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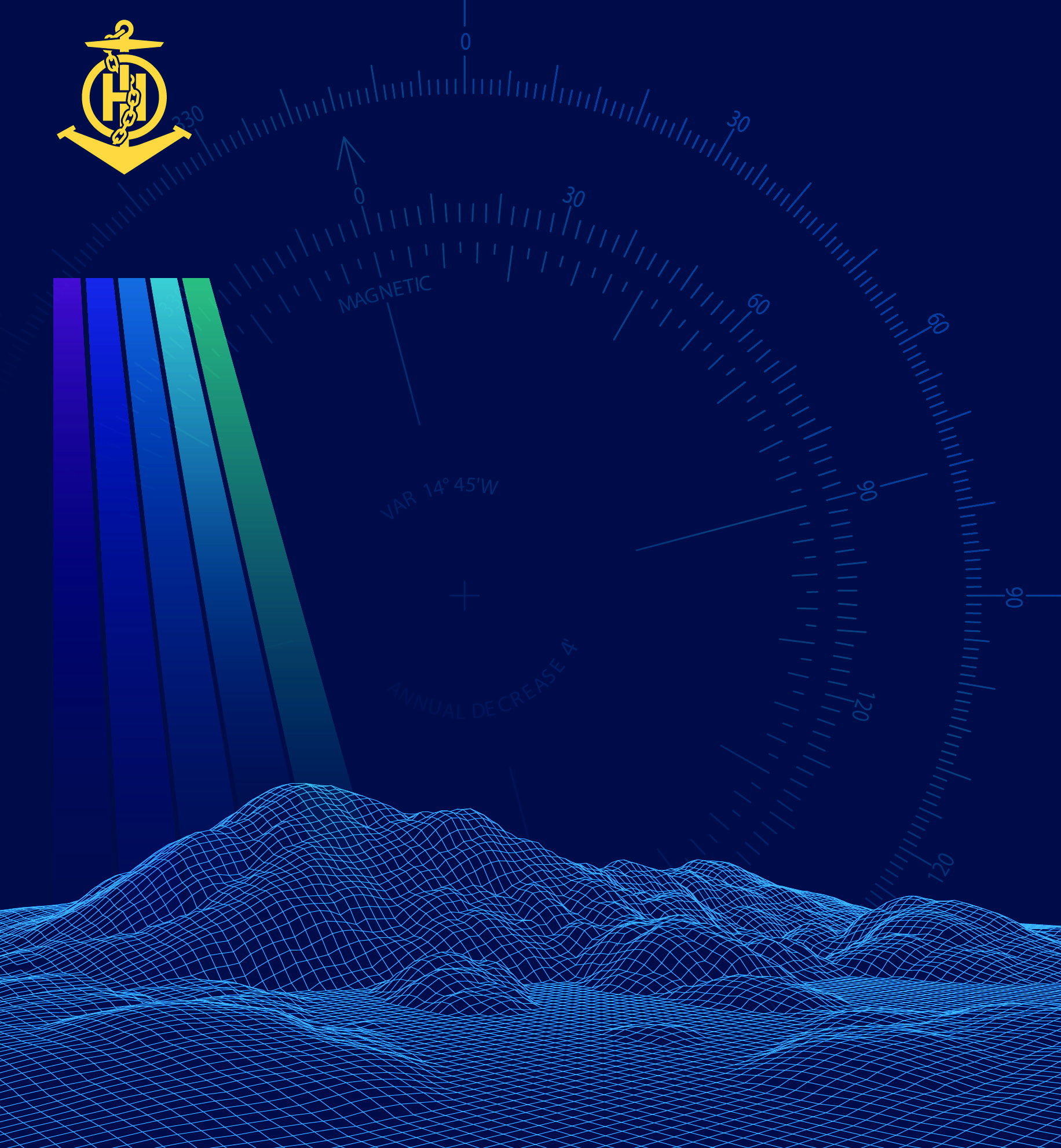
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International Hydrographic Organization Standards for Hydrographic Surveys



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**INTERNATIONAL HYDROGRAPHIC ORGANIZATION**

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**IHO STANDARDS FOR HYDROGRAPHIC SURVEYS**

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PREFACE

This Publication (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 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 its Circular Letter (CL) 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 three years. During this period, the team published a questionnaire for the entire hydrographic community, and received comments from IHO stakeholders about a preliminary version of this standard. These results were a valuable tool to express the needs of the community and drive the updates of edition 6while remaining committed to the IHO mandate.

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, 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 should be consulted for information on those topics (downloadable from the IHO homepage: [www.iho.int](https://iho.int/)).

In this edition a new, more stringent Exclusive Order has been introduced which, although not mandatory for navigational safety, satisfies the minimum requirements mandated for the other orders of survey. The other Orders for safety of navigation surveys have kept the same names, but their interpretation will change from the previous edition due to the introduction of the [bathymetric coverage](#Bathymetric_Coverage) concept. In the 6th edition, Special Order now explicitly requires full [bathymetric coverage](#Bathymetric_Coverage). Furthermore, the Orders have been divided into requirements above and below the vertical datum.

This edition aims to encourage the use of these standards for purposes beyond the safety of navigation. It introduces the concept of a [Matrix](#_Specification_Matrix) of parameters to define realisations of survey standards. This [Matrix](#_Specification_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. The [first annex](#_heading=h.vx12271) provides guidance on how the Matrix can be used for specification and classification of surveys.

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.

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, 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 completed an 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) Category A and/or B educational program) may be of considerable benefit in making this assessment.

The Annexes contain guidance for achieving and assessing the quality of hydrographic survey data using contemporary data processing techniques. Note: the annexes [B](#_ANNEX_B:_GUIDELINES), [C](#_ANNEX_C:_GUIDANCE) and [D](#_ANNEX_D:_GRIDDED) will be removed once the information is captured in appropriate IHO documentation.

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. 100% [bathymetric coverage](#Bathymetric_Coverage) must be considered as a systematic method of obtaining depths at a resolution equal to or higher than the relevant [feature detection](#Feature_Detection) requirement.

**Bathymetric model:** Digital representation of the topography of the bottom by coordinates and depths.

**Confidence level:** Probability that the true value of a measurement will lie within the specified [uncertainty](#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](#Error) can be categorised as a [systematic error](#Systematic_Error) or a [random error](#Random_Error).

**Feature**: Any object, whether natural or manmade, which is distinct from the surrounding area.

**Feature detection ability**: Ability of a system to detect [features](#feature) of a defined size.

**Feature search:** Systematic method of exploring the bottom undertaken to detect [significant features](#Significant_Feature) of specified minimum sizes.

**Metadata:** Data (describing) about a data set and usage aspect of it. [Metadata](#Metadata) is data implicitly attached to a collection of data. Examples of [metadata](#Metadata) include overall quality, data set title, source, positional [uncertainty](#Uncertainty) and ownership.

**Quality control:** Quality evaluation procedure for maintaining standards in products by testing the output (or a sample of) against the specification.

**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 depths:** Observed depths including all [corrections](#Correction) related to the survey and post processing and reduction to the appropriate vertical datum.

**Significant Feature:** [Feature](#feature) which is potentially hazardous to navigation. This standard defines these [feature](#feature)s that pose a danger to navigation, and include objects one would expect to see depicted on a nautical chart or product. Example: pipeline, rock, wreck.

**Systematic error:** Component of measurement [error](#Error) that remains constant or varies in a predictable manner.

**Total horizontal uncertainty (THU):** Component of [total propagated uncertainty](#Total_Propagated_Uncertainty) *(*TPU) calculated in the horizontal dimension. [THU](#Total_Horizontal_Uncertainty) is a two-dimensional quantity when all contributing horizontal measurement uncertainties have been included.

**Total propagated uncertainty (TPU):** Three dimensional [uncertainty](#Uncertainty) when all contributing measurement [uncertainties](#bookmark=kix.roylla3xdodg) have been included.

**Total vertical uncertainty (TVU):** Component of[total propagated uncertainty](#bookmark=kix.5ag6q7e00y0v) (TPU) calculated in the vertical dimension. [TVU](#Total_Vertical_Uncertainty) is a one-dimensional quantity when all contributing vertical measurement uncertainties have been included.

**Uncertainty:** Estimate characterising the range of values within which the true value of a measurement is expected to lie, defined within a particular [confidence level](#Confident_level). It is always expressed as a positive value.

**Uncertainty surface:** Model, typically grid based, which describes the depth [uncertainty](#Uncertainty) of the product of a survey over an area.

**Under-keel Clearance:** Distance between the lowest point of the ship's hull, normally some point on the keel, and the bottom.

# CLASSIFICATION OF SAFETY OF NAVIGATION SURVEYS

## Introduction

This chapter describes the orders of safety of navigation surveys which are generally 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, five different orders of survey are defined; each designed to cater to a range of needs.

The five 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](#_TABLE_1) and [Table 2](#_TABLE_2)) along with a new tool for enhancing and customising these orders (Specification [Matrix](#_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. It should be noted that 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 instance, in an area traversed by Very Large Crude Carriers (VLCCs) and expected to be deeper than 40 metres, an Order 1a survey may have been specified. However, if the surveyor discovers shoals extending to less than 40 metres, then it may be more appropriate to survey these shoals and surroundings to Special Order.

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

## 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, a [Bathymetric coverage](#Bathymetric_Coverage) of 5% is required for the survey area. 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 on surface navigation and yet still remain undetected by an Order 2 survey is considered to be unlikely.

## 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, a [Bathymetric coverage](#Bathymetric_Coverage) of 5% is required for the survey area. This order of survey is only recommended where [under-keel clearance](#Under_Keel_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](#feature) on the bottom that will endanger the type of surface vessel expected to navigate the area is low.

## Order 1a

This order is intended for areas where [features](#feature) on the bottom may become a concern for the type of surface shipping expected to transit the area but where the [under-keel clearance](#Under_Keel_Clearance) is considered not to be critical. Nevertheless [features](#feature) may exist that are of concern to surface shipping. A 100% [feature search](#Feature_Search) is required in order to detect [significant features](#Significant_Feature) of a specified size. [Bathymetric coverage](#Bathymetric_Coverage) less than or equal to 100% is appropriate as long as the least depths over all [significant features](#Significant_Feature) are obtained and the bathymetry provides an adequate depiction of the nature of the bottom topography. [Under-keel clearance](#Under_Keel_Clearance) becomes less critical as depth increases, so the size of the [feature](#feature) to be detected increases with depth in areas where the water depth is greater than 40 metres.

When the surveyed depth in a traffic area is shallower than the sum of: expected vessel draft; minimum required [under-keel clearance](#Under_Keel_Clearance); [total vertical uncertainty](https://docs.google.com/document/d/10scd4DXrM6Gs4xqePiJIjK2Neos_AYSM/edit#bookmark=id.3whwml4)*;* and minimum [feature](#feature) size to be detected; the survey criteria covering bottom search, [bathymetric coverage](#Bathymetric_Coverage), and [feature detection](#Feature_Detection), must meet the specifications of Special Order to ensure safety of navigation.

## Special Order

This order is intended for those areas where [under-keel clearance](#Under_Keel_Clearance) is critical. Because [under-keel clearance](#Under_Keel_Clearance) is critical, 100% [feature search](#Feature_Search) and 100% [bathymetric coverage](#Bathymetric_Coverage) are required and the size of the [significant features](#Significant_Feature) to be detected by this search (>1 metre cube) is deliberately more demanding than for Order 1a. Examples of areas that may warrant Special Order surveys are: berthing areas, harbours, and critical areas of fairways and shipping channels.

## Exclusive Order

Exclusive Order hydrographic surveys are an extension of IHO Special Order with stricter 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 [under-keel clearance](#Under_Keel_Clearance) and bottom characteristics are potentially hazardous to vessels. This order also applies to high precision engineering surveys. All [error](#Error) sources must be minimized; hence Exclusive Order requires very accurate hydrographic systems and a rigorous control on all aspects of the survey. For this order a 200% [feature search](#Feature_Search) and a 200% [bathymetric coverage](#Bathymetric_Coverage) are required. The size of [significant features](#Significant_Feature) that must be detected is 0.5m. The challenge presented by exclusive order is establishing the appropriate survey methodology to obtain the specified uncertainties, coverage, search and object detection criteria.

**Note**: Under exceptional circumstances, for safety of navigation purposes, the use of an accurately specified mechanical sweep to certify a safe navigable depth throughout an area may be considered sufficient for Special Order and Order 1 surveys.

# HORIZONTAL AND VERTICAL POSITIONING

## Introduction

Positioning is a fundamental part for every survey operation, and it should be noted that when we in this standard discuss position and THU it is the position of the surveyed depth or feature that we refer to, and not the position of the survey platform itself.

The use of “Chart Datum” as a reference is intentionally avoided within this specification, as one survey can be used for more than one chart presentation using different vertical datums. “Chart Datum” is the finally used horizontal and vertical references for a single chart, product or presentation according to the specification for that specific product.

## Geodetic Reference Frame

Positions should be referenced to a geodetic reference frame, which can be the realisation of either a global (e.g. ITRF2014, WGS84(G1674)) or a regional (e.g. ETRS89, NAD83) reference frame. As there are frequent updates to geodetic reference frames, it is essential that the epoch is recorded for surveys with low positioning [uncertainty](#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 during the survey process.

## 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. ITRF2014, WGS84(G1674)) or a regional (e.g. ETRS89, NAD83) reference frame. Transformations between reference frames/epochs have to be taken into account, especially for surveys with low [uncertainty](#Uncertainty).

## 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.

## Chart and Land Survey Vertical Datum Connections

In order for bathymetric data to be correctly utilised, chart and land survey vertical datum connections, or relationships, must be clearly determined and described. The IHO Resolution on Datums and Bench Marks, Resolution 3/1919, as amended, resolves practices which, where applicable, shall 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](http://www.iho.int).

## Uncertainties

This standard addresses [total propagated uncertainty](https://docs.google.com/document/d/1o65obQoKihTacWbVG3UfAap8duGcvqca/edit#bookmark=id.2bn6wsx) ([TPU](#Total_Propagated_Uncertainty)) by the two components; [total horizontal uncertainty](#Total_Horizontal_Uncertainty) ([THU](#Total_Horizontal_Uncertainty)) and [total vertical uncertainty](#Total_Vertical_Uncertainty) ([TVU](#Total_Vertical_Uncertainty)).

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

The capability of the survey system should be demonstrated by an *a priori* [uncertainty](#Uncertainty) calculation ([THU](#Total_Horizontal_Uncertainty) and [TVU](#Total_Vertical_Uncertainty)). Based on knowledge of the survey system, the [THU](#Total_Horizontal_Uncertainty) and [TVU](#Total_Vertical_Uncertainty) calculations are predictive and must be calculated for the survey system as a whole, including all instrument [uncertainty](#Uncertainty) sources (including those related to installation and vessel-based reference system measurements) and environmental [uncertainty](#Uncertainty) sources such as spatial and temporal variations. The a priori 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](#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](#Metadata) should include a description of the [uncertainty](#Uncertainty) type and the [uncertainty(s)](#Uncertainty) achieved.

Within this standard it is assumed that the horizontal [uncertainty](#Uncertainty) is circularly symmetric, meaning that the [errors](#Error) in latitude and longitudal directions are equal in size. Assuming a normal distribution this allows for a single number to describe the radial distribution of [errors](#Error) about the true value.

## Confidence Level

In this standard the term [confidence level](#Confident_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](#Confident_level) (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](#Error), the 95% [confidence level](#Confident_level) for 1D quantities (e.g. depth) is defined as 1.96 x standard deviation, and the 95% [confidence level](#Confident_level) for 2D quantities (e.g. position) is defined as 2.45 x standard deviation.

# DEPTH, BOTTOM COVERAGE, FEATURES, AND NATURE OF THE BOTTOM

## Introduction

The navigation of surface vessels requires accurate knowledge of depth and [features](#feature) in order to safely exploit the maximum available water. Where under-keel clearance is an issue, bathymetric coverage must be 100%, size of feature detection must be appropriate and depth uncertainties must be tightly controlled and well understood.

The standards presented below are specific to safety of navigation surveys. 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](#_Specification_Matrix) (See [section 7.5](#_Specification_Matrix) and [Annex A](#_ANNEX_A:_SPECIFICATION)).

## Depth

### Depth Measurement

Depths are to be understood as [reduced depths](#Reduced_Depths)of both soundings and [features](#feature) within a well-defined vertical reference frame.

The main consideration is the threshold above which safe navigation can be expected. 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.

The depth of a [feature](#feature) is expressed as the minimum depth of that [feature](#feature).

### Drying Heights

In areas with larger tidal ranges where the drying zone is sometimes navigable during high tide, elevations within the drying zone also needs to be accurately 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.

### Vertical Uncertainty

Recognising that there are both depth-dependent and depth-independent [error](#Error) sources that affect the measurements of depths, the formula below is used to compute an acceptance interval for vertical measurement uncertainties. The interval of the [total vertical uncertainties](https://docs.google.com/document/d/1o65obQoKihTacWbVG3UfAap8duGcvqca/edit#bookmark=id.3whwml4) of depth measurements calculated with a 95 % [confidence level](#Confident_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 TVU:

And the acceptance interval ATVU(d) is given by:

Where:

* a: represents that portion of the [uncertainty](#Uncertainty) that does not vary with the depth
* b: is a coefficient which represents that portion of the [uncertainty](#Uncertainty) that varies with the depth.
* d: is the depth
* b x d: represents that portion of the [uncertainty](#Uncertainty) that varies with depth

[Table 1](#_TABLE_1) specifies the parameters “a” and “b” to compute the acceptance intervals ATVU(d) for the [TVU](#Total_Vertical_Uncertainty) of [reduced depths](#Reduced_Depths) to be achieved to meet each survey order.

## Bathymetric Coverage

In the context of this standard, the [bathymetric coverage](#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](#Bathymetric_Coverage) implies that depth measurements, surveyed to the positional and [feature detection](#Feature_Detection) standards specified in [Table 1](#_TABLE_1), are such that they provide a depiction of the vast majority of the bottom, and can be considered as a “full” [bathymetric coverage](#Bathymetric_Coverage). A 100% [bathymetric coverage](#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).

A [bathymetric *coverage*](#Bathymetric_Coverage) less than 100% must follow a systematic survey pattern to maximise even distribution of depth data 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](#Bathymetric_Coverage) should be increased to meet the requirements for safety of navigation in the area, or could potentially be reduced, while still fulfilling the minimum requirements according to [Table 1](#_TABLE_1).

[Table 1](#_TABLE_1) specifies the [bathymetric coverage](#Bathymetric_Coverage) to be achieved by each survey order. Due to the importance for safety of navigation, a 200% [bathymetric coverage](#Bathymetric_Coverage) is required for Exclusive Order, and a 100% [bathymetric coverage](#Bathymetric_Coverage) is required for Special Order. For Order 1a [Bathymetric coverage](#Bathymetric_Coverage) less than or equal to 100% is appropriate as long as the least depths over all [significant features](#Significant_Feature) are obtained and the bathymetry provides an adequate depiction of the nature of the bottom topography. For Order 2 and Order 1b, the requirements are relaxed to 5%.

Example: A 5% [bathymetric coverage](#Bathymetric_Coverage) with a singlebeam with an 8° beam width is almost equivalent to an inter-line spacing of 3-times water depths according to the formula (100/5)\*2\*tan (8°/2).

## Feature Search

In the context of this standard, [feature search](#Feature_Search) implies the detection of [significant *features*](#Significant_Feature). A 100% [feature search](#Feature_Search) must be capable of detecting [significant features](#Significant_Feature) specified in this standard.

For Exclusive Order, Special Order, and Order 1a, [significant feature](#Significant_Feature) detection refers to the size of [features](#feature) specified in [Table 1](#_TABLE_1) and are the minimum requirements applicable when a [full](https://docs.google.com/document/d/1o65obQoKihTacWbVG3UfAap8duGcvqca/edit#bookmark=id.1ksv4uv) [feature search](#Feature_Search) is required. The survey system, including equipment, methodologies, procedures, and personnel, must demonstrate the capability of detecting [significant features](#Significant_Feature). It is the responsibility of the hydrographic office or authority that is gathering the data to assess the capability of any proposed survey systems.

It should be noted that no survey system can guarantee detection of all [features](#feature). If there is a concern that [significant features](#Significant_Feature) 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 100% [feature search](#Feature_Search) in conjunction with at least 100% [bathymetric coverage](#Bathymetric_Coverage). Such search may be conducted with a partial [bathymetriccoverage](#Bathymetric_Coverage), in which case depth measurements will be required for any detected [significant feature](#Significant_Feature).

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

## Hazards to Navigation

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

Sufficient data must be acquired over [features](#feature) that are potential hazards to navigation (e.g. wreck or other obstructions) to fully characterise these [features](#feature) to the requirements within this standard. The least depth and position of hazards to navigation should be determined by the most appropriate method while meeting the depth [uncertainty](#Uncertainty) standard of the appropriate Order in [Table 1](#_TABLE_1). Given current ship specifications, [features](#feature) with least depths deeper than 40m 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](#feature), is not required.

## Charted Object Confirmation / Disproval

It is recommended to confirm or disprove the existence of charted objects such as rocks, wrecks, obstructions, and doubtful data, and to address the findings in the report of survey.

### Charted Object Confirmation

Charted objects should be confirmed relative to their charted position.

### Charted Object Disproval

No empirical formula for defining the search area can cover all situations. For charted [significant features](#Significant_Feature), it is recommended that the search radius should be at least 3 times the estimated position [uncertainty](#Uncertainty) of the reported hazard at the 95% [confidence level](#Confident_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 from the chart.

## 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 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 characterisation may be achieved by a combination of remote sensing (inferred), sampling, and laboratory analysis.

There are currently no IHO safety of navigation standards for bottom characterisation methods or sample frequencies, as what is appropriate varies greatly based on the nature and configuration of the bottom as well as the intended use of the area. The hydrographer must exercise judgement in determining appropriate bottom characterisation methods and bottom sample frequency to adequately characterise the area.

# WATER LEVELS AND FLOW

## Introduction

Water levels and flow information are important for planning and performing nautical operations as water levels are tightly linked to the reference level and the survey quality. Therefore, observing water levels and flows (currents) is considered an integral part of hydrographic surveys for safety of navigation.

In this chapter, water level and flow observations are intended to be used for nautical information and for supporting the vertical solution of depth measurements. Tides and other changes in water levels impact the [TVU](#Total_Vertical_Uncertainty) of depth data and therefore must be considered for any hydrographic survey regardless of the technology used to conduct the survey.

For nautical safety, water level and flow observations may not always be relevant or necessary. However, if specified in the survey requirements, observations should meet the following standards.

For requirements to clearly determine chart and land survey vertical datum connections, or relationships, see [section 2.4](#_Chart_and_Land).

## 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 observation should cover as long of a period as possible and preferably not less than 30 days.

## 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](#Total_Vertical_Uncertainty) calculations for the [uncertainty](#Uncertainty) of the values. In most circumstances, observed values are preferred over predicted.

## 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 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 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 and the period of observation preferably not less than 30 days.

The speed and direction of the water flow (tidal stream and current) should be measured at 95% [confidence level](#Confident_level) as defined in [Table 2](#_TABLE_2).

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

# SURVEYS ABOVE THE VERTICAL DATUM

## Introduction

Surveys above the vertical datum are necessary for safe and efficient navigation and mooring. Topographic surveys that are of specific importance for navigation is presented in the following sections and their corresponding allowable positioning and measurement uncertainties ([THU](#Total_Horizontal_Uncertainty) and [TVU](#Total_Vertical_Uncertainty) as applicable) are defined in [Table 2](#_TABLE_2).

Additional information such as drawings or photographs of these [features](#feature) should be captured where possible to support the measurement.

For Chart and Land Survey Vertical Datum Connection requirements see [section 2.4](#_Chart_and_Land).

## Fixed Aids and Features Significant to Navigation

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

Topographic [features](#feature) significant to navigation are [features](#feature) which are essential for mooring, docking, and manoeuvring in confined spaces and / or provide some aid in navigation without being a dedicated aid to navigation. Essential harbour, mooring, and docking [features](#feature) include, but are not limited to: groins, moles, wharfs (quays), piers (jetties), mooring dolphins, piles, bollards, slipways, docks, lock gates, and breakwaters.

Allowable [THU](#Total_Horizontal_Uncertainty) and [TVU](#Total_Vertical_Uncertainty) for the positioning of these fixed aids and [features](#feature) significant to navigation are presented in [Table 2](#_TABLE_2).

One may consider drying [features](#feature) (including rocks) which are positioned by topographic means to be topographic [features](#feature) significant to navigation. However, regardless of the means of positioning, maximum allowable uncertainties for drying [features](#feature) shall not exceed those specified for the submerged area outside of the drying zone (see [section 3.2.2](#_Water_Level_(Tidal)) and [Table 1](#_TABLE_1)).

## Floating Objects and Aids to Navigation

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

For floating objects, the surveyed position [uncertainty](#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 reporting the mean position of these objects. The environmental conditions experienced during positioning must also be considered.

Allowable [THU](#Total_Horizontal_Uncertainty) for the positioning of these objects are presented in [Table 2](#_TABLE_2). Allowable [TVU](#Total_Vertical_Uncertainty) is not applicable to these measurements.

## 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. Allowable [THU](#Total_Horizontal_Uncertainty) for the positioning of these objects are presented in [Table 2](#_TABLE_2). Allowable [TVU](#Total_Vertical_Uncertainty) is not applicable to these measurements.

## Features Less Significant to Navigation

[Features](#feature) less significant to navigation are those non-conspicuous [features](#feature) which provide context and additional information, but likely do not aid in navigation. Topographic [features](#feature) 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](#Total_Horizontal_Uncertainty) and [TVU](#Total_Vertical_Uncertainty) for the positioning of these objects are presented in [Table 2](#_TABLE_2).

## 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](#Total_Horizontal_Uncertainty) and [TVU](#Total_Vertical_Uncertainty) for the positioning of overhead clearances (including associated horizontal clearances), range line and sector light heights are presented in [Table 2](#_TABLE_2).

## 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](#Total_Horizontal_Uncertainty) for the measurement of these angles is presented in [Table 2](#_TABLE_2). Allowable [TVU](#Total_Vertical_Uncertainty) is not applicable to these measurements.

# METADATA

[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](#Metadata) that is to be provided with hydrographic surveys conducted for safety of navigation. Where additional [metadata](#Metadata) is available this should be included to enhance the value of the survey data for other uses.

[Metadata](#Metadata) can be provided in any format such as in the Report of Survey or embedded within a specific [metadata](#Metadata) file. The chosen format should support discovery, clarity of understanding, and software compatibility. Each hydrographic office or authority may adopt [metadata](#Metadata) requirements beyond that specified here and should develop and document a list of additional [metadata](#Metadata) used for their survey data. The table below should be seen as a schema, and not a final data model.

[Metadata](#Metadata) should be comprehensive, but should include, as a minimum, information on:

|  |  |
| --- | --- |
| **Category or Group** | **Description** |
| Survey Type | E.g. reconnaissance/sketch, controlled, examination, passage |
| 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 |
| 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 is used |
| Uncertainties achieved (at 95% [Confidence Level](#Confident_level)) | For both horizontal and vertical components: [Total Horizontal Uncertainty](#Total_Horizontal_Uncertainty) ([THU](#Total_Horizontal_Uncertainty)) and [Total Vertical Uncertainty](#Total_Vertical_Uncertainty) ([TVU](#Total_Vertical_Uncertainty)) |
| Minimum size of [features](#feature) detected | In metres |
| [Feature search](#Feature_Search) coverage achieved | in percentage |
| [Bathymetric coverage](#Bathymetric_Coverage) achieved | In percentage |
| Survey date range | Survey’s start and end dates |
| Survey undertaken By | Surveyor, survey company, survey authority |
| Data ownership | E.g. funding body, government |
| Grid attributes | Where a grid is the deliverable (i.e.: resolution, method, underlying data density, [uncertainty surface](#Uncertainty_Surface)) |
| 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, or restricted |

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

# TABLES AND SPECIFICATION MATRIX

## Introduction

Previous editions of this document specified hydrographic survey standards for safety of navigation surveys predominantly in table format (Former edition, [Table 1](#_TABLE_1)). However, this format was rigid and did not accommodate hydrographic surveys conducted for purposes other than safety of navigation.

This edition of S-44 still presents safety of navigation survey specifications in table format (now [Table 1](#_TABLE_1)and [Table 2](#_TABLE_2)), but also provides a new Specification [Matrix](#_Specification_Matrix) for added flexibility. The new [Matrix](#_Specification_Matrix) allows for common customisation 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.

## Safety of Navigation Standards

Minimum bathymetry standards are defined in [Table 1](#_TABLE_1). Other minimum standards for positioning and tidal currents are defined in [Table 2](#_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](#_TABLE_1) and [Table 2](#_TABLE_2) are included in the specification [Matrix](#_Specification_Matrix) within ranges of specification values which are available to enhance and customise safety of navigation surveys. Although the [Matrix](#_Specification_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](#_Specification_Matrix).

### Bathymetry Standards

[Table 1](#_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](#_TABLE_1)) may be assessed independently of order achieved for other positioning data ([Table 2](#_TABLE_2)), so as not to unnecessarily degrade the representation of quality of bathymetry in nautical charts and products. [Table 1](#_TABLE_1) follows.

### Other Positioning Standards, Tidal Stream and Currents

[Table 2](#_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](#_TABLE_2) follows.

## 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, m = meters, all [uncertainties](#Uncertainty) at 95% confidence level, \* = Matrix Reference.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Reference** | **Criteria** | **2** | **1b** | **1a** | **Special** | **Exclusive** |
| [Chapter 1](#_CLASSIFICATION_OF_SAFETY)  [Note 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 considered not to be critical but features of concern to surface shipping may exist. | Areas where under-keel clearance is critical | Areas where there is strict minimum under-keel-clearance and maneuverability criteria such as shallow harbors, berthing areas, critical channels, engineering surveys, underwater structures and other like features |
| [Section 2.3](#_Horizontal_Reference_System) | **Depth** [**THU**](#Total_Horizontal_Uncertainty)  Constant [m]  +  Variable [% 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  +  0%  \*Ba9 | 1 m  +  0%  \*Ba10 |
| [Section 3.2](#_Depth)  Section 3.2.3 | **Depth** [**TVU**](#Total_Vertical_Uncertainty)  Constant (a) [m]  Variable (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  b = 0.0075  \*Bc12, Bd8 |
| [Section 3.3](#_Bathymetric_Coverage)  [Notes 2](#Note_2) | [**Bathymetric Coverage**](#Bathymetric_Coverage)  Depths produced / derived [%] | 5%  \*Bf3 | 5%  \*Bf3 | ≤ 100%  \*≤ Bf9 | 100%  \*Bf9 | 200%  \*Bf12 |
| [Section 3.4](#_Feature_Search)  [Notes 3](#Note_3) | [**Feature Search**](#Feature_Search)  Depths may not be produced / derived [%] | Recommended but Not Required | Recommended but Not Required | 100%  \*Be9 | 100%  \*Be9 | 200%  \*Be12 |
| [Section 3.3](#_heading=h.44sinio)  [Note 4](#Note_4) | [**Feature Detection**](#Feature_Detection)  Constant [m]  +  Variable [% of Depth] | Not Required | Not Required | Cubic features > 2 m, in depths down to 40 m; 10% of depth beyond 40 m  \*Bg5, Bh3 beyond 40m | Cubic features > 1 m  +  0%  \*Bg6 | Cubic features > 0.5 m  +  0%  \*Bg9 |

**Detailed Table Notes:**

**Note 1**: Order achieved for bathymetry data ([Table 1](#_TABLE_1)) and other positioning data ([Table 2](#_TABLE_2) can be assessed independently so as not to unnecessarily degrade the quality of bathymetry of nautical charts and products.

**Note 2**: [Bathymetric Coverage](#Bathymetric_Coverage) methods must result in depth data, fulfilling the respective order, suitable for use in safety of navigation products. [Bathymetric Coverage](#Bathymetric_Coverage) specified at less than 100% must follow a systematic survey plan to maximise even distribution of depth data across the survey area. Additionally, the nature of the bottom, the accompanying [Feature search](#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](#Bathymetric_Coverage) should be reduced or increased to meet the requirements of safe navigation in the area.

**Note 3**: [Feature search](#Feature_Search) methods may or may not result in depth data suitable for use in safety of navigation products.

**Note 4**: A cubic [feature](#feature) means a regular cube each side of which has the same length. It should be noted that the IHO Exclusive Order, Special Order, and Order 1a [feature detection](#Feature_Detection)requirements of 0.5, 1, and 2 metre cubes respectively, are minimum requirements. In certain circumstances, it may be deemed necessary by the hydrographic offices or authorities to detect smaller [features](#feature) to minimise the risk of undetected hazards to surface navigation, especially when under keel clearance becomes very small. For Order 1a, the relaxing of [feature detection](#Feature_Detection) criteria at 40 metres reflects the maximum expected draught of vessels.

## TABLE 2

Other Minimum Standards for Safety of Navigation Surveys. To be read in conjunction with the full text set out in this document, see [section 3.7](#_Nature_of_the) for information and recommendations related to bottom sampling and characterisation, all [uncertainties](#Uncertainty) at 95% confidence level, \* = Matrix Reference.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** | **Criteria** |  | **2** | **1b** | **1a** | **Special** | **Exclusive** |
| [Chapter 5](#_SURVEYS_ABOVE_THE)  [Note 5](#Note_5) | **Fixed Objects, Aids, Features Above the Vertical Reference Significant to Navigation** | [THU](#Total_Horizontal_Uncertainty) [m] | 5  \*Pa4 | 2  \*Pa6 | 2  \*Pa6 | 2  \*Pa6 | 1  \*Pa7 |
| [TVU](#Total_Vertical_Uncertainty) [m] | 2  \*Pb2 | 2  \*Pb2 | 1  \*Pb3 | 0.5  \*Pb4 | 0.25  \*Pb5 |
| [Chapter 5](#_SURVEYS_ABOVE_THE)  [Note 5](#Note_5) | **Floating Aids and Objects** | [THU](#Total_Horizontal_Uncertainty) [m] | 20  \*Pc2 | 10  \*Pc3 | 10  \*Pc3 | 10  \*Pc3 | 5  \*Pc4 |
| [Chapter 5](#_SURVEYS_ABOVE_THE)  [Note 5](#Note_5) | **Coastline**  (high, low, MWL water lines, etc) | [THU](#Total_Horizontal_Uncertainty) [m] | 10  \*Pd2 | 10  \*Pd2 | 10  \*Pd2 | 10  \*Pd2 | 5  \*Pd3 |
| [Chapter 5](#_SURVEYS_ABOVE_THE)  [Note 5](#Note_5) | **Features Above the Vertical Reference Less Significant to Navigation** | [THU](#Total_Horizontal_Uncertainty) [m] | 20  \*Pe1 | 20  \*Pe1 | 20  \*Pe1 | 10  \*Pe2 | 5  \*Pe3 |
| [TVU](#Total_Vertical_Uncertainty) [m] | 3  \*Pf1 | 2  \*Pf2 | 1  \*Pf3 | 0.5  \*Pf4 | 0.3  \*Pf5 |
| [Chapter 5](#_SURVEYS_ABOVE_THE)  [Note 5](#Note_5) | **Overhead Clearances and Range Line, Sector Light Heights** | [THU](#Total_Horizontal_Uncertainty) [m] | 10  \*Pg1 | 10  \*Pg1 | 5  \*Pg2 | 2  \*Pg3 | 1  \*Pg4 |
| [TVU](#Total_Vertical_Uncertainty) [m] | 3  \*Ph1 | 2  \*Ph2 | 1  \*Ph3 | 0.5  \*Ph4 | 0.3  \*Ph5 |
| [Chapter 5](#_SURVEYS_ABOVE_THE)  [Note 5](#Note_5) | **Angular Measurements** | [degrees] | 0.5  \*Pi4 | | | | |
| [Chapter 4](#_WATER_LEVELS_AND)  [Note 6](#Note_6) | **Water Flow Direction** | [degrees] | 10  \*Wa1 | | | | |
| [Chapter 4](#_WATER_LEVELS_AND)  [Note 6](#Note_6) | **Water Flow Speed** | [knots] | 0.1  \*Wb5 | | | | |

**Detailed Table Notes:**

**Note 5**: Standards for [Table 2](#_TABLE_2) data types only apply where such measurements are required for the survey.

**Note 6**: See Chapter 4 for information and recommendations related to tides, tidal stream and current observations.

## Specification Matrix

The Specification [Matrix](#_Specification_Matrix) provides a range of selectable criteria for bathymetric parameters and 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 versions.

It is important to note that the [Matrix](#_Specification_Matrix) alone does not define any standards for hydrographic survey. Safety of navigation survey standards (as defined in [Table 1](#_TABLE_1) and [Table 2](#_TABLE_2)) are referenced to the [Matrix](#_Specification_Matrix) criteria and the [Matrix](#_Specification_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](#_Specification_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](#_Specification_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](#_heading=h.vx12271) for guidance and additional information on how to use the Specification [Matrix](#_Specification_Matrix).

## SPECIFICATION MATRIX

Specification [Matrix](#_Specification_Matrix) for Hydrographic Surveys. To be read in conjunction with the full text set out in this document, m = metres, all [uncertainties](#Uncertainty) at 95% confidence level.

|  | **Criteria** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **B** | **BATHYMETRY** | | | | | | | | | | | | | | |
| **a** | **Depth** [THU](#Total_Horizontal_Uncertainty) (constant) [m] | 500 | 200 | 100 | 50 | 20 | 15 | 10 | 5 | 2 | 1 | 0.5 | 0.4 | 0.1 | 0.05 |
| **b** | **Depth** [THU](#Total_Horizontal_Uncertainty) (variable) [% of depth] | 20 | 10 | 5 | 2 | 1 | 0.5 | 0.25 | 0.1 |  |  |  |  |  |  |
| **c** | **Depth** [TVU](#Total_Vertical_Uncertainty) (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](#Total_Vertical_Uncertainty) (variable, "b") | 0.20 | 0.10 | 0.05 | 0.023 | 0.02 | 0.013 | 0.01 | 0.0075 | 0.004 |  |  |  |  |  |
| **e** | **Feature Search** Depths may not be produced / derived [%] | 1 | 3 | 5 | 10 | 20 | 30 | 50 | 75 | 100 | 120 | 150 | 200 | 300 |  |
| **f** | **Bathymetric Coverage** Depths produced / derived [%] | 1 | 3 | 5 | 10 | 20 | 30 | 50 | 75 | 100 | 120 | 150 | 200 | 300 |  |
| **g** | **Feature Detection Ability** (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** (variable)  [% of Depth] | 25 | 20 | 10 | 5 | 3 | 2 | 1 | 0.5 | 0.25 |  |  |  |  |  |

|  | **Criteria** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **P** | **OTHER POSITIONING ABOVE THE VERTICAL REFERENCE** | | | | | | | | | | | | | | |
| **a** | **Fixed Aids, Features Significant to Navigation** [THU](#Total_Horizontal_Uncertainty) [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](#Total_Vertical_Uncertainty) [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 |  |  |  |  |  |  |  |  |  |
| **d** | **Coastline** [THU](#Total_Horizontal_Uncertainty)  (high, low, MSL water lines, etc.) [m] | 20 | 10 | 5 | 1 |  |  |  |  |  |  |  |  |  |  |
| **e** | **Features Less Significant to Navigation** [THU](#Total_Horizontal_Uncertainty) [m] | 20 | 10 | 5 | 1 | 0.5 |  |  |  |  |  |  |  |  |  |
| **f** | **Features Less Significant to Navigation** [TVU](#Total_Vertical_Uncertainty) [m] | 3 | 2 | 1 | 0.5 | 0.3 |  |  |  |  |  |  |  |  |  |
| **g** | **Overhead Clearance and Range line, Sector Light Heights** [THU](#Total_Horizontal_Uncertainty) [m] | 10 | 5 | 2 | 1 | 0.5 | 0.2 | 0.1 |  |  |  |  |  |  |  |
| **h** | **Overhead Clearance and Range line, Sector Light Heights** [TVU](#Total_Vertical_Uncertainty) [m] | 3 | 2 | 1 | 0.5 | 0.3 | 0.1 |  |  |  |  |  |  |  |  |
| **i** | **Angular Measurements** [degrees] | 5 | 2.5 | 1 | 0.5 | 0.2 | 0.1 |  |  |  |  |  |  |  |  |

|  | **Criteria** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***W*** | ***WATER LEVELS AND FLOW*** | | | | | | | | | | | | | | |
| **a** | **Flow Direction** [degrees] | 10 | 7.5 | 5 | 2.5 | 1 | 0.5 | 0.25 | 0.1 |  |  |  |  |  |  |
| **b** | **Flow Speed** [knots] | 2 | 1 | 0.5 | 0.25 | 0.1 |  |  |  |  |  |  |  |  |  |

|  | **Criteria** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***N*** | ***NATURE OF THE BOTTOM*** | | | | | | | | | | | | | | |
| **a** | **Bottom Characterisation Method**  [Note 7](#Note_7) | 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**  [Note 7](#Note_7) | As Req to GT |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Note 7**: VIS = visual, PHY = Physical Analysis, INF = Inferred, GT = Ground Truth, w/ = With

# ANNEX A SPECIFICATION MATRIX AND GUIDANCE

## Introduction

The Specification [Matrix](#_Specification_Matrix), as presented in [section 7.5](#_Specification_Matrix), includes a range of selectable criteria for hydrographic Survey Parameters / Data Types. It is organised by the classes of data presented in the IHO Hydrographic Dictionary, S-32, definition of a hydrographic survey:

* **Bathymetry**: DEPTH of Water,
* **Other Positioning**: location of topographic [features](#feature) and fixed objects from survey and navigation purposes,
* **Water Levels and Flow**: Directions and Force of CURRENTS,
* **Nature of the Bottom**: Configuration of NATURE OF THE BOTTOM.

The [Matrix](#_Specification_Matrix) alone does not define any standards, but does incorporate the safety of navigation survey standards as defined in [Table 1](#_TABLE_1) and [Table 2](#_TABLE_2) along with a wider range of selectable criteria.

The [Matrix](#_Specification_Matrix) is intended to be used as a common framework to communicate hydrographic survey specifications for:

* Safety of navigation surveys (as presented in [Table 1](#_TABLE_1) and [Table 2](#_TABLE_2)),
* Enhanced or customised safety of navigation surveys (possibly based on [Table 1](#_TABLE_1) and [Table 2](#_TABLE_2) survey standards),
* Surveys conducted for purposes other than safety of navigation.

This is accomplished by using a series of alphanumeric codes to reference cells in the [Matrix](#_Specification_Matrix) that contain the criteria for the required data types.

Specifications derived from the [Matrix](#_Specification_Matrix) are expressed by criteria (e.g. Depth [TVU](#Total_Vertical_Uncertainty)) and their required values (e.g. >2, 2, 1, 0.5, etc.). A criteria requires three characters to reference a cell address:

1. The first character is a capital letter denoting the class of data:
   * **B**athymetry (**B**)
   * Other **P**ositions (**P**)
   * **W**ater Levels and Flows (**W**)
   * **N**ature of the Bottom (**N**)
2. The second character is a lower case letter referencing the intended criteria by row, e.g.:

* **B**athymetry (**B**)

**a** = Depth [THU](#Total_Horizontal_Uncertainty) (constant) [m]

**d** = Depth [TVU](#Total_Vertical_Uncertainty) (variable, "b")

* Other **P**ositions (**P**)

**a** = Fixed Aids, [Features](#feature) Significant to Navigation [THU](#Total_Horizontal_Uncertainty) [m]

**g** = Overhead Clearance and Range line, Sector Light Heights [THU](#Total_Horizontal_Uncertainty) [m]

1. The third character is a number referencing the intended criteria value by column, e.g.:

* **B**athymetry (**B**)

**Ba** column **1** (Ba1) = “500” for Depth [THU](#Total_Horizontal_Uncertainty) (constant) [m]

**Bd** column **6** (Bd6) = “0.013” for Depth [TVU](#Total_Vertical_Uncertainty) (variable, "b")

* Other **P**ositions (**P**)

**Pa** column **5** (Pa5) = “3” for Fixed Aids, [features](#feature) Significant to Navigation [THU](#Total_Horizontal_Uncertainty) [m]

**Ph** column **2** (Ph2) = “2” for Overhead Clearance and Range line, Sector Light Heights [THU](#Total_Horizontal_Uncertainty) [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 criteria and that “0” should be used in required formulas.

Examples:

* If [THU](#Total_Horizontal_Uncertainty) has to be compliant with 5% of water depth, then “Depth [THU](#Total_Horizontal_Uncertainty) (variable) [% of Depth]” should be equal to 5% (Bb3), and “Depth [THU](#Total_Horizontal_Uncertainty) (constant) [m]” is not specified. This indicated that a Depth [THU](#Total_Horizontal_Uncertainty) (constant) of 0 is added to the Depth [THU](#Total_Horizontal_Uncertainty) (variable) [% of Depth] of 5% to determine Total allowable [THU](#Total_Horizontal_Uncertainty).
* If [TVU](#Total_Vertical_Uncertainty) has to be compliant with 0.30 m, then “Depth [TVU](#Total_Vertical_Uncertainty) (constant) [m]” should be equal to 0.3 (Bc9), and “Depth [TVU](#Total_Vertical_Uncertainty) (variable, "b") is not specified, and so is equal to 0 in the formula of the acceptance interval ATVU(d):

## Examples of Matrix Realisations:

[Matrix](#_Specification_Matrix) realisations may be communicated in a variety of ways including: tables, text strings, and shaded matrices.

A.2.1 Table Examples

The following table presents three examples of “Matrix Realisations”: Special Order Surveys, Order 1a Surveys, and a Customised Specification based on Order 1a surveys. This table includes the values associated with a [Matrix](#_Specification_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 based on Order 1a surveys.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **B** | **BATHYMETRY** | **Special Order  Value** | **Matrix Cell Ref.** |  | **Order 1a Value** | **Matrix Cell Ref.** |  | **Custom**  **(Based on 1a)** | **Matrix Cell Ref.** |
| **a** | **Depth** THU (constant) [m] | 2 | Ba9 |  | 5 | Ba8 |  | 5 | Ba8 |
| **b** | **Depth** THU (variable) [% of depth] | --- | --- |  | 5 | Bb3 |  | 5 | Bb3 |
| **c** | **Depth** TVU (constant, "a") [m] | 0.25 | Bc10 |  | 0.5 | Bc8 |  | --- | --- |
| **d** | **Depth** TVU (variable, "b") | 0.0075 | Bd8 |  | 0.013 | Bd6 |  | 0.010 | Bd7 |
| **e** | **Feature Search** Depths may not be produced / derived [%] | 100 | Be9 |  | 100 | Be9 |  | 100 | Be9 |
| **f** | **Bathymetric Coverage** Depths produced / derived [%] | 100 | Bf9 |  | 100 | Bf9 |  | 100 | Bf9 |
| **g** | **Feature Detection Ability**(constant) [m] | 1 | Bg6 |  | 2 (≤40m) | Bg5 (≤40m) |  | --- | --- |
| **h** | **Feature Detection Ability**(variable) [% of Depth] | --- | --- |  | 10 (>40m) | Bh3 (>40m) |  | 10 | Bh3 |
| **P** | **OTHER POSITIONING** |  |  |  |  |  |  |  |  |
| **a** | **Fixed Aids, Features Significant to Navigation** THU [m] | 2 | Pa6 |  | 2 | Pa6 |  | 2 | Pa6 |
| **b** | **Fixed Aids, Features Significant to Navigation** TVU [m] | 0.5 | Pb4 |  | 1 | Pb3 |  | 1 | Pb3 |
| **c** | **Floating Aids and Objects** THU [m] | 10 | Pc3 |  | 10 | Pc3 |  | 10 | Pc3 |
| **d** | **Coastline** THU (high, low, MSL water lines, etc.) [m] | 10 | Pd2 |  | 10 | Pd2 |  | 10 | Pd2 |
| **e** | **Topographic Features Less Significant to Navigation** THU [m] | 10 | Pe2 |  | 20 | Pe1 |  | 5 | Pe3 |
| **f** | **Topographic Features Less Significant to Navigation** TVU [m] | 0.5 | Pf4 |  | 1 | Pf3 |  | 1 | Pf3 |
| **g** | **Overhead Clearance and Range line, Sector Light Heights** THU [m] | 2 | Pg3 |  | 5 | Pg2 |  | 5 | Pg2 |
| **h** | **Overhead Clearance and Range line, Sector Light Heights** TVU [m] | 0.5 | Ph4 |  | 1 | Ph3 |  | 1 | Ph3 |
| **i** | **Angular Measurements** [degrees] | 0.5 | Pi4 |  | 0.5 | Pi4 |  | 0.5 | Pi4 |
| **T** | **Water Levels and Flow** |  |  |  |  |  |  |  |  |
| **a** | **Flow Direction** [degrees] | 10 | Ta1 |  | 10 | Ta1 |  | 5 | Ta3 |
| **b** | **Flow Speed** Uncertainty [knots] | 0.1 | Tb5 |  | 0.1 | Tb5 |  | 0.1 | Tb5 |
| **N** | **NATURE OF THE BOTTOM** |  |  |  |  |  |  |  |  |
| **a** | **Bottom Characterisation Method** | --- | --- |  | --- | --- |  | --- | --- |
| **b** | **Bottom Sampling Frequency** | --- | --- |  | --- | --- |  | --- | --- |

A.2.2 Text String Examples

The following text strings present the same three examples of “Matrix Realisations”: Special Order Surveys, Order 1a Surveys, and a Customised Specification based on Order 1a surveys.

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

Special Order Matrix text string:

Ba9, Bc10, Bd8, Be9, Bf9, Bg6, Pa6, Pb4, Pc3, Pd2, Pe2, Pf4, Pg3, Ph4, Pi4, Wa1, Wb5.

Order 1a Matrix text string:

Ba8, Bb3, Bc8, Bd6, Be9, Bf9, Bg5 (≤40m), Bh3 (>40m), Pa6, Pb3, Pc3, Pd2, Pe1, Pf3, Pg2, Ph3, Pi4, Wa1, Wb5.

Customised Matrix text string (based on Order 1a):

Ba8, Bb3, Bd7, Be9, Bf9, Bh3, Pa6, Pb3, Pc3, Pd2, Pe1, Pf3, Pg2, Ph3, Pi4, Wa1, Wb5.

# ANNEX B GUIDELINES FOR QUALITY MANAGEMENT

**Note**: it should be noted that the information contained in annexes [B](#_ANNEX_B:_GUIDELINES), [C](#_ANNEX_C:_GUIDANCE), and [D](#_ANNEX_D:_GRIDDED) provide some guidance on [quality control](#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](#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](#Quality_Control) of the hydrographic products. [Quality control](#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 uncertainties. First, the total propagated uncertainties of all equipment and corrections used to derive the reported surveyed value must be included. In this [total propagated uncertainty](https://docs.google.com/document/d/1o65obQoKihTacWbVG3UfAap8duGcvqca/edit#bookmark=id.1ci93xb) 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](https://docs.google.com/document/d/1o65obQoKihTacWbVG3UfAap8duGcvqca/edit#bookmark=id.1ci93xb) in a certain environment, it can be determined if the instrumental setup is sufficient for the required quality.

Second, the equipment in use must be free of ([systematic](#Systematic_Error)) [errors](#Error) 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](#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](#Error). By describing the total of procedures, it is possible to incorporate checks and tests on [errors](#Error) that occur in an early stage of the process. This is important for [errors](#Error) 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**: it should be noted that the information contained in annexes [B](#_ANNEX_B:_GUIDELINES), [C](#_ANNEX_C:_GUIDANCE), and [D](#_ANNEX_D:_GRIDDED) provide some guidance on [quality control](#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 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](#Uncertainty) may differ greatly for each survey technique used.

## C.1 A Priori Uncertainty

The a priori [uncertainty](https://docs.google.com/document/d/1o65obQoKihTacWbVG3UfAap8duGcvqca/edit#bookmark=id.2bn6wsx) 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](#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](#Uncertainty) is improved.

## C.2 A Posteriori Uncertainty

Fundamentally the hydrographer is most interested in the a posteriori [uncertainty](#Uncertainty).

Outside of a reference area it is not possible to determine the a posteriori [uncertainty](#Uncertainty) from the data set. The data set is the end result and contains all [errors](#Error) involved in the total process but it is not possible to calculate the a posteriori [uncertainty](#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](#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](#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**: it should be noted that the information contained in annexes [B](#_ANNEX_B:_GUIDELINES), [C](#_ANNEX_C:_GUIDANCE), and [D](#_ANNEX_D:_GRIDDED) provide some guidance on [quality control](#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](https://www.gebco.net/about_us/faq/%23creating_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](#Bathymetric_Model). 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](#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](#Bathymetric_Model) 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](#Bathymetric_Model) 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)

**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](#Bathymetric_Model) 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](#Bathymetric_Model). 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](#feature) of set dimensions and the resultant gridded [bathymetric model](#Bathymetric_Model) is to represent the results of the survey, accurate [feature](#feature) representation within the grid will require a grid cell size no greater than the size of the [feature](#feature) the gridded [bathymetric model](#Bathymetric_Model) is required to depict.

The grid resolution should also be chosen to consider the achieved horizontal [uncertainty](#Uncertainty) of the input samples and the method for which this [uncertainty](#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 that allows for an accurate depiction of significant bottom [features](#feature) 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](#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](#Bathymetric_Model) 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](#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](https://docs.google.com/document/d/1o65obQoKihTacWbVG3UfAap8duGcvqca/edit#bookmark=id.2bn6wsx)-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](#Total_Vertical_Uncertainty) ([TVU](#Total_Vertical_Uncertainty)) 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](#feature) selection and nodal override methods should accompany the gridded [bathymetric model](#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](#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](#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](#Uncertainty) associated with the elevation value contained within gridded [bathymetric models](#Bathymetric_Model) 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](#Uncertainty)).

**Product Uncertainty** is a blend of Standard Deviation Estimator [uncertainty](#Uncertainty) and other measures which may include Raw Standard Deviation, and the average vertical [uncertainty](#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](#Uncertainty) types may be specified. Methods for [uncertainty](#Uncertainty) estimation should be documented within the accompanying grid [metadata](#Metadata).

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

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

## D.6 Applicability

Gridded [bathymetric models](#Bathymetric_Model) 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](#Bathymetric_Model) can provide valuable information regarding underway bottom sample density and identification of significant bottom [features](#feature). These models can be leveraged to assess where full [feature search](#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](#Bathymetric_Model) can serve as a comparison tool to examine depth data consistency within a survey and the presence of random and systematic data set [errors](#bookmark=id.2iq8gzs). 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](#Uncertainty) is another common method used in determining whether a survey data set complies with required [uncertainty](#Uncertainty) thresholds as well.

### D.6.3 Survey Data Deliverable

As mentioned throughout this annex, gridded [bathymetric models](#Bathymetric_Model) in the presence of survey logs, reports and other [metadata](#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](#Bathymetric_Model) are fit for purposes that include and extend beyond safety of navigation, an appropriate level of [metadata](#Metadata) describing the data set is required. IHO S-102, the Bathymetric Surface Product Specification, provides [Metadata](#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](#Metadata) for gridded [bathymetric models](#Bathymetric_Model) will include information describing the data set, depth [correction](#Correction) type, [uncertainty](#Uncertainty) type, grid reference and coordinate system information, as well as temporal descriptions, grid construction methods, and persons responsible for product generation.