S-44

IHO Standards for Hydrographic Surveys

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IHO

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Introduction

This publication aims to provide a set of standards for hydrographic surveys primarily used to compile navigational charts essential for the safety of navigation, knowledge and the protection of the marine environment. It specifies the **minimum standards** to be achieved based on the intended use. Where and when necessary, hydrographic offices or organisations are encouraged to define more stringent or specific requirements as national or regional realisations 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, *Manual on Hydrography*, should be consulted for information on those topics (downloadable from the IHO homepage: www.iho.int).

In this edition, a new, more stringent Exclusive Order has been introduced. The use of Exclusive Order should be limited to areas with exceptional conditions and specific requirements. The other orders for safety of navigation surveys have kept the same names, but their interpretation has changed from the previous edition due to the introduction of the bathymetric coverage concept. Special Order now explicitly requires full bathymetric coverage. Furthermore, the orders have been divided into requirements above and below the vertical datum.

This edition aims to encourage the use of S-44 for purposes beyond the safety of navigation. It introduces the concept of a Matrix of parameters and data types to define realisations of survey standards and specifications. This Matrix alone is not a standard. It should be considered as a reference to specifying dedicated surveys, as appropriate, and to provide a tool for a broader classification of surveys. It is, by design, expandable and can evolve in future S-44 versions. Annex A provides guidance on how the Matrix can be used for specification and classification of surveys.

S-44 vocabulary has been revised in order to more closely align with references typically used in metrology (e.g. Guide to the expression of uncertainty in measurement). Horizontal positioning standards for aids to navigation have been revised and standards on their vertical positioning have been added. Emphasis has been placed upon the main components of hydrographic surveys while being technology independent.

While the hydrographic surveyor may have some flexibility on how to conduct survey operations, it remains the decision of the responsible authority on whether the standard has been achieved. Furthermore, 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 may be a basis in making this assessment. Available education in this field is (amongst others) Category A and/or B educational programme formed by International Board on Standards of Competence for Hydrographic Surveyors and Nautical Cartographers (IBSC), International Hydrographic Organization (IHO), International Federation of Surveyors (FIG), International Cartographic Association (ICA).

The information contained in Annex B, Annex C, and Annex 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, *Manual on Hydrography*.

NOTE: The publication of this new edition of the standard does not invalidate surveys, or the safety of navigation products based on surveys conducted in accordance with previous editions.

PREFACE

This Publication (S-44) defines the standard applicable to hydrographic surveys and takes its place amongst the other International Hydrographic Organization (IHO) publications, designed 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 then, the IHO has endeavoured to update this standard regularly to keep pace with the existing technologies and methods. Four successive editions have thus been released since the 1968 original issue: the 2nd edition was published in 1982, the 3rd in 1987, the 4th in 1998, and finally, the 5th edition in 2008. The point of these being to maintain continuity of the original idea throughout successive changes.

By Circular Letter (CL) 68/2016 of 20 December 2016, the IHO established a Hydrographic Surveys 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, evaluate 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 was comprised of representatives from the IHO Member States, observers from international organisations (IFHS and FIG), other expert contributors, and the Secretariat of the IHO.

Hydrographic technologies and requirements are continually evolving, as is the expanding community of users. While hydrographers logically follow these changes, the S-44 standard needs to continue to evolve in order to remain the international reference for hydrographic surveys.

In the creation of this new edition, the IHO Hydrographic Surveys Project Team liaised with the hydrographic community and received input from IHO stakeholders (including industry). This input was crucial to express the needs of the community and drive the updates of this edition, while remaining committed to the IHO mandate.

GLOSSARY

NOTE: The terms defined below are those that are most relevant to this publication. A much larger selection of terms is defined in IHO Special Publication S-32 (Hydrographic Dictionary) and 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 a recommended requirement;
may	indicates an optional requirement;

Terms that are only used within the Annexes 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 measuring the depth and is based on the combination of the survey pattern and the theoretical area of detection of the survey instrumentation.
Confidence level	Probability that the true value of a measurement will lie within the specified uncertainty from the measured value.
Correction	Compensation applied to data to adjust for an estimated systematic effect.
Error	Difference between a measured value and the correct or true value. Errors can be categorised as systematic or random errors.
Feature	Any object, whether natural or manmade, which is distinct from the surrounding area.
Feature detection	Ability of a system to detect features of a defined size.
Feature search	Extent to which an area has been surveyed using a systematic method of identifying features.
Metadata	Data describing a data set and its usage.
Random error	Noise within a measurement caused by factors which vary between measurements and cannot be controlled but can be quantified by statistical means.
Reduced depth	Observed depth including all corrections related to the survey, post processing, and reduction to the appropriate vertical datum.
Significant Feature	Feature that poses a potential danger to navigation or object one would expect to see depicted on a nautical chart or product.
Systematic error	Component of measurement error that remains constant or varies in a predictable manner.
Total horizontal uncertainty (THU)	Component of total propagated uncertainty (TPU) calculated in the horizontal dimension. THU is a two-dimensional quantity with all contributing horizontal measurement uncertainties included.
Total propagated uncertainty (TPU)	Three dimensional uncertainty with all contributing measurement uncertainties included.
Total vertical uncertainty (TVU)	Component of total propagated uncertainty (TPU) calculated in the vertical dimension. TVU is a one-dimensional quantity with all contributing vertical measurement uncertainties included.
Uncertainty	Estimate characterising the range of values within which the true value of a measurement is expected to lie as defined within a particular confidence level. It is expressed as a positive value.

Underkeel Clearance Distance between the lowest point of the ship's hull and the seabed, riverbed, etc.

1. CLASSIFICATION OF SAFETY OF NAVIGATION SURVEYS

1.1. Introduction

This chapter describes the orders of safety of navigation surveys which are considered acceptable by hydrographic offices or authorities to generate navigational products and services that allow surface vessels to navigate safely. As requirements vary with water depth, geophysical properties, and expected shipping types, five different orders of survey are defined; each designed to cater to a range of needs.

The five orders are described below along with a description of the intended area(s) of usage. The minimum standards required to achieve each order (Table 1 and Table 2) along with a new tool for enhancing and customising these orders (Specification Matrix) is 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. A single order may not be appropriate for the entire area to be surveyed and, in these cases, the different orders should be explicitly defined through the survey area. For example, 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 of less than 40 metres depth, then it may be more appropriate to survey these shoals and surrounding areas to Special Order or even Exclusive Order in some limited circumstances.

To be fully compliant with an S-44 Order, a hydrographic survey must comply with all bathymetric and feature detection requirements (Table 1) for that order and with all the other requirements (Table 2) for the same order, where applicable. Additionally, the tables must be read in conjunction with the detailed text in the following chapters. The challenge presented by each order, in particular Special and Exclusive Orders, is establishing the appropriate survey methodology to achieve the specified standards.

To ensure surveys are systematic where bathymetric coverage is specified at less than 100%, the horizontal distance between registered positions of depths should be no greater than 3 times the depth or 25 metres, whichever is greater.

1.2. Order 2

This is the least stringent order and is intended for areas where the depth of water is such that a general depiction of the bottom is considered adequate. As a minimum, an evenly distributed bathymetric coverage of 5% is required for the survey area. It is recommended that Order 2 surveys are conducted in areas which are deeper than 200 metres. Once the water depth exceeds 200 metres, the existence of 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.

1.3. Order 1b

This order is intended for areas where the types of surface vessels expected to transit the area is such that a general depiction of the bottom is considered adequate. As a minimum, an evenly distributed bathymetric coverage of 5% is required for the survey area. This means some features will not be detected, although the distance between areas of bathymetric coverage will limit the size of those features. This order of survey is only recommended where underkeel clearance is considered not 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 areas where features on the bottom may become a concern for the type of surface traffic expected to transit the area but where the underkeel clearance is considered not to be critical. A 100% feature search is required in order to detect features of a specified size. bathymetric coverage less than or equal to 100% is appropriate as long as the least depths over all significant features are obtained and the bathymetry provides an adequate depiction of the nature of the bottom topography.

Underkeel 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 40 metres. Examples of areas that may require Order 1a surveys are coastal waters, harbours, berthing areas, fairways and channels.

1.5. Special Order

This order is intended for those areas where underkeel clearance is critical. Therefore, 100% feature search and 100% bathymetric coverage are required and the size of the features to be detected by this search is deliberately more demanding than for Order 1a. Examples of areas that may require Special Order surveys are: berthing areas, harbours, and critical areas of fairways and shipping channels.

1.6. Exclusive Order

Exclusive Order hydrographic surveys are an extension of IHO Special Order with more stringent uncertainty and data coverage requirements. Their use is intended to be restricted to shallow water areas (harbours, berthing areas and critical areas of fairways and channels) where there is an exceptional and optimal use of the water column and where specific critical areas with minimum underkeel clearance and bottom characteristics are potentially hazardous to vessels. For this order, a 200% feature search and a 200% bathymetric coverage are required. The size of features to be detected is deliberately more demanding than for Special Order.

2. HORIZONTAL AND VERTICAL POSITIONING

2.1. Introduction

Positioning is a fundamental part for every survey operation. The hydrographer must consider the geodetic reference frame, horizontal and vertical reference systems, their connections to other systems in use (e.g. land survey datums), as well as the uncertainty inherent within associated measurements.

In this standard, position and its uncertainty refer to the horizontal component of the sounding or feature, while the depth and its uncertainty refers to the vertical component of the same sounding or feature.

2.2. Geodetic Reference Frame

Positions should be referenced to a geodetic reference frame, which can be the realisation of either a global (e.g. ITRF2018, WGS84(G1762)) or a regional (e.g. ETRS89, NAD83) reference frame and their later iterations. As there are frequent updates to geodetic reference frames, 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/frame such as geodetic, geopotential, and height reference system/frame, they can be separated into horizontal and vertical components.

2.3. Horizontal Reference System

If horizontal positions are referenced to a local datum, the name and epoch of the datum should be specified and the datum should be tied to a realisation of a global (e.g. ITRF2018, WGS84(G1762)) or a regional (e.g. ETRS89, NAD83) reference frame and their later iterations. Transformations between reference frames/epochs should be taken into account, especially for surveys with low uncertainty.

2.4. Vertical Reference System

If the vertical component of the positions is referenced to a local vertical datum, the name and epoch of the datum should be specified. The vertical component of the 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, MWL, etc), on a physical model (i.e. geoid) or a reference ellipsoid.

2.5. Chart and Land Survey Vertical Datum Connections

In order for bathymetric data to be correctly and fully utilised, chart and land survey vertical datum connections or relationships must be clearly determined and described. The IHO Resolution on Datums and Benchmarks, Resolution 3/1919, as amended, resolves practices which, where applicable, should be followed in the determination of these vertical datum connections.

This essential resolution 3/1919, as amended, is available in the IHO Publication M-3, Resolutions of the International Hydrographic Organization, which is downloadable from the IHO homepage www.iho.int.

2.6. Uncertainties

This standard addresses total propagated uncertainty (TPU) by the two components; total horizontal uncertainty (THU) and total vertical uncertainty (TVU). The TVU and THU values must be understood as an interval of ± the stated value.

A statistical method, combining all uncertainty sources for determining both the horizontal and the vertical positioning uncertainty should be adopted to obtain THU and TVU respectively. The uncertainties at the 95% confidence level must be recorded with the survey data.

The ability of the survey system should be demonstrated by a *priori* uncertainty calculations (THU and TVU). These calculations are predictive and must be calculated for the survey system as a whole, including all instrument, measurement, and environmental uncertainty sources. This estimation should be updated during the survey to reflect changes from environmental conditions such as wind, waves, etc. in order to make appropriate changes to survey parameters.

Final uncertainty values for the survey may consist of an a priori and a posteriori calculation, explicitly empirical values (e.g. based on standard deviation of vertical depths alone), or some combination of the aforementioned values. The metadata should include a description of the uncertainty type and the uncertainty(s) achieved.

Within this standard, for ease of use, allowable horizontal uncertainty is assumed to be equal in both dimensions. Therefore, assuming a normal distribution of error, the position uncertainty is expressed as a single number.

2.7. Confidence Level

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.

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.

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. Where underkeel clearance is potentially an issue, bathymetric coverage must be at least 100%, feature detection must be appropriate, and depth uncertainties must be tightly controlled and understood.

For customisation or enhancement of safety of navigation survey orders or other applications, survey criteria may be specified by selecting required criteria values from the Matrix (See Section 7.5 and Annex A).

3.2. Depth

3.2.1. Depth Measurement

Depths are to be understood as reduced depths within a well-defined vertical reference frame. The depth of a feature is expressed as the minimum depth of that feature.

In waters with very high turbidity, e.g. estuaries, this minimum depth may be determined on the basis of sediment concentrations in the water.

Under exceptional circumstances, for safety of navigation purposes, the use of a high precision method (e.g. mechanical sweep) that the hydrographic office or other responsible authority deems able to confirm the safe depth in an area, or over a feature / wreck, can be used to certify a safe depth. In this case, the uncertainty of the vertical measurement will define the survey order to be quoted.

3.2.2. Drying Heights

In areas with larger tidal ranges where the drying zone is sometimes navigable during high tide, elevations within the drying zone also need to be thoroughly surveyed. Depending on the situation and available equipment, the drying heights may either be surveyed bathymetrically or topographically. However, regardless of the survey method, maximum uncertainties shall not exceed those specified for the submerged area outside of the drying zone.

3.2.3. Maximum Allowable Vertical Uncertainty

Recognising that there are both depth-dependent and depth-independent error sources that affect the measurements of depths, the formula below is used to compute the maximum allowable vertical measurement uncertainty.

The parameters “a” and “b”, together with the depth “d”, have to be introduced into the formula below in order to calculate the maximum allowable TVU:

$$\mathrm{TVU}_{\mathrm{max}}(d) = \sqrt{a^2 + (b \times d)^2}$$

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

d is the depth

Table 1 specifies the parameters “a” and “b” to compute the maximum allowable TVU of reduced depths for each survey order. The total vertical uncertainties of depth measurements calculated with a 95% confidence level must not exceed this value.

3.3. Feature Detection

Minimum standards for feature detection are specified in Table 1. A cubic feature is used as a basic shape reference for a system feature detection ability and implies a symmetrical 3-D shape of six equal square sides.

In assessing a survey system’s feature detection ability, the entire survey system, including equipment, methodologies, procedures, and personnel, must be assessed. It is the responsibility of the hydrographic office or authority that is gathering the data to assess the capability of any proposed survey systems to detect significant features.

Specified feature detection abilities are not implicit determinations of what constitutes a hazard to navigation. In some cases, significant features smaller than the defined sizes specified in Table 1 can be classified as hazards 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 navigation. However, no single survey system can guarantee detection of all features. If there is a concern that hazards to navigation may exist within an area that may not be detected by the survey system, consideration should be given to use an alternative survey system.

3.4. Feature Search

Minimum standards for Feature Search are specified in Table 1.

For Order 1a, a 100% feature search may be achieved with a survey system that does not measure depth. Under those circumstances, least depth measurements from an independent bathymetric system will be required for any detected significant feature. Whenever possible, it is recommended to conduct a 100% feature search in conjunction with 100% bathymetric coverage.

A feature search greater than or equal to 100% must be planned and conducted with the intent of detecting all features of the sizes specified in this standard. Where more than 100% feature search is required, including 200% for Exclusive Order, it may be accomplished by adequately overlapping collection or by acquiring more than one independent dataset within a survey.

3.5. Bathymetric Coverage

The concept of bathymetric coverage was introduced in this edition of S-44, in order to make the standard technology independent. Acquisition of bathymetric coverage requires use of a sensor that measures and records depths. Table 1 specifies the minimum bathymetric coverage to be achieved by each survey order.

3.5.1. 100% Bathymetric Coverage

A 100% bathymetric coverage should be interpreted as “full” bathymetric coverage. 100% bathymetric coverage does not guarantee continuous depth measurements, since the depth measurements are discrete and based on the inherent physical and survey instrumentation limitations.

3.5.2. Less than 100% Bathymetric Coverage

bathymetric coverage of less than 100% must follow a systematic survey pattern to maximise uniform distribution of depth data across the survey area and must not be lower than 5%. Additionally, the nature of the bottom (e.g. roughness, type, slope) and the requirements for safety of surface navigation in the area must be taken into account early and often to determine whether the survey pattern should be adapted to meet the requirements for safety of navigation in the area, while still fulfilling the minimum requirements according to Table 1. To ensure surveys are performed systematically where bathymetric coverage is specified at less than 100%, the horizontal distance between registered positions of depths should be no greater than 3 times the average depth or 25 metres, whichever is greater.

For Order 1a, bathymetric coverage less than or equal to 100% is appropriate as long as the least depths over all significant features are obtained and the bathymetry provides an adequate depiction of the nature of the bottom topography. The system independent parameter bathymetric coverage (expressed in percentage) is used for all Orders. In the 5th edition, line spacing was used as the parameter for Order 2 and 1b. In transition from line spacing to an extent in percentage for bathymetric coverage, a single beam with 8-12° beam width was used as a realistic reference, with an inter-line spacing of 3-4 times water depths[1]. 5% is therefore the appropriate value for the Order 2 and 1b bathymetric coverage requirement.

3.5.3. Greater than 100% Bathymetric Coverage

Greater than 100% bathymetric coverage, including 200% for Exclusive Order, may be accomplished by adequately overlapping collection or by acquiring more than one independent dataset within a survey.

[1] Example: For a singlebeam echosounder with an 8° beam width, considering a line spacing of 3-times depth for the main lines and 10 times the main line spacing for the cross lines, according to the formula, the bathymetric coverage is: % coverage = surveyed area / total area = (footprint diameter*total line length) / total area = 2*tan (8°/2)*(1/3+1/(3*10)) = 0.051 = 5.1%. This formula is provided as an example and does not constitute part of this standard.

3.6. Hazards to Navigation

Hydrographic offices and authorities must consider the expected local traffic (e.g. draught of vessels) as well as general configuration of depths when assessing hazards to navigation.

Sufficient data must be acquired over features that are potential hazards to navigation (e.g. wreck or other obstructions) to ensure the least depth and position are adequately determined by appropriate methods, while meeting the minimum requirements of the appropriate order in Table 1.

Given current ship specifications, features with least depths deeper than 40m would not likely constitute a hazard to surface navigation. However, this statement should be constantly re-evaluated based on local circumstances and their potential changes.

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 features, is not required.

3.7. Charted Object Confirmation / Disproval

For an object which has previously been recorded/presented in a chart, document, electronic publication, or database, it is recommended to confirm or disprove the existence of those charted objects such as rocks, wrecks, obstructions, aids to navigation, and doubtful data. Findings should be addressed in the report of survey.

Doubtful data includes, but is 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”. Charted objects should be confirmed or disproved relative to their charted position.

No empirical formula for defining the search area can cover all situations. For object confirmation or disproval it is recommended that the search radius should be at least 3 times the estimated position uncertainty of the reported hazard. If a charted object is not located or indicated within the search radius, the charted object can then be recommended as disproved.

It is the responsibility of the hydrographic office or authority which is gathering the data to assess whether the charted object has been sufficiently disproved before removing it from the chart.

3.8. Nature of the Bottom

The nature of the bottom should be determined in potential anchorage areas, other critical areas, and in areas where bottom conditions are suspected to have significant influence on required feature detection. Bottom Characterisation Methods include: physical sampling (PHY) with visual (VIS) and / or laboratory (LAB) analysis, inference technique (INF) from other sensors (e.g. backscatter or reflectivity), or inference technique with physical ground truth sampling (INF w/ GT) and visual (VIS) and / or laboratory (LAB) analysis.

Bottom Sampling Frequency may be at a spacing sufficient for the intended product (e.g. chart), seabed geology, and as required to ground truth any inference technique. Bottom sampling for ground truth of inference technique does not require a regular sampling pattern, or distances. An average value, or maximum value, for the distance between samples can be used. If bottom sampling has been performed in specific areas, such as anchorage or other areas of interest of the surveyed area, the limits for the sampling area should be recorded.

There are currently no IHO safety of navigation standards for bottom characterisation methods or bottom sample frequencies. However, the Matrix may be used to task and classify any such work performed. What is appropriate for these parameters varies greatly based on the nature and configuration of the bottom as well as the intended use of the area. The surveyor should exercise judgement in determining appropriate bottom characterisation methods and bottom sample frequency to adequately characterise the area.

4. WATER LEVELS AND FLOW

4.1. Introduction

In this chapter, water levels are considered in the context of supporting the vertical solution of depth measurements, rather than water level measurements as a discrete dataset to define tidal harmonics etc, which are covered within other IHO documents. Tides and other changes in water levels which impact the TVU of depth data must be considered for any hydrographic survey regardless of the technology used to conduct the survey. Flow observations will often be required to support safe navigation, and when specified in the survey requirement, those observations must meet the parameters presented in this standard.

For requirements to clearly determine chart and land survey vertical datum connections, or relationships, see Section 2.5.

4.2. Water Level (Tidal) Predictions

Water level observations may be required to facilitate generation and maintenance of tidal prediction models and the production of Tide Tables. Water level observations should cover as long a period as possible and preferably not less than 30 days.

4.3. Reductions for Water Level Observations

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

4.4. Water Flow (Tidal Stream and Current) Observations

The speed and direction of water flows (tidal streams and currents) which may exceed 0.5 knots should be observed in key areas, if not already defined. For example, 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 recommended to measure coastal and offshore streams and currents when they are of sufficient strength to affect surface navigation.

The water flow (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. It is recommended that the period of observation be at least 30 days.

The speed and direction of the water flow (tidal stream and current) must 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 water flows, measurements should be made to cover the entire period of variability.

5. SURVEYS ABOVE THE VERTICAL DATUM

5.1. Introduction

Surveys above the vertical datum are necessary for safe and efficient navigation and mooring. Topographic and geodetic measurements that are of specific importance for navigation are presented in the following sections. Their corresponding allowable uncertainties (THU and TVU as applicable) are defined in Table 2.

Additional information such as drawings or photographs of these features should be captured where possible to support the measurement.

For Chart and Land Survey Vertical Datum Connection requirements see Section 2.5.

5.2. Fixed Aids and Topographic Features Significant to Navigation

Fixed aids to navigation include, but are not limited to: beacons, day marks, range markers, and lighthouses.

Topographic features significant to navigation are conspicuous features, landmarks, and objects which assist mooring, docking, and manoeuvring in confined spaces and / or provide some aid in navigation.

Conspicuous features which provide some aid in navigation without being a dedicated aid to navigation may include, but are not limited to, conspicuous natural features, cultural features, and landmarks such as: chimneys, flare stacks, hill or mountain tops, masts, monuments, towers, refineries, religious buildings, silos, single buildings, tanks, tank farms, towers, and windmills. Features of this type may be both significant to navigation and less significant to navigation (Section 5.5) depending on the feature's individual characteristics and surroundings.

Essential harbour, mooring, and docking features include, but are not limited to: groins, moles, wharfs (quays), piers (jetties), mooring dolphins, piles, bollards, slipways, docks, lock gates, and breakwaters.

Allowable THU and TVU for the positioning of these fixed aids and features significant to navigation are presented in Table 2.

One may consider drying features (including rocks) which are positioned by topographic means to be topographic features significant to navigation. Regardless of the positioning methodology, maximum allowable uncertainties for drying features shall not exceed those specified in this standard for the adjacent permanently submerged features (unless a different order of survey has intentionally been specified by the commissioning authority).

5.3. Floating Objects and Aids to Navigation

Floating objects and aids to navigation include, but are not limited to: buoys, articulated beacons, fish farms, and floating docks.

For floating objects, the surveyed position uncertainty should be significantly lower than the sway (object's allowed movement). Sway due to currents, wind, and water level must be taken into account when computing the mean position of these objects.

Allowable THU for the positioning of these objects are presented in Table 2. Allowable TVU is not applicable to these measurements.

5.4. Coastline

IHO S-32, *IHO Hydrographic Dictionary*, generally defines coastline or shoreline as the line where shore and water meet. IHO S-4, *Regulations of the IHO for International (INT) Charts and Chart Specification of the IHO*, describes it more specifically as high water mark, or the line of mean water level where there is no appreciable tide or change in water level. The coastline may also be defined as the low water line. Allowable THU for the positioning of these objects are presented in Table 2. Allowable TVU is not applied to these measurements within this standard.

5.5. Features Less Significant to Navigation

Features less significant to navigation are non-conspicuous features which provide context and additional information, but are not likely to aid navigation. As stated in Section 5.2, topographic features of the same type may be both conspicuous / significant to navigation and less conspicuous / less significant to navigation depending on the feature's individual characteristics and surroundings. Topographic features less significant to navigation may include, but are not limited to non-conspicuous landmarks such as: chimneys, flare stacks, hill or mountain tops, masts, monuments, towers, refineries, religious buildings, silos, single buildings, tanks, tank farms, and windmills.

Allowable THU and TVU for the positioning of these objects are presented in Table 2.

5.6. Overhead Clearances, Range Line and Sector Lights Heights

Overhead obstructions such as bridges and cables may pose a hazard to navigation. Range line and sector light heights may be of use for determining distance from shore. Allowable THU and TVU for the positioning of overhead clearances (including associated horizontal clearances), range line and sector light heights are presented in Table 2.

5.7. Angular Measurements

Angular measurements include, but are not limited to: limits of sectors and arcs of visibility of lights, alignments of leading lights and clearing lights, directions for passing off-lying dangers, and alignment of recommended tracks. Allowable THU for the measurement of these angles is presented in Table 2. Allowable TVU is not applicable to these measurements

6. METADATA

6.1. Introduction

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. Examples of metadata include overall quality, data set title, source, positional uncertainty, and ownership.

6.2. Metadata Content

Metadata can be provided in any format such as in the Report of Survey, or embedded within a specific metadata 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. The table below should be seen as a schema, and not a final data model.

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

Category or Group	Description
Survey Type	e.g. safety of navigation, passage, reconnaissance/sketch, examination
Technique of vertical / depth measurement	e.g. echo-sounder, side scan sonar, multi-beam, diver, lead-line, wire-drag, photogrammetry, satellite derived bathymetry, lidar
Order of survey achieved	In accordance with S-44
Horizontal and vertical datum and separation models used	Including ties to a geodetic reference frame based on ITRS (e.g. WGS84) and epoch information, if a local datum or realisation is used
Uncertainties achieved (at 95% Confidence Level)	For both horizontal and vertical components: THU and TVU
Feature detection ability	In metres
Feature search	% of survey area searched
bathymetric coverage	% of survey area covered
Survey date range	Survey's start and end dates
Survey undertaken by	Surveyor, survey company, survey authority
Data ownership	e.g. funding body, government

Category or Group	Description
Grid attributes	Where a grid is the deliverable (i.e. resolution, method, underlying data density, uncertainty)
Data density	Description of average or range of density of source data (e.g. number of accepted points per surface unit)
Usage constraints	e.g. none, classified, not for navigation, or restricted

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.

7. TABLES AND SPECIFICATION MATRIX

7.1. Introduction

As in previous editions, this edition of S-44 presents key elements of safety of navigation survey specifications in table format. This edition has two Tables (1 and 2) and provides a new specification Matrix for added flexibility for other types of hydrographic surveys carried out for purposes beyond safety of navigation. The new Matrix allows for customisation and enhancement of safety of navigation survey standards.

7.2. Safety of Navigation Standards

Minimum bathymetry standards are defined in Table 1. Other minimum standards for positioning and water flow measurements 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 Table 1 and Table 2 are included in the specification Matrix within ranges of specification values which are available to enhance and customise 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. The 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. Table 1 follows.

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. Finally, requirements are set for direction and speed measurements for tidal stream and current. These standards only apply where such measurements are required for the survey. Table 2 follows.

7.3. Minimum Bathymetry Standards for Safety of Navigation Hydrographic Surveys

To be read in conjunction with the full text set out in this document, m = metres, all uncertainties at 95% confidence level, * = Matrix Reference.

Table 1

Reference	Criteria	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
Chapter 1	**Area description** (Generally)	Areas where a general description of the sea floor is considered adequate.	Areas where underkeel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas where underkeel clearance is considered not to be critical but features of concern to surface shipping may exist.	Areas where underkeel clearance is critical	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria
Section 2.6	**Depth THU** [m] + [% of Depth]	20 m + 10% of depth *Ba5, Bb2	5 m + 5% of depth *Ba8, Bb3	5 m + 5% of depth *Ba8, Bb3	2 m *Ba9	1 m *Ba10
Section 2.6 Section 3.2 Section 3.2.3	**Depth TVU** (a) [m] and (b)	a = 1.0 m b = 0.023 *Bc7, Bd4	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.25 m b = 0.0075 *Bc10, Bd8	a = 0.15 m b = 0.0075 *Bc12, Bd8
Section 3.3	Feature Detection [m] or [% of Depth]	Not Specified	Not Specified	Cubic features > 2 m, in depths down to 40 m; 10% of depth beyond 40 m *Be5, Bf3 beyond 40m	Cubic features > 1 m *Be6	Cubic features > 0.5 m *Be9
Section 3.4	Feature Search [%]	Recommended but Not Required	Recommended but Not Required	100% *Bg9	100% *Bg9	200% *Bg12
Section 3.5	bathymetric coverage [%]	5% *Bh3	5% *Bh3	≤ 100% *≤ Bh9	100% *Bh9	200% *Bh12

7.4. Other Minimum Standards for Safety of Navigation Surveys

To be read in conjunction with the full text set out in this document. Standards for Table 2 data types only apply where such measurements are required for the survey.

m = metres. All uncertainties at 95% confidence level. * = Matrix Reference.

Table 2

Reference	Criteria	Uncertainty Type	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
Section 5.2	**Fixed Objects, Aids, Features Above the Vertical Reference Significant to Navigation**	THU [m]	5 m *Pa4	2 m *Pa6	2 m *Pa6	2 m *Pa6	1 m *Pa7
		TVU [m]	2 m *Pb2	2 m *Pb2	1 m *Pb3	0.5 m *Pb4	0.25 m *Pb5
Section 5.3	**Floating Objects and Aids to Navigation**	THU [m]	20 m *Pc2	10 m *Pc3	10 m *Pc3	10 m *Pc3	5 m *Pc4
Section 5.4	**Coastline** (high, low, MWL water lines, etc)	THU [m]	10 m *Pd2	10 m *Pd2	10 m *Pd2	10 m *Pd2	5 m *Pd3
Section 5.5	**Features Above the Vertical Reference Less Significant to Navigation**	THU [m]	20 m *Pe2	20 m *Pe2	20 m *Pe2	10 m *Pe3	5 m *Pe4
		TVU [m]	3 m *Pf1	2 m *Pf2	1 m *Pf3	0.5 m *Pf4	0.3 m *Pf5
Section 5.6	**Overhead Clearances and Range Line, Sector Light Heights**	THU [m]	10 m *Pg1	10 m *Pg1	5 m *Pg2	2 m *Pg3	1 m *Pg4
		TVU [m]	3 m *Ph1	2 m *Ph2	1 m *Ph3	0.5 m *Ph4	0.3 m *Ph5
Section 5.7	**Angular Measurements**	[degrees]	0.5 degrees *Pi4				
Section 4.4	**Water Flow Direction**	[degrees]	10 degrees *Wa1				
Section 4.4	**Water Flow Speed**	[knots]	0.1 knots *Wb5				

7.5. Matrix Description

The Specification Matrix provides a range of selectable criteria for bathymetric parameters and other data types collected, reported, and delivered as part of a hydrographic survey. It is introduced to allow flexibility and customisation 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. By design, it is expandable and can evolve in future S-44 editions. The Matrix can be used both as a tool when specifying a survey, but also as a tool for classification of data after a completed survey.

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) are referenced to the Matrix criteria and the Matrix can be used to customise 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 categorise 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.

7.6. MATRIX

Matrix for Hydrographic Surveys. To be read in conjunction with the full text set out in this document, m = metres, all uncertainties at 95% confidence level.

	Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14
B	**BATHYMETRY**														
a	**Depth** THU [m]	500	200	100	50	20	15	10	5	2	1	0.5	0.35	0.1	0.05
b	**Depth** THU [% of depth]	20	10	5	2	1	0.5	0.25	0.1						
c	**Depth** TVU "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 "b" NOTE 1	0.20	0.10	0.05	0.023	0.02	0.013	0.01	0.0075	0.004	0.002				
e	Feature Detection [m]	50	20	10	5	2	1	0.75	0.7	0.5	0.3	0.25	0.2	0.1	0.05
f	Feature Detection [% of Depth]	25	20	10	5	3	2	1	0.5	0.25					
g	Feature Search [%]	1	3	5	10	20	30	50	75	100	120	150	200	300	
h	Bathymetric Coverage [%]	1	3	5	10	20	30	50	75	100	120	150	200	300	
P	**OTHER POSITIONING ABOVE THE VERTICAL REFERENCE**														
a	**Fixed Aids, Features 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	0.25	0.1	0.05	0.01						
c	**Floating Aids and Objects** THU [m]	50	20	10	5	2	1	0.5							
d	Coastline THU (high, low, MWL water lines, etc.) [m]	20	10	5	1	0.5	0.25	0.1							
e	**Features Less Significant to Navigation** THU [m]	50	20	10	5	3	2	1	0.5	0.2	0.1	0.05	0.01		
f	**Features Less Significant to Navigation** TVU [m]	3	2	1	0.5	0.3	0.25	0.1	0.05	0.01					

	Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14
g	**Overhead Clearance and Range line, Sector Light Heights** THU [m]	10	5	2	1	0.5	0.2	0.1	0.05	0.01					
h	**Overhead Clearance and Range line, Sector Light Heights** TVU [m]	3	2	1	0.5	0.3	0.1	0.05	0.01						
i	**Angular Measurements** [degrees]	5	2.5	1	0.5	0.2	0.1	0.05							
W	**WATER FLOW**														
a	**Flow Direction** [degrees]	10	7.5	5.0	2.5	1.0	0.5	0.25	0.10						
b	**Flow Speed** [knots]	2	1	0.5	0.25	0.10									
N	**NATURE OF THE BOTTOM**														
a	**Bottom Characterisation Method** NOTE 2	PHY —VIS	PHY —LAB	PHY —VIS & LAB	INF	INF w/ GT (VIS)	INF w/ GT (LAB)	INF w/ GT (VIS & LAB)							
b	**Bottom Sampling Frequency approximate** [m] NOTE 2	As Req to GT	10,000	5,000	2,500	1,852	1,000	500	250	100	75	50	25	10	5

NOTE 1: To use the parameter “b”, as a percentage of depth, multiply it by 100.
NOTE 2: PHY = Physical Sampling. VIS = Visual Analysis. LAB = Laboratory Analysis. INF = Inference Technique. w/ = With. GT = Ground Truth. As Req to GT = As Required to Ground Truth any Inference Technique (see Section 3.8).

Annex A
MATRIX GUIDANCE

A.1. Introduction

The Matrix, as presented in Section 7.6, includes a range of selectable criteria for hydrographic survey parameters / data types. It is organised by the following data classes: Bathymetry, Other Positioning, Water Flow, and Nature of the Bottom.

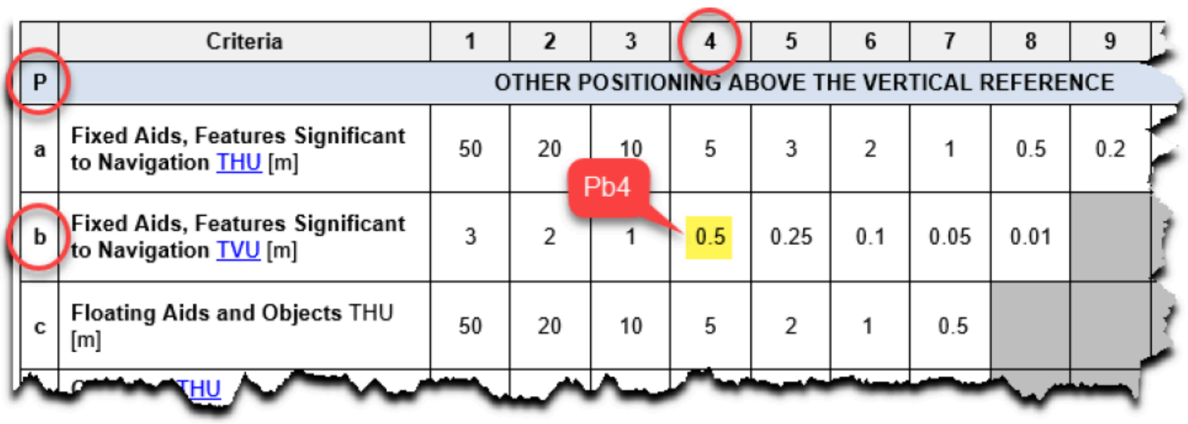
The criteria are derived through a series of alphanumeric codes which reference the cells in the Matrix. A criterion requires three characters to reference a cell address:

1) The first character is a capital letter denoting the class of data.
2) The second character is a lower-case letter referencing the intended criteria by row.
3) The third character is a number referencing the intended criteria value by column.

The string should include only those parameters and data types required for both specification and classification of surveys. Omission of a cell reference indicates that there is no requirement for the associated criteria and that "0" should be used in required formulas.

Table A.1 — Matrix Classes and Description

	Class	Description
B	Bathymetry	Depth and features
P	Other Positioning	Location of features above the vertical reference
W	Water Flow	Direction and speed of currents
N	Nature of the Bottom	Bottom characterisation



	Criteria	1	2	3	4	5	6	7	8	9
P	OTHER POSITIONING ABOVE THE VERTICAL REFERENCE									
a	Fixed Aids, Features Significant to Navigation THU [m]	50	20	10	5	3	2	1	0.5	0.2
b	Fixed Aids, Features Significant to Navigation TVU [m]	3	2	1	0.5	0.25	0.1	0.05	0.01	
c	Floating Aids and Objects THU [m]	50	20	10	5	2	1	0.5		

Figure A.1 — Example: (Pb4) derivation of Fixed Aids, Features Significant to Navigation TVU = 0.5 m

A.2. Examples of Matrix Realisations:

A.2.1. Matrix Representations

Matrix realisations may be communicated in a variety of representations including: diagrams, tables, text strings, and shaded matrices.

A.2.2. Table Examples

The following table presents two examples of "Matrix Realisations": Order 1a Surveys, and a Customised Specification. This table includes the values associated with a Matrix cell. Although it may be helpful to provide those values in a technical specification for a survey, it is not explicitly necessary in order to communicate the requirement. Cells in colour highlight the differences between Order 1a and the customised specification, which is more demanding.

B	BATHYMETRY	Order 1a Value	Matrix Cell Ref.	Custom	Matrix Cell Ref.
a	**Depth** THU [m]	5	Ba8	5	Ba8
b	**Depth** THU [% of depth]	5	Bb3	5	Bb3
c	**Depth** TVU “a” [m]	0.5	Bc8	---	---
d	**Depth** TVU “b”	0.013	Bd6	0.010	Bd7
e	**Feature Detection** [m]	2 (≤40 m)	Be5 (≤40 m)	1 (≤40 m)	Be6
f	**Feature Detection** [% of Depth]	10 (>40 m)	Bf3 (>40 m)	10	Bf3
g	**Feature Search** [%]	100	Bg9	100	Bg9
h	**Bathymetric Coverage** [%]	≤ 100	≤ Bh9	100	Bh9
P	**OTHER POSITIONING**				
a	**Fixed Aids, Features Significant to Navigation** THU [m]	2	Pa6	2	Pa6
b	**Fixed Aids, Features Significant to Navigation** TVU [m]	1	Pb3	1	Pb3
c	**Floating Aids and Objects** THU [m]	10	Pc3	10	Pc3
d	**Coastline** THU (high, low, MWL water lines, etc.) [m]	10	Pd2	10	Pd2
e	**Topographic Features Less Significant to Navigation** THU [m]	20	Pe2	5	Pe4
f	**Topographic Features Less Significant to Navigation** TVU [m]	1	Pf3	1	Pf3
g	**Overhead Clearance and Range line, Sector Light Heights** THU [m]	5	Pg2	5	Pg2
h	**Overhead Clearance and Range line, Sector Light Heights** TVU [m]	1	Ph3	1	Ph3
i	**Angular Measurements** [degrees]	0.5	Pi4	0.5	Pi4
T	**WATER FLOW**				
a	**Flow Direction** [degrees]	10	Ta1	5	Ta3
b	**Flow Speed Uncertainty** [knots]	0.1	Tb5	0.1	Tb5
N	**NATURE OF THE BOTTOM**				
a	**Bottom Characterisation Method**	---	---	INF w/ GT (VIS & LAB)	Na7
b	**Bottom Sampling Frequency**	---	---	As Req to GT	Nb1

A.2.3. Text String Examples

The following text strings present examples of “Matrix Realisations”: Order 1a Surveys, and a Crowd Sourced dataset example.

EXAMPLE 1 — Order 1a Matrix text string example: Classified according to the S-44 Matrix as:

Ba8, Bb3, Bc8, Bd6, Be5 (≤40m), Bf3 (>40m), Bg9, ≤Bh9, Pa6, Pb3, Pc3, Pd2, Pe1, Pf3, Pg2, Ph3, Pi4, Wa1, Wb5.

Can be divided into the separate parts as not all parameters need to be surveyed at all times depending on area and survey specification requirements. Classified according to the S-44 Matrix as:

- Bathymetry: *Ba8, Bb3, Bc8, Bd6, Be5 (≤40m), Bf3 (>40m), Bg9, ≤ Bh9*
- Fixed Objects, Aids, Features Above the Vertical Reference Significant to Navigation: *Pa6, Pb3*
- Floating Aids and Objects: *Pc3*
- Coastline: *Pd2*
- Features Above the Vertical Reference Less Significant to Navigation: *Pe2, Pf3*
- Overhead Clearances and Range Line, Sector Light Heights: *Pg2, Ph3*
- Angular Measurements: *Pi4*
- Water Flow: *Wa1, Wb5*

EXAMPLE 2 — Crowd Sourced Dataset Example: A “Crowd Sourced” bathymetric dataset acquired in deep water, with a single beam echosounder and no sound velocity correction, could be classified by the use of TVU and THU (the coverage is of no use as it is not a systematic survey):

Classified according to the S-44 Matrix as: *Ba3, Bc5, Bd3*

Referencing:

The use of text strings for classification of datasets should be articulated with a clear reference to the S-44 Survey Order and / or Matrix, highlighting any variance from the Survey Order.

Examples could be: “*Classified according to the S-44 Matrix as: (Ba8, Bb3…)*” or “*Classified according to the S-44 Survey Order and Matrix as: Special Order, **Ba12***” (where Ba12 shows a further augmentation of Special Order in this case).

NOTE: the use of text strings alone has a higher probability of translation error.

A.2.4. Matrix Example

Example: Order 1b using the SPECIFICATION MATRIX
m = metres, all uncertainties at 95% confidence level, **Order 1b cells**

	Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14
B	**BATHYMETRY**														
a	**Depth** THU [m]	500	200	100	50	20	15	10	**5**	2	1	0.5	0.35	0.1	0.05
b	**Depth** THU [% of depth]	20	10	**5**	2	1	0.5	0.25	0.1						
c	**Depth** TVU “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 “b” NOTE 1	0.20	0.10	0.05	0.023	0.02	**0.013**	0.01	0.0075	0.004	0.002				
e	**Feature Detection** [m]	50	20	10	5	2	1	0.75	0.7	0.5	0.3	0.25	0.2	0.1	0.05
f	**Feature Detection** [% of Depth]	25	20	10	5	3	2	1	0.5	0.25					
g	**Feature Search** [%]	1	3	5	10	20	30	50	75	100	120	150	200	300	
h	**Bathymetric Coverage** [%]	1	3	**5**	10	20	30	50	75	100	120	150	200	300	
P	**OTHER POSITIONING ABOVE THE VERTICAL REFERENCE**														
a	**Fixed Aids, Features 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	0.25	0.1	0.05	0.01						
c	**Floating Aids and Objects** THU [m]	50	20	**10**	5	2	1	0.5							
d	**Coastline** THU (high, low, MWL water lines, etc.) [m]	20	**10**	5	1	0.5	0.25	0.1							
e	**Features Less Significant to Navigation** THU [m]	50	**20**	10	5	3	2	1	0.5	0.2	0.1	0.05	0.01		
f	**Features Less Significant to Navigation** TVU [m]	3	**2**	1	0.5	0.3	0.25	0.1	0.05	0.01					

	Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14
g	**Overhead Clearance and Range line, Sector Light Heights** THU [m]	**10**	5	2	1	0.5	0.2	0.1	0.05	0.01					
h	**Overhead Clearance and Range line, Sector Light Heights** TVU [m]	3	**2**	1	0.5	0.3	0.1	0.05	0.01						
i	**Angular Measurements** [degrees]	5	2.5	1	**0.5**	0.2	0.1	0.05							
W	**WATER FLOW**														
a	**Flow Direction** [degrees] Section 4.4	**10**	7.5	5.0	2.5	1.0	0.5	0.25	0.10						
b	**Flow Speed** [knots] Section 4.4	2	1	0.5	0.25	**0.10**									
N	**NATURE OF THE BOTTOM**														
a	**Bottom Characterisation Method** Section 3.8 NOTE 2	PHY —VIS	PHY —LAB	PHY —VIS & LAB	INF	INF w/ GT (VIS)	INF w/ GT (LAB)	INF w/ GT (VIS & LAB)							
b	**Bottom Sampling Frequency approximate** [m] Section 3.8 NOTE 2	As Req to GT	10,000	5,000	2,500	1,852	1,000	500	250	100	75	50	25	10	5

NOTE 1: To use the parameter as a percentage of depth multiply by 100.
NOTE 2: PHY = Physical Sampling. VIS = Visual Analysis. LAB = Laboratory Analysis. INF = Inference Technique. w/ = With. GT = Ground Truth. As Req to GT = As Required to Ground Truth any Inference Technique.

Annex B
Guidelines for Quality Management

NOTE: This annex is **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, *Manual on Hydrography*.

Quality control Quality evaluation procedure for maintaining standards in products by testing the output against the specification.

B.1. Quality Control

Quality control requires more than 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; rather it is 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 standards. First, the total propagated uncertainties of all equipment and corrections used to derive the reported surveyed value must be included. The temporal and spatial influence of the medium, in which measurements take place, must be considered in this total propagated uncertainty calculation. 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. If uncertainties cannot be calculated prior to the survey, an alternative methodology of describing the achieved uncertainties must be undertaken to verify that the required standards will be met.

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

The use of calibrated equipment that can achieve the 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 occurs 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, such as from CAT A and B accredited courses are preferred, but proven working experience may be sufficient. Personal professional accreditation schemes should also be considered.

Annex C
GUIDANCE FOR A PRIORI AND A POSTERIORI QUALITY CONTROL

NOTE: This annex is **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, *Manual on Hydrography*.

The S-44 standards refer to quality standards for both *a priori* and *a posteriori* results. In this guidance a brief view on how to determine the uncertainties for *a priori* and *a posteriori* is given. Determining uncertainties is necessary for any technique used in hydrographic surveys. Methods 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 uncertainties to the grand total. Calculating the total uncertainty horizontally and vertically prior to the survey will affirm to 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 achieved, 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 hydrographer is most interested in the *a posteriori* uncertainty.

Outside of a reference area it is not possible to determine the *a posteriori* uncertainty from the data set. The data set 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 the data set. 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, however no tool will calculate the *a posteriori* uncertainty of an area that is not well-known.

A preliminary task is to check the capability of the total system, to ensure that it can meet the minimal horizontal and vertical specifications and feature detection requirement, according to the specified order. 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 the survey, consideration should be given to confirm the validity of the vertical model by assessing the spatial and temporal repeatability of the survey system.

Annex D
GRIDDED BATHYMETRY CONSIDERATIONS

NOTE: This annex is **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, *Manual on Hydrography*.

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 such as 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 characterisation. 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 compilations, 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)
Bathymetric model	Digital representation of the topography of the bottom by coordinates and depths.
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)
Holiday	An unintentional unsurveyed area within a given hydrographic survey where the spacing between sounding lines or surveys exceeds the maximum allowable limits (IHO Dictionary S-32).
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, although it is recommended that a cell size of half the feature is used.

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.

Grid resolution should ultimately be determined based on the intended use of the grid and therefore a survey may require grids of different resolutions to satisfy multiple purposes.

D.3.2. Sample Density

It is the responsibility of the hydrographic office, or authority, to determine an acceptable data density requirement which 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 data set 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 data sets exist. The hydrographic office or authority is responsible for determining the appropriate method for the intended purpose of the resultant gridded data set. 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 data sets:

- 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 data set.
- 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 minimise 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 (e.g. 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 are a common product of a hydrographic survey; however, the utility of the model representation begins well before a survey data set is finalised as this data can also be used to verify survey requirements during hydrographic collection and certify quality of a data set during data set 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 data set 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 prioritisation scheme for future product updates. Comparison of gridded depth and associated nodal uncertainty is another common method used in determining whether a survey data set complies with required uncertainty thresholds as well.

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. Gridded models also serve 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 include and extend beyond safety of navigation, an appropriate level of metadata describing the data set 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 data set, 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.

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