AusSeabed

Australian Multibeam
GUIDELINES

Australian Multibeam Guidelines

AusSeabed

GEOSCIENCE AUSTRALIA
RECORD 2018/19

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Version 1.1

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ISSN 2201-702X (PDF)
ISBN 978-1-925297-89-8 (PDF)
eCat 121571

Bibliographic reference: Picard, K., Austine, K., Bergersen, N., Cullen, R., Dando, N., Donohue, D., Edwards, S., Ingleton, T., Jordan, A., Lucieer, V., Parnum, I., Siwabessy, J., Spinoccia, M., Talbot-Smith, R., Waterson, C., Barrett, N., Beaman, R., Bergersen, D., Boyd, M., Brace, B., Brooke, B., Cantrill, O., Case, M., Dunne, S., Fellows, M., Harris, U., Ierodiaconou, D., Johnstone, E., Kennedy, P., Leplastrier, A., Lewis, A., Lytton, S., Mackay, K., McLennan, S., Mitchell, C., Nichol, S., Post, A., Price, A., Przeslawski, R., Pugsley, L., Quadros, N., Smith, J., Stewart, W., Sullivan J., Tran, M., Whiteway, T., 2018. Australian Multibeam Guidelines. Record 2018/19. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2018.019

Version: 1801

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Record of changes

Date	Change	Authority
4 June 2018	Version 1.1 created	Kim Picard

Acknowledgements

The authors would like to thank the Product and Promotion Team from Geoscience Australia for the assistance in publishing these guidelines and for the design of the cover page. We would also like to thank Lindsay Gee from the Ocean Exploration Trust and Simone Burzacott-Gorman from Wilderness School Adelaide for their reviews of these guidelines and associated constructive comments.

1 Introduction

High-resolution seafloor mapping has developed into a significant area of marine surveying in the past few decades and has had an increasingly large number of drivers and applications:

- Navigation and safety of life at sea
- Environmental assets management (including Fisheries management)
- Ocean and climate modelling
- Hydrodynamic modelling
- Coastal and nearshore sediment mapping
- Resource development
- Aquaculture planning
- Oil and gas subsea assets integrity
- Telecommunication cable deployment
- Renewable energy assessments
- Marine spatial planning
- Territorial claims
- Demonstration of Antarctic presence
- Underwater cultural heritage management
- Artificial reef development

These applications have resulted in seafloor mapping in locations from the upper reaches of estuaries to the abyssal plain.

In Australia, much of the focus has been on continental shelf and slope waters at varying levels of coverage and resolution reflecting the drivers for mapping, vessel and gear availability, and the combination of targeted and opportunistic data collection. However, despite a significant increase in survey coverage in the past decade, less than 25% of the seafloor in Australia's maritime jurisdiction is mapped at high-resolution.

Since only the narrow coastal margin of the seafloor can be seen from aerial or satellite images, or mapped using laser airborne systems, swath acoustic mapping systems, principally multibeam echosounders (MBES) and bathymetric sidescan (interferometric sonar), have been the systems most used to map Australia's seafloor. These swath systems collect several specific measurements: water depth, seabed backscatter (commonly known as seabed hardness), and in some cases with MBES, water column backscatter. While MBES data is acquired by many groups to meet specific purposes, with increasing coverage and specific mapping programs in government agencies, research institutions and industry, it is important to ensure swath mapping data is made available to use for a range of applications (Table 1).

The primary objective of this guideline is thus to establish common approaches of acquisition and processing that will result in greater applicability and interoperability of swath acoustic mapping data. These approaches will also provide improved consistency in the collection and description of the data, increasing utility.

To achieve this objective, AusSeabed, a national seabed mapping coordination program run by a consortium of representatives from Commonwealth and State governments, universities and industry, was formed. AusSeabed's role is to encourage and facilitate the initial collection of seabed mapping data and make it available for use by all stakeholders. As such, the program is running a series of coordinated initiatives, including:

- the production of maps identifying priority areas for Commonwealth and State Government agencies that are part of current initiatives
- **Australian Multibeam Guidelines** presented here
- a website hosting various resources, planning and data management tools, including a data portal.

Table 1 Key stakeholders benefiting from better coordination and availability of seabed mapping data and type of data preferentially used (note the list is not exhaustive, but intended to give examples)

Stakeholder	Preferred data type	
	Source data (raw or processed files)	Products (e.g. maps of seabed depths, habitat, morphology)
Department of Defence (e.g. Hydrography, Mine warfare)	X	X
Marine parks (Australia or States Marine Parks)		X
Department of Industry, Innovation and Science (e.g. NOPSIMA)		X
Industry (Oil & Gas; Infrastructure)	X	X
State coastal planning and management groups		X
Maritime Jurisdiction (Geoscience Australia)	X	
Australian Tsunami Advisory group		X
State and Commonwealth research institutions (e.g. CSIRO, Geoscience Australia, State environment and fisheries agencies)	X	X
Universities	X	X

Overall these initiatives aim to achieve a number of specific outcomes, including:

- document a historically sorted dataset at an identified level of quality standard data available to all stakeholders within Australia and beyond
- identify areas where new data is needed most
- enable stakeholders to leverage Australia's seabed mapping expertise and capabilities
- provide tools to allow efficient and consistent pre-survey planning for stakeholders
- promote collaboration and innovation by stakeholders

- utilise national resources and efforts to map the seabed of our national waters
- provide clear guidelines that aim to improve standards of data acquisition
- increase data usage and availability for stakeholders
- ensure better management of Australian waters by informing decision makers with relevant data

1.1 Scope

Australia's Multibeam Guidelines were established by the AusSeabed consortium. The guidelines provide procedures mainly on survey planning, data acquisition and submission i.e. from the pre-survey planning phase to the data submission phase, off the ship. They are designed for a range of audiences, from those experienced in seafloor mapping using swath acoustic systems, non-experts who are developing mapping capabilities, and those contracting seafloor mapping surveys using swath systems.

These guidelines aim to improve interoperability, discoverability and accessibility of swath system data, and encourage improved acquisition standards to meet more user requirements. We acknowledge that to achieve such an aim, adaptation of the project might be necessary and could impact time and cost. For example, a project needing higher quality backscatter may require tighter line spacing, while a hydrographic survey for charting will need more detailed assessment and greater sounding density than for a habitat mapping project. However, in most cases, the inconvenience of varying parameters will be outweighed by the increased relevance of the data to more users.

These guidelines should be used as an overarching document, providing a minimum set of requirements for seafloor mapping activities conducted in Australian waters. These guidelines should be complemented with purpose-based requirements and associated documentation, such as hydrographic surveys, marine park monitoring, and marine infrastructure planning or installation (Figure 1).

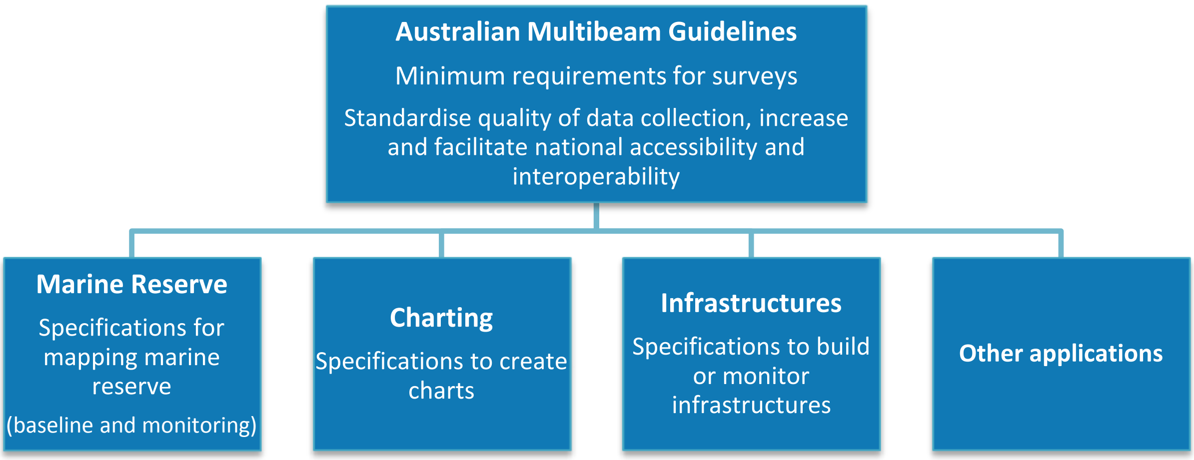


Figure 1 Anticipated areas of influence for the Australian Multibeam Guidelines. These use-cases are those which the minimum set of requirements delivered through the guidelines will ensure accessibility and interoperability of collected seabed mapping data.

This includes a broad examination of data processing as guidance for data submission (Figure 2). These guidelines are relevant to all water depths (>2m) and provide recommendations on all three types of swath acoustic data (bathymetry, backscatter and water column backscatter), adopting international guidelines where appropriate. This document does not present any preparation activities like bench/workshop tests, and personnel requirements, and does not provide costing information (see section 5.3.4 of Przeslawski et al. 2018a for MBES Costing).

1.2 How to use guidelines

To help navigate these guidelines, Table 2 identifies sections that are more relevant to various user-groups while Figure 2 provides a flow-chart summarising the content. They also contain a glossary of abbreviations and terms (Appendix A and B), and refer to a variety of tools and resources available (Table 3) or in-development and shared in the common portal, AusSeabed.

These guidelines do not include a full and comprehensive description of swath bathymetry systems, but rather, provide a list of pertinent references, such as Hughes-Clarke (2017a). They also refer to related guidelines where relevant, particularly *Field manuals for marine sampling to monitor Australian waters* (Przeslawski and Foster 2018). Such manuals provide recommendations for standard operating procedures for a range of seafloor sampling tools, including swath acoustics relevant specifically to marine monitoring (Lucieer et al. 2018)

Table 2 Relevance to the various user groups by document section number. However, all stakeholders will find useful information in all sections

Section	Non-expert groups	Expert groups
1 Introduction	All	All
2 Pre-survey planning	All	2.1; 2.2; 2.4; 2.5; 2.6
3 Mobilisation, Calibration & Validation	3.1; 3.9	All
4 Acquisition	4.1; 4.6	All
5 Processing and Rendering	5.3	All
6 Reports	All	All

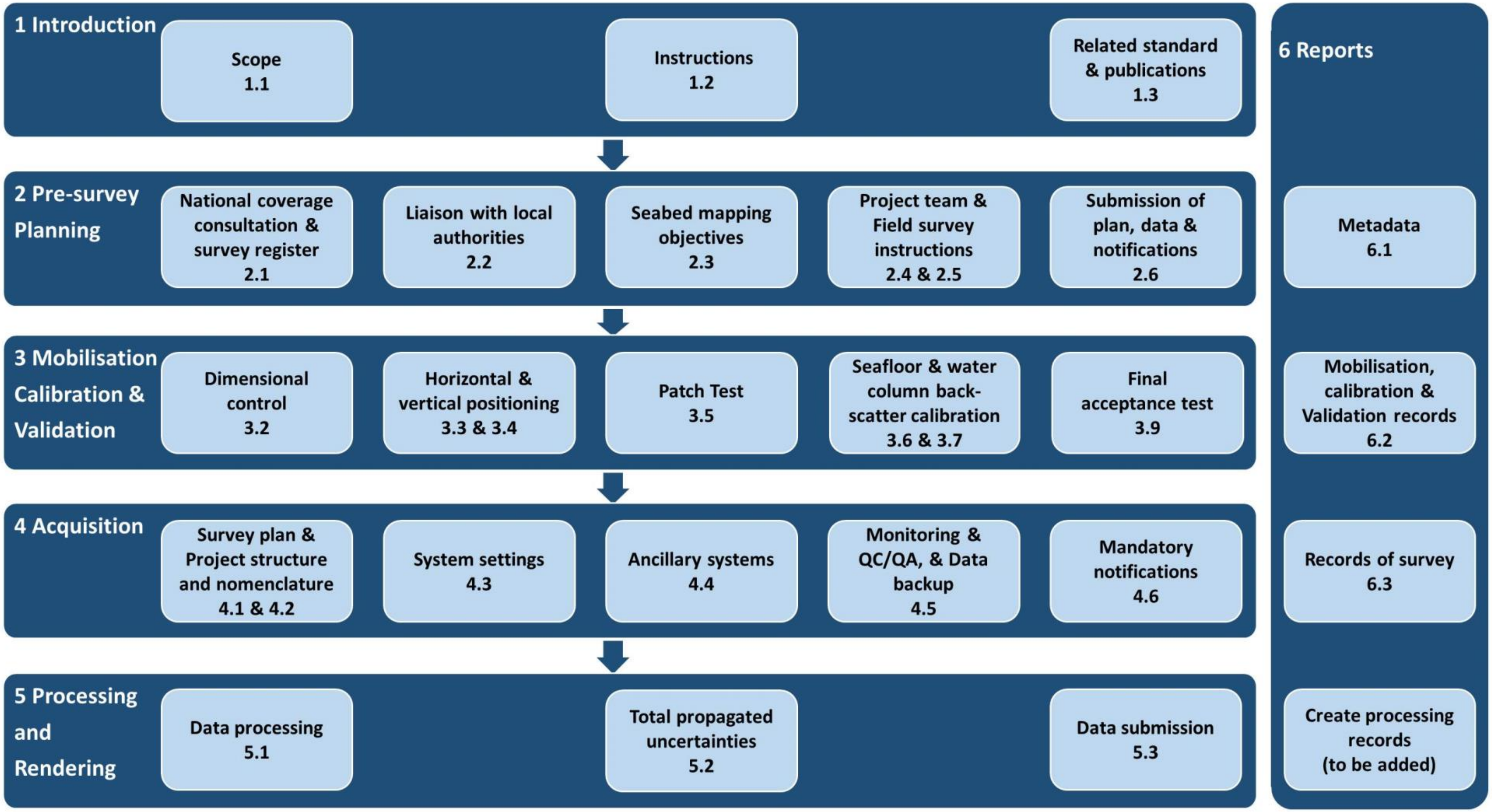


Figure 2 Flow chart summarising the information contained in this guideline.

1.3 Related standards and publications

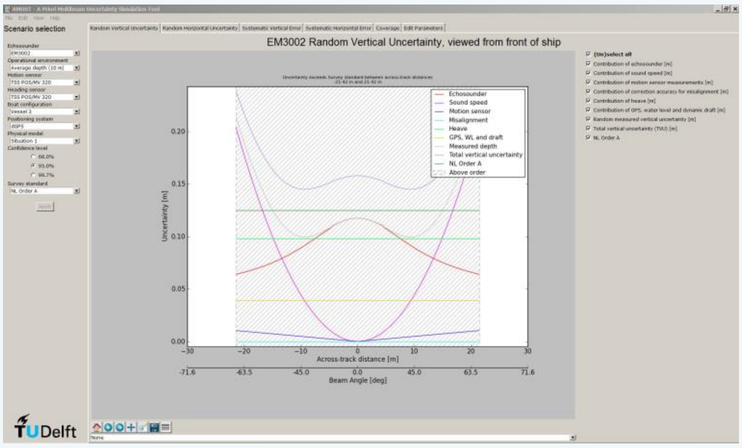
The following publications should underpin the collection of geospatial data and augment these standards. The complete references for these documents can be found in section 7, but the most recent published versions of the following documents apply:

1. AHO, 2017. Hydroscheme Industry Partnership Program - Statement of requirements
2. AHO. Hydrographic Note, Australian Hydrographic Office
3. AHO. Seafarer's Handbook for Australian Water (AHP20)
4. CHS, 2013. Hydrographic survey management guidelines
5. Mills J. and Dodd D., 2014. Ellipsoidally Referenced Surveying for Hydrography. FIG Publication No. 62
6. GeoHab Backscatter Working Group, 2015. Backscatter measurements by seafloor-mapping sonars: Guidelines and Recommendations.
7. Godin, A., 1998. The Calibration of Shallow Water Multibeam Echo-Sounding Systems, Technical Report No. 190.
8. Hughes-Clarke, J.E., 2003. A reassessment of vessel coordinate systems: what is it that we are really aligning?
9. ICSM, 2018. Geocentric Datum of Australia Technical Manual.
10. ICSM, 2004. Australian Tides Manual (SP9).
11. ICSM, 2014a. Guidelines for Control Surveys by GNSS (SP1).
12. ICSM, 2014b. Guidelines for Control Surveys by Differential Levelling (SP1).
13. ICSM, 2014c. Standard for the Australian Survey Control Network (SP1).
14. IHO, 2008. IHO Standards for Hydrographic Survey, (S-44)
15. IHO, 2013. Manual on Hydrography (C-13).
16. IHO, 2015. INT1 Symbols, Abbreviations and Terms used on Charts.
17. IOGP, 2018. Seabed Survey Data Model (SSDM)
18. Lamarche G. and Lurton X., 2017. Recommendations for improved and coherent acquisition and processing of backscatter data from seafloor-mapping sonars.
19. LINZ, 2016, Contract Survey Specifications for Hydrographic Surveys, Vers. 1.3
20. Lucieer V. et al., 2018. NESP field manual for multibeam sonar.
21. Lucieer V. et al., 2017. Seamap Australia
22. Przeslawski R. et al., 2018. NESP field Manual for grab and box core sampling

2 Pre-survey planning

The acquisition phase of a survey is the most expensive element. Therefore it is essential that this phase is optimised by undertaking adequate pre-survey planning. This section of the guidelines identifies key aspects of the planning phase that can be improved for more efficient and effective surveys. They also present tools and resources available (some imminent) that can help (Table 3). These resources are also hosted on the AusSeabed website, and we encourage using the website to discover the full breath of available resources. The IHO C-13 Manual on Hydrography also provides an appendix on planning considerations and how to best calculate survey timings.

Table 3 Summary list of pre-survey planning tools proposed in the section

Tool or Resource	Description
Upcoming Survey Register	Register the survey to encourage collaboration and contribute to national coverage
National Coverage	Coverage of MBES dataset by various agencies.
Seabed Survey Data Model	The SSDM is a GIS model that has been developed since 2010 by the International Association of Oil & Gas Producers (IOGP) to facilitate management, integration and sharing of survey data at all levels, i.e. international, national, local, etc (IOGP, 2017).
A priori tools **1) Amust**	These tools help to determine expected uncertainties for a system. Amust link points to a registration page on the Rijkswaterstaat (Dutch Hydrographic Service) website. See also Appendix E for a list of possible errors to take into account. 
2) Hydrobib	Hydrobib provides integrated utilities for survey planning. It is more specific to R2Sonic echosounder, but can be adopted for other echosounders.
Datum tools **1) VDatum** **2) AusCoastVDT**	 1) Designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums. 2) A vertical datum transformation tool for the Australian coast.
Line planning tool	Most survey acquisition software packages (QPS, EIVA, HYPACK) have line planning capability built into them. See also **Hydrobib** above

2.1 National coverage consultation and upcoming survey register

AusSeabed is currently developing a suite of pre-survey tools that allow one to view the current extent of national bathymetry data holdings, consult a map of national seabed mapping priority areas, and interact with an upcoming survey register. These tools are aimed at providing seabed mappers with information to promote collaboration in areas of common interest and eliminate repeat collection. This initiative is likely to benefit all parties by reducing overall costs and leading to more efficient collection efforts in Australian waters.

Seamap Australia is a complementary mapping and analysis service that provides information about the Australian shelf (e.g. seafloor imagery, habitat classification) that may also inform proposed mapping areas (Lucieer et al., 2017).

2.1.1 Existing Data coverage

At the time of writing these guidelines, the AusSeabed data centre was under development and no complete repository for swath mapping data collected in Australian waters existed. We recommend consulting the Bathymetry coverage tool hosted on the AusSeabed website to plan data acquisition that will contribute to the expansion of the national coverage (e.g. transit data). The tool contains the spatial extents and metadata of all surveys submitted to Geoscience Australia (GA) and is being continually developed towards displaying national coverage from all entities.

As marine sediment samples are often collected during seabed mapping surveys, consult the GA MARS database for existing samples analysed and held by GA. Links to other entity data samples to come.

2.1.2 National Bathymetry priorities

The AusSeabed website also hosts an interactive map of national bathymetry priorities of areas that are considered important to government in terms of safety of life at sea, conservation, and environmental monitoring. It is recommended that this tool be consulted in the early stages of survey planning to see if the voyage will be covering any areas of government interest.

2.1.3 Upcoming survey register

It is also highly recommended that the upcoming seabed mapping survey details (see section 2.3.2) be registered on the upcoming survey register to enable further collaboration and future tracking of new data. The survey planning register includes a set of metadata that are considered a minimum to any seabed mapping activities and will be required for the survey report and data submission following the survey (Figure 3). If desired, a more detailed planning document can also be attached.

Figure 3 Interim workflow for data coverage consultation and submission of upcoming survey register information. Note that at present, the coverage map in AusSeabed consists only of GA data coverage and that other data portals are listed on the website. This workflow is intended to be automated in the future as we progress AusSeabed initiatives.

2.2 Liaison with local authorities

Various permissions are required to undertake research in Commonwealth, State and Territory waters. Due to the complexity of laws and intersecting jurisdiction's, information on this page should be treated as a guide only and information from the relevant governing bodies should be consulted to ascertain that the correct permissions have been acquired prior to any research undertaking.

Operators should contact and inform relevant national and local authorities well in advance of any intended survey work ashore and afloat. These include the local harbour authority that should be consulted at all stages of the planning and execution of any harbour surveys, marine reserves, etc. Be mindful that approvals, permits (e.g. Environment Protection and Biodiversity Conservation, Environmental Plan, local marine parks permits, etc), may be needed before undertaking a survey. Legislation for approvals is slightly different in each state. More information regarding legislation and permitting can be found on the AusSeabed website. Appendix C provides a list of Authorities that may need to be consulted and some links to general research permits for state waters.

2.3 Seabed mapping objectives

When planning a seabed mapping survey the objectives generally dictate the standards to follow. This national guideline provides the minimum requirements for all seabed mapping activities to enable national coordination and compilation. It is thus aimed as an overarching document that can be complemented by more specific requirements surpassing these. Appendix D provides some approximate timeframes as a guide for the various activities related to seabed mapping surveys.

If the survey objectives are to map marine parks, refer also to the NESP MBES field manual (Lucieer et al., 2018). If it is for charting purposes, consult the Australian Hydrographic Office.

2.3.1 Data types and formats

2.3.1.1 Data type

The types of data derived from a MBES survey are:

- bathymetry: essential
- seabed backscatter: essential
- water column backscatter: encouraged

The minimum essential requirements of any seafloor mapping survey are the bathymetric data and seabed backscatter data (which may require manual activation). Water column backscatter data acquisition is encouraged if the system can collect it. In addition to scientific applications, water column data is a common method used to confirm least depth over features and to identify bathymetric artefacts. It is both used in terms of 3D visualisation of the seabed and also in observing oceanographic turbulence, such as internal waves, which may result in bathymetric artefacts (Hughes-Clarke, 2017b).

2.3.1.2 Data format

This document covers only the digital data formats. At the time of writing these guidelines, no specific formats had been adopted by AusSeabed; thus the following instructions are generalised.

There are five main data formats or products created during a seabed mapping survey:

1. Raw files: These should always include files in formats that are proprietary to the acquisition systems, i.e. all systems, including ancillaries and calibration data. Raw data refers to measurements (angles, ranges, rates, accelerations, azimuths) and not to derivations (depths, heights, times). This will allow future processing or greater use of the data.

2. Processed files: These include all files from each systems component that have been refined with ancillary information (e.g. tide, SVP, base station corrections, etc) and cleaned to meet the project requirement.

3. Surface layer: Generally a regularly gridded product made from the soundings.

4. Point files: Usually referred to as Point cloud and include irregularly spaced soundings with various attributes (minimum attributes are XYZ).

5. Images: These are visual products that are georeferenced or not. They generally do not contain sounding information, such as depth, but are rather colour-coded (e.g. geotiff, tiff, jpg, png, etc).

6. Others: The most common other formats that may be encountered are contours and fairsheet, which are sheets generally highlighting particular soundings, such as shoal soundings. These are mainly produced for hydrographic purposes.

2.3.2 Survey area characterization

Operational requirements, gear availability and technical capacity will determine the most appropriate type of swath mapping system to use (see Bathyswath for general system type information). The characteristics of the survey area and mapping requirements are also key issues to consider, including:

- survey duration and size of the area
- depth range as this will affect line planning (section 2.5.6) and acquisition parameter settings (section 4.3)
- wind and wave conditions and seasonal weather changes
- tidal regime and tidal infrastructure
- feature detection and sounding density requirements; reflected in required pulse repetition (ping rates), swath width and survey speed
- the nature of the seabed, which is important for seabed backscatter data acquisition (section 4.3.1). If one of the objectives of the mapping is to understand the nature of the seabed and to predict it over the area of interest, sediment sampling needs to be considered (section 2.6).
- water column anomalies and feature anomalies, which may benefit from recording seabed water column backscatter (section 2.3.1)
- the time of year and relevance to whale migrations for low frequency instruments
- potential interactions with surface fishing gear

2.3.3 Data representation (seafloor coverage and resolution)

Data representation, with respect to seafloor coverage, depends primarily on the swath system utilised. For MBES systems, data representation will be dependent on the beam width of the system and the associated footprint on the seafloor (Table 4). It is important to consider that the data representation of the final output has to be greater or equal to the beam footprint. For bathymetric sidescan however, sounding interval on the seafloor is constant. For more details on the two systems, refer to Bathyswath.

Two key factors of resolution should also be taken into consideration when choosing the right equipment or designing a survey plan: horizontal and vertical accuracy (sections 3.3 and 3.4). These can be assessed by listing all sources of error and calculate interactively the total propagated uncertainties of a sounding (TPU; section 5.2). The Total Vertical Uncertainty (TVU) must not exceed the depth accuracy, and total horizontal accuracy (THU) actually refers to the accuracy of the position of sounding on the seafloor and not the accuracy of the GPS [GNSS] position of the survey vessel alone. Survey speed can also affect the data representation and accuracy (Hughes-Clarke, 2017b).

If data representation is not the primary driver in the choice of the system to use, it is recommended that data be collected at the best resolution achievable by the system.

Table 4 MBES footprint (m) at nadir and beam width (deg). The beam footprint for a MBES increases in the outer beams.

		Beam Width (deg)					
		0.5	**0.7**	**1**	**2**	**3**	**4**
DEPTH (m)	**10**	0.09	0.12	0.17	0.35	0.52	0.70
	25	0.22	0.31	0.44	0.87	1.31	1.74
	50	0.44	0.61	0.87	1.74	2.62	3.49
	75	0.65	0.92	1.31	2.62	3.92	5.23
	100	0.87	1.22	1.75	3.49	5.23	6.97
	250	2.18	3.05	4.36	8.72	13.08	
	500	4.36	6.11	8.73	17.45		
	1000	8.73	12.22	17.45			
	1500	13.09	18.33				
	2500	21.82					

It is important to highlight that identification of features of specific sizes rely on a combination of parameters. It is generally accepted that when using side scan sonar as the feature detection tool, that a minimum of five boresight hits are made on the feature target. When using MBES as the feature detection tool, the common requirement is to achieve a minimum 3 along track hits and 3 across track hits on the feature target. The above requirements are to be considered necessarily conservative and in line with accepted sampling theory. Refer to section 7.5 from AHO (2018) for further information and diagrams

The general formula to calculate the depth at which five pulses should ensonify a target of a given size at different speed is (GBHD, 1996):

$$D = \frac{\left(Sx\left(\frac{1852}{3600}\right)x\left(\frac{5}{prr}\right)\right) - t}{2\tan(\frac{\Phi}{2})}$$

Where:

D = least depth of detection (metres below transducers)

S = speed in knots

t = along track dimension of target to be detected (metres)

ф= echo sounder's beam width (fore and aft) in degrees.

prr = pulse repetition rate (pulses per second (Hz))

2.3.4 Quality assessment / uncertainty scheme

The International Hydrographic Organisation (IHO) publishes a document for hydrographic standards – IHO Special Publication (SP-44). Appendix G of this publication details a range of survey standards for varying purposes. By surveying and providing data to these minimum standards, a collaborative approach to providing safe maritime navigation in future surveying areas can be assured in areas where there may be a future need to conduct operations.

However, these standards may not fit the purpose of the survey or be flexible enough (Figure 1). Therefore, it is recommended that each parameter be evaluated separately when planning a survey. Consideration should be given to other user specifications or requirements, such as Port Authorities and Marine Parks, as these could also be met with little additional time, effort or cost (e.g. PPA, 2017, Lucieer et al., 2018). The data would then benefit more users and contribute to the National Seabed Mapping effort.

Regardless of the standards used, it is important to provide quality and uncertainty statements based upon calibration and validation evidence to ensure consistency. These should be quantitative statements where numerical analysis is conducted e.g. TVU = +/-0.1m, THU = +/-1.0m.

2.3.5 Platforms & Systems

Seabed mapping can be conducted from a variety of platforms, including ships, which can have hull or pole-mounted systems, towed-platform or automated underwater and remotely operated vehicles (AUV and ROV respectively). While this guideline provides information that applies to any platform, this section only provides general information on the various platforms and does not address the specific requirements of each. Refer to the material listed for more information.

2.3.5.1 Hull or pole-mounted systems

A hull-mounted system refers to a system fixed to the vessel, and is the most robust way to mount a transducer. However, due consideration must be given to the effects of acoustic interference and bubble sweep down over the face of the MBES transmit and receive arrays.

A pole-mounted system refers to a system fixed to the end of a pole, which is commonly fixed to the side or the bow of the vessel. They are commonly used for smaller installations, allowing for permanent or deployable mounting. Rigidity and minimisation of the vibration of the pole are key to acquiring good quality data. It is also recommended that where possible, the motion reference unit (MRU) be installed and ‘tightly coupled’ on the pole at the transducer.

For deployable pole-mounted systems, it is important to consider that every time the system is deployed, there should be assurance that the system returns to exactly the same position in order to negate the requirement for another patch test. An operating check, which is less robust than a patch test but verifies the mount is returned to the correct position, should be conducted if the pole is reset. This may be as simple as performing cross perpendicular lines over a significant feature and analysing for incorrect alignments.

Regardless of which method is used to deploy the swath system, it is important to understand the negative impact of vessel hull, machinery noise and bubble sweep down on the system. Care should be taken to install the transducers as far away from acoustic noise sources as possible and to ensure a smooth flow of water over the sonar(s) when the vessel is underway at the planned survey speed. Clients should be made aware that it is rarely possible to guarantee an acoustically silent installation on any vessel being used for the first time. Unfortunately, it is often a case of undertaking the installation and subsequently testing, before the suitability of the vessel and installation can be known.

This website provides additional information on various possible mounts and considerations. Note that the working group is not endorsing the company that this information is taken from.

2.3.6 Dimension control of sensor offsets

Dimensional control, otherwise known as a sensor offset survey, is essential to any seafloor mapping survey and needs to be reported (see section 3.2).

2.4 Project team

The project team should include personnel with relevant and adequate experience in swath acoustic instrumentation and survey requirements. These may consist of qualified people from various backgrounds, such as geophysicists, geologists, engineers, and hydrographic surveyors, but also increasingly includes marine ecologists and spatial analysts that manage seafloor mapping programs.

It is recommended that for all reports each team member should be identified and details provided on their qualifications/accreditations (including ORCID number for researchers, if available). This provides traceability and accountability for decisions and the data acquired. It is also highly recommended that a member of the team has completed professional training in the principles and operation of swath systems and provides evidence of recent field experience with swath acoustic systems.

2.5 Field survey instructions

2.5.1 Geodetic control and Horizontal Datum

Seabed mapping surveys conducted within the Australian EEZ shall be referenced to a geodetic reference frame based on the International Terrestrial Reference System (ITRS), e.g. ITRF 2014 (GRS80 Spheroid) during collection.

The Geocentric Datum of Australia 2020 (GDA2020, Figure 4) is being implemented to modernise the geodetic positioning, based on 1994 models (ICSM, 2018). Stage 1 of GDA2020 will be fixed to the epoch 2020.0 and Stage 2 (anticipated in 2020) will transition to a time dependent reference frame and will be known as the Australian Terrestrial Reference Frame (ATRF). Considering this upcoming change, it is thus a recommended practice to horizontally transform data to GDA2020 during processing and rendering. Specific information regarding GDA2020, including transformation parameters, can be found on GA's website.

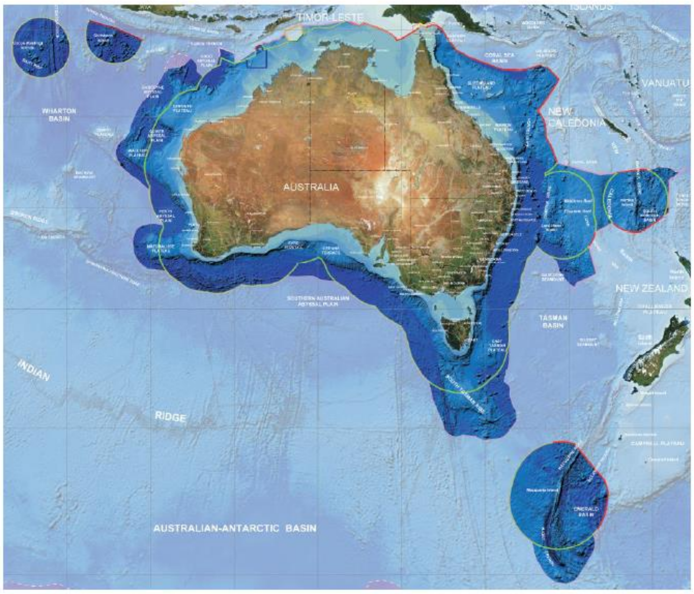


Figure 4 Extent of GDA2020 on the Australian continental shelf (Geoscience Australia)

Proposed Horizontal control should be reviewed for accuracy and if local control such as RTK base stations are to be used, then sites for local positioning systems should be determined. To establish shore-based geodetic control, refer to the procedures described in Intergovernmental Committee on Surveying and Mapping (ICSM, 2014a-c).

Grid positions shall be referenced to the Universal Transverse Mercator (UTM) Grid.

2.5.2 Tidal or ellipsoidal datum

The datum to which depths are to be reduced is fundamental to any seafloor mapping survey. Many datum can be used (Figure 5), but the common datum are the ellipsoidal or tidal chart datum (sections 2.5.2.1 and 2.5.2.2). While mapping however, the sounding datum should be used.

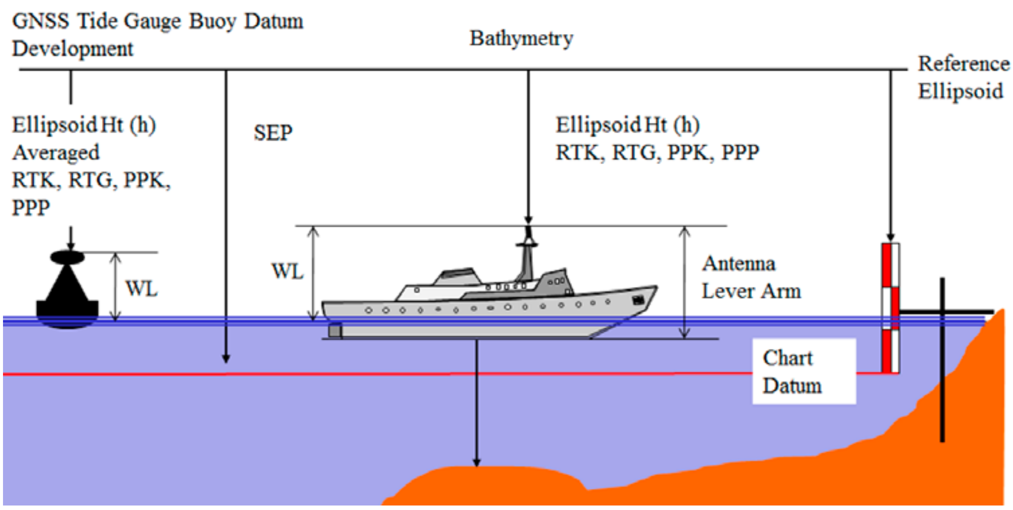


Figure 5 Schematic of datum and associated reduction information (Mills & Dodd, 2014)

Regardless of the datum used for the final products, the following points need to be considered:

- direct tide from the GNSS (GPS tide) should be recorded
- all data should be acquired in WGS84 or ITRF (equipment-dependant), and reprocessed in ITRF
- all raw GNSS observations should be kept to allow post-processing
- all efforts should be made to improve positions to the highest accuracy possible, and post-processing will usually also improve horizontal positioning and minimise heave artefacts.

Typically, post-processing would involve:

- offshore: Precise Point Positioning (PPP) corrections using the final International GNSS Service (IGS) products
- coastal regions: kinematic post processing against land based fixed GNSS base stations, either permanent or deployed.

Transformation to the required 'publication datum' can be made after this process but retains the benefits of being connected to the global datum. These transformations can be done using AusCoastVDT, which is a free software tool with a blanket accuracy of ± 0.5 m for MSL to LAT reductions. AusCoastVDT was developed by the Intergovernmental Committee on Surveying and Mapping (ICSM), a collaboration between the Australian states, defence force and New Zealand. Note that geoid models are terrestrial products and using these for marine data transformation should exercise caution as geoid models are not thoroughly tested for marine uses. Further information can be found here.

2.5.2.1 Ellipsoidal Datum

With the advancement of modern GNSS positioning systems and post-processing methods, ellipsoidal datum connections can be employed as an alternative to the established Lowest Astronomical Tide (LAT) or chart datum (CD) connections. The GRS80 ellipsoid vertical reference surface has benefits to scientific and environmental disciplines with a consistent surface separation of seafloor features globally.

When used in conjunction with GNSS connected/levelled tide gauge data, connections to CD/LAT can be estimated where required. For details on the issues of this method see "Ellipsoidally Referenced Surveying for Hydrography" (Mills and Dodd, 2014).

2.5.2.2 Tidal Datum

When surveying for the purposes of nautical charting, it is essential to have knowledge of local tides. In many areas around Australia, the tidal network infrastructure is sparse and additional temporary tidal infrastructure will be required. To acquire 'observed tide' from a tide gauge, a number of tide gauges will need to be installed depending on the tidal complexity of the environment, albeit it is desirable to have at least one gauge installed.

For specific advice regarding recommended tidal infrastructure for your survey area, please contact tides.support@defence.gov.au.

2.5.3 Sound velocity profiling

Sound Velocity Profiling (SVP) of the water column is essential to the acquisition of swath mapping data, and is used for ray tracing through the water column. SVP influences directly the accuracy and uncertainty of both the horizontal and vertical position of each sounding and its impact is greatest towards the outer beams of the swath (farthest sounding).

Physical processes such as fresh water influx, solar warming of the upper water column, presence of mesoscale currents, and storm mixing can affect the temperature and salinity profile, and hence the SVP. These changes can occur at various spatial and temporal scales and can sometimes be observed in the water column backscatter data.

Acquisition of SVPs must be planned with the relevant number and distribution of profiles, and monitored carefully. It is recommended to commence a survey area with frequent SVPs until the behaviour of the water column is understood and then reduce the time and spatial interval as required to maintain best quality depth data. It is recommended that SVPs are conducted with a minimum interval of 6 hours. If sounding is restricted to the daytime only then SVPs should be conducted at the beginning and end of the day as the absolute minimum, but this is not recommended. The SVP can be determined using one of the following methods:

1. direct observation via deployment of a SVP measuring device
2. calculation of SVP through deployment of an expendable bathy thermograph (XBT)
3. bar check
4. calculation of SVP using CTD (Conductivity/Temperature/Depth) data and applying the UNESCO formula or
5. calculation of SVP from sea surface temperature and climatology using SVP builder software (Sinquin et al. 2016).

2.5.4 Time and date

All digital data, field notebooks (logs) and samples should be set and recorded using the Coordinated Universal Time (UTC) and associated date.

For descriptive text used in reporting, the time zone should be clearly specified (AWST, ACWST, AEST).

2.5.5 Line planning

Survey line planning will vary based on the seafloor mapping objectives. However, the following minimum recommendations have to be taken into consideration:

1. Seabed topography: lines should be designed parallel to the general direction of seabed contours as much as possible for swath systems.
2. Depth range: the depth of the survey area changes the swath width and consequently the line spacing. Large areas should be divided into similar depth ranges so that the requirement to run in-fill lines is reduced.

3. Swath width (angle): depends on what type of swath system is used for the project (e.g. dual versus single-head MBES system), and hence the line spacing will differ. It is nearly always necessary to operate the swath system at less than published 'maximum' swath angles in order to improve the quality of the data collected and to improve the sounding density of the data collected.

4. Overlap: for full (100%) seabed mapping coverage, a minimum of 10% overlap of the good data swath (data meeting the 95% uncertainty level) is recommended. This will enable validation by comparison of the data acquired at the edge of each swath. For partial coverage, where possible, it is recommended to use line spacing that will enable a subsequent in-fill mapping effort to complete the mapping of the area.

5. Other requirements: acquisition of other sonar data, seabed and water column backscatter data (see below), etc. may dictate a different line spacing.

6. Regular checks: where there is an object of interest on the seabed detected in the survey, additional lines should be run to better delineate the feature and overall area.

7. Crosslines: crosslines are essential quality indicators, especially for data uncertainty management, and hence it is **highly recommended** to plan multiple crosslines.

   As a minimum, one cross line per "block" of data mapped should be acquired. Crossline(s) should normally be run first as this may highlight any problems with the tidal (or height) solution adopted for the project.

8. Turn data: consists of data that is recorded during a vessel turning from one survey line to the next. While data quality may not be at its best during turns due to poor MRU stabilisation, this data nevertheless provides new information that can be useful for some users.

   It is thus strongly recommended to record turns as a separate file and submit in a separate project post survey.

9. Transit data: consists of data generally acquired between port and the primary survey area and is used as "discovery" data. Data from transit or passage sounding, contributes significantly to the national good by increasing knowledge of our seabed, and oceanography.

   Transit data should be:

   a. logged whenever possible unless the sea conditions are deemed too bad

   b. collected over new ground, i.e. not where previously mapped

   c. recorded and identified as a separate file to the primary survey lines

10. File length: depending on the system used, the rate of data acquisition and data type being collected, the size of the digital file recorded will vary. To avoid data loss and facilitate data management, it is recommended that file size be managed and kept at < 500 Mb per line.

Where **seabed backscatter data is the primary objective** of the survey, the same recommendations as above apply with the following exceptions:

11. Incidence angles: overlap should be as the swath coverage but limited to incidence angles between 20 and 60 degrees (Figure 6; Lamarche and Lurton, 2017). This angle requirement is needed in order to compensate for the high variability of individual backscatter intensities (Gavrilov and Parnum, 2010; Kloser, 2017).

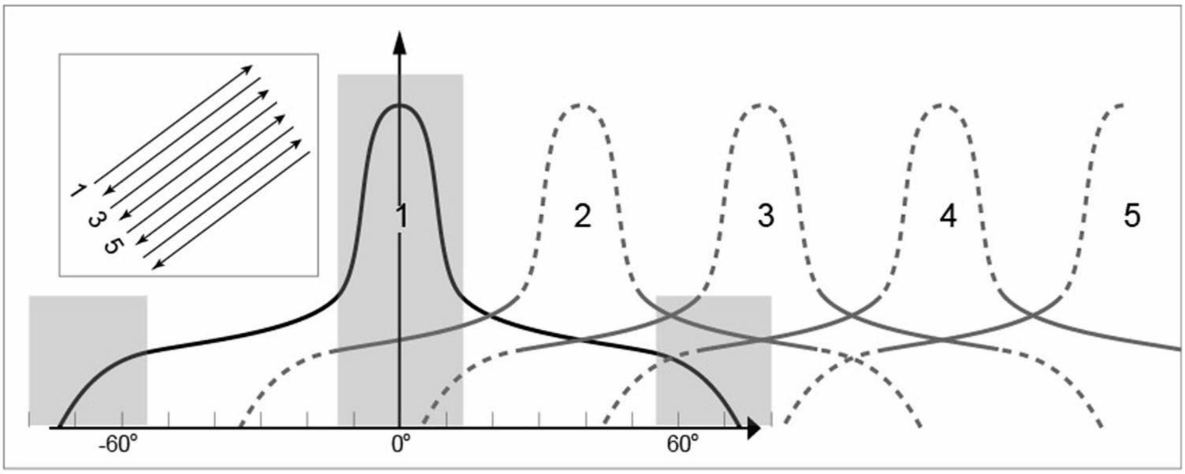


Figure 6 Diagram of ideal swath overlap (After Lamarche and Lurton, 2017).

12. Repeated seabed backscatter survey: For survey using the same swath system, it is recommended that the survey strategies, such as survey direction and orientations, and the system settings are kept identical. Frequency should also not be changed.

See section 4.3 which provides information regarding the project structure and nomenclature

2.5.6 Seabed samples

Seabed samples are often acquired during a seafloor mapping survey for various purposes, including seabed characterisation and seafloor backscatter data calibration. It is thus recommended that procedures outlined in the relevant chapters of the 'Field manuals for marine sampling to monitor Australian waters' (Przeslawski and Foster 2018) are followed.

This manual recommends sending the samples to Geoscience Australia for analyses, such as grain-size, carbonate content, and results will be delivered in MARS public database. This analysis of data contributes significantly to the knowledge of our seabed, oceanography, the national good and provides for other scientific research.

2.6 Submission of plan, data and notifications

See sections 2.1.3, 4.6, and 5.3.

3 Mobilisation, Calibration and Validation

Mobilisation refers to the process of combining multiple equipment sets (echo sounder, positioning system, motion reference unit & sound velocity instrumentation) into a single functioning high precision and accurate system. Calibration refers to the measurement and removal of systematic errors in all installed sensors. For most installations, errors mainly consist of small offsets and rotations between system components. Validation refers to testing calibrated systems against known controls by conducting multiple observations in order to provide an analysis of the repeatability, precision and accuracy of an individual or combined system.

3.1 Overview

Mobilisation must be done with care since compromise to any part of the integrated equipment set will increase the risk of degrading the whole system and can result in no capacity to correct or post-process the problem. Calibration and validation are vital to assess the performance of the installed system against survey specifications, particularly TVU, TPU and datum control, as elaborated throughout this section.

The mobilisation, calibration and validation process will vary between vessels. For example, a ‘vessel of opportunity’ commonly involves significantly more planning and setup time than permanently setup survey vessels. The steps below generalise the detailed processes outlined in the hardware and software manufacturer’s instructions for the deployed equipment. Specific information on some of the steps of the mobilisation, calibration and validation are included as a brief glossary in the following sub-sections.

Generalised steps for mobilising a vessel of opportunity:

1. During the pre-survey planning phase, attempt to source previous mobilisation reports for the planned survey vessel and equipment (even if from another vessel). This information will assist in understanding any engineering requirements or complications, thus saving downtime during mobilisation.

2. Ensure adequate resources are assigned for mobilisation of the swath acoustic system on the vessel of opportunity, which typically requires days (2-3 days), not hours.

3. Confirm vessel reference frame to be used along with offsets and keep records and diagrams by either organising a survey of the vessel or re-use the results of a recent one. This establishes the spatial layout of equipment and sensors relative to each other. The responsible seabed mapper should conduct QC on any offset report received from a third party or conducted by the team.

4. Make equipment structures as rigid as possible to ensure stable geometry. e.g. moon-pool, and/or over the side rigid mounts should return to exactly the same location when deployed.

5. Take care with the physical installation, particularly cable runs and joins, and account for vessel vibrations, vessel traffic, water ingress, power-stability (pure sine wave for inverters, earthing), etc. Consider under-keel and overhead clearances.

6. Minimise acoustic and vibration noise sources to acoustic sensors, IMU and electronics.

7. Check vessel sounder or engine vibration and noise over engine revolution range. Test a range of survey speeds for noise changes. Where possible check the swath systems performance at desired survey speed and sea state.

8. Check sky view of observed GNSS satellites in positioning system and minimise radio interference on GNSS antennas. Lost GNSS observations cannot be recovered.

9. Perform all manufacturer's self-tests and calibrations (positioning system, swath sonar, sound velocity instruments) to ensure validity of entire system. This includes a patch test (section 3.5)

10. Record all sign conventions and calibrated geometries of installed sensors (screen captures and reports; section 6.2).

11. Backup system and parameter files on a separate location (i.e. USB stick). It is also important for rolling back configurations when accidental, unknown system changes are made.

12. Preferably complete mobilisation and testing before leaving port for the survey area.

13. Check tidal observation equipment for connections to local tidal datum if required.

14. Double check all geodetic parameter settings in positioning and acquisition systems for consistency. Ensure no undesired/undocumented transformations are taking place.

15. Consider processing capability on vessel for near real-time assessment of acquired data.

16. Confirm on-board vessel storage has enough capacity to capture all required raw data, including backup strategy.

17. Discuss planned survey lines with vessel master, survey ground sea-states, forecast weather and implication for survey plan. Communication strategies between swath system operator and helm (including installing swath system helm display).

18. Describe the equipment and actions undertaken on the vessel before, during and after the survey to form part of a 'mobilisation and calibration' report to be submitted along with the data (section 6.2).

3.2 Dimensional control

This is the process of establishing the spatial relationships of the mounted equipment locations on the vessel. This includes the physical vessel offsets (section 3.2.1) and angular rotational offsets (section 3.2.1.2) of the installed equipment, and the integration of them into the complete swath acoustic system. All recommended calibration and alignment procedures specified in the manufacturer's equipment manuals should be carried out. These measurements are validated and refined during the patch test process.

3.2.1 Physical offset survey

Establish the physical offsets of the installed equipment to permanent locations or marks on the vessel (Figure 7). This is achieved by adding equipment specific offsets to the previously carried out static (slipped) vessel system offsets survey or via surveyed measurements to the installed equipment. Preferably offsets should be known with centimetre level uncertainties or better to establish spatial relationships between soundings and external earth reference frame (WGS84, ITRF) via the GNSS equipment installed on the vessel.

It is important to note that the systematic errors and uncertainties associated with this control will feed directly into the overall quality of the data and will greatly increase with water depth. Acquiring accurate data ensures the long term benefits that accompany the “collect once, use many times” mantra. For more information, refer to Hughes-Clarke (2003).

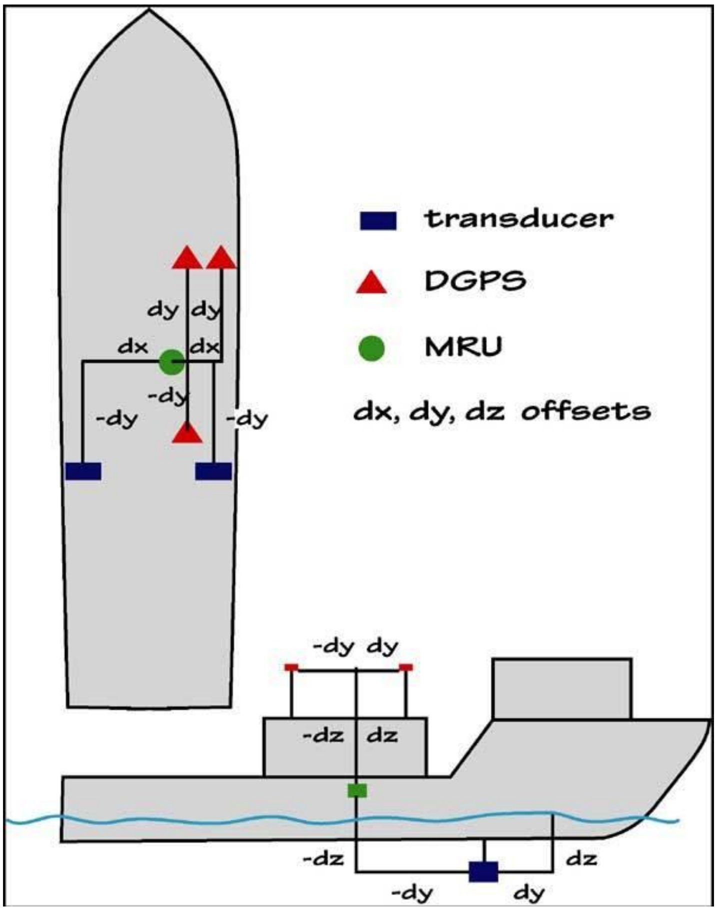


Figure 7 Diagram of dimensional control for MBES system (After Gardner et al., 2002)

3.2.2 Rotation offset survey

A rotation offset survey checks the alignment of individual equipment relative to the vessel’s reference frame.

Establish all known rotations (angular offsets between the vessel and the reference frames of the installed equipment) for each equipment set. The offsets between rotational frame conventions (if any) of each equipment set should be accounted for as part of this process and recorded in the mobilisation, calibration and validation report (section 6.2). If equipment rotations (physical measurement) are known separately to calibrated rotations (patch test) and applied as such in the acquisition software, these details should also be included in the report.

Rotation offset survey is normally associated with permanently-installed systems.

3.3 Horizontal positioning

It is recommended to use a tightly coupled GNSS-Inertial system comprising of dual GNSS antennae and IMU integrated system that is tested. The GNSS-Inertial system has to be calibrated and validated prior to the commencement of the survey as this is critical to detect and correct setup errors, and estimate uncertainties. This process involves both static and dynamic validation if possible:

Static validation of GNSS positioning equipment involves verifying the performance of the system against a known reference position. This should be preferably done using land survey methods, however should a known reference point not exist near the point of mobilisation, points may be established and should be in accordance with ICSM (2014a-c).

Dynamic validation or confidence checks involves carrying out dynamic comparisons between positioning systems (where more than one system is mobilised). These dynamic calibrations should be performed regularly and whenever any component or changes to the vessel positioning systems or setup are made.

Validations may include:

- alongside checks using baseline and offset measurements to vessel datum points while logging on acquisition system.
- check of independent positioning system mounted on vessel with known offset to transducer and on-board primary positioning system. Vessel records of all systems while conducting a box, then perform comparative analysis between logged system data and the independent positioning system. The least preferred method is to conduct this while static, but this may be the only operational option.

Setting up positioning systems to transmit data to the swath system topside at a frequency of 1 Hz is adequate for most scenarios.

3.4 Vertical positioning

3.4.1 Depth validation

Depth validation should be done once the patch test (section 3.5) has been performed. The system should be used to run a series of parallel and perpendicular sounding lines over a reference bottom surface where the depths have been previously determined and verified with an independent system of known accuracy.

If none of these comparative methods are available, then a “bar check” can be undertaken understanding that the results will not be as accurate as the precedent methods. The results obtained by any of the methods should compare favourably and be within the accuracy requirements of the survey.

Prior to sailing, a lead line observation may also be conducted.

3.4.2 Settlement and squat

Settlement occurs once the vessel is in a constant transit and is a vertical displacement which is constant at a given speed through water. Squat is a relationship between depth of water and speed through water.

All vessels are subject to settlement and squat, and measurements of these parameters should be made wherever practically possible by the most appropriate validation method. Ideally tests should be performed at various vessel speeds over a flat bottom using RTK GNSS or orthometric levelling heights at the transducer location. The heights should be measured at rest and then in increments of vessel speed with RPM noted, and then used to derive an appropriate squat/settlement table. A squat table is not necessary when using ellipsoidal reduction methods, however, should you need to revert to sounding reduction by tide, a table is best practice.

3.4.3 Vessel draft

Vessel draft may be difficult to measure. However, it is possible to approximate distance from arbitrary reference points to the waterline before and after a survey as this is likely to change with fuel consumption. For validation, the vessel draft should be derived using quantitative measurement methods as for section 3.4.2 (Settlement and squat).

3.4.4 Sound velocity

To ensure proper calibrated sound velocity reading, at least one probe (SVS or SVP) needs to be independently calibrated. Use a comparative method to validate other sensors (SVS at head and SVP). Assess speed of sound at the swath sonar head against SVP at same depth below surface. Where possible, compare SVP readings with external sensors (e.g. derived sound velocity from CTD).

3.4.5 Tidal station

For shallow inshore work (<30m), water level tidal observations, including local environmental affects, should be conducted for a minimum period of 35 days. If this is not possible, predictions based on tidal constituents may be used and in this instance tidal station should be installed and calibrated as directed by ICSM (2004).

3.5 Patch test

The patch test confirms timing and alignment of the MBES sensor, vessel and IMU reference frames. It is essential to execute the standard patch test method as appropriate for sensor type (single or dual-head) and vessel (Appendix F). A patch test should be conducted at the beginning of the field season or whenever a piece of equipment is replaced or repaired and has to be undertaken once the calibration for the GNSS inertial system is complete (section 3.3). The results of the patch test should be reported in the Mobilisation and Calibration Report (Appendix H).

3.6 Seafloor backscatter calibration

Lamarche and Lurton (2017) provide a comprehensive review of seafloor backscatter from data acquisition to processing. Calibrated seafloor backscatter is essential to enable comparison of data acquired by various systems. There are two types of calibrated backscatter: absolute and relative backscatter.

Calibration is executed through the use of reference areas of known seabed types (preferably flat, smooth, and geologically and acoustically homogeneous areas). Use roll lines of the patch test (no need to rerun for backscatter) and list overlap (for backscatter quality survey). For systems with multiple transmitting sectors it is recommended that the average backscatter level be consistent across all sectors and for different modes.

It is also recommended that sediment samples and/or imagery samples be taken from the area to ground truth and calibrate backscatter data. As part of a sea-acceptance test practice, an overall calibration must be performed once the sonar system has been installed on the vessel. This involves both the customer's technical team and operators.

3.7 Water column backscatter calibration

Calibration of water column data is desirable into the future and is best acquired if available on system. The same procedure for seabed backscatter calibration should be applicable for the water column backscatter calibration. While it is not practical to use the sphere calibration technique, inter-calibration with a calibrated fisheries single-beam echo sounder through the use of reference areas (Demer et al. 2015; Foote et al. 1987). This at least provides insurance of self-consistency.

3.8 Built-in systems test

Built-in test, such as built-in systems test (BIST) or built-in test environment (BITE) is a test of sonar head communication with software controllers and is useful for the validation of communication between systems. It becomes integral when trouble shooting and should be logged. It is recommended that, at a minimum, a BIST be done at the start and end of the mapping. The results should be reported in Mobilisation and Calibration Report (section 6.2).

3.9 Final acceptance test

A final check should be performed to ensure that all the equipment is working properly and that the logging systems are operating correctly. Care should be taken to ensure depth, position and if necessary water level values are being logged correctly. The positioning system should be checked for operation and periodically throughout the survey.

4 Acquisition

4.1 Survey plan

Acquisition of the swath acoustic data should follow the pre-survey plan discussed in section 2, unless the on-board seabed mapping lead decides otherwise based on the environmental situation and new information at-hand, which are difficult to account for in the planning stage. It is recommended that any changes to the acquisition plan are captured in the ROS (section 6.3). Wherever possible, nearing the conclusion of data acquisition, a review of data coverage is highly recommended and infill lines conducted to ensure there are no gaps in the bathymetry, as this impacts the suitability of the data for end use. Additional lines over significant shoal features are also recommended to ensure good density of soundings and determination of least depth. For efficiency, such lines may be conducted concurrently to other activities such as during transits or seabed sampling. Emphasis here is put on the system settings and other specifics that were not recommended in section 2, especially section 2.5.

4.2 Project structure and nomenclature

Although the project structure and nomenclature is specific to the project, it is recommended that the following be considered to facilitate data submission and interoperability:

- project structure:
    a. reports
    b. tides
    c. QA DataPack
    d. products
    e. raw data (see 2.3.1)
    f. processed data
    g. backscatter
    h. WC data
- file naming convention should be sequential, include timestamp and system type, e.g. nnnn_yyyymmdd_hhmmss_system, where: nnnn is the sequential number; yyyymmdd is the date; hhmmss is the time
- use the Seabed Survey Data Model (SSDM) to plan seabed mapping expeditions and submit plans and data (section 2.6).

4.3 Systems settings

System settings should depend on the purpose of the seafloor mapping and the data types that are being recorded.

4.3.1 Bathymetry

While acquiring data, the power, pulse width and gain need to be monitored and adjusted during the course of the survey to ensure good bathymetry. For high resolution/high frequency operations a short pulse width is desirable. As water depth increases, longer pulse widths will become necessary.

4.3.2 Backscatter

While acquiring bathymetry data, it is also important to consider the following minimum recommendations to ensure backscatter data quality:

- Minimise constant saturation of the seabed backscatter signal. This can be done by monitoring the waterfall plot or the signal trace.
- Minimise the changes in settings to prevent artefact in the resulting backscatter products.
- Monitor and record the environmental parameters controlling sound speed and absorption within the water column, and weather conditions.

Further details about best-practice for backscatter data acquisition in Lamarche and Lurton (2017).

4.3.3 Transit data

It is recommended that the system settings during transit data acquisition be set to maximise data quality by considering the overall characteristics of the transit rather than maximise data coverage or swath width. Refer also to section 2.5.6.

Unless a deep water CTD or XBT cast is available throughout the transit and when water depth is greater than 200m, a generic SVP tool, such as the Hydroffice Sound Speed Manager tool can be used to improve profiles. Should no SVP option be available, the sound velocity should be set to 1500m/sec.

4.4 Ancillary systems

4.4.1 Sound velocity Profile

It is recommended that:

- for shelf water (< 200m water depth), at least one SVP be conducted every 24 hours. However, every 6 hours would better align with Bureau of Meteorology (BOM) weather reporting requirements
- for "off the shelf" survey (> 200 m), SVP may not be necessary daily, but monitoring of the SVP is still recommended as per point below.

- SV be constantly monitored and SVP be collected if visual changes are observed in the acquired swath (e.g. frown or smiles), or the SV vessel probe indicate greater changes than 2 or 3 m/s at the sonar head for a consistent period of time.

Note that SVP for all depths are also highly valued by other types of users, such as oceanographers and ecologists. To further accommodate such users it is recommended that SVPs are also collected during deployment and retrieval of deep-tow systems, ROVs and AUV.

4.4.2 Tides

During a survey, acquisition of GNSS tide (ellipsoidal height of the vessel minus the geoid model at the same location) can be monitored; however, it is difficult to monitor tide gauges unless regular download of the data is undertaken. Therefore, for GNSS tides acquisition, it is recommended to:

- ensure that all the bathymetry files include GNSS height, otherwise GNSS tides will be computed to less than 10 cm vertical accuracy.
- use an updated Geoid model (e.g. AUSGeoid2020) keeping in mind that this model is unsuitable offshore.
- acquire the delayed heave from the MRU without gaps and ensure that the bathymetry data has a complete delayed heave coverage applied.
- compute GNSS tide for all the files.

During the survey, data QC should be done using predicted tides from the Bureau of Meteorology (BOM) for standard ports or AusTides for secondary ports. Refer also to section 2.5.2.

4.5 Monitoring, QA/QC & Data backup

During a survey the following information should be constantly monitored, including:

- depth
- vessel draft
- GNSS (see section 4.5.1) or subsea positioning for sub-sea platform
- motion sensor
- sound velocity
- backscatter consistency and saturation
- overlap
- data density

To ensure safe data backup and submission (section 5.3), it is recommended that multiple copies of the data be made and transported separately.

4.5.1 GNSS positioning

Most seafloor mapping and GNSS software provide real-time monitoring capabilities. The quality of the GNSS should be monitored while mapping to ensure that the horizontal positioning falls within the seafloor mapping specification. Any deviations outside of the survey specification should be noted and included within the ROS (section 6.3). Maintaining a minimum QC requirement will provide data that is interoperable with many providers and uses. This integrity information includes (LINZ, 2016):

- Sigma values or semi-major axis of the positional error ellipse are not to exceed 3.5m at the 95% confidence level.
- The DGNSS correction age is not to exceed 10 secs.
- PDOP is not to exceed 6 for recording and continued sounding. If PDOP is greater than 7 then surveying is to be halted until it improves.
- The minimum number of observable healthy satellites being tracked during survey operations is to be 5.
- The minimum elevation for SVs is to be 10° above the horizon.

4.6 Mandatory notifications

4.6.1 Dangers found – hydrographic notes

It is imperative that any feature found, which may be a potential navigational hazard to vessels, is reported to the AHO by hydrographic note (AHO, AH102) and if an immediate danger exists, Joint Rescue Coordination Centre (JRCC) Australia (AMSA). Once danger is reported and received by these agencies, the following agencies assume responsibility for further reporting to mariners. Should reports not be lodged and an incident occurs, liability may be passed on to operators who failed to notify dangers during operational activities.

4.6.2 Underwater cultural heritage notification

Thousands of historic ship and plane wrecks are known to exist within Australian waters, although the locations of many of these remain unknown. Information about known shipwrecks can be found using the Australian National Shipwreck Database. Notifying relevant State and Commonwealth management agencies, when underwater cultural heritage sites are discovered, will greatly assist these organisations to manage fragile and irreplaceable resources (Table 5). Notification of underwater cultural heritage finds is also a legal requirement under the *Historic Shipwrecks Act 1976* (Cth) (HSA) and state heritage protection legislation (see section 17 (1) of the Act).

A notification report should include a snap shot of the scan image, coordinates, water depth and a brief description of the site giving dimensions of the object.

Table 5 Contact details of management agencies to notify for wrecks

Commonwealth: Historic Heritage Section Department of the Environment and Energy GPO Box 787 CANBERRA ACT 2601 Tel: (02) 6274 2116 Website: www.environment.gov.au/heritage/historic-shipwrecks	**Northern Territory**: Heritage Branch Department of Lands, Planning and the Environment GPO Box 1680 DARWIN NT 0801 Tel: (08) 8999 5039 Email: heritage@nt.gov.au Website: www.dlp.nt.gov.au/heritage/maritime-heritage
Commonwealth: Great Barrier Reef Marine Park Authority Heritage, International and Governance Project Manager, Maritime Cultural Heritage GPO Box 1379 TOWNSVILLE QLD Tel: (07) 4750 0618 Email: info@gbrmpa.gov.au Website: www.gbrmpa.gov.au/	**South Australia:** State Heritage Unit Department for Environment, Water and Natural Resources GPO Box 1047 ADELAIDE SA 5001 Tel: 08) 8124 4960 Email: DEWNRheritage@sa.gov.au Website: www.environment.sa.gov.au/our-places/cultural-heritage/Maritime_heritage
Queensland: Heritage Branch Department of Environment and Heritage Protection GPO Box 2454 BRISBANE QLD 4001 Tel: 13 74 68 Email: info@ehp.qld.gov.au Website: www.qld.gov.au/environment/land/heritage/archaeology/maritime/	**Tasmania:** Historic Heritage Parks and Wildlife Service GPO Box 1751 HOBART TAS 7001 Tel: 1300 827 727 Email: mike.nash@parks.tas.gov.au Website: www.parks.tas.gov.au/index.aspx?base=1729
New South Wales: Heritage Division Office of Environment and Heritage Locked Bag 5020 PARRAMATTA NSW 2124 Tel: (02) 9873 8500 Email: heritage@heritage.nsw.gov.au Website: www.environment.nsw.gov.au/maritimeheritageapp/WebsiteSearch.aspx	**Victoria:** Heritage Victoria Department of Planning and Community Development GPO Box 2392 MELBOURNE VIC 3001 Tel: (03) 9938 6894 Email: heritage.victoria@delwp.vic.gov.au Website: www.dtpli.vic.gov.au/heritage/shipwrecks-and-maritime
Norfolk Island: Norfolk Island Museum Kingston NORFOLK ISLAND 2899 Tel: (0011) 672 323 788 Email: admin@museums.gov.nf Website: http://norfolkislandmuseum.com.au/exhibitions/hms-sirius/	**Western Australia:** Western Australian Museum Maritime Archaeology Department 45-47 Cliff Street FREMANTLE WA 6160 Tel: (01) 300 134 081 Email: reception@museum.wa.gov.au Website: http://museum.wa.gov.au/research/research-areas/maritime-archaeology

5 Processing, rendering and submission

5.1 Data processing

5.1.1 During survey

Processing during a survey should at a minimum be done to QC the data, both bathymetry and backscatter data. QC includes:

- checking for artefacts
- consistency of seabed backscatter
- meeting the required specifications, e.g. data density

A processing log should be kept.

5.1.2 Post-survey

Post-survey processing should include:

- reduction of sounding to appropriate vertical datum (observed or post-processed GNSS tides).
- application of SVPs and refraction correction applied (where allowed).
- data cleaning, which may vary depending on the purpose of the survey.
- data QA using crosslines (if collected). If specific crosslines are not collected, consider using transit lines that crosses main survey lines (e.g. data acquired while going to a sampling location).
- TPU calculation for each sounding (section 5.2).

See also section 10 of AHO, 2018 for more information on processing.

5.2 Total propagated uncertainties (TPU)

The total propagated uncertainty (TPU) for each sounding should be computed and included in the data submission (Section 5.3).

The TPU is the combination of the total horizontal uncertainties (THU) and the total vertical uncertainties (TVU) of that sounding (Appendix E). THU is a 2-dimensional quantity in the horizontal plane and is assessed only after the GNSS-Inertial system has been calibrated. TVU is a 1-dimensional quantity in the vertical dimension. TPU is not a linear addition of uncertainties in each system's component. It is a propagated combination of uncertainties for the non-linear set of equations comprising the integrated swath acoustic-GNSS Inertial system.

Uncertainty calculation is best addressed using most internationally accepted statistical models for determination of TPU, which are derived from Hare et al. (1995). Current international best-practice statistical model for resolving the system of equations is the Combined Uncertainty Bathymetric Estimator (CUBE). The average horizontal and vertical TPU estimates determined by the software for a range of water depths is provided with respect to the IHO S-44 standard for position and depth accuracy in Table 6. The following link also provides assistance in understanding and calculating TPU.

Table 6: Example Sounding Accuracy - TPU (calculated at 1σ, but most software computes at 2σ)

Depth band (m)	0-5	5-20	20-50	50-100	100-200
Position Accuracy (m)					
IHO Standard	5.25	5.50	6.00	6.50	7.25
TPU Estimate	0.27	0.27	0.30	0.34	0.42
Depth Accuracy (m)					
IHO Standard	0.38	0.39	0.44	0.50	0.63
TPU Estimate	0.27	0.27	0.28	0.31	0.35

5.3 Data Submission

5.3.1 Final QA/QC

The final QA/QC checklist for data acceptance includes:

- Vessel configuration file for the survey is updated with the latest information received from the survey acquisition report. Ensure to not apply the calibration values twice, i.e. in the acquisition and processing software.
- If appropriate, accurate tide file was loaded to the whole survey/dataset.
- All ancillary systems, SVP, true heave, etc, are applied and if not, these should be noted in the survey report or logs.
- SV artefacts were applied where necessary and noted in processing report.
- Any other surface artefacts, e.g. resulting from calibration errors have been addressed.
- Random errors (ambient noise) have been removed using Filters/CUBE or manual techniques.
- Two images (eg. Geotiff) of the gridded bathymetry data using sun-illumination from two orthogonal directions and five times exaggeration are included. Where possible, deliver an image of the backscatter mosaic. These are used to quickly assess the data quality.

5.3.2 Submission

At the time of writing these guidelines there is not currently a complete repository for swath acoustic data collected in Australian waters. However, several agencies house specific survey data (e.g. AHO, GA, IMOS) and promote their accessibility and visualisation in various ways. Initiatives led by

AusSeabed are underway for a single repository to be linked to appropriate visualisation platforms, and this is expected to be addressed in Version 2 of these guidelines (Update of present and future workflow can be found here).

In the meantime, following the interim steps listed below will ensure timely release of data and maximise data discoverability (Figure 8):

1. Send copies of raw and processed (if available) swath data files (section 2.3.1) and all records (section 6) generated during the survey to GA using hard drives or via another secure, publicly accessible online repository. Inform GA (ausseabed@ga.gov.au) and AHO (datacentre@hydro.gov.au) of the submission. If hard drives are used, they will be returned to sender within 2 weeks.

2. Create metadata record(s) describing the survey and data collection (section 6.1).

3. Publish metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QC-d. This can be done in one of two ways:

   - If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.
   - Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.

4. Generate interactive map imagery of the following derived data layers:

   - Location map with limits of the survey area;
   - Bathymetric map showing the depths, slope and bathymetric hill shading results;
   - Location of auxiliary data sampling (point features of sediment grabs); and

5. Add links to the location of raw data and derived map imagery to the previously published metadata record. Metadata accompanied by map imagery as described above may be additionally showcased through the AODN portal.

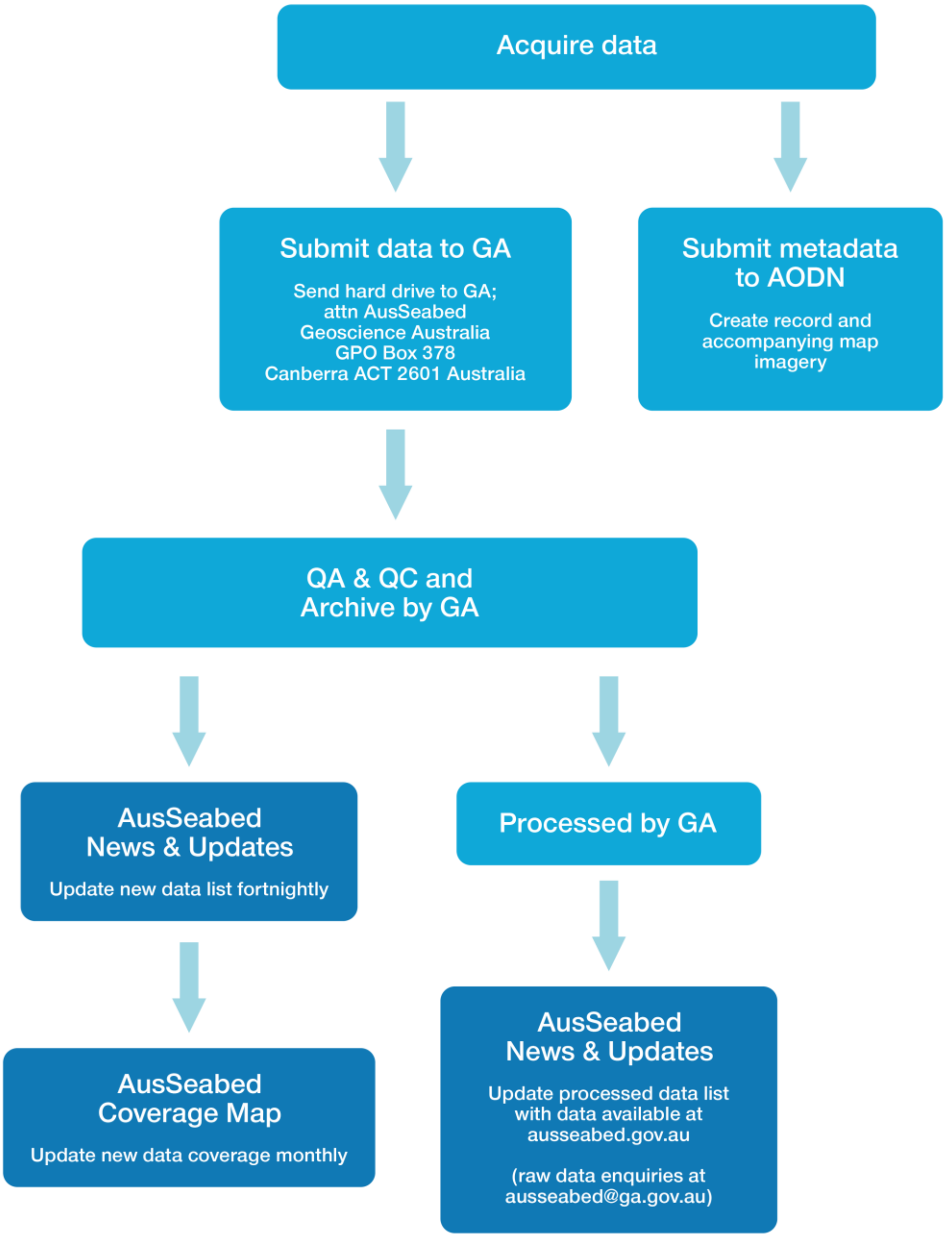


Figure 8 Interim submission workflow for data that can be submitted to GA. If your data is submitted and archived elsewhere, consider submitting your survey coverage to GA. The submission workflow is intended to be automated in the long term as we progress AusSeabed initiatives.

6 Reports

In order to ensure consistent documentation of all aspects of survey planning, mobilisation, calibration and acquisition, all information (reports and logs) should be recorded throughout the process. At a minimum, metadata (section 6.1), records for Mobilisation, Calibration and Validation (section 6.2), and records of survey (section 6.3) are recommended. Details of these are provided in the following sections and proposed templates in Appendix H.

6.1 Metadata

All types of vessel, survey, swath acoustic system, ancillary data and equipment deployed should be recorded in the metadata. At a minimum, these should include (also in line with IHO S44 minimum requirements (IHO, 2008)):

- data owner
- surveyor in charge and qualifications / certifications
- survey area
- survey start date
- survey end date
- vessel name
- operator(s)
- geodetic parameters
- line plan
- equipment list
- level of standards expected or achieved
- additional data (samples, videos)
- sound velocity profile being used and refraction applied
- tidal data used (if any)
- MBES data types and explanation why not collecting a type

As noted in the previous chapters, there are a large number of specific survey, calibration and acquisition parameters that need to be recorded to ensure complete documentation of the full process. These are categorised and detailed in the following sections.

6.2 Mobilisation, calibration and validation records

Methodology and results of the mobilisation and calibration should be outlined in the mobilisation and calibration report, and the associated records created using templates provided in in Appendix H.

6.2.1 Logs

Mobilisation and calibration logs should include:

- tests survey lines, including patch test and final acceptance test
- SVP deployments (Filename, Time, Lat, Long, Depth, SV sonar head reading (used for comparison)
- squat and draft tables

6.2.2 Report

Mobilisation and calibration report should document the integrated survey system, methodology, raw results and processed results, i.e. once the calibration is accepted. At a minimum, it is recommended to include the following (modified from AHO, 2018) and if needed, Appendix H provides a template:

Report Heading:

- seabed mapping survey title and associated reference number
- mapped by (agency/company/etc and Seabed mapping lead)
- dates of mapping
- mobilisation, calibration and validation report
- version
- date of the report

Introduction: includes an overview of the procedures conducted for the installation and calibration of equipment that comprise the seabed mapping system (SMS).

- Background and outline of events: a narrative giving an overview and timeline for the set-to-work of the survey platform(s).
- Platforms: a description of, and justification for, the survey platforms chosen to undertake the survey.
- Geodetic controls: geodetic parameters for the control survey, station diagrams and descriptions outlining the Geodetic control utilised for the survey.

Equipment: summary of equipment that forms the SMS as installed on the survey platforms, including all relevant offsets and calibrations.

- Hardware: summary of the hardware relating to data acquisition including manufacturer, model and serial number is to be tabulated.

- Software: summary of the acquisition and processing software, including version numbers is to be tabulated.
- Sensor mounting systems: a description of the mounting system utilised for data acquisition is to be provided, e.g. pole mount, gondola, moon pool etc.
- Sensor offsets: the measurement method and results for the dimension control that determine the relationship between the measurement sensors and the platform CRP are to be provided. Sensor offsets may be annexed to the report.
- MRU heading checks.
- Built-in test results (eg. BIST, BITE).

Underway calibration: the checks and calibrations of platform when underway are to be outlined. These may include:

- acoustic sensor bar checks
- draft, settlement and squat
- primary and secondary positioning
- patch test; the method undertaken, and results of the patch test for the pitch, roll and heading bias are to be calculated and rendered
- reference surface (if performed): difference statistics between manoeuvring lines and the reference surface are to include; beam number; mean, maximum and minimum differences and standard deviation
- target detection (if performed): the ability of the SMS to meet the target detection criteria of the specified order are to be demonstrated
- acoustic interference check (if performed): results of the pre-survey acoustic interference check are to be rendered

6.3 Records of Survey

This section includes logs that should be used during acquisition of data as well as information required in the ROS provided at the end of the survey. This section also points to legal notification requirements in regards to Dangers found (section 4.6.1) and Underwater Cultural Heritage (section 4.6.2). Templates of the reports and logs can be found in Appendix H for a summary of minimum requirements and in the IHO M-13 Manual on Hydrographic Surveying for a comprehensive report.

6.3.1 Logs

Survey logs should include:

- relevant information on survey lines, including data types recorded and daily events. Minimum parameter requirements found in Appendix H.
- system parameters relevant to backscatter data acquisition include:
    - environmental parameters controlling sound speed and absorption within the water

  - column
  - weather and sea conditions
  - backscatter intensity
  - source level
  - pulse length
  - transmit beam patterns
  - receive beam patterns
  - receiver time varying gain functions
  - path length attenuation characteristics (spherical spreading and absorption co-efficient)
  - seabed grazing angle

- SVP deployments (filename, time, lat, long, depth, SV sonar head reading (used for comparison)

- log for additional data collected, such as seabed samples (section 2.6)

6.3.2 Report

The report of survey (ROS) should give a comprehensive account of how the seabed mapping survey was carried out, the results achieved, and any difficulties encountered. A template can be found in Appendix H, but at a minimum, it is recommended to include the following (modified from AHO, 2018):

Report heading:

- seabed mapping survey title and associated reference number
- mapped by (agency/company/etc and seabed mapping lead)
- dates of mapping
- report of seabed mapping
- version
- date of the report

Introduction:

- dates: give start and end dates with activities that took place during the survey, especially where swath acoustic data was acquired while executing other activity (transit and sampling)
- map: give general map of where the data was collected, including coordinates of coverage
- setting conditions: general statement on weather and sea conditions as these are essential to understand data quality. Provide also information on oceanographic conditions which explain SVP frequency
- completion: comment on completeness of the survey, including opinion in regards to coverage and line spacing, and MBES data type recorded

Standards:

- local datum epoch and transformation parameters: provide a table with the relevant information that was used within the acquisition software. In addition, all software used on the survey must contain the correct datum parameters and this should be checked independently and evidenced here.

- horizontal and vertical accuracy: the following section confirms that the horizontal and vertical accuracy of soundings acquired during the Survey *Name* seabed mapping survey are compliant/non-compliant with the (IHO/LINZ/Other) standard for position and depth accuracy
- TPU: comment on TPU in reporting relative to various industry standards and provide a Table (see example Table 5 from section 5.2) with a detailed analysis of the TPU estimates for the relevant depth bands mapped for the project, using *name of software*

Seabed sampling:

- method: describe method used and problems with equipment or recovery of the samples, state sampling interval and any particular samples obtained from interesting features, state the number, plan for analysis and submission of samples

Tides and sounding datum (see section 13.4.1.9 in AHO, 2018)

Wrecks and danger found:

- Provide a table with any notifications made in accordance with legislation (section 4.6)

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Appendices

Appendix A – Abbreviations

Table A1 Abbreviations used in this document.

AHO	Australian Hydrographic Office
AUV	Autonomous underwater vehicle
BIST	Built-in Systems Test (Kongsberg specific)
BITE	Built-in test environment (Reson specific)
BM	Benchmark
CD	Chart Datum
CTD	Conductivity / Temperature / Depth
CRP	Common Reference Point
DGNSS	Differential Global Navigation Satellite System
DOP	Dilution of Precision
GA	Geoscience Australia
GNSS	Global Navigation Satellite System
GPS	Global positioning system
HAT	Highest Astronomical Tide
ICSM	Inter-Governmental Committee on Surveying and Mapping
IHO	International Hydrographic Organisation
IMU	Inertial motion unit
ITRF	International Terrestrial Reference Frame
LAT	Lowest Astronomical Tide
LINZ	Land Information New Zealand
MBES	Multibeam Echo Sounder (inclusive of interferometric bathymetric swath systems)
MHHW	Mean High High Water
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
M	International Nautical Mile
MRU	Motion Reference Unit
MSL	Mean Sea Level
PPK	Post Processed Kinematic
PPS	Pulse Per Second
QA	Quality Assurance
QC	Quality Control
ROS	Report of Survey
ROV	Remotely operated vehicle
RTK	Real Time Kinematic
SD	Sounding Datum
SIC	Seabed mapper in Charge

SMS	Seabed Mapping System
SO	Special Order
SV	Sound Velocity
SVP	Sound Velocity Probe or Sound Velocity Profile
SVS	Sound velocity sensor
THU	Total Horizontal Uncertainty
TPU	Total Propagated Uncertainty
TVU	Total Vertical Uncertainty
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
WGS-84	World Geodetic System 1984
XBT	Expendable Bathythermograph

Appendix B – Glossary

Below are some of the terms used in this guideline. However, more terms and definitions can be found in Table 2.1.2 of AHO, 2008.

% Overlap: refer to the amount of overlap between adjacent swaths. 0% overlap means that the ship tracks are run so that the outer beams of the swath meet the outer beam of the adjacent swath (Figure B.1). 100% overlap means that the adjacent ship track is run along the outer beam edge (meeting the required specification) of the previous swath (Figure B.2). Refer to section 7.4 of AHO, 2018 for more details

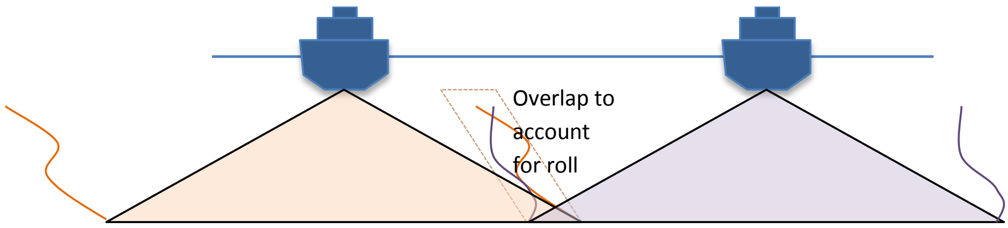

Figure B1 100% swath coverage with 0% or barely any overlap to cover ship roll (AHO, 2018)

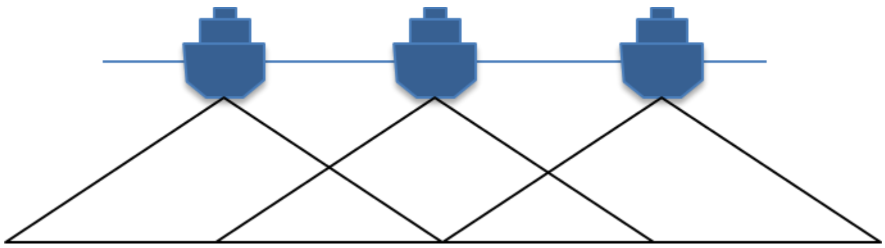

Figure B2 200% swath coverage with 100% overlap (AHO, 2018)

Blunders: See Error, gross.

Checkline: Sounding lines that are run perpendicular to the main survey lines and used to QA the soundings.

Coverage: portion of the seabed cover by the multibeam swath. 100% coverage refers to 100% of the seabed covered by the swath without any overlap (Figure B.1), while 200% coverage refers to 100 % overlap (Figure B.2). Partial coverage refers to a seabed coverage that is less than 100%.

Crossline: also known as checkline

Depth: Depth is a vertical distance from a given vertical datum. Depths are derived by MBES from measurements of angles and ranges corrected for environmental factors. Horizontal Position is provided to derived depth by GNSS-Inertial system thus providing an x,y,z value. GNSS Inertial system derived vertical position from measurements of angular rates and acceleration.

Dimension control: consists of determining the relationship between the measurement sensor and the platform Common Reference Point.

Error: The difference between an observed or computed value of a quantity and the ideal or true value of that quantity.

Error, gross: The result of carelessness or a mistake; may be detected through repetition of the measurement. Also called *blunder.*

Error, random: remaining uncorrelated noise in the system, or noise, also known as accidental error.

Patch test: A Patch test is a specific survey performed prior to principal survey to allow adjustments of the MBES data for parameters such as transducer error (pitch, roll and yaw), and navigation latency. This test is done since the MBES has no reference to external fixed frame of reference (satellite constellation isn't visible underwater), the MBES receives its "frame" from GNSS-Inertial system.These adjustments are entered in the acquisition software.

Seabed backscatter: Defined as the amount of acoustic energy being received by the sonar after a complex interaction with the seabed. Measured as the ratio between the intensity of the acoustic pulse scattered back by the seafloor and the incident intensity, this information can be used to determine bottom type, knowing that the different bottom types "scatter" sound energy differently. The intensity of the backscatter received at the transducer depends on the transmitted source level, the transmission loss (absorption in the water column and geometrical spreading), and the target strength. Many multibeam sonar systems offer two types of seabed backscatter data namely "one-per-beam" backscatter (either beam average or max intensity) and "time series" backscatter. For further information on backscatter refer to Lamarche and Lurton, 2017

Sounding datum: This datum is used while mapping. It is a low-water plane to which soundings are reduced and above which drying heights are given on the Standard Sheet and in other survey records. However, for chart datum, tidal reduction is essential (Figure 5).

Swath system: Current swath sounding systems utilize two differing technologies to achieve bathymetry measurements across a "swath" of the sea floor: 1) Beam forming (multibeam echo sounders), and 2) interferometric or phase discrimination sonars, also known as bathymetric sidescan. Both of these techniques have their merits; however, the same end results are achieved.

Systematic error: see error.

Transit data: Transit data include any data collected outside the survey specific area, e.g. data collected between port and survey area or between sampling sites. In hydrographic terms, this is referred to passage soundings.

Water Column backscatter: Recently developed multibeam sonars have the capability to record the sonar time series for each beam, which maps the water column in addition to the seafloor. Water column data could be used for direct mapping of fish and marine mammals, the mapping of plumes and vents, the location of mid-water targets, and a wide range of physical oceanographic processes.

Appendix C – Legislation and permitting

Table C1 List of documents relevant to multibeam activities in the Commonwealth waters (defined as 3 nautical miles seaward to the outer boundary of the EEZ, 200 nautical miles). Extracted from Marine Sampling Field Manuals (Przeslawski and Foster, 2018). Similar issues should be considered when working in coastal waters of States and the Northern Territory.

Activity	Activity Type	Jurisdiction	Responsible Agency	Legislation/Treaty/ Documents	Requirements for approval	Link
Research and monitoring	All activities	Australian Marine Parks	Department of Environment and Energy (DoEE)	*Environment Protection and Biodiversity Conservation Act 1999 (Cth)* (EPBC Act)	Authorisation is required for all zones	https://parksaustralia.gov.au/marine/
	Activities with potentially significant impact on a matter of national environmental significance	EEZ 3 – 200nm	DoEE	Australian Marine Park Management Plans EPBC Act	EPBC Act referral Public consultation, including indigenous stakeholders	http://www.environment.gov.au/protection/environment-assessments/ http://www.environment.gov.au/epbc/what-is-protected
Interactions with Cetaceans	Acoustic equipment with received exposure level 160dB re 1 µPa2.s for 95% of shot at 1km range (seismic)	EEZ 3 – 200nm	DoEE	EPBC Act Policy Statement 2.1	EPBC Referral and comply with Policy Statement 2.1	http://www.environment.gov.au/resource/epbc-act-policy-statement-21-interaction-between-offshore-seismic-exploration-and-whales
	Vessel interaction	EEZ 3 – 200nm	DoEE	*EPBC Act. Regulations 2000* (Cth) (EPBC Regulations) part 8	Report death, injury, stranding or entanglement of whales and dolphins to DoEE. Specific requirements for vessels	https://www.legislation.gov.au/Details/F2016C00914
Interaction with Heritage	Historic Ship wrecks	Continental shelf waters (incl. some areas > 200 nm)	DoEE	*Historic Shipwrecks Act 1976 (Cth)*	Ship wrecks and relics older than 75 years and lying within protected zones.	http://www.environment.gov.au/heritage/historic-shipwrecks

Activity	Activity Type	Jurisdiction	Responsible Agency	Legislation/Treaty/ Documents	Requirements for approval	Link
Restricted vessel movement and moored scientific equipment that create navigation hazards			Australian Hydrographic Service AHS Australian Marine Safety AMSA		Notice to mariners 2-3 weeks prior to survey commences. Vessel to RCC to update NAVAREA X alerts	https://www.amsa.gov.au/safety-navigation/navigation-systems/maritime-safety-information-database datacentre@hydro.gov.au rccaus@amsa.gov.au
Research in the Great Barrier Reef Marine Park GBRMP	Research, except for limited impact research.	GBRMP	Great Barrier Reef Marine Park Authority GBRMPA	*Great Barrier Reef Marine Park Act 1975 (Cth)* *EPBC Act*	Limited impact research may be conducted under a letter of authority issued by an accredited educational or research institutions All other research requires permission	http://www.gbrmpa.gov.au/zoning-permits-and-plans/permits http://www.gbrmpa.gov.au/zoning-permits-and-plans/permits/research-permissions
Research around petroleum and other infrastructure		3nm seaward to EEZ or outer limits of the continental shelf		*Sea Installations Act 1987*	Vessels prohibited to go within a safety zone of 500m	http://www.environment.gov.au/topics/marine/marine-pollution/sea-dumping/sea-installations

Laws and regulations regarding multibeam sonar acquisition in State and Territory waters (less than 3 nm from the coast) vary slightly across jurisdictions, but they are generally not restricted or subject to permit requirements, with the exception of:

- Survey undertaken in Marine Protected Areas (for guidance see Marine Protected Areas section above).
- Survey carrying out extractive work (marine biota) or work that could be considered destructive to marine habitats.
- Surveys undertaken across areas with access restrictions (e.g., naval waters, commercial ports, or shipping channels).
- Surveys carried out In New South Wales for the purposes of resource exploration (permission through NSW Resources and Energy - Environment and Planning).

Table C.2 Web links to States and Territory permits

VIC Research	SA Research	NSW Research	NT Research	TAS Research	QLD Research	WA Research

Appendix D – Guideline on timeframe for actions

Table D1 Estimated time frame required to perform some of the swath system related tasks. These estimates are to assist in survey planning, but note that they can vary considerably depending on the difficulty or the issues arising from the task performed.

Action	Timeline to be expected
Authorisation/permits from authority	Months
Mobilisation, calibration, validation (does not include time to manufacture mounts to fit the system)	3-5 days
Patch test	2 hrs to 0.5 day
Self-system test	2-5 minutes
SVP cast (depends on water depth and device)	20 min plus deployment time of the SVP, which depends on water depth (based on SVP not XBT device)
Crossline	0.5 day (depends on survey area)
Acquisition vs Processing ratio (depends on the quality of the input data and the level of cleaning)	1:1 to 1:3

Appendix E – Total Propagated Uncertainties

Table E10 Sounding Accuracy - Example MBES Total Propagated Uncertainty Estimates

Uncertainty Source	Value	Reference to Accuracy Value for Total Propagated Uncertainty Computation
Heading (degrees)	0.05	(Make/Model) – Manufacturer Accuracy Value
Smart Heave (Amplitude %) Real-Time Heave (Amplitude %)	2.5 5.0	(Make/Model) – Manufacturer Accuracy Value
Smart Heave (m) Real-Time Heave (m)	0.025 0.05	(Make/Model) – Manufacturer Accuracy Value
Roll (degrees)	0.01	(Make/Model) – Manufacturer Accuracy Value
Pitch (degrees)	0.01	(Make/Model) – Manufacturer Accuracy Value
Navigation (m)	0.10	(Make/Model) – Manufacturer Accuracy Value
Transducer Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Navigation Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Heading Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Heave Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Pitch Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Roll Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Offset X (m)	0.02	Estimated – (Description of Dimensional Control method)
Offset Y (m)	0.02	Estimated - (Description of Dimensional Control method)
Offset Z (m)	0.02	Estimated - (Description of Dimensional Control method)
Speed (knots)	0.10	Not Applicable
Loading (m)	0.02	Estimated
Draft (m)	0.05	Estimated – (Description of measurement)
Delta Draft (m)	0.02	Estimated - Vessel Dynamic Draft (Squat/Settlement) Calibration
MRU Heading Alignment (degrees)	0.05	Estimated - Multi-beam Patch Test Calibration
MRU Pitch/Roll Alignment (degrees)	0.05	Estimated - Multi-beam Patch Test Calibration
Tidal Measurements (m)	0.02 0.02 0.03 0.05	(Make/Model) TG – Manufacturer Accuracy Value (Make/Model) Barometer – Manufacturer Accuracy Value Estimated - GNSS Buoy TG calibration Estimated – Accounting for above Contributions
Tidal Zoning (m)	0.10	Estimated - Co-Tidal Model
SVP Profile Measurement (m/s)	0.02 0.50	(Make/Model) – Manufacturer Accuracy Value Estimated - Temporal and Spatial Variation
SVP Surface Measurement (m/s)	0.017	Make/Model) - Manufacturer Accuracy Value
Sonar Measurement		MBES Device Models File

Appendix F – Patch test

The figure below shows the pattern to use for the patch test of a MBES system with one or two sonar heads configuration.

For **backscatter calibration**, run the line schema for various modes. Alternatively, change the settings along a line where the seafloor is expected to be homogeneous.

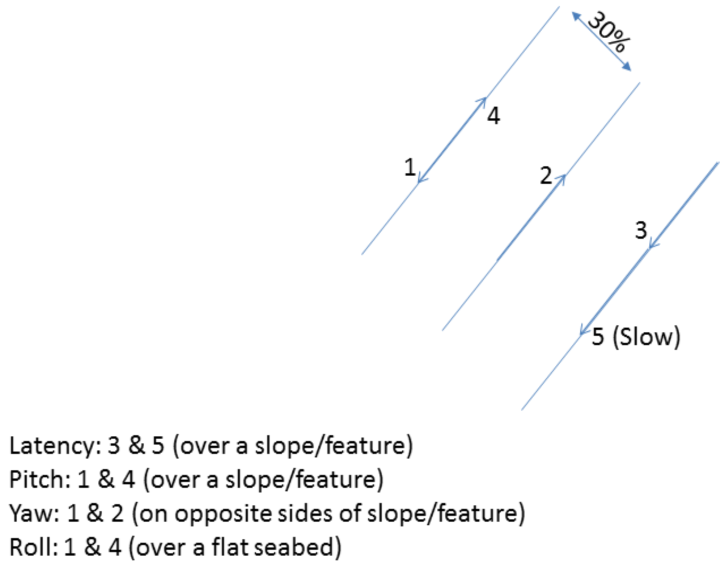

Figure F11 Proposed line pattern for single head sonar patch test

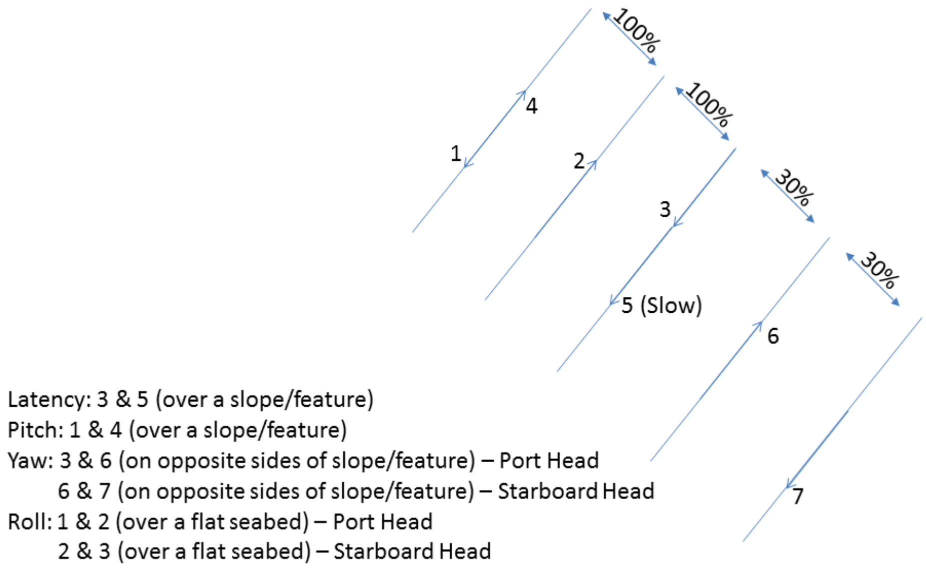

*Figure F2. Proposed line pattern for **dual-head** sonar patch test*

Appendix G – IHO Standards

Table G11 IHO standards for hydrographic surveys (S-44). Read in conjunction with document (IHO, 2008). These are presently in review by the IHO.

Reference	Order	Special	1a	1b	2
Chapter 1	**Description of areas.**	Areas where under-keel clearance is critical	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.
Chapter 2	**Maximum allowable THU 95% *Confidence level***	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Para 3.2 and note 1	**Maximum allowable TVU 95% *Confidence level***	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Glossary and note 2	***Full Sea floor Search***	Required	Required	Not required	Not required
Para 2.1 Para 3.4 Para 3.5 and note 3	***Feature Detection***	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Para 3.6 and note 4	**Recommended maximum Line Spacing**	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Chapter 2 and note 5	**Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)**	2 metres	2 metres	2 metres	5 metres
Chapter 2 and note 5	**Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)**	10 metres	20 metres	20 metres	20 metres
Chapter 2 and note 5	**Mean position of floating aids to navigation (95% *Confidence level*)**	10 metres	10 metres	10 metres	20 metres

Table G2 HIPP standards for hydrographic surveys (AHO, 2018)

HIPP ORDER		**HIPP - Precise**	**IHO – Special**	**IHO - 1a**	**IHO - 1b**	**HIPP - 2**	**IHO - 2**	**HIPP-Passage**
TOTAL HORIZONTAL UNCERTAINITY (THU)								
TOTAL HORIZONTAL UNCERTAINITY (95% Confidence Level)		1m	2m	5m + 5% of depth	5m + 5% of depth	5m + 1% of depth	20m + 10% of depth	5m +5% of depth
SEAFLOOR SEARCH REQUIREMENTS (COVERAGE)								
Swath Systems (1)		Full Seafloor Coverage (FSC)	Full Seafloor Coverage	Full Bathymetric Coverage (FBC) (LIDAR – 200% Coverage)(2)	Full Seafloor Ensonification (FSE)	Full Bathymetric Coverage	Not Required	Offset tracklines (if applicable)(3)
FEATURE DETECTION								
Water Depth <40m	Swath	50cm	1m	2m	As Specified	As Specified	Not Applicable	4m
Water Depth >40m	Swath	1m	2.5% of depth	5% of depth	As Specified	2% of depth	Not Applicable	10% of depth
TOTAL VERTICAL UNCERTAINITY (TVU) (4)								
TOTAL VERTICAL UNCERTAINITY (95% Confidence Level)		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 = 0.6m b = 0.0085	a = 1.0m b = 0.023	a = 0.5m b = 0.023

Appendix H – Records templates

The following appendix provides suggested templates for Records that should be produced during a seabed mapping survey. These templates can also be downloaded on the AusSeabed website

H.1 Mobilisation, calibration and validation report

The following link provides you with the template.

H.2 Survey log sheet templates

MBES LOG SHEET

SURVEY NAME:	VESSEL:	JULIAN DAY:	UTC OFFSET:	PAGE:

OPERATOR		GENERAL DESCRIPTION:
Name:	Signed:	

WEATHER:

Local Time		Line Name	Heading	Speed	Event (e.g. settings, SVP, Transit, Turn, etc.)	Comments (e.g. mode, frequency, pulse length, etc)
Start	Stop					

SVP LOG SHEET

SURVEY NAME:	VESSEL:	LOCAL DATE:	UTC OFFSET:	PAGE:

OPERATOR		GENERAL DESCRIPTION:
Name:	Signed:	

Local Time	Position		Water Depth	Surface SV (SVS)	Weather			Comments
	Deploy	Recover			Wind speed	Direction	Sea state	

H.3 Report of Survey template

The following template has been modified from AHO Survey Summary Template, which can be found in full here. Guidance on Confidence Levels and Error Ellipse scaling is contained in ICSM (2014a), uncertainties from IHO publication S-44 or by contacting the Bathymetric Data Assessment Section at the Australian Hydrographic Office on 02 4223 6500.

Introduction

Survey Title and ID	**Locality**
Survey Authority	**Survey Sponsor/Custodian**
Surveyor in Charge and qualification	**Date this Survey Summary was completed**
Start Date of Survey	**End Date of Survey**
Survey Platform/Vessel Name	**Survey Platform/Vessel Name**
Purpose of the Survey	
Survey Title and ID	**Locality**
Survey Authority	**Survey Sponsor/Custodian**
Surveyor in Charge and qualification	**Date this Survey Summary was completed**
Start Date of Survey	**End Date of Survey**

Horizontal Control

Soundings are on the following datum (WGS84 preferred but not essential)	
Datum	

Spheroid	
Projection and Zone	
Was the positioning system validated?	
Were laybacks applied?	
Estimated horizontal accuracy of soundings at 2 Sigma (95%) confidence level (Calculations can be included as an attachment. Don't know? Enter "Not Known")	

Vertical Control

Tides Applied	
Soundings Datum	
Tide Station 1 Details	
Benchmark (BM) used and Datum connection	
Geoid details if using GPS tides	
Tide Station 2 Details	
Benchmark (BM) used and Datum connection	
Geoid details if using GPS tides	
Tide Station 3 Details	
Benchmark (BM) used and Datum connection	
Geoid details if using GPS tides	
Tide Model comments (if applicable)	

Were soundings corrected for draught?	
Were the soundings corrected for sound velocity?	
Estimated vertical accuracy of soundings at 1.96 Sigma (95%) confidence level (Calculations can be included as an attachment. Don't know? Enter "Not Known")	

Details of Survey Execution

The following positioning systems were used:		
Positioning System 1		
Positioning System 2		
Base station (If applicable)		
The following sounding systems were used:		
Model / System Details	**Frequency (kHz)**	
Echosounder 1		
Echosounder 2		
Logging and Processing Systems used, and Versions:		
Logging		
Processing		
Was the survey systematically controlled with planned survey lines or methods?		
Was full feature detection achieved as defined in IHO publication S-44, Edition 5, February 2008?		

If feature detection was achieved, what Order of features is applicable?	
Feature detection comments (if applicable)	
Were all shoal depths systematically investigated and their least depths determined?	
Has data been thinned from that collected?	
If thinned, what thinning method and bin size was used?	
Remarks (If applicable)	

Shoals and Dangers

This section seeks comments on any features that may be dangerous to surface navigation. (Comments as required. General location and depth references, pictures, screen dumps, etc will assist. Has a Hydrographic Note or Danger to Navigation Report been submitted?)

Wrecks

This section seeks comments on any wrecks detected during the course of survey. (Comments as required. General location and depth references, pictures, screen dumps, etc will assist.)