S-44

IHO Standards for Hydrographic Surveys

6th Edition draft 1.7.0

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IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44)
6th Edition draft 1.7.0 July 2019

CONTENTS

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

PREFACE

This Special Publication 44 (S-44) defines the standard applicable to hydrographic surveys and takes its place amongst the other International Hydrographic Organization (IHO) publications, dedicated to improve the safety of navigation, knowledge and protection of the marine environment.

Formal discussions on establishing standards for hydrographic surveys began at the 7th International Hydrographic Conference (IHC) in 1957. The 1st Edition of S-44 entitled "Accuracy Standards Recommended for Hydrographic Surveys" was published in January 1968. Since this edition, the IHO has endeavoured to update this standard regularly to keep pace with the existing technologies and methods. Five successive editions have thus been released since the 1968 original issue: the 2nd edition was published in 1982, the 3rd in 1987, the 4th in1998 and finally, the 5th edition in 2008. The point of these being to maintain continuity of the original idea throughout successive changes.

By its Circular Letter 68/2016 of 20 December 2016, the IHO established a Hydrographic Survey Project Team (HSPT) tasked with updating the standard and in its CL 26/2017 further defined the composition of the team. The HSPT tasks consist of three goals: firstly upgrade the 5th edition of the standard, secondly, prepare an S-44 6th edition and finally, if necessary, set up a permanent Working Group tasked with addressing all hydrographic surveys concerns. The HSPT team comprises representatives from the IHO Member States, observers from International Organizations (IFHS and FIG), other expert contributors, and the Secretariat of the IHO.

Between 2008, date of release of the S-44 5th edition and 2017, date of establishment of the Project Team, hydrographic technologies and requirements have evolved. In particular, hydrographic acquisition and processing systems have become more efficient and widespread, thus serving an expanding community of users having varying intended purposes. While hydrographers logically follow these changes, the S-44 standard needs to evolve in order to remain the international reference that hydrographic surveys require.

The HSPT activities took place over four years. The team published a questionnaire for the entire hydrographic community. This questionnaire was a valuable tool to structure the work of the team and best meet the needs of the community while remaining committed to the IHO mandate.

Thus, the S-44 in this 6th edition meets several requirements. The classification by "Orders", as defined in the previous version, has been retained Specifications for Special Order and Order 1a has incurred slight modifications. Indeed, for both orders, full bathymetric coverage is now explicitly stated, and for Order 1a, the depth requirement for 2 m cubic feature detection is now 50 m instead of 40 m. The references to specific technologies have been suppressed in order to focus the document on the requirements to be achieved, regardless of the systems used. The S-

44 vocabulary has been revised in order to match the references used in metrology. Most chapters have been updated to keep pace with current methods. Horizontal positioning requirements for aids to navigation have been revised and specifications on their vertical positioning have been added.

Finally, there will be a notable change compared to the previous version which results in the emergence of the *Matrix*. This *Matrix* responds to a very strong need from a diverse community beyond hydrographic offices for an opening of the S-44 to address new issues, other than safety of navigation. The *Matrix* provides an opportunity for this standard, and therefore for the IHO, to meet the expectations of the community as a whole, not just the Hydrographic Offices. This *Matrix* alone is not a standard. It should be considered as a reference to specifying dedicated surveys, as appropriate, and also to provide a tool for a broader classification of surveys.

And as a final note, it seems important for the team to remind readers of the following two points: firstly, this document is validated by all IHO Member States. It results from various considerations on which a consensus had to be reached. Secondly, this standard imposes specific minimum requirements to surveys focused on safety of navigation in support of protection of marine environment. Hydrographic offices or authorities[1] may decide to define more stringent requirements, in which case they are encouraged to use the *Matrix*.

[1] A responsible authority may be an organization, public or private, responsible for the surveys, including fixed and floating aids to navigation (e.g. harbor master, organization responsible for the upkeep of fairways).

INTRODUCTION

This publication aims to provide a set of standards for hydrographic surveys primarily used to compile navigational charts to be used for the safety of navigation and the protection of the marine environment. It specifies the minimum standards to be achieved based on the intended use of the area. Where necessary, hydrographic offices / organizations are encouraged to define more stringent or specific requirements as national or regional realizations of the standard. This publication does not contain procedures for setting up equipment, conducting the survey or for processing the resultant data. IHO Publication C-13 should be consulted for information on those topics (downloadable from the IHO homepage https://www.iho.int).

This edition aims to encourage the use of these standards beyond safety of navigation. It introduces the concept of a *Matrix* of parameters to define realizations of survey standards. It is, by design, expandable and can evolve in future S-44 versions. For hydrographic surveys outside the scope of the Orders, the *Matrix* is intended to be used to help define survey specifications.

The Orders for safety of navigation surveys remain unchanged from the previous edition. However, in the 6th edition, Special Order and Order 1a now explicitly require a full *bathymetric coverage*. Furthermore, the Orders have been divided into requirements above and below the vertical chart datum. Depth dependency has been updated to be more consistent with chart specifications.

Emphasis has been placed upon the main components of hydrographic surveys while being technology independent. It remains the decision of the hydrographic surveyor on how to achieve the standard. Furthermore, it has to be noted that 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.

The Annexes contain guidance which, while not part of this standard, are provided as best practice for achieving and assessing the quality of hydrographic survey data using contemporary data processing techniques. The first annex provides guidance on how to use the *Matrix*.

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

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.

For the purpose of this Publication the words:

> **must**: indicates a mandatory requirement;
> **should**: indicates an optional requirement;
> **may**: means 'allowed' or 'could possibly'

Terms that are only used within the Annexes and may be moved to C-13 are not included in this Glossary; these are defined within the Annexes.

Bathymetric coverage: Extent to which an area has been surveyed using a systematic method of exploring the bottom undertaken to obtain homogenous and relevant depth information. A 100% bathymetric coverage must be considered as a systematic method of mapping most of the bottom to the horizontal and vertical positioning standards specified in this standard.

> Example: A 5% bathymetric coverage with an 8° beam width singlebeam is almost equivalent to an inter-line spacing of 3-times water depths according to the formula $\frac{100}{5} * 2 * \tan(\frac{8}{2})$.

Bathymetric model: A digital representation of the topography (bathymetry) of the sea floor (or lake, river etc bottom) by coordinates and depths.

Confidence level: Probability that the true value of a measurement will lie within the specified *uncertainty* from the measured value.

> Example: In order to comply with the *total vertical uncertainty* requirement for Special Order in 15m depth, a comparison between the sounding measurements and some other reference measurements should demonstrate that the interval [μ - 1.96 × σ , μ + 1.96 × σ], where μ and σ are respectively the mean and standard deviation of the sounding to reference measurement difference, is contained within the acceptance interval [-0.27m , +0.27m].
>
> Note 1 to entry: It must be noted that *confidence levels* (e.g. 95%) depend on the assumed statistical distribution of the data and are calculated differently for one-dimensional (1D) and two-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.
>
> Note 2 to entry: In this standard the term *confidence level* is not the strict statistical definition, but is equivalent to the terms "level of confidence" or "coverage probability" as discussed in the *Guide to the Expression of Uncertainty in Measurement*, JCGM 100:2008, section 6.2.2.

Correction: Compensation for an estimated systematic effect.

Error: The difference between a measured value and the correct or true value. *Errors* can be categorized as a *systematic error* or a *random error*.

Feature: Any object, whether natural or manmade, which is distinct from the surrounding area. This standard defines features of minimum sizes that pose a danger to navigation as *significant features*. Reportable features for a safety of navigation survey generally include those objects one would expect to see depicted on a nautical chart or product.

Example: pipeline, rock, wreck

Feature detection: The ability of a system to detect significant *features* of a defined size.

Feature search: A systematic method of exploring the bottom undertaken to detect significant *features* of specified minimum sizes. A 100% feature search must be capable of detecting most significant *features* specified in this standard.

Metadata: 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: Actions necessary (i.e. process) to provide adequate confidence that a product or a service will satisfy a standard of Quality Management.

Quality control: A system of maintaining standards in products by testing a sample of the output against the specification.

Random error: component of measurement *error* that in replicate measurements varies in an unpredictable manner.

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

Systematic error: component of measurement *error* that in replicate measurements remains constant or varies in a predictable manner.

Total horizontal uncertainty (THU): The component of *total propagated uncertainty* (TPU) calculated in the horizontal plane. THU is a two-dimensional quantity. The THU of a position expresses, in terms of a radial distance about a coordinate pair, the probability, as specified by the confidence level, that the true position is contained within the uncertainty interval.

Note 1 to entry: The assumption has been made that the horizontal 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 one-dimensional quantity. The vertical uncertainty of a depth or elevation value is the distance about that measurement that will likely contain the true depth or elevation within the specified geodetic or vertical reference frame. Vertical uncertainty of depth data is to be understood as the uncertainty of the *reduced depths*.

Uncertainty: Non-negative parameter characterizing the dispersion of the quantity values being attributed to the measurand based on the information used.

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.

Underkeel Clearance: The distance between the lowest point of the ship's hull, normally some point on the keel, and the bottom.

CHAPTER 1 CLASSIFICATION OF SAFETY OF NAVIGATION SURVEYS

1.1 Introduction

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

The four orders are described below along with an indication of the need that the order is expected to meet. The minimum standards required to achieve each order (*Table 1* and *Table 2*) along with a new tool for enhancing and customizing these orders (Specification *Matrix*) will be presented in Chapter 7.

The hydrographic offices or authorities responsible for acquiring surveys should select the order of survey that is most appropriate for the requirements for safety of 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 50 metres, an Order 1a survey may have been specified. However, if the surveyor discovers shoals extending to less than 50 metres, then it may be more appropriate to survey these shoals, including a well-balanced area, to Special Order.

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

1.2 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. *Bathymetric coverage* is required for 4% of the survey area leaving 96% of the area unsurveyed. It is recommended that Order 2 surveys are conducted in areas deeper than 200 metres. Once the water depth exceeds 200 metres, the existence of *features* that are large enough to impact surface navigation but remain undetected by an Order 2 survey is considered to be unlikely.

1.3 Order 1b

This order is intended for areas where the type of surface vessels expected to transit the area is such that a general depiction of the seabed is considered adequate. *Bathymetric coverage* is required for 5% of the survey area, leaving 95% of the survey area unsurveyed. 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 bottom characteristics are such that the likelihood of there being a *feature* on the bottom that will endanger the type of surface vessel expected to navigate the area is low.

1.4 Order 1a

This order is intended for those areas where the sea is sufficiently shallow to allow *features* on the seabed to be of concern to the type of surface shipping expected to transit the area but where the under-keel clearance is critical. Because *features* may exist that are of concern to surface shipping, a 100% *feature search* and 100% *bathymetric coverage* are required in order to detect significant *features* of a specified size. Under-keel clearance becomes less critical as depth increases, so the size of the *feature* to be detected increases with depth in areas where the water depth is greater than 50 metres.

As a minimum, when the surveyed depth in a trafficked area becomes shallower than the sum of *expected vessel draft*, *minimum required underkeel clearance*, *total vertical uncertainty* and *minimum feature size to be detected*, a change to Special Order is required to ensure safety of navigation.

1.5 Special Order

This order, the strictest in this standard, is intended for those areas where under-keel clearance is more critical than for Order 1a. Because under-keel clearance is critical, 100% *bottom search* and 100% *bathymetry coverage* are required and the size of the *features* to be detected by this search is deliberately kept smaller than for Order 1a. Examples of areas that may warrant Special Order surveys are: berthing areas, harbours and critical areas of shipping channels.

Note: 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

CHAPTER 2 HORIZONTAL AND VERTICAL POSITIONING

2.1 Introduction

Positioning is the fundamental framework and starting point for every survey operation. The position of any point (e.g. sounding, *feature*, etc.) can be referenced using either geodetic coordinates defined by latitude (ϕ), longitude (λ) and ellipsoid height (h) or Cartesian coordinates (x, y, z).

Positions should be referenced to a geodetic reference frame, which can be the realization of either a global (e.g. ITRS, WGS84) or a regional (e.g. ETRS89, NAD83) reference system. As there are frequent updates to geodetic reference systems, it is essential that the epoch is recorded for surveys with low positioning uncertainty.

Since positions are most often referenced in a compound coordinate reference system such as geodetic, geopotential, and height reference system, they can therefore be separated into horizontal and vertical components during the survey process (see sections 2.2 and 2.3)

2.2 Horizontal Reference Frame

If horizontal positions are referenced to a local horizontal datum, the name and epoch of the datum should be specified and the datum should be tied to a realisation of the ITRS (i.e. ITRFxx,) or equivalent global geodetic reference frame (e.g. ITRS, WGS84, ETRS89, NAD83 realisations). Transformations between reference frames/epochs have to be taken into account, especially for surveys with low uncertainty.

2.3 Vertical Reference Frame

If positions are referenced to a local vertical datum, the name and epoch of the datum should be specified. Vertical positions (e.g. depths, drying heights) should be referenced to a vertical reference frame that is suitable for the data type and intended use. This vertical reference frame may be based on tidal observations (e.g. LAT), on a physical model (i.e. geoid) or on a geometric reference frame.
height system that is suitable for the data type and intended use such as Lowest Astronomical Tide (LAT), a geoid model, or a reference ellipsoid.

2.4 Uncertainties

Position *uncertainties* must be expressed at the 95% *confidence level* and should be recorded together with the survey data.

The capability of the survey system should be demonstrated by an *a priori* positioning *total propagated uncertainty* (TPU) calculation. This statistical calculation is predictive in nature and must be calculated for the survey system as a whole, including all instrument, system integration and *in-situ* environmental *uncertainty*. The *a priori* calculation should be updated during the survey to reflect deviations from expected environmental conditions (e.g. waves, sound velocity, bottom roughness) in order to optimize the *a priori* TPU calculation. Whenever possible, an *a priori* positioning TPU should be supplemented by an *a posteriori* positioning *uncertainty* assessment based on measurement repeatability or comparison that will validate the agreement between the *a priori* TPU and the *a posteriori* *uncertainty* assessment.

The positioning TPU may be separated into *total horizontal uncertainty* (THU) and *total vertical uncertainty* (TVU) components.

CHAPTER 3 DEPTH, BOTTOM COVERAGE, FEATURES, AND NATURE OF THE BOTTOM

3.1 Introduction

The navigation of surface vessels requires accurate knowledge of depth and *features* in order to exploit safely the maximum available water. Where under-keel clearances are an issue, *bathymetric coverage* needs to be augmented and depth *uncertainties* must be tightly controlled and well 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.

3.2 Depth

3.2.1 Depth Measurement

Depths are to be understood as *reduced depths* of both soundings and *features* within a well-defined vertical reference frame.

For safety of navigation, the main consideration is the threshold above which safe navigation can be guaranteed. In waters with very high turbidity, e.g. estuaries, this threshold may be determined on the basis of sediment concentrations in the water, in which case one may prefer using the term: safe navigation threshold.

For safety of navigation, the depth of a *feature* is expressed as the minimum depth of that *feature*.

3.2.2 Vertical Uncertainty

Recognising that there are both depth-dependent and -independent *error* sources that affect the measurements of the depths, the formula below is used to compute an acceptance interval for measurement uncertainties. *Total vertical uncertainties* of depth measurements calculated with a 95 % confidence level must comply with this acceptance interval.
The parameters “a” and “b”, together with the depth “d”, have to be introduced into the formula below in order to calculate the acceptance interval A(d):

$$\mathrm{A}(d) = [-\sqrt{a^2 + (b \times d)^2}\,;\, +\sqrt{a^2 + (b \times d)^2}]$$

Where:

- a — represents that portion of the *uncertainty* that does not vary with the depth
- b — is a coefficient which represents that portion of the *uncertainty* that varies with the depth. It is given in percent format and must be devided by 100 when used in the equation above (i.e. for 0.75% of depth, use b = 0.0075).
- d — is the depth
- b x d — represents that portion of the *uncertainty* that varies with depth

Table 1 specifies the parameters "a" and "b" to compute the acceptance intervals A(d) for the TVU of *reduced depths* to be achieved to meet each survey order.

3.3 Bathymetric Coverage

In the context of this standard, the *bathymetric coverage* is to be understood as the surveyed spatial extent of depth measurement based on the combination of the survey pattern and the theoretical area of detection of the survey instrumentation.

A 100% *bathymetric coverage* does not guarantee that the density of depth measurements is sufficient for the intended product resolution. Similarly, a 100% *bathymetric coverage* does not guarantee continuous depth measurements, since the depth measurements are discrete and based on the inherent limitations of the physical principle used by the survey instrumentation (e.g. ensonification, illumination). Nevertheless, a 100% *bathymetric coverage* implies that depths measurements, surveyed to the positional standards specified in *Table 1*, are such that they provide a depiction of vast majority of the bottom, and can be considered as a "full" bathymetric coverage.

A *bathymetric coverage* less than 100% is to follow a systematic survey pattern to maximize even distribution across the survey area. Additionally, the nature of the bottom (e.g. roughness, type) and the requirements for safety of surface navigation in the area must be taken into account early and often to determine whether bathymetric coverage should be increased to meet the requirements for safety of navigation in the area, or could potentially be reduced without jeopardizing the fulfilment of those same requirements.

Table 1 specifies the bathymetric coverage to be achieved by each survey order. Due to their importance for safety of navigation, a 100% *bathymetric coverage* is required for Order 1a and Special Order. For Order 2 and Order 1b, the requirements are relaxed and correspond approximately to an inter-line spacing, respectively of 4 and 3-times water depth for most common singlebeam echosounders.

3.4 Feature Search

In the context of this standard, *feature search* implies the detection of significant *features*.

3.4.1 Feature detection

The Special Order and Order 1a significant *feature detection* requirements of cubic features of the dimensions specified in *Table 1* are minimum requirements applicable when a full *feature search* is required. The detection system must be demonstrably capable of detecting such significant *features* and must ensure that there is a high probability that these significant *features* will indeed be detected. It is the responsibility of the hydrographic office or authority 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 significant *features*.

It should be noted that no detection system can guarantee a 100% detection of *significant features*. If there is a concern that significant *features* may exist within an area that may not be detected by the survey system being used, consideration should be given to use an alternative detection system to increase the confidence in the minimum safe clearance depth across the survey area.

Whenever possible, it is recommended to conduct a full *feature search* in conjunction with a full *bathymetric coverage*. Nevertheless, a full *feature search* may be conducted with a partial *bathymetric coverage*, in which case depth measurements will be required for any new detected significant *feature*.

In some cases, significant *features* smaller than the defined sizes can be classified as significant hazard to navigation. It may therefore be deemed necessary by the hydrographic office or authority to detect smaller significant *features* in order to minimise the risk of undetected hazards to surface navigation.

3.5 Hazards to Navigation

Hydrographic offices and authorities must consider the traffic likely to take place (e.g. density, draught of vessels) of the area as well as general configuration of depths in the area when assessing hazards to navigation.

Sufficient data must be acquired over *features* that are potential hazards (wreck or other obstructions) to determine if they are, indeed, hazards to navigation. The least depth and position (of the least depth) over hazards to navigation should be determined by the best available method while meeting the depth *uncertainty* standard of the appropriate Order in *Table 1*. Given current ship specifications, *features* with least depths deeper than 50m would not likely constitute a hazard to surface navigation. However, this statement must be constantly re-evaluated based on local circumstances and potential changes to local circumstances.

The hydrographic office, or authority, responsible for survey quality, may define a depth limit beyond which a detailed bottom investigation, and thus an examination of anomalous *features*, is not required.

3.6 Charted Object Confirmation / Disproval

For safety-of-navigation surveys, it is recommended to confirm or disprove the existence of charted objects such as rocks, wrecks, obstructions, and doubtful data with survey data and address the findings in the report of survey. Doubtful data include, but are not limited to, data which are usually denoted on charts by PA (Position Approximate), PD (Position Doubtful), ED (Existence Doubtful), SD (Sounding Doubtful), or as "reported danger."

3.6.1 Charted Object Confirmation

Charted objects should be confirmed relative to their charted position.

3.6.2 Charted Object Disproval

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 a charted object is not located within the search radius, the charted object can then be disproved.

Sufficiently disproved charted objects are recommended to be noted in the report of survey providing hydrographer recommendations to the cartographer (e.g. Recommend remove from chart). It is the responsibility of the hydrographic office or authority that is gathering the data to assess whether the charted object has been sufficiently disproved before removing it.

3.7 Nature of the Bottom

For safety of navigation surveys, the nature of the bottom should be determined in potential anchorage areas as well as other critical areas and in areas where bottom conditions are suspected to have significant influence on required object detection. The nature of the bottom can be determined by physical sampling or inferred from other sensors (e.g. backscatter or reflectivity). Physical samples may be gathered at a spacing dependent on the scale of the intended product (e.g. chart), seabed geology and, as required to ground truth, any inference technique. Sedimentological characterization may be achieved by a combination of visual/remote sensing and laboratory analysis of samples.

CHAPTER 4 TIDES, WATER LEVELS AND CURRENTS

4.1 Introduction

Current and tidal information is important for planning and performing nautical operations while tidal levels may be tightly linked to the chart datum and the survey quality. Therefore, observing current and tidal levels is considered an integral part of hydrographic surveys for safety of navigation. Current and tidal observations may not always be relevant or necessary. However, if they are specified in the survey requirements, observations should meet the following standards.

4.2 Chart and Land Survey Vertical Datums Connection

In order for the bathymetric data to be unambiguously exploited, it is essential that the directives set out in the IHO Technical resolution 3/1919 is followed during hydrographic surveys.

The directive 3/1919 with its last amendment can be found in the IHO M-3, downloadable from the IHO homepage https://www.iho.int.

The adopted Chart Datum should be clearly defined against the geodetic datum used for heights in land survey applications.

4.3 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 period of time as possible and preferably not less than 30 days.

Note: For high precision tidal prediction, 40 years of observation is recommended as a targeted objective (see IHO Resolution TWCWG1/7.1/1 A2.5).

4.4 Reductions for Tides / Water-level Observations

Whenever surveyed/predicted tides or water levels, are used to reduce soundings to a datum, allowance shall be made in the TVU calculations for the *uncertainty* of the used values. In most circumstances observed values are preferred over predicted.

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 at 95% *confidence level* as defined in *Table 2*.

Where there is reason to believe that other factors (e.g. seasonal river discharge) influence the tidal streams and currents, measurements should be made to cover the entire period of variability.

CHAPTER 5 SURVEYS ABOVE THE VERTICAL CHART DATUM

5.1 Introduction

Topographic surveys on land need to be conducted for safety of navigation and efficient mooring. Objects that are of specific importance for navigation are the positions of fixed aids to navigation, such as lighthouses, leading lines, and beacons as well as the coastline. For mooring purposes, highly accurate positioning of harbour details such as jetties, quayside, and breakwaters is essential for safe manoeuvring in confined spaces and automated docking, especially for autonomous ships.

For Chart and Land Survey Vertical Datums Connection see 4.2

5.2 Positioning

For some purposes, such as preparing quaysides for automated docking, high accuracy measurements, both vertical and horizontal, of navigation lights, and leading lights, are required. The adopted datum should be clearly defined against the geodetic datum used for heights in land survey applications.

For safety of navigation surveys, the maximum allowable horizontal and vertical *uncertainties*, identified in *Table 2*, concern *features* such as jetties, piers, coastlines near fairways, channel banks, etc.

5.3 Floating objects

For floating objects, the positioning *uncertainty* obtained whilst surveying its position needs to be significantly lower than the objects allowed movement (sway). It is up to each hydrographic office, or other responsible authority, to determine the required *uncertainty* of the surveyed position of floating objects, taking into account allowed sway due to currents, wind and water level. The environmental conditions when undertaking such measurements needs also to be considered.

5.4 Drying Heights

In areas with larger tidal ranges, where the drying zone sometimes is navigable during high tide, the elevations of the drying zone also needs to be accurately surveyed. Maximum uncertainties shall not exceed those specified for the submerged area outside the drying zone. Drying heights should be referenced to the Chart Datum.

5.5 Uncertainties

For uncertainties of surveys above the vertical chart datum, see Table 2

CHAPTER 6 METADATA

Metadata is fundamental to ensure that survey data is correctly understood and utilised as required for chart production, or other purposes. This Standard identifies the minimum metadata that is to be provided with hydrographic surveys conducted for safety of navigation. Where additional metadata is available this should be included to enhance the value of the survey data for other uses.

Metadata can be provided in any format such as in the Survey Report or embedded with the observations such as in a Project File. The chosen format should support discovery, clarity of understanding and software compatibility. Each hydrographic office or authority may adopt metadata requirements beyond that specified here and should develop and document a list of additional metadata used for their survey data.

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

Attribute	Description
Survey Type	Such as cartographic attribute SURTYP – reconnaissance/sketch, controlled, examination, passage, remote sensed, satellites, etc.
Technique of vertical measurement	Such as cartographic attribute TECSOU – found by echo-sounder, side scan sonar, multi-beam, diver, lead-line, wire-drag, photogrammetry, satellite derived bathymetry, lidar, etc.
Order of survey achieved	In accordance with S-44 if applicable
Horizontal and vertical datum	Including ties to a geodetic reference frame based on ITRS (e.g.: WGS84) and epoch information, if a local datum is used
Uncertainties achieved and respective confidence levels	For both horizontal and vertical components: Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU)
Significant Feature Detected	A True value is an indication that the characteristics of a hydrographic survey are such that significant seafloor features could be detected.
Feature search achieved	
Bathymetric coverage achieved	A True value is an indication that full depth measurement coverage for an area covered by hydrographic survey(s) has been achieved.
Category of temporal variation of the bottom	where observed
The Survey Date Range	Survey’s start and end dates
Survey undertaken By	Surveyor, survey company, survey authority
Grid attributes	Where a grid is the deliverable (i.e.: resolution, method, underlying data density, uncertainty surface)
Data density	Density of source data (e.g.: bathymetry, laser scanner, satellite imagery).

The metadata for Surveys above the Vertical Chart Datum should include, as a minimum, information on:

Attribute	Description
Survey Type	
Technique of measurement	
Order of survey achieved	In accordance with S-44 if applicable
Horizontal and vertical datum	Including ties to a geodetic reference frame based on ITRS (e.g.: WGS84) and epoch information, if a local datum is used
Uncertainties achieved and respective confidence levels	For both horizontal and vertical components: Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU)
The survey Date Range	Survey's start and end dates
Survey Undertaken By	Surveyor, survey company, survey authority
Data Density	The density of the source data (e.g.: laser scanner, satellite image resolution).
Vertical Unit of Measure	The attribute encodes the units of measurement for depths.

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.

CHAPTER 7 TABLES AND SPECIFICATION MATRIX

7.1 Introduction

Previous editions of this document specified hydrographic survey standards for safety of navigation surveys predominantly in table format (Former edition, *Table 1*). However, this rigid format did not allow for common customization and enhancement of safety of navigation survey standards and did not accommodate hydrographic surveys conducted for other purposes.

This edition of S-44 still presents safety of navigation survey specifications in table format (now *Table 1* and *Table 2*), but also provides a new Specification *Matrix* for added flexibility. The new matrix allows for common customization and enhancement of safety of navigation survey standards. It also provides a common framework by which to task and assess hydrographic surveys conducted for purposes other than safety of navigation.

7.2 Safety of Navigation Standards

Minimum bathymetry standards are defined in *Table 1*. Other minimum positioning standards and tidal currents are defined in *Table 2*. Both tables **must** be read in conjunction with the detailed text in this document.

As stated above, all standards defined in Tables 1 and 2 are included in the specification matrix within ranges of specification values which are available to enhance and customize safety of navigation surveys. Although the matrix is available for this purpose, its usage will not reduce the minimum standards defined for safety of navigation survey orders. See Annex A for guidance on how to use the Specification *Matrix*.

7.2.1 Bathymetry Standards

Table 1 defines minimum bathymetry standards for safety of navigation surveys. The standards are intended to be purpose specific but technology independent in design. This means that bathymetric data collected with, or derived from, various technologies such as single or multibeam sonar, sidescan, lidar, other optical techniques (such as satellite derived bathymetry, photogrammetric point clouds or structure from motion) and any other technology must conform to these tables to meet the specific order of survey. Order achieved for bathymetry data (*Table 1*) may be assessed independently of order achieved for other positioning data (*Table 2*) so as not to unnecessarily degrade the representation of quality of bathymetry in nautical charts and products.

7.2.2 Other Positioning Standards, Tidal Stream and Currents

Table 2 defines minimum navigational aid, structural, and topographic positioning standards for safety of navigation surveys above the vertical datum. It also includes minimum standards for angular measurement in relation to range lines, sectors lights, and similar aids to navigation used on an established course or heading. In this table, requirements are also set for direction and speed measurements for tidal stream and current.

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

7.3 Specification Matrix

The Specification *Matrix* provides a range of selectable specifications for bathymetric parameters and data types collected, reported, and delivered as part of a hydrographic survey. It is introduced to allow flexibility and customization in the tasking and assessing of hydrographic surveys, accommodation of new and emerging technologies, and inclusion of hydrographic surveys conducted for purposes other than safety of navigation. It is, by design, expandable and can evolve in future S-44 editions.

It is important to note that the matrix alone does not define any standards for hydrographic survey. Safety of navigation survey standards (as defined in *Table 1* and *Table 2*) have direct references to cells in the matrix and the matrix can be used to customize and enhance these minimum standards. Standards for surveys conducted for purposes other than safety of navigation (e.g. geophysical, oil and gas, dredging and geotechnical) are not currently defined in this document. However, the range of accuracies presented in the matrix was designed to accommodate these surveys and to provide a common framework for tasking and assessing hydrographic surveys in general.

Additionally, with the emergence of new nautical products and associated specifications / data models (e.g. Electronic Nautical Charts (ENC) and S-101 ENC Product Specification), additional types of information will be available to the mariner. The matrix can be used to help define and categorize the increasing variety of data that will be used in these evolving products.

See Annex A for guidance and additional information on how to use the Specification *Matrix*.

Table 1, *Table 2*, Detailed Table Notes, and the Specification *Matrix* follow.

7.4 TABLE 1

Minimum Bathymetry Standards for Safety of Navigation Hydrographic Surveys (*to be read in conjunction with the full text set out in this document*).

Reference	Parameter Order	2	1b	1a	Special
Chapter 1, Note 1	**Area description** (Generally)	Areas where a general description of the sea floor is considered adequate.	Areas where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas where under-keel clearance is less critical but features of concern to surface shipping may exist.	Areas where under-keel clearance is critical
Chapter 2.3	**Depth THU** Constant [m] + Variable [% of Depth]	20 metres + 10% of depth *(Ba5,Bb2)	5 metres + 5% of depth *(Ba8,Bb3)	5 metres + 5% of depth *(Ba8,Bb3)	2 metres + 0% *(Ba8)
Chapter 3.2, Note 2	**Depth TVU** Constant (a) [m] Variable (b) [% of depth]	a = 1.0 metres b = 2.3 *(Bc3,Bd5)	a = 0.5 metres b = 1.3 *(Bc4,Bd7)	a = 0.5 metres b = 1.3 *(Bc4,Bd7)	a = 0.25 metres b = 0.75 *(Bc6,Bd9)
Chapter 3.4, Note 3	**Feature search** Depths may not be produced / derived (e.g. SSS, MBES) [%]	Not Applicable *(Be2)	Not Applicable *(Be2)	100% *(Be8)	100% *(Be8)
Chapter 3.3, Note 4	**Bathymetric Coverage** Depths produced / derived (e.g. MBES, SBES) [%]	4% *(Bf3)	5% *(Bf4)	100% *(Bf4)	100% *(Bf4)
Chapter 3.4.1, Note 5	**Feature Detection** (System Capability) Constant [m] or Variable [% of Depth]	Not Applicable	Not Applicable	Cubic features > 2 metres, in depths up to 50 metres; 10% of depth beyond 50 metres *(Bg5,Bh3 beyond 50m)	Cubic features > 1 metre *(Bg6)

Brief Notes:
(See detailed notes below)

Uncertainties at 95% confidence level
THU = Total Horizontal Uncertainty
TVU = Total Vertical Uncertainty

m = metres
kn = knots
deg = degrees

SSS = Sidescan sonar
MBES = Multibeam Echosounder
SBES = Single Beam Echosounder

* = Matrix cell reference

7.5 TABLE 2

Other Minimum Positioning Standards for Safety of Navigation Surveys (*to be read in conjunction with the full text set out in this document*).

Reference	Data Type	2		1b		1a		Special	
		THU	TVU	THU	TVU	THU	TVU	THU	TVU
Chapter 5, Note 6	**Fixed Aids, Features Significant to Navigation** [m]	5 *(Pa4)	2 *(Pb2)	2 *(Pa6)	2 *(Pb2)	2 *(Pa4)	1 *(Pb3)	2 *(Pa6)	0.5 *(Pb4)
Chapter 5, Note 6	**Floating Aids to Navigation** [m]	20 *(Pc2)	---	10 *(Pc3)	---	10 *(Pc3)	---	10 *(Pc3)	---
Chapter 5, Note 6	**Natural Coastline** (high and low water lines) [m]	20 *(Pd1)	---	10 *(Pd2)	---	10 *(Pd2)	---	10 *(Pd2)	---
Chapter 5, Note 6	**Features** (above surface not significant to navigation) [m]	20 *(Pe1)	3 *(Pf1)	20 *(Pe1)	2 *(Pf2)	20 *(Pe1)	1 *(Pf3)	10 *(Pe2)	0.5 *(Pf4)
Note 6	**Overhead clearances and Range line, Sector Light Heights** [m]	10 *(Pg1)	3 *(Ph1)	10 *(Pg1)	2 *(Ph2)	5 *(Pg2)	1 *(Pa3)	2 *(Pg3)	0.5 *(Ph4)
Note 6	**Angular** Including range line, sector light limit azimuths THU [deg]	0.5 *(Pi4)							
Chapter 4.5 Note 7	**Tidal Stream and Current Direction** THU [deg]	10 *(Ta1)							
Chapter 4.5 Note 7	**Tidal Stream and Current Speed** Uncertainty [knts]	0.1 *(Tb5)							

Detailed Table Notes:

1: Order achieved for bathymetry data (*Table 1*) and other positioning data (*Table 2*) can be assessed independently so as not to degrade unnecessarily the quality of bathymetry of nautical charts and products.

2: See section 3.2.2

3: Feature search methods may or may not result in depth data suitable for use in safety of navigation products. Some examples of technologies used to achieve feature search specifications include but are not limited to: sidescan sonar (SSS) & singlebeam echosounder (SBES), multibeam echosounder (MBES) for acoustic techniques, and lidar & satellites for optical remote sensors.

4: Bathymetric Coverage methods must result in depth data suitable for use in safety of navigation products. Some examples of technologies used to achieve Bathymetry Coverage specifications include but are not limited to: sidescan sonar (SSS) & singlebeam echosounder (SBES), multibeam echosounder (MBES) for acoustic techniques, and lidar & satellites for optical remote sensors. Bathymetric Coverage specified at less than 100% must follow a systematic survey plan to maximize even distribution of depth data across the survey area. Additionally, the nature of the bottom, the accompanying Feature search, and the requirements of safe surface navigation in the area must be taken into account early and often to determine whether Bathymetric Coverage should be reduced or increased to meet the requirements of safe navigation in the area.

5: 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 metres cubes respectively, are minimum requirements. In certain circumstances it may be deemed necessary by the hydrographic offices or authorities to detect smaller *features* to minimise the risk of undetected hazards to surface navigation. For Order 1a the relaxing of *feature detection* criteria at 50 metres reflects the maximum expected draught of vessels.

6: Standards for *Table 2* data types only apply where such measurements are required for the survey.

7: See *Chapter 4*, for information and recommendations related to Tides and information and recommendations related to tidal stream and current observations.

8: See *section 3.7* for information and recommendations related to bottom sampling and characterization.

ANNEX A: SPECIFICATION MATRIX AND GUIDANCE

A.1 Introduction

The Specification *Matrix* includes a range of selectable specifications for hydrographic survey parameters and data types. The matrix alone does not define any standards, but does incorporate the safety of navigation survey standards as defined in *Table 1* and *Table 2* along with a wider range of selectable specification.

The matrix can be used as a common framework to enhance safety of navigation surveys and to customize hydrographic surveys conducted for purposes other than safety of navigation. This is accomplished by assigning a series of alphanumeric codes to reference cells in the matrix that contain the required specification.

Specifications derived from the matrix are expressed by parameter / data type (e.g. Depth TVU) and their required values (e.g. >2, 2, 1, 0.5, etc.). A specification requires three characters to reference a cell address:

1. The first character is a capital letter denoting the category of parameter / data type:
    - **B**athymetry
    - Other **P**ositions
    - **T**ides, Water Levels, and Currents
    - **N**ature of the Bottom

2. The second character is a lower case letter referencing the intended parameter / data type by row, e.g.:
    - Bathymetry (B)
      a = Depth THU (constant) [m]
      d = Depth TVU (variable, "b") [% of Depth]
    - Other Positions (P)
      a = Fixed Aids, *Features* Significant to Navigation THU [m]
      g = Overhead Clearance and Range line, Sector Light Heights THU [m]

3. The third character is a number referencing the intended specification value by column, e.g.:
    - Bathymetry (B)
      Ba column **1** (Ba1) = "500" for Depth THU (constant) [m]
      Bd column **6** (Bd6) = "0.5" for Depth TVU (variable, "b") [% of Depth]
    - Other Positions (P)
      Pa column **5** (Pa5) = "3" for Fixed Aids, *features* Significant to Navigation THU [m]
      Ph column **2** (Ph2) = "2" for Overhead Clearance and Range line, Sector Light Heights THU [m]

The string should include only those parameters and data types required by the stakeholder. Omission of a cell reference indicates that there is no requirement for the associated parameter / data type.
Examples:

- If THU has to be compliant with 5% of water depth, then “Depth THU (variable) [% of depth]” should be equal to 5 (Bb3), and “Depth THU (constant) [m]” is not used.
  Add zero to the Depth THU (constant) [m]
- If TVU has to be compliant with 0.30 m, then “Depth TVU (constant) [m]” should be equal to 0.3 (Bc9), and “Depth TVU (variable, "b") [% of Depth]” is not used in the formula $\pm\sqrt{a^2 + (b\ x\ d)^2}$.

A.2 Examples of “Matrix Realizations”:

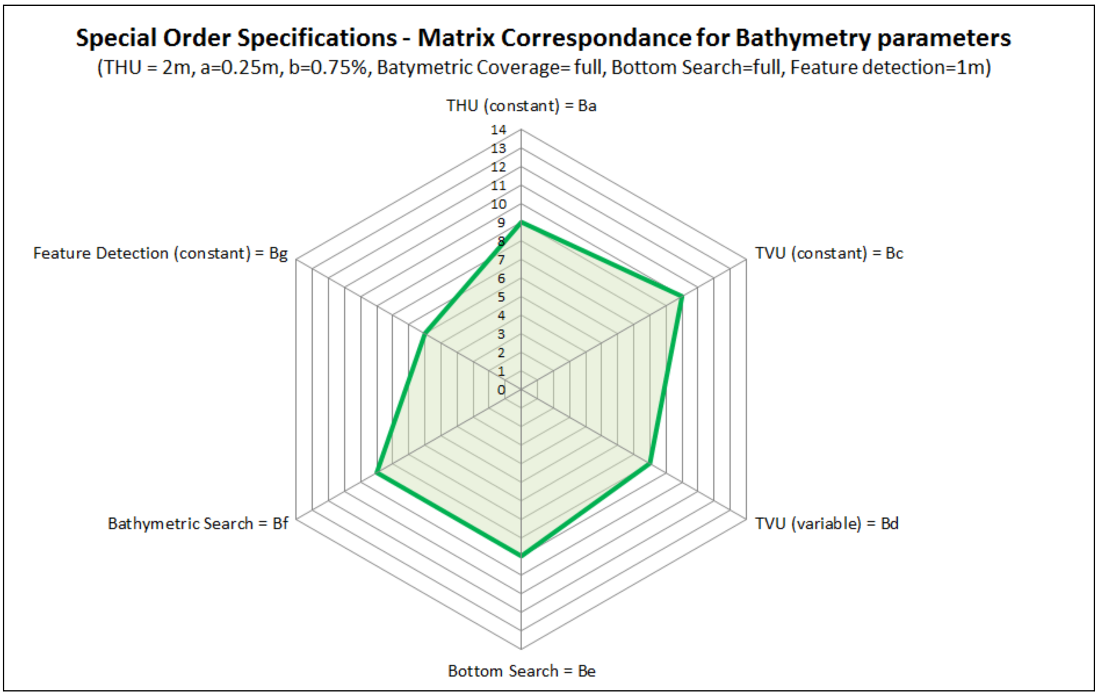
1. **The Special Order standard** for safety of navigation surveys is derived as:
   Bathymetry:
   - “Ba9”: Depth THU (constant) [m] = 2 metres
   - “Bc10”: Depth TVU (constant, "a") [m] = 0.25 metre
   - “Bd8”: Depth TVU (variable, "b") [% of Depth] = 0.75%
   - “Be9”: Feature search [%] = 100 (full)
   - “Bf9”: Bathymetric Coverage [%] = 100 (full)
   - “Bg6”: Feature Detection [m] = 1 metre

   Positioning Fixed Aids Features:
   - “Pa6”: Fixed Aids, Features and Coastline Significant to Navigation THU [m] = 2 metres

   Positioning Floating Aids to navigation:
   - “Pc3”: Floating Aids to Navigation THU [m, unless other indicated] = 10 metres

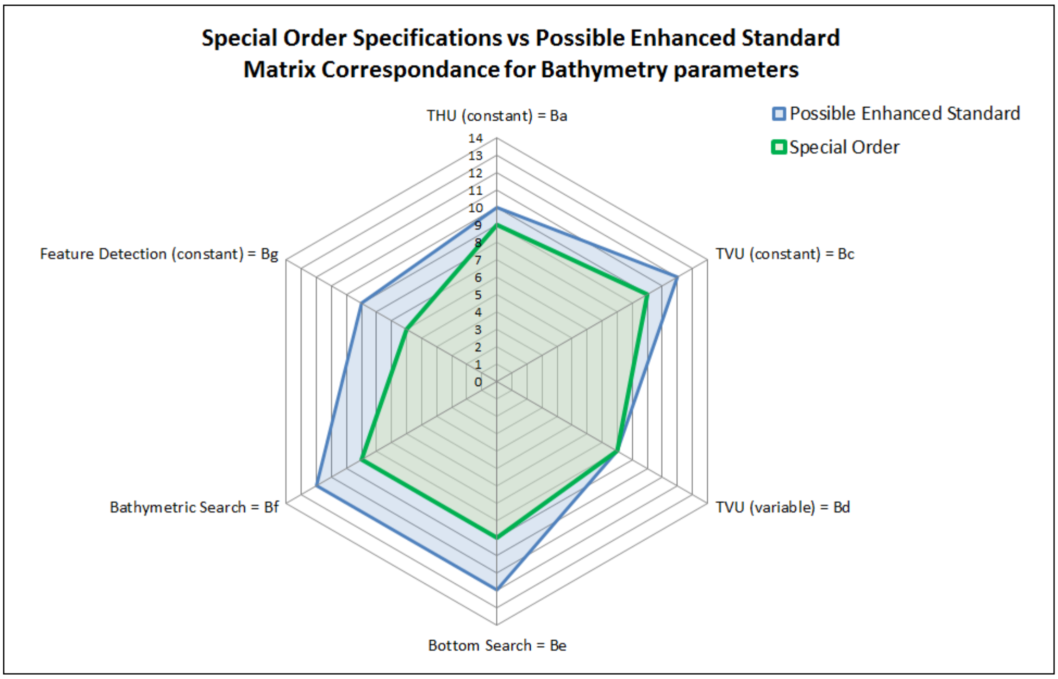
   Positioning Natural Coastline:
   - “Pd3”: Natural Coastline THU (high and low water lines) [m] = 10 metres

   Positioning Features:
   - “Pe2”: Topographic Features (not significant to navigation) THU [m] = 2 metres



"Special Order": Illustration of bathymetric specifications according to Matrix correspondence

2. **Example of a possible Enhanced standard** surveys (i.e. more strict than special order):
   Bathymetry:
   - "Ba10": Depth THU (constant) [m] = 1 metre
   - "Bc12": Depth TVU (constant, "a") [m] = 0.15 metre
   - "Bd8": Depth TVU (variable, "b") [% of Depth] = 0.75%
   - "Be12": Feature search [%] = 200%
   - "Bf12": Bathymetric Coverage [%] = 200%
   - "Bg9": Feature Detection [m] = 0.5 metre



"Special Order" vs "Possible Enhanced Standard": Illustration of bathymetric specifications according to Matrix correspondence

A.3 MATRIX

Specification Matrix for Hydrographic Surveys (to be read in conjunction with the full text set out in this document).

	Parameter / Data Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14
B	BATHYMETRY														
a	**Depth** THU (constant) [m]	500	200	100	50	20	15	10	5	2	1	0.5	0.4	0.1	0.05
b	**Depth** THU (variable) [% of depth]	20	10	5	2	1	0.5	0.25	0.1						
c	**Depth** TVU (constant, "a") [m]	100	50	25	10	5	2	1	0.5	0.3	0.25	0.2	0.15	0.1	0.05
d	**Depth** TVU (variable, "b") [% of Depth]	20	10	5	2.3	2	1.3	1	0.75	0.4					
e	**Bottom Search** Depths may not be produced / derived (e.g. SSS, MBES) [%]	3	4	5	10	20	30	50	75	100	120	150	200	300	
f	**Bathymetric Coverage** Depths produced / derived (e.g. MBES, SBES) [%]	3	4	5	10	20	30	50	75	100	120	150	200	300	
g	**Feature Detection** Capability of system (constant) [m]	50	20	10	5	2	1	0.75	0.7	0.5	0.3	0.25	0.2	0.1	
h	**Feature Detection** Capability of system (variable) [% of Depth]	25	20	10	5	2.5	1	0.5	0.25						

	Parameter / Data Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14
P	OTHER POSITIONING														
a	**Fixed Aids, Features and Coastline Significant to Navigation** THU [m]	50	20	10	5	3	2	1	0.5	0.2	0.1	0.05	0.01		
b	**Fixed Aids, Features Significant to Navigation** TVU [m]	3	2	1	0.5	0.2	0.1	0.05	0.01						
c	**Floating Aids to Navigation** THU [m, unless other indicated]	50	20	10	5	2									
d	**Natural Coastline** THU (high and low water lines) [m]	20	10	5	1										
e	**Features** (above surface, not significant to navigation) THU [m]	20	10	5	1										
f	**Features** (above surface, not significant to navigation) TVU [m]	3	2	1	0.5										
g	**Overhead Clearance and Range line, Sector Light Heights** THU [m]	10	5	2	1	0.5	0.2	0.1							

	Parameter / Data Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14
h	**Overhead Clearance and Range line, Sector Light Heights** TVU [m]	3	2	1	0.5	0.1									
i	**Angular** Including range line, sector light limit azimuths THU [deg]	5	2.5	1	0.5	0.2	0.1								

	Parameter / Data Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14
T	TIDES, WATER LEVELS, AND CURRENTS														
a	**Tidal Streams and Currents Direction** THU [deg]	10	7.5	5	2.5	1	0.5	0.25	0.1						
b	**Tidal Streams and Currents Speed Uncertainty** [knts]	2	1	0.5	0.25	0.1									

	Parameter / Data Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14
N	NATURE OF THE BOTTOM														
a	**Bottom Characterization**	Required													
b	**Bottom Sampling**	Required													

Brief Notes:

Uncertainties at 95% confidence level
THU = Total Horizontal Uncertainty
TVU = Total Vertical Uncertainty

m = metres
knts = knots
deg = degrees

SSS = Sidescan sonar
MBES = Multibeam Echosounder
SBES = Single Beam Echosounder

ANNEX B: GUIDELINES FOR QUALITY MANAGEMENT

NOTE: it should be noted that the information contained in Annexes B, C and D provide some guidance on *quality control*, data processing and considerations for gridded bathymetry. 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 C-13.

B.1 Quality Control

Quality control is not just proving that the end results of the survey are within the required limits stated in the S-44. To achieve the required quality there are three important fields affecting the quality: Material, Procedures and Personnel. All fields are essential for the *quality control* of the hydrographic products. *Quality control* is not just about figures and computations it is about a complete overview of all factors affecting the survey.

B.2 Equipment

The equipment in use must be capable of producing data that meets the required uncertainties. This is not just about the single equipment *uncertainty* (as provided in technical documentations) but the total of propagated uncertainties of all equipment and corrections used to derive the reported surveyed value. In this *total propagated uncertainty* calculation the temporal and spatial influence of the medium in which measurements take place must be accounted for. By an a priori calculation of the *total propagated uncertainty* in a certain environment it can be determined if the instrumental setup is sufficient for the required quality.

Secondly the equipment in use must be free of (systematic) *errors* which must be determined by calibration and qualification.

The use of calibrated equipment that is capable to achieve required data quality is the first step for the *quality control* process. It is preferred to check the entire system in real conditions (in situ) before surveying and every time a doubt is occurring during the survey.

B.3 Procedures

Using standardised procedures for hydrographic data collection and processing can reduce the risk of *errors*. By describing the total of procedures, it is possible to incorporate checks and tests on *errors* that occur in an early stage of the process. This is important for *errors* that cannot be detected afterwards.

Procedures may involve complete flow schedules that can be used for external auditing and standardised data products. In the procedures the a posteriori quality checks must be admitted.

B.4 Personnel

All survey work must be performed by qualified personnel. The personnel must be trained and capable. Formal qualifications like CAT A and B are preferred but proven working experience may be sufficient.

ANNEX C: GUIDANCE ON A PRIORI AND A POSTERIORI QUALITY CONTROL

NOTE: it should be noted that the information contained in Annexes B, C and D provide some guidance on quality control, data processing and considerations for gridded bathymetry. 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 C-13.

The S-44 standards are mentioning quality standards for both a priory and a posteriori results. In this guidance a brief view on how to determine the uncertainties a priory and a posteriori is given. Determining uncertainties is necessary for any technique used in hydrographic surveys. Ways how to establish the *uncertainty* may differ greatly for each survey technique used.

C.1 A Priori Uncertainty

The a priori *uncertainty* is a theoretical value based on best practise estimations of all factors affecting the measurements. Each instrument used in the measurement and the environmental influences will add their uncertainties to the grand total. Calculating the total uncertainty horizontally and vertically prior to the survey will affirm the hydrographer that the required survey standards will be feasible with the selected equipment in the environment of the survey area. If the survey standards are not met, other equipment or survey techniques may be necessary for that particular environment.

During the survey, estimations of the equipment and environment uncertainties should be adjusted or assessed. By this adjustment, the a priori *uncertainty* is improved.

C.2 A Posteriori Uncertainty

Fundamentally the a posteriori *uncertainty* is what the hydrographer is most interested in. Have all survey efforts led to results meeting the required standards?

Outside a reference area it is not possible to determine the a posteriori *uncertainty* from the data set. The dataset is the end result and contains all *errors* involved in the total process but it is not possible to calculate the a posteriori *uncertainty* from it. There are many techniques and procedures to check the hydrographic data set and they can provide proof that the data set is to be trusted but no tool will calculate the a posteriori *uncertainty* on a not well-known area.

A preliminary task is to check the capability of the system during acceptance tests and at least, consider vertical qualification, horizontal qualification and detection *features* face to the dedicated needs. Well-known reference areas should be used to prevent any vertical offset on measurements. Qualification on these reference areas should be carried out periodically.

During a survey, according to the dedicated needs, the surveyors should at least, consider the vertical qualification by checking the reproducibility of the hydrographic system (using cross lines for example). The results (mean offset, *uncertainty* at the 95% confidence level) face to the survey specifications (acceptance interval) have to be provided for each survey. Even if this method will not highlight the existence of an absolute vertical offset, it helps to qualify the quality of the survey.

ANNEX D: GRIDDED BATHYMETRY CONSIDERATIONS

NOTE: it should be noted that the information contained in Annexes B, C and D provide some guidance on quality control, data processing and considerations for gridded bathymetry. 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 C-13.

REFERENCES: Content from the following references was used in the composition of this Annex.

IHO S-100, The Universal Hydrographic Data Model – Edition 3.0.0
IHO S-102, Bathymetric Surface Product Specification – Edition 1.0.0
IHO B-11, IHO-IOC GEBCO Cook Book – September 2018
ISO 19107:2003 Geographic information - Spatial Schema
ISO 19115:2003 Geographic information - Metadata
ISO 19123:2005 Geographic information - Schema for coverage geometry and functions
Open Navigation Surface Working Group, Requirements Document – Version 1.0
Open Navigation Surface Working Group, Format Specification Document - Description of Bathymetric Attributed Grid Object (BAG) - Version 1.6.3
Open Navigation Surface Working Group, A Variable Resolution Grid Extension for BAG Files – Version 1.2
Digital Elevation Model Technologies and Applications: The DEM User's Manual – 3rd Edition
GEBCO – Frequently Asked Questions:
https://www.gebco.net/about_us/faq/#creating_a_bathy_grid

D.1 Introduction

As data sample densities from hydrographic sensors have increased, methods of sea floor representation have shifted from vector-based products like selected soundings and contours, to gridded bathymetric models. The result of an individual hydrographic survey is now commonly stored as a digital grid or series of grids of differing resolutions. These grids often include node values for both depth and *uncertainty* and may also include accompanying information regarding contributing sample standard deviation, sample density, shoal sample values within the vicinity of the grid node and even information to allow conversion between tidal datum and reference ellipsoid. For many Hydrographic Offices, production workflows now focus on these gridded bathymetric models as the data source instead of the full resolution sounding files. Exploitation of the gridded bathymetric data can reduce production timelines as they provide an appropriate level of information in a lighter-weight, digital package.

Gridded bathymetric models are also used for small-scale applications such as regional bottom characterization. In many instances these grids are a combination of observed sample data, survey gridded data, estimated data and interpolated data. This Annex will not address considerations for these types of grids, as substantial information on this topic is maintained by the Joint IHO-IOC Committee for the General Bathymetric Chart of the Oceans (GEBCO).

D.2 Definitions

Area Representation: Representation of gridded data where the entire cell is assumed to be the same value, and changes only occur at the borders of cells. (The DEM User's Manual)

Holiday: An unintentional unsurveyed area within a given hydrographic survey where the spacing between sounding lines or surveys exceeds the maximum allowable limits.

Grid: A network composed of two or more sets of curves in which the members of each set intersect the members of the other sets in a systematic way. (ISO 19123)

Grid Cell: An area defined within the interstices between the grid lines. (ISO 19123)

Grid Line Registration: Registration method where grid nodes are centred on the intersection of the grid lines. (GEBCO)

Grid Node: A data point, with an exact geographic location referenced by grid definition and registration. The value contained within the grid describes selected information at this location. (ONSWG)

Pixel Centred Registration: Registration method where grid nodes are centred in the grid cells. (GEBCO)

Surface Representation: Representation of gridded data where the grid node represents the surface value at the centroid of each cell. The area between cell centres is assumed to be a value between that of adjacent cells. (The DEM User's Manual)

D.3 Grid Considerations

D.3.1 Grid Resolution

Gridded bathymetric models are commonly generated using a fixed resolution per a pre-defined depth range. A compromise is often made when selecting a fixed resolution over a given depth range, where ultimately the grid resolution cannot be chosen at the same time for the shallowest and the deepest depths.

In addition to the fixed resolutions per depth range, recent efforts in hydrographic data processing have allowed for the generation of variable resolution gridded bathymetric models. These models can be generated using fixed resolution per a pre-defined depth range (as with individual grids) or automated methods based on depth and achieved data density.

When the survey requirement calls for detection of *features* of set dimensions and the resultant gridded bathymetric model is to represent the results of the survey, accurate *feature* representation within the grid will require a grid cell size no greater than the size of the *feature* the gridded bathymetric model is required to depict.

The grid resolution should also be chosen to consider the achieved horizontal *uncertainty* of the input samples and the method for which this *uncertainty* is used in the chosen gridding method or algorithm.

D.3.2 Sample Density

It is the responsibility of the hydrographic office, or authority, to determine an acceptable data density requirement that allows for an accurate depiction of significant bottom *features* and reliable estimate of depth within the local vicinity of the grid nodes without allowing opportunity for data *holidays* to be masked by grid resolution. This determination requires surveyors to verify sensor *feature detection* performance prior to its use; including selection and employment of appropriate collection parameters.

If statistical gridding methods are to be employed, acceptable data densities should be specified with a minimum threshold of accepted samples per area, e.g. greater than or equal to five (5) samples per node. Data density requirements should also describe the percentage of nodes within the grid that are required to achieve this density, e.g. at least 95% of all nodes within the grid shall be populated with the minimum required density.

D.3.3 Grid Coverage

It is the responsibility of the hydrographic office, or authority, to define a data gap or data holiday. The definition should describe the area on the bottom, by number of continuous nodes with no depth present.

When gridded bathymetric models are generated using a fixed resolution per a pre-defined depth range, overlap between adjacent grids should exist in order to ensure that no gaps in coverage between neighbouring grids are generated.

D.3.4 Hydrographer Overrides to Grid Nodes

When statistical gridding methods are employed, it is possible for the gridding algorithm to omit a significant shoal depth on a *feature* of interest. Tools exist inside many hydrographic data processing packages to override node values and manually force the model to honour a shoal depth. It is the responsibility of the hydrographic office or authority, to define the thresholds for when overrides are appropriate. Some thresholds will be *uncertainty*-based, e.g., only override the statistically significant nodal depth value when the difference between the node value and nearest shoal sample exceeds the allowable Total Vertical Uncertainty (TVU) at the nodal depth. Other thresholds may be defined by scale of the product that the dataset was collected to support. Comments on *feature* selection and nodal override methods should accompany the gridded bathymetric model to allow the end users to determine if it is appropriate for the intended use.

D.4 Gridding Methods

Several possible gridding methods for both dense and sparse datasets exist. The hydrographic office or authority is responsible for determining the appropriate method for the intended purpose of the resultant gridded dataset. This determination should consider the implementation of the gridding method or algorithm in the selected software package. This determination should also consider the method of grid node representation and portrayal within the selected software.

The following list provides some of the methods commonly used when gridding bathymetric datasets:

- The **Shoalest Depth** method examines depth estimates within a specific area of influence and assigns the shoalest value to the nodal position. The resulting surface represents the shallowest depths across a given area. The use of shoalest depth values is often used for safety of navigation purposes.

- The **Deepest Depth** method examines depth estimates within a specific area of influence and assigns the deepest value to the nodal position. The resulting surface represents the deepest depths across a given area. The use of a deep depth surface is often used during post processing to identify outliers in the dataset.

- The **Basic Mean** method computes a mean depth for each grid node where all soundings within the cell have the same weight.

- The **Statistical Median** method computes a depth for the node by ordering contributing samples sequentially and selecting the median value.

- The **Basic Weighted Mean** method computes an average depth for each grid node (whereby the inverse to the distance from the sounding location to the nodal position is used as weighting schema). Contributing depth estimates within a given area of influence are weighted and averaged to compute the final nodal value.

- The **Total Propagated Uncertainty (TPU) Weighted Mean** method makes use of the elevation and associated total propagated *uncertainty* for each contributing depth estimate to compute a weighted average depth for each nodal position.

- The **Combined Uncertainty and Bathymetric Estimator (CUBE)** algorithm makes use of the elevation and associated total propagated *uncertainty* for each contributing sounding to compute one or many hypotheses for an area of interest. The resulting hypotheses are used to estimate statistical representative depths at each nodal position.

- The **Nearest Neighbour** method identifies the depth value of the nearest sounding in distance from the nodal point within an area of interest. This method does not consider values from other neighbouring points.

- The **Natural Neighbour** interpolation method identifies and weights (as a function of the inverse of the surface of the smallest polygon – Voronoi tessellation – around the sounding value) a subset of input samples within the area of interest to interpolate the final nodal value.

- The **Polynomial Tendency** gridding method attempts to fit a polynomial trend, or best fit surface to a set of input data points. This method can project trends into areas with little to no data, but does not work well when there is no discernible trend within the data set.

- The **Spline** gridding method estimates nodal depths using a mathematical function to minimize overall surface curvature. The final "smoothed" surface passes exactly through the contributing input depth estimates. This Spline algorithm is considered a sparse data gridding method.

- The **Kriging** gridding method is a geostatistical interpolation method that generates an estimated surface from a scattered set of points with a known depth.

D.5 Grid Uncertainty

The *uncertainty* associated with the elevation value contained within gridded bathymetric models can be described using a variety of methods, which may include:

- **Raw Standard Deviation** is the standard deviation of samples that contributed to the node.

- **Standard Deviation Estimator** is the standard deviation of samples captured by a hypothesis algorithm (eg., CUBE's standard output of *uncertainty*).

- **Product Uncertainty** is a blend of Standard Deviation Estimator *uncertainty* and other measures which may include Raw Standard Deviation, and the average vertical *uncertainty* from the subset of samples used to generate the hypothesis that represents the node.

- **Historical Standard Deviation** is an estimated standard deviation based on historical/archive data.

Other *uncertainty* types may be specified. Methods for *uncertainty* estimation should be documented within the accompanying grid metadata.

The *uncertainty* types listed above describe the vertical *uncertainty* of the node depth. The resultant grid may exhibit a higher than expected *uncertainty* value if the bathymetric profile is not represented at an appropriate grid resolution, e.g., a node *uncertainty* value may be higher than anticipated along sharp sloping bathymetry.

If required, obtaining a horizontal *uncertainty* for a grid node could be accomplished by calculating a basic or distance weighted mean of the horizontal *uncertainty* values from the samples that contributed to the grid node.

D.6 Applicability

Gridded bathymetric models commonly are one of the products of a hydrographic survey; however, the utility of this representation begins well before a survey dataset is finalized as this data can also be used to verify survey requirements during hydrographic collection and certify quality of a dataset during dataset validation efforts.

D.6.1 Survey Data Collection

Gridded bathymetric models can provide valuable information regarding underway bottom sample density and identification of significant bottom *features*. These models can be leveraged to assess where full feature search has been achieved and conversely where holidays exist. Monitoring of these items during survey operations is necessary for the qualification of field data completeness prior to departing the survey area.

D.6.2 Survey Data Validation

Gridded bathymetric models can serve as a comparison tool to examine depth data consistency within a survey and the presence of random and systematic dataset *errors*. These models can also serve as a comparison tool between neighbouring surveys and between different collection sensors. Comparisons between high resolution gridded data and legacy point data can also be accomplished to provide statistics on differences and aid in the prioritization scheme for future product updates. As mentioned in Annex B.2, the comparison of gridded depth and associated nodal *uncertainty* is another common method used in determining whether a survey dataset complies with required *uncertainty* thresholds.

D.6.3 Survey Data Deliverable

As mentioned throughout this annex, gridded bathymetric models in the presence of survey logs, reports and other metadata, are sufficient to serve as the authoritative result and deliverable of the survey and as the direct input for the generation of products supporting safety of navigation and other protection of the marine environment objectives.

D.7 Metadata

To ensure gridded bathymetric models are fit for purposes that extend beyond safety of navigation, an appropriate level of metadata describing the dataset is required. IHO S-102, the Bathymetric Surface Product Specification, provides metadata elements derived from S-100 and from ISO 19115 and ISO 19115-2. Elements described within S-102 include mandatory, optional and conditional items. Following this specification, conclusive metadata for gridded bathymetric models will include information describing the dataset, depth correction type, *uncertainty* type, grid reference and coordinate system information, as well as temporal descriptions, grid construction methods and persons responsible for product generation.