IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44)
5th Edition February 2008

ANNEX A

GUIDELINES FOR QUALITY CONTROL

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

A.1 Introduction

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

Standard ~~calibration~~ verification techniques should be completed ~~prior to~~ before and after the data acquisition ~~of data~~ . Furthermore, ~~and after~~ any major system modification ~~takes place~~should also result in a verification stage.

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

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

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

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

A.2 Error Sources

In metrology, the TPU comes from: the measurand (measure of the object itself), the measurement system, the environment, the operators and the survey methodology.

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

Overall, it may be very difficult to determine the position *uncertainty* for each sounding as a function of depth. The *uncertainties* are a function not only of the system (swath or not) but also of the location~~ of~~, offsets~~ to~~ and accuracies of the auxiliary sensors.

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

Contributing factors to the vertical *uncertainty* include:

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

A.3 “A~~a~~ priori” and “a posteriori” TPU

In order to estimate an appropriated TPU, both “a priori” and “a posteriori” TPU verification have to be considered. A survey can be qualified as succeed if these two TPU are consistent.

A.3.1 “a priori” TPU verification:

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

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

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

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

A.3.2 “a posteriori” TPU verification:
During a survey, cross lines or overlapping swaths indicate the level of agreeability or repeatability of measurements. These cross lines dedicated to repeatability have to be reliable (for instance reduced swath, cleaned data, etc.). These data do not indicate absolute *accuracy* in that there are numerous sources of potential common *errors* (see A.2) between data from main lines and check lines. The *quality control* procedure should include statistical analysis of differences and the consideration of common *errors* to provide an indication of compliance of the survey with the standards given in Table 1. The effect of spikes and *blunders* should be eliminated prior to this analysis. Remaining anomalous differences should be further examined with a systematic analysis of contributing *uncertainty* sources. All discrepancies should be resolved, either by analysis or re-survey during progression of the survey task.

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

Furthermore, the TVU and THU of a bathymetric system can be verified on a very well-known reference area.

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~~A.2 Positioning~~

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

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~~A.3 Depth Data Integrity~~

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

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

~~A.3.1 Single-beam Echo Sounders (SBES)~~

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

~~A.3.2 Swath Echo Sounders~~

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

~~A.3.3 Sweep Systems (multi-transducer arrays)~~

~~It is essential that the distance between individual transducers and the acoustic area of ensonification should be matched to the depths being measured to ensure full sea floor coverage across the measurement swath. A number of check lines should be run.~~

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

~~A.3.4 Bathymetric LIDAR~~

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

~~A.4 Error Sources~~

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

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

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

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

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

~~Contributing factors to the vertical *uncertainty* include:~~

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

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

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~~A.5 Propagation of Uncertainties~~

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

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

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

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

~~ANNEX B~~

~~GUIDELINES FOR DATA PROCESSING~~

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

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

~~B.1 Introduction~~

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

~~The following workflow should be followed:~~

~~B.1.1 Position~~

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

~~B.1.2 Depth corrections~~

~~*Corrections* should be applied for water level changes, measurements of motion sensors, and changes of the draught of the survey vessel (e. g. squat changing with speed; change over time caused by fuel consumption). It should be possible to re-process data for which *corrections* were applied in real-time.~~

~~B.1.3 Attitude data~~

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

~~B.1.4 Sound speed correction~~

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

~~B.1.5 System Time Latencies~~

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

~~B.1.6 Merging positions and depths~~

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

~~B.1.7 Analysis of returning signal~~

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

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~~B.1.8 Automatic (non-interactive) data cleaning~~

~~During this stage, the coordinates (i.e. positions and depths) obtained should be controlled automatically by a programme using suitable statistical algorithms which have been documented, tested and demonstrated to produce repeatable and accurate results. When selecting an algorithm, robust estimation techniques should be taken into consideration as their adequacy has been confirmed. Many high-density bathymetry processing packages have built-in statistical processing tools for detecting and displaying outliers. Generally speaking, higher-density data sets with large amounts of overlap between lines provide an increased likelihood of detecting *blunders*. In addition to statistics, threshold values for survey data can be used to facilitate the detection of *blunders*. Each agency is responsible for the validation of the algorithm used and the procedures adopted.~~

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

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~~B.1.9 Manual (interactive) data cleaning~~

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

~~For this stage the use of 3-D visualisation tools is strongly recommended. Decision making about whether to accept or reject apparently spurious soundings can often be enhanced by viewing combined data sets in three dimensions. These tools should allow viewing the data using a zoom facility. The interactive processing system should also offer different display modes for visualisation, e.g. depth plot, *uncertainty* plot, single profile, single beam, backscatter imagery etc. and should allow for the visualisation of the survey data in conjunction with other useful information e.g. shoreline, wrecks, aids to navigation etc. Editing the data should be possible in all modes and include an audit trail. When editing sounding data, it can often be useful to understand the spatial context of the examined data points. What may appear to be bad soundings (*blunders*) out of context may be recognised as real sea floor artefacts (submerged piles, wrecks, etc.) when viewed in the context of a chart backdrop for example. If feasible, data displays should be geo-referenced. The ability to~~

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

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

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

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~~The flags set during the automatic stage, which correspond to depths shallower than the surrounding area, should require explicit operator action, at least, for Special Order and Order 1 a/b surveys. If the operator overrules flags set during the automatic stage, this should be documented. If a flag is set by the operator, the type of flag used should indicate this.~~

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~~B.2 Use of *uncertainty surfaces*~~

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

~~B.3 Validation Procedures~~

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

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