In order for the bathymetric data to be fully exploited the vertical datum used for tidal observations should be connected to the general land survey datum via prominent fixed marks in the vicinity of the tide gauge/station/observatory. Ellipsoidal height determinations of the vertical reference marks used for tidal observations should be made relative to a geocentric reference frame based on ITRS, preferably WGS84, or to an appropriate geodetic reference level.

4.4 Tidal Predictions

Tidal data may be required for analysis for the future prediction of tidal heights and the production of Tide Tables in which case observations should cover as long a period of time as possible and preferably not less than 30 days.

4.5 Tidal Stream and Current Observations

The speed and direction of tidal streams and currents which may exceed 0.5 knot 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 streams and currents when they are of sufficient strength to affect surface navigation.

The tidal stream and current at each position should be measured at depths sufficient to meet the requirements of normal surface navigation in the survey area. In the case of tidal streams, simultaneous observations of tidal height and meteorological conditions should be made and the period of observation should ideally be 30 days.

The speed and direction of the tidal stream and current should be measured to 0.1 knot and the nearest 10^{o} respectively, at 95% *confidence level.*

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

CHAPTER 5 – DATA ATTRIBUTION

5.1 Introduction

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 the survey data is collected.

5.2 Metadata

Metadata should be comprehensive but should comprise, as a minimum, information on:

- the survey in general e.g. purpose, date, area, equipment used, name of survey platform;
- the geodetic reference system used, i.e. horizontal and vertical datum including ties to a geodetic reference frame based on ITRS (e.g. WGS84) if a local datum is used;
- calibration procedures and results;
- sound speed *correction* method;
- tidal datum and reduction;
- *uncertainties* achieved and the respective *confidence levels*;
- any special or exceptional circumstances;
- rules and mechanisms employed for data thinning.

Metadata should preferably be an integral part of the digital survey record and conform to the "IHO S-100 Discovery *Metadata* Standard", when this is adopted. Prior to the adoption of S-100, ISO 19115 can be used as a model for the *metadata*. If this is not feasible similar information should be included in the documentation of a survey.

Agencies responsible for the survey quality should develop and document a list of *metadata* used for their survey data.

5.3 Point Data Attribution

All data should be attributed with its *uncertainty* estimate at the 95% *confidence level* for both position and, if relevant, depth. The computed or assumed scale factor applied to the standard deviation in order to determine the *uncertainty* at the 95% *confidence level*, and/or the assumed statistical distribution of *errors* should be recorded in the survey's *metadata*. (For example, assuming a Normal distribution for a 1 Dimensional quantity, such as depth, the scale factor is 1.96 for 95% confidence. A statement such as "*Uncertainties* have been computed at 95% confidence assuming a standard deviation scale factor of 1.96 (1D) or 2.45 (2D), corresponding to the assumption of a Normal distribution of *errors*," would be adequate in the *metadata*.) For soundings this should preferably be done for each individual sounding; however a single *uncertainty* estimate may be recorded for a number of soundings or even for an area, provided the difference between the individual *uncertainty* estimates and the collectively assigned *uncertainty* estimate is negligible. The attribution should, as a minimum, be sufficient to demonstrate that the requirements of these Standards have been met.

5.4 Bathymetric Model Attribution

If a *Bathymetric Model* is required, *metadata* should include: the model resolution; the computation method; the underlying data density; *uncertainty* estimate/*uncertainty surface* for the model; and a description of the underlying data.

5.5 Report of Survey

The Report of Survey is the principal means by which the Surveyor in Charge approves the contents of all survey records. It must give a clear and comprehensive account of how the survey was carried out, the results achieved, the difficulties encountered and the shortcomings. Emphasis should be placed on the analysis of achieved accuracies and whether the survey specifications have been met.

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 cover all situations. For this reason, it is recommended that the search radius should be at least 3 times the estimated position *uncertainty* 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 *uncertainty* must be estimated by other means as, for example, a more general assessment of positioning and depth measurement *uncertainties* 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 nature of the *feature,* the area in which the doubtful data is reported and the estimated danger of the potential hazard to surface 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 if 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 delete it.

TABLE 1
Minimum Standards for Hydrographic Surveys
(*To be read in conjunction with the full text set out in this document*.)

Reference	Order	Special	1a	1b	2
Chapter 1	**Description of areas.**	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Chapter 2	**Maximum allowable THU 95% *Confidence level***	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Para 3.2 and note 1	**Maximum allowable TVU 95% *Confidence level***	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Glossary and note 2	***Full Sea floor Search***	Required	Required	Not required	Not required
Para 2.1 Para 3.4 Para 3.5 and note 3	***Feature Detection***	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Para 3.6 and note 4	**Recommended maximum Line Spacing**	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Chapter 2 and note 5	**Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)**	2 metres	2 metres	2 metres	5 metres
Chapter 2 and note 5	**Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)**	10 metres	20 metres	20 metres	20 metres
Chapter 2 and note 5	**Mean position of floating aids to navigation (95% *Confidence level*)**	10 metres	10 metres	10 metres	20 metres

Notes:

1: Recognising that there are both constant and depth dependent *uncertainties* that affect the *uncertainty* of the depths, the formula below is to be used to compute, at the 95% *confidence level*, the maximum allowable TVU. The parameters "a" and "b" for each Order, as given in the Table, together with the depth "d" have to be introduced into the formula in order to calculate the maximum allowable TVU for a specific depth:

$$\pm\sqrt{a^2 + (b \times d)^2}$$

Where:

a represents that portion of the *uncertainty* that does not vary with depth
b is a coefficient which represents that portion of the *uncertainty* that varies with depth
d is the depth
b x d represents that portion of the *uncertainty* that varies with 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 1a surveys.

3: A cubic *feature* means a regular cube each side of which has the same length. It should be noted that the IHO Special Order and Order 1a *feature detection* requirements of 1 metre and 2 metre cubes respectively, are minimum requirements. In certain circumstances it may be deemed necessary by the hydrographic offices / organizations to detect smaller *features* to minimise the risk of undetected hazards to surface navigation. For Order 1a the relaxing of *feature detection* criteria at 40 metres reflects the maximum expected draught of vessels.

4: The line spacing can be expanded if procedures for ensuring an adequate sounding density are used.
"Maximum Line Spacing" is to be interpreted as the:
- Spacing of sounding lines for single beam echo sounders, or the
- Distance between the useable outer limits of swaths for swath systems.

5: These only apply where such measurements are required for the survey.

GLOSSARY

Note: The terms defined below are those that are most relevant to this publication. A much larger selection of terms are defined in IHO Special Publication S-32 (Hydrographic Dictionary) and this should be consulted if the required term is not listed here. If a term listed below has a different definition in S-32, the definition given below should be used in relation to these standards.

Accuracy: The extent to which a measured or enumerated value agrees with the assumed or accepted value (see: *uncertainty*, *error*).

Bathymetric Model: A digital representation of the topography (bathymetry) of the sea floor by coordinates and depths.

Blunder: The result of carelessness or a mistake; may be detected through repetition of the measurement.

Confidence interval: See *uncertainty.*

Confidence level: The probability that the true value of a measurement will lie within the specified *uncertainty* from the measured value. It must be noted that confidence levels (e.g. 95%) depend on the assumed statistical distribution of the data and are calculated differently for 1 Dimensional (1D) and 2 Dimensional (2D) quantities. In the context of this standard, which assumes Normal distribution of *error*, the 95% confidence level for 1D quantities (e.g. depth) is defined as 1.96 x standard deviation and the 95% confidence level for 2D quantities (e.g. position) is defined as 2.45 x standard deviation.

Correction: A quantity which is applied to an observation or function thereof, to diminish or minimise the effects of *errors* and obtain an improved value of the observation or function. It is also applied to reduce an observation to some arbitrary standard. The correction corresponding to a given computed *error* is of the same magnitude but of opposite sign.

Error: The difference between an observed or computed value of a quantity and the true value of that quantity. (NB The true value can never be known, therefore the true error can never be known. It is legitimate to talk about error sources, but the values obtained from what has become known as an error budget, and from an analysis of residuals, are *uncertainty* estimates, not errors. See *uncertainty*.)

Feature: in the context of this standard, any object, whether manmade or not, projecting above the sea floor, which may be a danger for surface navigation.

Feature detection: The ability of a system to detect *features* of a defined size. These Standards specify the size of *features* which, for safety of navigation, should be detected during the survey.

Full sea floor search: A systematic method of exploring the sea floor undertaken to detect most of the *features* specified in Table 1; utilising adequate detection systems, procedures and trained personnel. In practice, it is impossible to achieve 100% ensonification / 100% bathymetric coverage (the use of such terms should be discouraged).

Integrity monitor: Equipment consisting of a GNSS receiver and radio transmitter set up over a known survey point that is used to monitor the quality of a Differential GNSS (DGNSS) signal. Positional discrepancies are continuously monitored and timely warnings are transmitted to users indicating when the system should not be used.

Integrity monitoring: This is the ability of a system to provide timely warnings to users when the system should not be used.

Metadata: Information describing characteristics of data, e.g. the *uncertainty* 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 uncertainty and copyright.

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.

Reduced depths: Observed depths including all *corrections* related to the survey and post processing and reduction to the used vertical datum.

Sea floor search: A systematic method of exploring the sea floor in order to detect *features* such as wrecks, rocks and other obstructions on the sea floor.

Sounding datum: The vertical datum to which the soundings on a hydrographic survey are reduced. Also called 'datum' for sounding reduction.

Total horizontal uncertainty (THU): The component of *total propagated uncertainty* (TPU) calculated in the horizontal plane. Although THU is quoted as a single figure, THU is a 2 Dimensional quantity. The assumption has been made that the *uncertainty* is isotropic (i.e. there is negligible correlation between *errors* in latitude and longitude). This makes a Normal distribution circularly symmetric allowing a single number to describe the radial distribution of *errors* about the true value.

Total propagated uncertainty (TPU): the result of *uncertainty* propagation, when all contributing measurement *uncertainties,* both random and systematic, have been included in the propagation. *Uncertainty* propagation combines the effects of measurement *uncertainties* from several sources upon the *uncertainties* of derived or calculated parameters.

Total vertical uncertainty (TVU): The component of *total propagated uncertainty* (TPU) calculated in the vertical dimension. TVU is a 1 Dimensional quantity.

Uncertainty: The interval (about a given value) that will contain the true value of the measurement at a specific *confidence level.* The *confidence level* of the interval and the assumed statistical distribution of *errors* must also be quoted. In the context of this standard the terms uncertainty and *confidence interval* are equivalent.

Uncertainty Surface: A model, typically grid based, which describes the depth *uncertainty* of the product of a survey over a contiguous area of the skin of the earth. The uncertainty surface should retain sufficient *metadata* to describe unambiguously the nature of the *uncertainty* being described.

ANNEX A

GUIDELINES FOR QUALITY CONTROL

NOTE: it should be noted that the information contained in Annexes A and B provide some guidance on *quality control* and data processing. These Annexes are **not** an integral part of the S-44 Standards and will be removed when the information therein is fully incorporated into IHO Publication M-13.

A.1 Introduction

To ensure that the required *uncertainties* are achieved it is necessary to monitor performance. Compliance with the criteria specified in this document has to be demonstrated.

Standard calibration techniques should be completed prior to and after the acquisition of data and after any major system modification takes place.

Establishing *quality control* procedures should be a high priority for hydrographic offices / organizations. These procedures should cover the entire system including navigation sensors, data collection and processing equipment and the operators. All equipment should be confirmed as functioning within its calibration values and the system should be assessed to ensure that the relevant *uncertainties* in Table 1 can be met. Other parameters, e.g. vessel motion and speed, which can affect the quality of the collected data, should also be monitored.

The processing procedures used prior to the introduction of Multi Beam, Echo Sounders (MBES) and bathymetric LIDAR systems are inefficient, in terms of both manpower and the time required to process the high volume of data gathered by these systems. Processing procedures are needed that allow the reduction, processing and production of the final data set within acceptable manpower and time constraints while maintaining data integrity. As hydrographic offices / organizations continue to be responsible (liable) for their products, these processing procedures should be well documented.

The original survey data (raw data from the different sensors) should be conserved adequately before commencing with the processing of data. The final processed data set should also be conserved. The long-term storage of data, in this era of rapidly changing electronic systems, needs careful planning, execution and monitoring.

Each office is responsible for the definition of its long-term conservation policy for both raw and processed data sets.

A.2 Positioning

Integrity monitoring for Special Order and Order 1a/b surveys is recommended. When equipment is installed to determine or improve the positioning of survey platforms (e.g. Global Navigational Satellite Systems (GNSS) *corrections*), the *uncertainty* of the equipment position relative to the horizontal datum must be included in the calculation of THU.

A.3 Depth Data Integrity

Check lines or overlapping swaths indicate the level of agreeability or repeatability of measurements but do not indicate absolute *accuracy* in that there are numerous sources of potential common *errors* (see A.4) between data from main lines and check lines. The *quality control* procedure should include statistical analysis of differences and the consideration of common *errors* to provide an indication of compliance of the survey with the standards given in Table 1. The effect of spikes and *blunders* should be eliminated prior to this analysis. Remaining anomalous differences should be further examined with a systematic analysis of contributing *uncertainty* sources. All discrepancies should be resolved, either by analysis or re-survey during progression of the survey task.

The ability to compare surfaces generated from newly collected data to those generated from historical information can often be useful in validating the quality of the new information, or alternatively, for notifying the collecting agency of an unresolved systematic *uncertainty* that requires immediate attention.

A.3.1 Single-beam Echo Sounders (SBES)

Check lines should be run at discrete intervals. These intervals should not normally be more than 15 times the spacing of the main sounding lines.

A.3.2 Swath Echo Sounders

An appropriate assessment of the *uncertainty* of the depths at each incidence angle (within each beam for a MBES) should be made. If any of the depths have unacceptable *uncertainties,* the related data should be excluded. A number of check lines should be run. Where adjacent swaths have a significant overlap the spacing between check lines may be extended.

A.3.3 Sweep Systems (multi-transducer arrays)

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 full sea floor coverage across the measurement swath. A number of check lines should be run.

Vertical movements of booms must be monitored carefully as the sea state increases, especially where the effects of heave on the transducers are not directly measured (e.g. decoupled booms systems). Once the heave on the transducers exceeds the maximum allowable value in the *uncertainty* budget, sounding operations should be discontinued until sea conditions improve.

A.3.4 Bathymetric LIDAR

Hazards to navigation detected by bathymetric LIDAR should be examined using a bathymetric system capable of determining the shallowest point according to the standards set out in this document. A number of check lines should be run.

A.4 Error Sources

Although the following text focuses on *errors* in data acquired with swath systems, it should be noted that it is in principle applicable to data acquired with any depth measurement system.

With swath systems the distance between the sounding on the sea floor and the positioning system antenna can be very large, especially in deep water. Because of this, sounding position *uncertainty* is a function of the *errors* in vessel heading, beam angle and the water depth.

Roll and pitch *errors* will also contribute to the *uncertainty* in the positions of soundings. Overall, it may be very difficult to determine the position *uncertainty* for each sounding as a function of depth. The *uncertainties* are a function not only of the swath system but also of the location of, offsets to and accuracies of the auxiliary sensors.

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

a) Positioning system *errors*;
b) Range and beam *errors;*
c) The error associated with the ray path model (including the sound speed profile), and the beam pointing angle;
d) The error in vessel heading;
e) System pointing *errors* resulting from transducer misalignment;
f) Sensor location;
g) Vessel motion sensor *errors* i.e. roll and pitch;
h) Sensor position offset *errors*; and
i) Time synchronisation / latency.

Contributing factors to the vertical *uncertainty* include:

a) Vertical datum *errors*;
b) Vertical positioning system *errors*;
c) Tidal measurement *errors,* including co-tidal *errors* where appropriate;
d) Instrument *errors;*
e) Sound speed *errors;*
f) Ellipsoidal / vertical datum separation model *errors;*
g) Vessel motion *errors*, i.e. roll, pitch and heave;
h) Vessel draught;
i) Vessel settlement and squat;
j) Sea floor slope; and
k) Time synchronisation / latency.

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

A.5 Propagation of Uncertainties

TPU is a combination of random and bias based *uncertainties.* Random and short period *uncertainties* have to be recognised and evaluated both in horizontal and vertical directions.

The propagated *uncertainty* may be expressed as a variance (in meters^2) but is more often reported as an *uncertainty* (in meters) derived from variance with the assumption that the *uncertainty* follows a known distribution. In the latter case, the level of confidence (e.g., "at 95% *confidence level*") and the assumed distribution shall be documented. Horizontal *uncertainties* are generally expressed as a single value at a 95% level, implying an isotropic distribution of *uncertainty* on the horizontal plane.

In the hydrographic survey process it is necessary to model certain long period or constant factors related to the physical environment (e.g. tides, sound speed, dynamics, squat of the survey vessel). Inadequate models may lead to bias type *uncertainties* in the survey results. These *uncertainties* shall be evaluated separately from random type *uncertainties*.

TPU is the resultant of these two main *uncertainties*. The conservative way of calculating the result is the arithmetic sum, although users should be aware that this may significantly overestimate the total *uncertainty.* Most practitioners, and the appropriate ISO standard, recommend quadratic summation (i.e., summation of suitably scaled variances).

ANNEX B

GUIDELINES FOR DATA PROCESSING

NOTE: it should be noted that the information contained in Annexes A and B provide some guidance on *quality control* and data processing. These Annexes are **not** an integral part of the S-44 Standards and will be removed when the information therein is fully incorporated into IHO Publication M-13.

The text of this annex originates from IHB CL 27/2002 entitled "Guidelines for the processing of high volume bathymetric data" dated 8 August 2002. Sections 2, 3.1 and 4 of these guidelines have been incorporated into the main body of the 5th Edition of S-44 whilst the remaining sections, with a few amendments, are reproduced below.

B.1 Introduction

The following processing guidelines concentrate on principles and describe **minimum requirements.** The processing steps outlined below are only to be interpreted as an indication, also with regard to their sequence, and are not necessarily exhaustive. Adaptations may be required due to the configuration of the survey as well as the processing system actually used. In general, processing should strive to use all available sources of information to confirm the presence of navigationally significant soundings.

The following workflow should be followed:

B.1.1 Position

This step should comprise merging of positioning data from different sensors (if necessary), qualifying positioning data, and eliminating position jumps. Doubtful data should be flagged and not be deleted.

B.1.2 Depth corrections

Corrections should be applied for water level changes, measurements of motion 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.

B.1.3 Attitude data

Attitude data (heading, heave, pitch, roll) should be qualified and data jumps be eliminated. Doubtful data should be flagged and not be deleted.

B.1.4 Sound speed correction

Corrections due to two-way travel time and refraction should be calculated and applied during this step. If these *corrections* have already been applied in real-time during the survey, it should be possible to override them by using another sound speed profile.

B.1.5 System Time Latencies

Time latencies in the survey system may include both constant and variable components. The acquisition system or the processing system should check for latency and remove it whenever practicable.

B.1.6 Merging positions and depths

For this operation the time offset (latency) and the geometric offsets between sensors have to be taken into consideration.

B.1.7 Analysis of returning signal

When a representation of the time series of the amplitude of the returning signal is available, this information may be used to check the validity of soundings.

B.1.8 Automatic (non-interactive) data cleaning

During this stage, 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. When selecting an algorithm, robust estimation techniques should be taken into consideration as their adequacy has been confirmed. Many high-density bathymetry processing packages have built-in statistical processing tools for detecting and displaying outliers. Generally speaking, higher-density data sets with large amounts of overlap between lines provide an increased likelihood of detecting *blunders*. In addition to statistics, threshold values for survey data can be used to facilitate the detection of *blunders*. Each agency is responsible for the validation of the algorithm used and the procedures adopted.

All *blunders* and erroneous and doubtful data should be flagged for subsequent operator control. The type of flag used should indicate that it was set during the automatic stage.

B.1.9 Manual (interactive) data cleaning

Following automated processing procedures, there is a requirement for an experienced and responsible hydrographer to review the automated results and validate those results and/or resolve any remaining ambiguities.

For this stage the use of 3-D visualisation tools is strongly recommended. Decision making about whether to accept or reject apparently spurious soundings can often be enhanced by viewing combined data sets in three dimensions. 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, *uncertainty* plot, single profile, single beam, backscatter imagery etc. and should allow for the visualisation of the survey data in conjunction with other useful information e.g. shoreline, wrecks, aids to navigation etc. Editing the data should be possible in all modes and include an audit trail. When editing sounding data, it can often be useful to understand the spatial context of the examined data points. What may appear to be bad soundings (*blunders*) out of context may be recognised as real sea floor artefacts (submerged piles, wrecks, etc.) when viewed in the context of a chart backdrop for example. If feasible, data displays should be geo-referenced. The ability to compare surfaces from newly collected data to ones generated from historical information can often be useful in validating the quality of the new information, or alternatively, for notifying the collecting agency of an unresolved systematic *uncertainty* that requires immediate attention.

If feasible, these tools should include the reconciliation of normalised backscatter imagery with bathymetry and, provided that automated object detection tools were used, the display of flagged data for both data modes should be possible.

The rules to be observed by operators during this stage should be documented.

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 a/b 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.

B.2 Use of *uncertainty surfaces*

Many statistical bathymetry processing packages also have the ability to generate an *uncertainty surface* associated with the bathymetry using either input *error* estimates or by generating spatial statistics within grid cells. Displaying and codifying these *uncertainty surfaces* is one method of determining whether the entire survey area has met the required specifications. If some areas fall outside the specifications, these areas can be targeted for further data collection or use of alternative systems in order to reduce the *uncertainty* to within an acceptable tolerance. When performed in real-time, the sampling strategy can be adapted as the survey progresses, ensuring the collected data are of an acceptable quality for the intended use. Each agency is responsible for the validation of these processing capabilities prior to use.

B.3 Validation Procedures

The final data should be subject to independent in-house validation employing documented *quality control* procedures.