Appendix D.8

Canadian Hydrographic Service Standards for Hydrographic Surveys

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Canadian Hydrographic Service

STANDARDS FOR HYDROGRAPHIC SURVEYS

PREFACE

These standards are based on the latest edition of IHO Special Publication No. 44 (S-44),and on the previous standards versions of the Canadian Hydrographic Service (CHS).

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

The principal aim of these standards is to specify requirements for hydrographic surveys in order that hydrographic data collected according to these standards is sufficiently accurate. An additional aim of the standard is to ensure that the spatial uncertainty of data is adequately quantified.

Previous versions of CHS Survey Standing Order (SSO) concentrated primarily on specifying accuracies for hydrographic surveys for the compilation of nautical charts. These standards do not include procedures that are included in other related documents. These standards must be used in conjunction with the Hydrographic Survey Management Guidelines, the ISO quality system process documentation, and the data coding guides. These standards will help Hydrographers and contractors to meet CHS survey precision and quality requirements.

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List of major changes

N.	Date	Section	Description
1	2010-03-25	2.4	A paragraph has been added to give more precision on the order to use when positioning navigational aids and other features.
2	2012-02-01	1	Revision of the Table 1. Change the order number and description to correspond with IHO S44, 5th edition. All references to these orders in the document have been replaced.
3	2012-02-01	2.1	In 4th paragraph, a clarification on the use of horizontal datum is added.
4	2012-02-01	2.2	Reference to the *“CHS GPS Survey Standing Orders”* document has been removed.
5	2012-02-01	2.3	In 3rd paragraph, the exception on the accuracy of the position of the sounding has been removed.
6	2012-02-01	2.4	Revision of the Table 2. Change the order number to correspond with IHO S44, 5th edition.
7	2012-02-01	3.1	Change the vertical sounding datum to LLWLT.
8	2012-02-01	3.2	Change the vertical elevation datum to HHWLT.
9	2012-02-01	4.2.1	In the 1st paragraph, 3rd sentence, add the following clarification: “with respect to the motion reference unit”.
10	2012-02-01	4.3.1	The end of the last sentence has been changed from “the sound speed data ***needs to*** be considered“ to “the sound speed data ***must*** be considered”.
11	2012-02-01	4.3.3.1	The entire paragraph has been reformulated to make the use of surface sound speed sensors mandatory for all type of transducers.
12	2012-02-01	6.1	Adding a reference to “*CUBE Bathymetric data Processing and Analysis (CHS February 2012)*”.
13	2012-02-01	8.3	Replace “Total Propagated Errors (TPE)” by “Total Propagated Uncertainty (TPU)”.
14	2013-04-04	4.4	All section has been modified to include MBES systems.
15	2019-11-22	5.6	New sub-section for acoustic backscatter added.
16	2021-02-02	1.0	Amended spelling mistakes, removed reference to specific S-44 Edition
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INTRODUCTION

Hydrographic surveying is undergoing fundamental changes in measurement technology. The advent of satellite positioning systems, multibeam and multitransducer acoustic systems and sophisticated data processing systems have drastically changed the way hydrographic surveys are conducted. With these advanced technologies, the Canadian Hydrographic Service and contractors can now collect data with higher precision and quality. It is therefore necessary to update the standards taking into account these technological advancements.

The required positioning accuracy in previous versions of SSO was largely based on the practical limitations of draftsmanship at a given scale. Automated data management allows data to be presented at any scale. Therefore, the accuracy requirements for positions in this standard are a function of the errors contributed by positioning and sounding systems to some degree, but is mostly based on the perceived accuracy requirements of the user.

These standards are based on those of the IHO. The CHS adopted the conclusions of the S44 working group of this organization on the evaluation of the measurement equipment technologies stating that it is likely that many hydrographic surveys will continue to be conducted with single beam echo sounders that only sample discrete profiles of the seafloor, with the 100% seafloor search only being employed in critical areas. This assumption led to the decision to retain the concept of line spacing even though it is no longer directly related to survey scale.

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

Equipment and procedures used to achieve the standards laid down in this document are left to the Survey Management Guideline and the quality system procedures.

1 CLASSIFICATION OF BATHYMETRY

To accommodate different accuracy requirements for areas to be surveyed and to classify old surveys, six orders of survey are defined. These are described below and in Table 1 and summarize the overall accuracy requirements.

Unlike IHO S44, the 100% bottom search is not compulsory. In the CHS, it is strongly recommended to obtain 100% bottom search in critical areas, but in certain circumstances (client need, costs, time, etc.), it may not be achievable.

One other major difference with the IHO S44 is the way CHS classify surveys. The classification is divided into four components: the horizontal accuracy, the vertical accuracy, the target detection capability and the type of coverage. For instance, a survey can attain an horizontal accuracy of Special Order, a vertical accuracy and a feature detection of Order 1a and the type of coverage could be 1a (complete coverage).

TABLE 1
Standards for Hydrographic Surveys

	ORDER	Exclusive	Special	1a	1b	2	3 (Imprecise)
	Examples of Typical Areas	Shallow water in Harbours, berthing areas, and associated critical channels with minimum under-keel clearances or engineering surveys	Harbours, berthing areas, and associated critical channels with minimum under-keel clearances	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.	All areas where the accuracies do not meet the requirements of the previous orders
H	**Horizontal Accuracy (95% Confidence Level)**	1m	2m	5m + 5% of depth	5m + 5% of depth	20m + 10% of depth	> 20m + 10% of depth
V	**Depth Accuracy for Reduced Depths (95% Confidence Level)** [1]	*a* = 0.15m *b* = 0.0075	*a* = 0.25m *b* = 0.0075	*a* = 0.5m *b* = 0.013	*a* = 0.5m *b* = 0.013	*a* = 1.0m *b* = 0.023	Same as order 2
D	**System Detection Capability**	Features > 0.5m cubed	Features > 1m cubed	Features > 2m cubed in depths up to 40 m; 10% of depth beyond 40m [3]	N/A	N/A	N/A

	Type of coverage (M270)	
C	1. complete coverage	(multibeam, multi-transducer, acoustically swept);
	2. systematic survey	(single-beam echo sounder lines run parallel at pre-planned line spacing, LiDAR);
	3. sparse coverage	(lead-line surveys, reconnaissance, track soundings, spot soundings);
	4. unsurveyed	

Guidelines for single beam and punctual surveys

		Exclusive / Special / 1a	1b	2	3 (Imprecise)
SBES	**Maximum Line Spacing** [4]	The lesser of: 3x average depth or 25m in depths to 10m; or 50m in depth of 10-40m; or 100m in depths deeper than 40m. Closer line spacing may be required in doubtful areas.	The lesser of: 3x average depth or 200m.For Bathymetric LiDAR a spot spacing of 5x5 metres or less.	The lesser of: 3x average depth or 1000m.	N/A

(1) To calculate the error limits for depth accuracy the corresponding values of *a* and *b* listed in Table 1 have to be introduced into the formula

$$\pm\sqrt{[a^2+(b*d)^2]}$$

where a........ constant depth error, i.e. the sum of all constant errors in metres
*b*d*.... depth dependent error, i.e. the sum of all depth dependent errors
b........ factor of depth dependent error
d........ depth in metres

(2) For safety of navigation purposes, the use of an accurately specified mechanical sweep may be considered sufficient to guarantee a minimum safe clearance depth throughout an area for Special Order and Order 1a surveys.

[3] The value of 40 m has been chosen considering the maximum expected draught of vessels.

[4] The line spacing can be reduced or expanded if procedures for ensuring an adequate sounding density are used (see § 4.4.2 Line Spacing).

The rows of Table 1 are explained as follows:

Row 1 "Examples of Typical Areas" gives examples of areas to which an order of survey might typically be applied.

Row 2 "Horizontal Accuracy" lists minimum positioning accuracy for each depth sounding to be achieved to meet each order of survey.

Row 3 "Depth Accuracy" specifies parameters to be used to calculate minimum accuracy of reduced depths to be achieved to meet each order of survey.

Row 4 "System Detection Capability" specifies the detection capabilities of systems used when 100% bottom search is required.

Row 5 “Coverage type” specifies the seabed coverage bases on the system and the methodology used to achieve a survey.

Row 6 "Maximum Line Spacing" is to be interpreted as:
- Spacing of sounding lines for single beam sounders and spot soundings surveys.

This table gives the different accuracy requirements for different areas to be surveyed according to a specific order of precision. The highest accuracy requirements are found in Exclusive order while the least order of precision is given in Order 3.

Feature detection implies that the bottom will be completely ensonified for the width of the multibeam or the multitransducer array and that there will be no gaps (areas of no ensonification) between sounding lines. When the feature to be detected is smaller, 200% coverage is recommended. It implies that the surface ensonified by the multibeam or multitransducer will be covered at least twice from a minimum of two separate passes or swaths.

This, however, does not necessarily mean that all targets will have been detected. The detection of targets as described in the various survey orders will depend on the following factors:

- the speed of the sounding platform
- the depth of water (multitransducer systems will not give full bottom coverage in shallow waters)
- the stability in maintaining straight line navigation
- beam angle
- beam width
- ping rate

Even though an echo sounding system may be capable of detecting target features as defined in Table 1 System Detection Capability, efforts will have to be taken to ensure that all the cubic features are found when conducting a full bottom search.

1.1 Exclusive Order

Exclusive Order hydrographic surveys are based on the IHO Special Order with higher accuracy and their use is intended to be restricted to shallow water areas (harbours, berthing areas and critical channels) where there is an optimal use of the water column and where specific critical areas with minimum under-keel clearance and bottom characteristics are potentially hazardous to vessels. This order also applies to high precision engineering surveys. All error sources must be minimized. Exclusive Order requires very precise positioning systems, closely spaced lines (when target detection is required) and a rigorous control on all aspects of the surveys.

The use of side scan sonar or multi-transducer arrays or high-resolution multibeam echo sounders is required to detect the feature size to be detected. In required areas, appropriate sounding equipment and methodologies must be employed in order to ensure that all features greater than 0.5m cubed are detected. The use of side scan sonar in conjunction with multibeam or multitransducer echo sounders may be necessary in areas where pinnacles and dangerous obstacles may be encountered.

1.2 Special Order

Special Order hydrographic surveys are intended to be restricted to specific critical areas with minimum under-keel clearance and where bottom characteristics are potentially hazardous to vessels. These areas have to be explicitly designated by the agency responsible for survey quality (harbours, berthing areas, and associated critical channels. All error sources must be minimized. Special Order requires the use of closely spaced lines (when target detection is required).

The use of side scan sonar, or multi-transducer arrays, or high-resolution multibeam echo sounders is required detect the feature size to be detected. In required areas, appropriate sounding equipment and methodologies must be employed in order to ensure that all features greater than 1m cubed are detected. The use of side scan sonar in conjunction with multibeam or multi-transducer echo sounders may be necessary in areas where pinnacles and dangerous obstacles may be encountered.

1.3 Order 1a

Order 1a hydrographic surveys are intended for harbours, harbour approach channels, recommended tracks, inland navigation channels, and coastal areas of high commercial traffic density where under-keel clearance is less critical and the properties of the seafloor are less hazardous to vessels (e.g. soft silt or sand bottom). Order 1a surveys shall be limited to areas with less than 100 m water depth. Although the requirement for seafloor search is less stringent than for Exclusive Order and Special Order, full bottom search may be required in selected areas where the bottom characteristics and the risk of obstructions are potentially hazardous to vessels. In required areas, appropriate sounding equipment and methodologies must be employed in order to ensure that all features greater than 2m cubed in water depths up to 40m, or features representing 10% or more of the depth in areas deeper than 40m are detected.

1.4 Order 1b

Order 1b hydrographic surveys are intended for areas with depths less than 200 m not covered by Exclusive Order, Special Order and Order 1a. These are areas where a general description of the bathymetry is sufficient to ensure there are no obstructions on the seafloor that will endanger the type of vessel expected to transit or work the area. Full bottom search may be required in selected areas where the bottom characteristics and the risk of obstructions may be potentially hazardous to vessels.

1.5 Order 2

Order 2 hydrographic surveys are intended for all areas not covered by Exclusive Order, Special Order, and Orders 1a and 1b in water depths in excess of 200 m.

1.6 Imprecise order

This order is intended for the classification of old imprecise surveys. It must not be used to determine the precision of a new survey.

1.7 Order classification

The choice of technology is normally made to meet a specific order. The classification of the bathymetry is applied to a set of data and may include as many systems and/or survey vessels. The order is determined by the worst horizontal and vertical accuracy found in the data of a dataset. It is recommended to separate the data with the same type of coverage to help the identification of the survey type. It is strongly recommended to classify surveys by statistical method after completion of these surveys. If the use of statistical method is not feasible or practical, the survey techniques shall be rigorously controlled to ensure the best results.

Notes:

- For Exclusive Order, Special Order and Order 1a surveys the Project Manager may define a depth limit beyond which a detailed investigation of the seafloor is not required for safety of navigation purposes in the surveyed areas.
- Side scan sonar shall not be used for depth determination but to define areas requiring more detailed and accurate investigation.

2 POSITION

2.1 Introduction

The accuracy of a position is the accuracy at the position of a feature (e.g. depth sounding, navigational aid) to be located within a geodetic reference frame (see § 2.4 Table 2).

If the accuracy of a position is affected by different parameters, the contributions of all parameters to the total position error must be accounted for.

A statistical method, combining different error sources, for determining positioning accuracy must be adopted. The position error, at 95% confidence level, must be recorded together with the survey data (see § 8 Data Attribution).

Positions must be referenced to the World Geodetic System 84 (WGS 84) or the North American Datum 83 (NAD 83, CSRS). It is important to understand and document which coordinate system was used to account for the fact that these two systems are no longer considered equivalent.

Whenever positions are determined by terrestrial systems, redundant lines of position shall be observed. Standard quality assurance checks techniques shall be completed prior to, during and after the acquisition of data. Satellite systems shall be capable of tracking at least five satellites simultaneously, and integrity monitoring for Exclusive Order, Special Order and Order 1a surveys is recommended.

2.2 Horizontal Control

Primary shore control points shall be established by ground survey methods to a relative accuracy of 1 part in 100,000. When geodetic satellite positioning methods are used to establish such points, the error shall not exceed 10cm at 95% confidence level with respect to WGS84 or NAD83(CSRS).

Secondary stations for local positioning which will not be used for extending the control shall be located such that the error does not exceed 1 part in 10,000 for ground survey techniques or 50cm at 95% confidence level using geodetic satellite positioning.

For more information on GPS positioning, refer to the appropriate national and/or provincial geodetic agencies.

2.3 Soundings

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

The accuracy of the position of a sounding is the accuracy at the position of the sounding on the bottom located within a geodetic reference frame.

2.4 Navigation Aids and other Features

The horizontal positions and/or elevations of navigation aids and other conspicuous features shall be determined to the accuracy stated in Table 2, at 95% confidence level.

The order to use for the positioning of navigation aids and other features such as bridge piers, wall, *clearances, etc. should be determined in accordance with the importance for the safety of navigation in the surveyed area. As an example, bridge piers located along a critical channel have a higher significance than those located in an intertidal area and should therefore be positioned with higher accuracy. The examples of typical areas stated in Table 1 can be used as a guideline.*

Table 2
Standards for Positioning of Navigation Aids and Important Features

	Exclusive Order		Special Order		Order 1a		Order 1b		Order 2	
	HOR	VER	HOR	VER	HOR	VER	HOR	VER	HOR	VER
Fixed aids to navigation and features significant to navigation	20cm	30cm	50cm	50cm	1m	1m	3m	2m	10m	3m
Mean position of floating aids to navigation.[1]	5m	N/A	10m	N/A	15m	N/A	20m	N/A	25m	N/A
Natural Coastline (high and low water lines)	2m	N/A	5m	N/A	10m	N/A	20m	N/A	75m	N/A
Topographical features (not significant for navigation)	5m	30cm	10m	50cm	15m	1m	20m	2m	25m	3m
Overhead clearances	1m	30cm	3m	50cm	5m	1m	10m	2m	10m	3m
Range line and sector lights limits azimuths	All range lines and sector lights limits must be drifted to confirm the theoretical azimuth. The maximum difference between the theoretical and drift azimuths is : 0.5°									

3 VERTICAL DATUM

3.1 Sounding Datum

All depths must be reduced to a low water datum, which can be defined as “a level where the water level will but seldom fall below it during the navigation season”.

In tidal waters, soundings are reduced to Lowest Low Water Large Tide (LLWLT) whereas in non-tidal waters the soundings are reduced to a low water datum determined from long term (period) water level records.

Sounding datum must be referred to a minimum of 3 vertical benchmarks whose elevations must be determined to the accuracy stated in the Canadian Tidal Manual.

3.2 Datum for elevations

All elevations and clearances must be referenced to a specific datum. In tidal waters, elevations and clearances are referenced to Higher High Water Large Tide (HHWLT). In non-tidal waters, elevations are referenced to sounding datum (ex. IGLD ’85)

3.3 Water Level Observations

Water level observations should be made throughout the course of a survey for the purpose of:

1. Providing water level reductions for soundings.

1 The accuracy of the position of a floating aid to navigation is the accuracy of the positioning, including parameters like: the buoy movement; how close the vessel (antenna) was from the buoy, etc.

2. Providing data for tidal analysis and subsequent tidal constituent determination and prediction. For new sites or sites with poor historical records, observations should extend over the longest possible period and preferably not less than 29 days.
3. To establish the vertical datum, (both Low Water and High Water), of an area. For this purpose, observations should extend over the longest possible period.

Water level heights should be observed so that the total measurement error at the gauging station, including timing and filtering errors, does not exceed +/- 5cm at 95% confidence level for Exclusive Order and Special Order surveys, for tidal analysis and for the determination of vertical datum. For other orders +/- 10cm at 95% confidence level should not be exceeded.

In order for the bathymetric data to be fully exploited in the future using advanced satellite observation techniques, water level observations and consequently sounding datum should be related both to a low water datum (usually Chart Datum) and also to a geocentric reference system, preferably the World Geodetic System 84 (WGS 84) ellipsoid or the North American Datum 1983 (NAD83) ellipsoid.

Independent water level measurement techniques should be used to verify the calibration and operation of the water level gauge. As a minimum, these are to be made at the beginning and the end of the tide gauge deployment and if possible at both high and low stage and more frequently during sounding operations.

4 DEPTH MEASUREMENT

4.1 Introduction

The navigation of commercial vessels requires increasingly accurate and reliable knowledge of the water depth in order to exploit maximum cargo capabilities safely. It is imperative that depth accuracy standards in critical areas, particularly in areas of marginal under-keel clearance and where the possibility of obstructions exists, are more stringent than those established in the past and that the issue of adequate bottom search is addressed.

4.2 Sensor Calibration

4.2.1 Multibeam Echo Sounding Systems (MBES)

Field procedures prior to any survey must be undertaken to determine any residual biases and the corrections that will be used to fine-tune the calibration of the MBES. These field procedures are commonly referred to as a “Patch Test” and involve logging data while the survey vessel is run over specific lines over different types of bathymetric relief at differing speeds, reciprocal directions, and offset to identifiable targets. The aim of the patch test is to determine any residual roll angle, pitch angle, azimuth angle, and time offset of the MBES with respect to the motion reference unit. The patch test is also conducted at the end of the survey to confirm that the system has not changed during the course of the survey. A patch test must also be conducted whenever there is a change of significant mechanical, hardware, or software components of the system.

More information on patch tests calibration can be found in “**The Calibration of Shallow Water Multibeam Echo-Sounding Systems” by André Godin**.

4.2.2 Multitransducer Vertical Sweep System (MTES)

At the beginning of the survey season with a multi-transducers system, it is essential to calibrate every components of the system. The Hydrographers will have to measure and position the components on the launch like: establish the spatial coordinates (xyz) of the GPS antennas, moving sensor, each transducers including the individual draught of those transducers. They will then have to calibrate components like the moving sensor, the gyro, etc. over a known area and analyze the results. It is recommended to establish a ground truth area to validate the system and compare the results with other vessels.

On a daily basis, it is necessary to calibrate the system with a "bar check" on at least one transducer to determine the sound speed in the surveyed area. It is also required to measure the draught variation of the vessel (vary with the fuel and water expense and after re-supplying).

4.2.3 Single beam Vertical System (SBES) and MTES

The "Bar Check" is the field procedure for calibrating the MTES and SBES and involves a metal cone or plate device lowered to a maximum depth of 60 meters and recording the true depth versus the measured depth and compiling a depth correction table that will be used later to correct the measured depths. The bar check may be used to determine the correct draft entry in a MBES if the size and shape of the vessel permit. This methodology should be used at least once a day and possibly at the end of the day to ensure that no problems occurred during the day.

4.2.4 Sound Velocity Profile Sensors

These sensors are to be factory calibrated according to the manufactures schedule and specifications or sooner if the data has become suspect.

4.3 Sound Speed Measurement

4.3.1 Introduction

The speed of sound in the water column shall be measured either directly, using a sound speed sensor, or indirectly calculated from conductivity, temperature and pressure measurements. In planning the measurement of sound speed profiles, the type of acoustic survey instrumentation as well as other potential uses for the sound speed data must be considered.

4.3.2 Single Beam or Multitransducer System Survey

The measurement of sound speed profiles for the use of a single beam survey is desired to correct for the sound speed propagation differences caused by changes in sound speed through the water column. This results in a vertical correction only. Sound speed profiles are to be taken at an interval dictated by the variability of conditions in the survey area. Where possible, the entire sound speed profile shall be applied directly by the echo sounder. If only a single value is accepted by the echo sounder in use, a calculated harmonic sound speed shall be used. Bar checks shall be done at a frequency sufficient to validate the sound speed being used.

4.3.3 Multibeam Survey

The measurement of sound speed profiles for a multibeam survey is required to correct for the sound speed propagation and ray path variability through the water column. This results in a vertical and across-track correction. Sound speed profiles shall be measured at a sufficient frequency to ensure that the horizontal and depth accuracies for the order of the survey as defined in Table 1 are met. If a continuous profiling system is available, sound speed profiles shall be measured at the maximum rate that logistics and vessel traffic allows.

Continuous monitoring is required to determine if a change in the sound speed profile has occurred. Monitoring is done in two distinct means, the data and observable water conditions. Data monitoring consists of watching for refraction effects in the data. These will include mismatch in the overlap of survey lines and a trend towards an arcuate ping profile. Observable water conditions consist of effects that give an indication of a change in the sound speed profile. These include, but are not limited to, an observation of: a change in measured surface sound speed, an inflow of fresh water, or a sediment plume, wind/wave action causing surface mixing, significant rainfall, traversing of currents, surface water temperature change, etc. Any such indications shall result in a new sound speed profile being measured.

4.3.3.1 Surface sound speed

The surface speed of sound shall always be measure and applied in real time for a multibeam sounder whether it is an arcuate array (e.g. barrel array) or a flat, electronically steered array.

4.3.4 Oceanographic purposes

Sound speed profile measurements shall be recorded with the sensor details, UTC time and geographic position of measurement. When sound speed is measured directly, it is desirable to measure temperature as well to enable the calculation of salinity for oceanographic purposes. When sound speed is calculated from conductivity, temperature and pressure, these values shall be retained along with the calculated sound speeds.

4.4 Sounding Density

4.4.1 Introduction

In planning the density of soundings, both the nature of the seabed in the area and the requirements of the users have to be taken into account to ensure adequate bottom search.

It should be noted that no method (not even 100% search, although desirable) guarantees the reliability of a survey by itself. Furthermore, it cannot disprove the existence of hazards to navigation with certainty; in particular, the existence or non-existence of isolated natural hazards or man-made objects such as wrecks between survey lines if conducting a SBES survey, or in the absence of redundant overlap in the case of MBES surveys.

If 100% seafloor search is required, it is recommended to use MBES/MTES or SBES combined with accurate sidescan sonar to achieve your results

4.4.2 Line Spacing

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

These procedures may include an appropriate statistical error analysis which shall take into consideration interpolation errors, as well as depth and positioning errors of the measured depths (see § 8.5 Error Sources and Budget).

For MBES, line spacing is replaced with percentage of coverage or density of soundings per square grid cell. To ensure adequate sounding density in shallow waters (<50m water depth) which are deemed critical to navigation, it is recommended that surveys use 200% coverage or 100% overlap. The sounding density should be at least 5 pings per cell to achieve the desired resolutions as described in table 1 of the *CUBE Bathymetric data Processing and Analysis (CHS February 2012).*

4.4.3 Shoal Examination

A shoal is a distinct rise of the seabed, which could be a hazard to navigation. Considering the draught of some modern ships, any isolated indication of shoaling of less than 50m may be of sufficient importance to warrant an examination for a possible shoal. A 10% rise in the seabed depending on the depth, the relative character and the navigation type (maximum draught, etc.) of the surrounding area may indicate the existence of a shoal or some other serious hazard to surface navigation and therefore be investigated.

One method of shoal examination, when operating a SBES, consists of running a detailed pattern of sounding lines over the shoal area. The line pattern and density is determined by the surrounding bathymetry, the system used and the navigational characteristics of the area. Another method is to sweep an area for 100% bottom coverage by either a mechanical or electronic sweep system.

Depending on the bottom characteristics, systems used and the client's needs, the Project Manager will determine if the shallowest depth at each shoal examination shall be verified and bottom sample obtained (mechanical or inference method).

For MBES surveys, ensure that there has been sufficient redundant data over the peak of the shoal to ensure the least depth has been accurately determined.

4.4.4 Depth Measurement over hazards

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

For wrecks and obstructions that may have less than 50 m clearance above them and may be dangerous to normal surface navigation, the least depth over them shall be determined either by high definition sonar examination or physical examination (diving). Mechanical sweeping may be used when guaranteeing a minimum safe clearance depth.

All anomalous features previously reported in the survey area and those detected during the survey shall be examined in greater detail and, if confirmed, their least depth is to be determined. The Project Manager responsible for survey quality may define a depth limit beyond which a detailed seafloor investigation, and thus an examination of anomalous features, is not required.

5 VARIOUS OTHER MEASUREMENTS

5.1 Aids to navigation

All aids to navigation (fixed and floating) and conspicuous objects significant to navigation shall be determined to the accuracies given in Table 2.

All range lines and sector lights limits must be drifted to confirm the theoretical azimuth. The maximum difference between a theoretical and a drifted azimuth is given in Table 2.

5.2 Elevations and clearances

All elevations and clearances shall be determined to the accuracies given in Table 2.

5.3 Bottom Sampling

The nature of the seabed shall be determined by sampling or may be inferred from other sensors (e.g. single beam echo sounders, side scan sonar, sub-bottom profiler, video, etc.) up to the depth required by local anchoring or trawling conditions; under normal circumstances sampling is not required in depths greater than 200 m. Samples have to be spaced according to the seabed geology. Spacing of samples shall normally be 10 times that of the selected line spacing. In areas intended for anchorage, density of sampling shall be increased. Any inference technique (e.g. Acoustic Seafloor Classification from single-beam echo sounder, multibeam echo sounder or sidescan sonar) must be ground-truthed by physical sampling, or use a standard catalogue developed for that specific sonar and vessel.

5.4 Natural coastline

The high and low water line shall be determined to the accuracies given in Table 2.

5.5 Current Observations

The speed and direction of tidal streams and currents, which may be of sufficient strength to affect surface navigation (normally more than 0.5 knots), should be observed at the entrances to harbours and channels, at any change in direction of a channel, in anchorage and adjacent to wharf areas. Survey parties should verify all current information portrayed on Charts and Field Sheets of the survey area during the course of their surveys. Survey parties are encouraged to make note of channels and harbours that exhibit negligible current as this information can be provided to mariners through Sailing Directions. It is also desirable to measure coastal and offshore currents when they are of sufficient strength to affect surface navigation.

5.6 Acoustic Backscatter

Surveys conducted with multibeam or interferometric echosounders require that the acoustic backscatter be logged and may be required to be rendered at the end of the survey.

6 DATA PROCESSING

6.1 Data verification

All calculations must be verified and counter-signed by an experienced hydrographer before the results can be used to further the acquisition of hydrographic data. The bathymetric data must be processed as soon as possible after it has been collected to analyse and verify the work.

Processing best practise is outlined in the document "*CUBE Bathymetric data Processing and Analysis (CHS February 2012)*".

6.2 Data codification and presentation

All data must be coded using the most recent version of CHS coding and presentation standards, otherwise, data must be separated into layers and a comprehensive layering documentation must be included as metadata information or in a final report including all pertinent information that may help CHS to qualify the data better.

7 QUALITY CONTROL

7.1 Introduction

To ensure that the required accuracy is achieved it is necessary to check and monitor performance. Establishing quality control procedures shall be a high priority. All related pertinent documentation should be preserved for further consultation.

7.2 Positioning

Quality control for positioning involves monitoring the proprietary hardware/software quality indicators for accuracy, precision, signal strength, signal to noise ratio, cycle tracking, solution type, etc. A position check by the survey vessel occupying or offset to a known ground position must be done at the start of a survey, periodically during, and at the end of the survey. Redundant lines of position or redundant satellites must always be observed. The use of a position monitor station to monitor position accuracy and system performance is desirable but often not practical. The use of two independent positioning systems along with ground position checks is also a very desirable situation.

7.3 Depths

A standard quality control procedure shall be to check the validity of soundings by conducting additional depth measurements. Differences shall be statistically tested to ensure compliance of the bathymetric data with the standards given in Table 1. Anomalous differences shall be further examined with a systematic analysis of contributing error sources. All discrepancies shall either be resolved by analysis or re-survey during progression of the survey task.

7.4 Check lines

Check lines crossing the regular lines shall always be done to confirm the accuracy of the positioning, the depth measurement and other depth corrections. They shall be run as close to perpendicular to the principal lines as possible. The differences between principal lines and check lines shall fall within the limits of the survey order. If possible, check lines shall be collected using an independent system, different survey vessel and/or time and on a rough bottom.

Check lines crossing the principal sounding lines shall always be run to confirm the accuracy of positioning, sounding, and depth corrections. Check lines shall be spaced so that an efficient and comprehensive control of the principal sounding lines can be done. As a guide, it may be assumed that the interval between check lines shall normally be no more than 15 times that of the principal sounding lines.

7.5 Sounding Density requirements

7.5.1 Single-beam Echo Sounders (SBES)

Depending on the characteristics of the seafloor the line spacing from Table 1 may have to be reduced or, if circumstances permit, expanded. Check lines shall be run at discrete intervals (see § 7.4 Check lines).

7.5.2 Side scan Sonar (SSS)

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

7.5.3 Multibeam Echo sounders (MBES)

MBES have great potential for accurate seafloor coverage if used with proper survey and calibration procedures. An appropriate assessment of the accuracy of measurement with each beam is compulsory when full bottom coverage is required for use in areas surveyed to Exclusive Order, Special Order and Order 1a standards. If any of the outer beams have unacceptable errors, the related data are to be excluded or weighted accordingly. If not hampered by geographical constraints, all lines shall be crossed, at least once, by a check line to confirm the accuracy of positioning, depth measurement and depth corrections – squat, draft, tide, and sound speed. Accuracy's can also be confirmed by redundant measurement on a small seafloor target.

7.5.4 Multitransducer systems (MTES)

Multitransducer (sweep) systems provide one technology for ensuring the accuracy while a full bottom coverage is required for Exclusive Order, Special Order and Order 1a standards. It is essential that the distance between individual transducers shall be matched to ensure 100% bottom coverage. If not hampered by geographical constraints, all lines shall be crossed, at least once, by a check line to confirm the accuracy of positioning, depth measurement and depth corrections – squat, draft, tide, and sound speed. Accuracy's can also be confirmed by redundant measurement on a small seafloor target.

7.5.5 Airborne systems

Airborne laser systems are capable of measuring depths to 50 m or more provided the water is clear. Hazards to navigation detected by airborne laser shall be examined using an independent method (see § 4.4.3 Shoal Examination). A check line to confirm the accuracy of positioning, depth measurement and depth corrections shall cross all lines, at least once.

8 DATA ATTRIBUTION

8.1 General

To allow a comprehensive assessment of the quality of survey data it is necessary to record or document certain information together with the survey data. Such information is important to allow exploitation of survey data by a variety of users with different requirements, especially as requirements may not be known when survey data is collected.

The process of documenting the data quality is called data attribution; the information on the data quality is called metadata.

Metadata shall comprise at least information on:

- The survey in general as e.g. date, area, equipment used, name of survey platform
- The geodetic reference system used, i.e. horizontal and vertical datum; including ties to WGS 84 if a local datum is used
- Calibration procedures and results
- Sound velocity
- Tidal datum and reduction
- Accuracy achieved and the respective confidence levels.

Metadata shall preferably be in digital form and an integral part of the survey record. If this is not feasible, similar information shall be included in the documentation of a survey such as the final field report.

8.2 Point Data Attribution

All soundings should be attributed with a 95% statistical error estimate for both position and depth. Although this should preferably be done for each individual sounding, a global estimate will be provided for an entire dataset and the worst-case survey error must be shown.

In the case of positions, they shall be qualified by analyzing redundant lines of position (terrestrial systems) or independent positioning check (satellite systems); in the case of depth observations, they could be qualified by analyzing redundant depths observed at, for example, check line crossings.

It is understood that each sensor (i.e. positioning, depth, heave, pitch, roll, heading, seabed characteristic sensors, water column sensor parameters, tidal reduction sensor, data reduction models etc.) possesses unique error characteristics. Each survey system shall be uniquely analyzed to determine appropriate procedure(s) to obtain the required spatial statistics. See the Survey Management Guideline.

8.3 Depth Accuracy

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

1. measurement system and sound speed errors
2. tidal measurement and modeling errors, and
3. data processing errors.

A statistical method for determining depth accuracy by combining all known errors shall be adopted and checked. For example, CUBE processing can provide this information.

The TPU, determined statistically at the 95% confidence level, is the value used to describe the depth accuracy achieved. The TPU shall be recorded together with the sounding value.

Recognizing that there are both constant and depth dependent errors that affect the accuracy of depths, the formula under Table 1 is to be used to compute the allowable depth errors using *a* and *b* from row 3.

8.4 Geostatistics

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

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

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

Table 3
Bathymetric Model Accuracy

ORDER	Exclusive	Special	1	2	3
Bathymetric Model Accuracy (95% Confidence Level)	a = 0.02 b = 0.01	a = 0.5 b = 0.01	*a* = 1.0 m *b* = 0.026	*a* = 2.0 m *b* = 0.05	*a* = 5.0 m *b* = 0.05

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

8.5 Error Sources and Budget

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

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

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

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

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

Project managers responsible for the survey quality shall develop and document error budgets for their particular systems.

9 DATA MANAGEMENT

9.1 Data security and archiving

The Project Manager responsible for all survey data shall ensure that original sensor datagrams are secured on a suitable media and stored in a safe location promptly after acquisition. Processed data shall be backed-up on a daily basis on a suitable media and stored in a safe location.

10 REPORTING

10.1 Reporting of Navigational Hazards

Upon discovery of any depth or obstruction that may be considered a hazard to navigation, the Project Manager shall inform the closest Canadian Coast Guard office and have a Navigational Warning issued.

All actions shall be documented and a copy sent to the Regional Director of Hydrography and the Regional Manager of Hydrographic Surveys, who will initiate appropriate actions.