SeaBed NSW

Standard operating procedures for multibeam surveying

Acknowledgments

We wish to thank Dr Alan Jordan and Dr Gweneal Cadiou from the NSW Department of Primary Industries (Fisheries) for their valuable input and recommendations during the review stages of this document.

Published by:

Office of Environment and Heritage
59 Goulburn Street, Sydney NSW 2000
PO Box A290, Sydney South NSW 1232
Phone: +61 2 9995 5000 (switchboard)
Phone: 1300 361 967 (OEH and national parks enquiries)
TTY users: phone 133 677, then ask for 1300 361 967
Speak and listen users: phone 1300 555 727, then ask for 1300 361 967
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

Report pollution and environmental incidents
Environment Line: 131 555 (NSW only) or info@environment.nsw.gov.au
See also www.environment.nsw.gov.au

ISBN 978-1-925755-58-9
OEH 2019/0101
March 2019

Find out more about your environment at:

www.environment.nsw.gov.au

Contents

List of tables

List of figures

1. Introduction

This report details the standard procedures used for multibeam mapping of sediment compartments surveyed as part of the SeaBed NSW mapping program. The guide was produced to accompany data reports and contains further details about multibeam acquisition including mobilisation of Office of Environment and Heritage (OEH) vessels, installation and calibration, prioritisation as well as planning and data acquisition, processing, ground-truthing, analysis, interpretation and map production.

Standard operating procedures (SOPs) as outlined in the National Environmental Science Program (NESP) field manual for multibeam sonars, along with the International Hydrographic Survey Standard, were considered in preparation of this document (Lucieer et al. 2018, IHO 2008). The SeaBed NSW program achieves high resolution baseline surveys for mapping sediment distribution. The data acquired has a high level of positional accuracy and achieves baseline level survey standards as stipulated in the NESP field manual.

This guide details general day-to-day operations and does not include variations arising from unforeseen field circumstances. These variations are detailed in the data reports for each compartment. It is also recognised that methods may change over time with the implementation of new equipment and software. Where a significant change to SOPs arises, this guide will be updated accordingly. Metadata pertaining to variations in the SOPs are also captured and provided in an OEH rigour statement that is issued with the data on the Australian Oceanographic Data Network (https://portal.aodn.org.au) and the NSW Environmental Data Portal (www.seed.nsw.gov.au).

2. Equipment and mobilisation

NSW OEH operates a range of vessels and equipment to map (using remote sensing) areas of estuaries and nearshore coastal waters. One of the first major nearshore coastal mapping campaigns was completed by the Department of Public Works in the mid-1980s, covering an area from Avoca to Port Hacking and to 60 metres water depth. This survey mapped the seabed using a single-vessel, mini-ranger system, radio telemetry, a single-beam echosounder and towed side-scan fish system operated by a team of water and land-based staff.

With the advent of new technologies, mapping of the seafloor has become easier and the accuracies that can be achieved have increased significantly. Swath bathymetry systems, multiphase echo sounders (MPES) or MPES with side-scan, and multibeam echo sounders (MBES) using real-time kinematic (RTK) G2 (combined GLONASS and GPS) positioning now provide near-100% seafloor ensonification and sub-decimetre XYZ precision. These types of technologies have been used by OEH since 2005 for habitat mapping projects and are now being employed for the SeaBed NSW mapping program. Details on the current vessels, systems, and setups operated by OEH for hydro surveying are provided below. A brief history of system changes since 2005 is provided in Appendixes A and B.

2.1 Vessels

2.1.1 *Bombora*

OEH's offshore survey vessel is the RV *Bombora* (Figure 2.1). Commissioned in late 2009, *Bombora* is a fibreglass single-hull 11.8 metre Stebercraft built in Taree, New South Wales. *Bombora* is powered by twin Yanmar 250 kilowatt inboard diesel engines. With a cruising speed of 15–20 knots and a fuel capacity of 650 litres/side, *Bombora* has a range of ~150–200 nautical miles. MBES/MPES equipment is deployed using an over-the-side pole mount secured to a gunnel hinge plate on the port side of the vessel. This setup was translocated from OEH's previous survey vessel *Glaucus* and based on a design by the Flinders Ports Authority, Adelaide. *Bombora* can carry up to 10 persons and is in commercial survey classes 2B and 2C (NSW Roads and Maritime Services (RMS)), allowing it to operate to 100 and 30 nautical miles from shore, respectively.

2.1.2 *Sea Scan*

RV *Sea Scan* is OEH's estuarine and nearshore trailer-able survey vessel, commissioned in 2008 by the Coastal Branch of the Department of Lands for hydro surveying work. *Sea Scan* is a 7.5 metre twin-hull aluminium catamaran powered by twin 170 horsepower Mercury outboards (Figure 2.2). The vessel is registered as commercial class 2C (NSW RMS) allowing it to operate offshore to within 30 nautical miles of the coast. Although *Sea Scan* can cruise at a speed of up to 25 knots and has a 150 litre/side fuel capacity, generally the vessel is limited to operating in low sea state conditions and within ~10–20 nautical miles of a navigable port.

While originally having been used for operating single-beam, in 2011 an R2Sonic MBES was purchased and the vessel was modified to accommodate a through-hull mount.

Figure 2.1 RV *Bombora* underway off the northern beaches, Sydney, New South Wales. Photo: S Holtznagel/OEH

Figure 2.2 Trailer-able Hydro survey vessel RV *Sea Scan*. Photo: S Holtznagel/OEH

2.2 Sonar equipment

2.2.1 Geoswath

From 2005–2016 OEH operated a 125 kilohertz Geoswath (GeoAcoustics, now Kongsberg) for offshore surveying using the vessel *Glaucus* and then later *Bombora* (post-2009). Geoswath is a swath bathymetry system that utilises an interferometer or multiphase echo sounder (MPES) to obtain bathymetric information (0–200 metre water depth) and a side-scan to provide data on seabed hardness. The 125 kilohertz system was purchased to map areas of coastal seabed to better inform planning around NSW marine parks. The system was replaced in 2016 in favour of a 'true' multibeam system and is no longer in operation. Archival datasets are contained within the NSW Government online data portal (www.seed.nsw.gov.au). Further information about Geoswath operation and data processing procedures can be found in Appendixes A and B.

2.2.2 R2Sonic

OEH's first multibeam echo sounder (MBES) system was purchased in 2011 in the form of a 200–400 kilohertz R2Sonic 2022 (R2Sonic, USA) with a depth range of 0–400 metres. The R2Sonic was acquired to conduct surveys in shallow nearshore environments and enclosed waterways to support work in coastal hydrology and assessments of hazard and risk. The benefit of the R2Sonic is that it is a 'true' multibeam and suited to relatively shallow water (<50 metre) conditions. The system is also flexible in its operation and adaptable to a wider range of applications. The R2Sonic is multifrequency, can obtain data as either equidistant or equiangle, and can steer beams for surveying walls and infrastructure.

Initial setup of the system used Differential Global Positioning Systems (DGPS) with RTK corrections for positioning and OEH's Teledyne DMS-05 IMU; however, in 2012 a second POS system (Wavemaster 320) was purchased for MBES operations on *Sea Scan*.

2.3 Motion and positioning

Both OEH survey vessels now operate Applanix POS MV systems to provide position and 3D motion information to support MBES/MPES acquisition. The POS couples Global Navigation Satellite System (GNSS) data and 3D motion (IMU) information to provide a blended solution for real-time vessel trajectory at 50 hertz.

POS real-time data is recorded using POSView software (Applanix, USA). Depending on the area of operation, error budget, and accuracies required, the data are either applied in real time or logged and then smoothed in post-processing to improve the vessel trajectory solution.

In real-time, sub-decimetre XYZ level accuracies for motion and positioning are provided through delivery of base station data (SmartNet) across a mobile phone network with an RTK link through Networked Transport of RTCM Internet Protocol (NTRIP). This method is generally used for enclosed and nearshore waters where the mobile phone network is reliable. Post-processing of motion and positioning is required when drop-outs in RTK NTRIP data links occur but will also improve XYZ accuracies through use of updated ephemeris data (delayed ephemeris) or base-station rinex data.

The RV *Bombora* POS system utilises all four currently available GNSS constellations in both GPS and GLONASS satellites called the G2 corrections signal (Fugro, USA). This signal provides RTK-equivalent corrections while surveying offshore. POS data are processed in POSPac using the Single Base Station (SBS) solution for improved SBET, and routinely provide XYZ accuracies at a sub-decimetre level.

SBETs are then applied to survey soundings during multibeam processing in Hypack's MBMAX (Hypack, USA).

2.4 Mobilisation and setup

2.4.1 *Bombora*

OEH's R2Sonic 2022 200–400 kilohertz MBES system was installed on *Bombora* for offshore mapping in September 2016.

The R2Sonic system is operated using an over-the-side pole mount with lever arm offsets relative to the centre of mass (COM) at the waterline (Figures 2.3–2.5).

A critical aspect of any multibeam setup is consistency of the position of the sonar heads when deployed relative to the reference frame of the vessel.

This is achieved on RV *Bombora* by:

- sonar heads attached to a rigid aluminium-sailing mast pole (200 millimetre LD) and frame mounted to the underlying structure of the otherwise fibreglass hulled vessel through gunnel attachment plate (Figure 2.3(i))
- forward fixed-length stainless-steel wire strop and 'Dyneema' aft strop tightened through a rear-mounted block to restrict movement in the fore–aft-plane (Figures 2.3(ii) and (iii))
- a through-gunnel stainless-steel arm attached to the sonar pole and secured on the in-board side of the hull with a locking screw system securing the arm in the same port–starboard-plane position for each survey (Figure 2.3(iv)).

(i)


(ii)


(iii)


(iv)


Figure 2.3 (i) Over-the-side pole mount and mounting plate, (ii) 'aft' securing strop, (iii) 'fore' securing strop, and (iv) through-hull securing arm plate. Photos: T Ingleton/OEH

Frame of reference and initial lever arm offsets were established on RV *Bombora* while the vessel was on hardstand in 2009 (Steber, Taree) by OEH's hydrosurveyor using a theodolite and laser levelling system. Values were checked again while the vessel was in dry dock in 2012 (Port Stephens) and 2018 (Port Hacking) with CRKennedy (Sydney) (Figure 2.4). Both re-surveys confirmed that the offsets are within 0.005 metres of original values. Positioning of R2Sonic heads relative to the reference frame were measured at the time. The sonic centre to waterline value for the R2Sonic installation was determined to be –0.849 metres.

Details on lever arm offsets as of are provided in Table 2.1 and Figure 2.5.

Figure 2.4 RV *Bombora* hardstand survey March 2018 – R2Sonic 2022 single-head locked into position with fore and aft strops. Photo: T Ingleton/OEH

Table 2.1 Hardstand survey frame of reference values for RV *Sea Scan* 20 November 2011

Point	East (m)	North (m)	Z (m)	Comment
1	0.000	0.000	0.000	Centre of mass at waterline
2	0.005	1.849	–0.133	POS MV top
3	–1.201	–0.421	3.251	Port GPS phased
4	1.174	–0.424	3.250	Starboard GPS phased
5	–2.139	–2.019	–0.619	Transmit GS zero
6	–2.127	–1.966	1.405	Top GS pole
7	0.000	–4.493	0.312	CL transom
8	1.647	–3.888	0.170	IM mark starboard aft
9	–1.630	–3.898	0.168	IM mark port aft
10	0.000	1.525	0.177	Top ADCP moonpool
11	–1.098	–0.075	3.401	Top DGPS
12	–0.017	5.609	0.005	Approx. WL bow
13	–1.621	–3.767	0.167	IM mark port aft
14	–0.099	5.723	0.270	IM mark port bow
15	–0.005	1.522	–0.837	CL moonpool keel

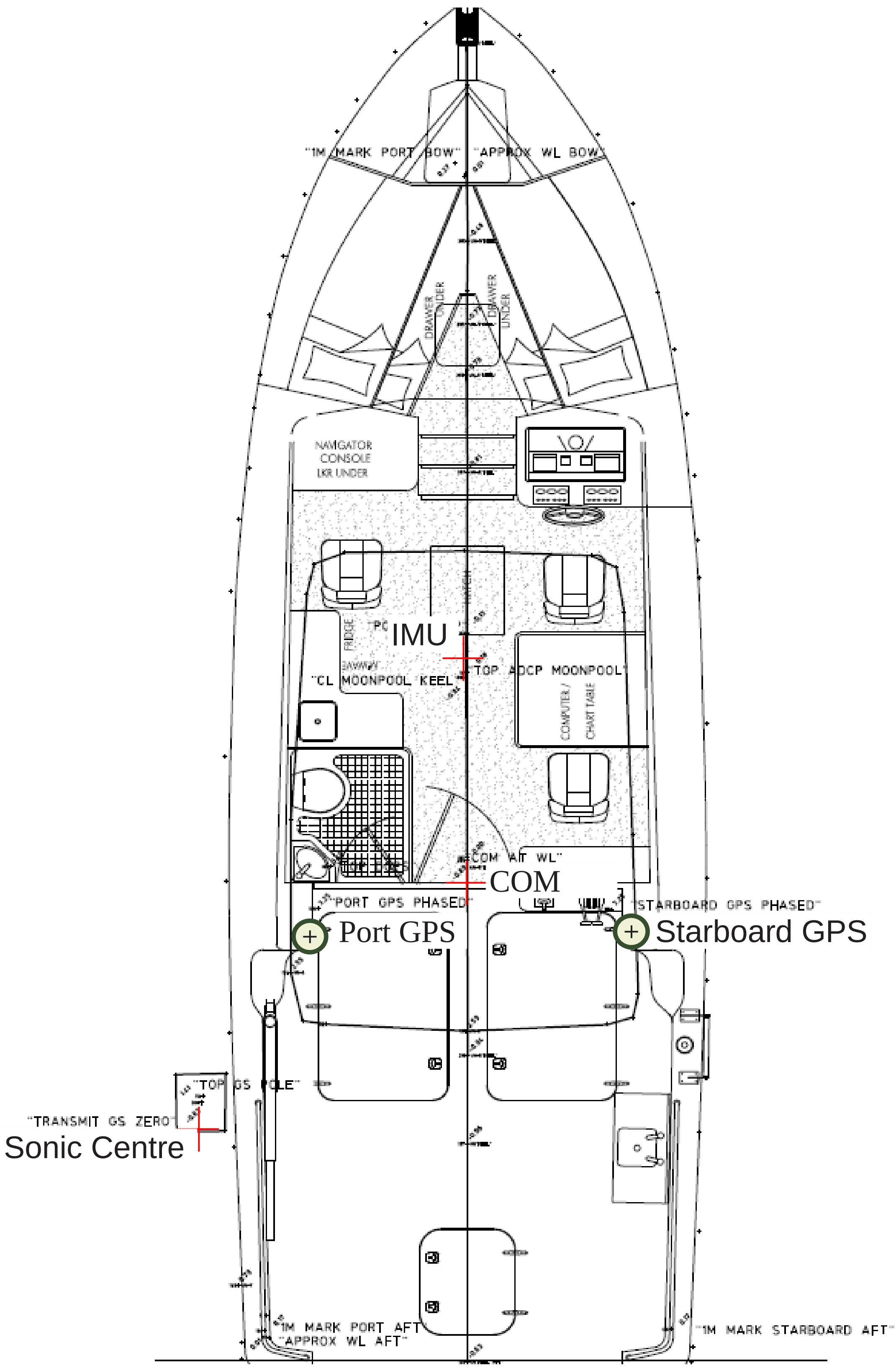


Figure 2.5 Architectural drawing of RV *Bombora* with surveyed reference points for the Geoswath setup with centre of mass (COM) at the waterline as the XYZ zero

Note: Z offset water line to sonic centre is –0.619 metres for Geoswath (Transmit GS Zero) and –0.849 metres for the R2Sonic.

2.4.2 *Sea Scan*

A hardstand survey of the setup on *Sea Scan* was completed in December 2011 when the through-hull mount was installed (Figure 2.6). Details of the reference frame and derived lever arm offsets are provided in Figure 2.7 and Table 2.2.

In 2012 a second POS system (Wavemaster 320) was acquired and installed aboard *Sea Scan* to support MBES operations (Figure 2.8). Similar to operations aboard *Bombora*, POS data are acquired during a survey and then post-processed to calculate an SBET and applied to soundings post-survey.

Figure 2.6 RV *Sea Scan* hardstand survey 20 December 2011 with surveyors CR Kennedy (Sydney). Photo: S Holtznagel/OEH

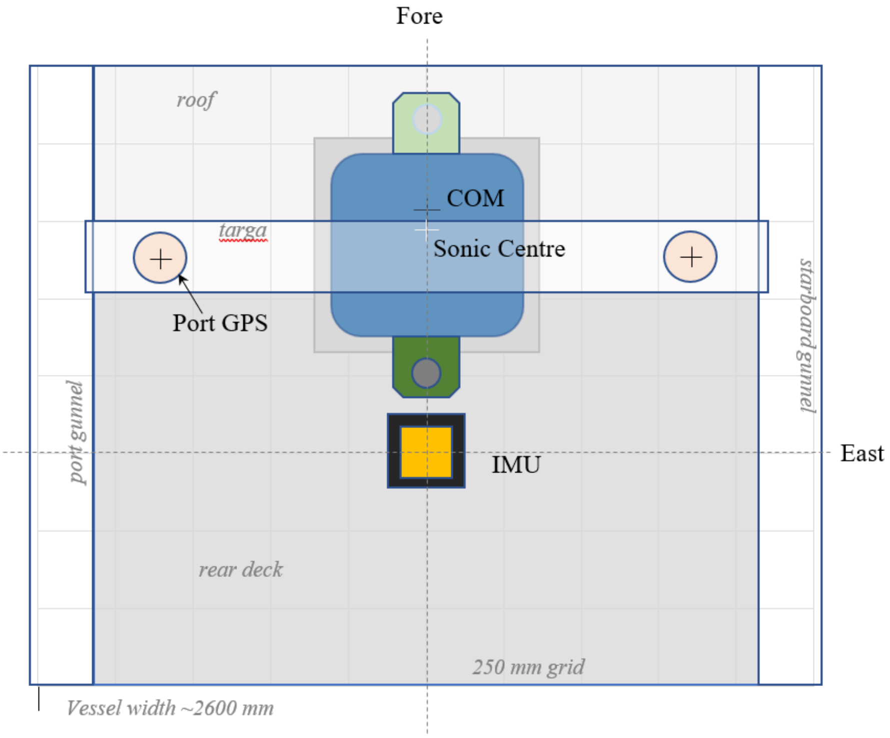


Figure 2.7 Plan view of centre section and reference frame survey points for RV *Sea Scan*

Table 2.2 Hardstand survey frame of reference values for RV *Sea Scan* 11 October 2013

MRU origin (0,0,0) point	Offset (m) East	North	Elevation	Code
1	–0.852	0.640	2.181	Port GPS
2	–0.852	0.640	2.181	Starboard GPS
3	–0.949	0.844	–0.881	Transducer port
4	0.996	0.809	–0.872	Transducer starboard
5	0.001	0.454	–1.055	Multibeam stern punch
6	0.005	0.879	–1.043	Multibeam bow punch
7	0.000	0.728	–0.998	Multibeam centre
8	0.001	0.592	2.132	Spoiler stern punch
9	0.003	0.763	2.145	Spoiler bow punch
10	–0.015	–2.816	–0.115	Bow punch
11	0.000	0.000	0.000	MRU
12	–0.253	0.367	–0.166	Hatch
13	–0.016	–2.806	–0.087	Bow punch 2
14	0.000	0.786	2.650	Centre of mass at waterline

2.4.3 GNSS Azimuth Measurement System offsets

A GNSS Azimuth Measurement System (GAMS) test to establish 3-dimensional IMU offsets for heading was performed for each POS system on RV *Bombora* and RV *Sea Scan* following initial installation, servicing or replacement of GNSS sensors, and following *Bombora* POS system upgrades in 2016 (see POS manual).

During the first survey after an installation or servicing procedure, >10–12 hours of POS vessel data are acquired following GAMS tests to perform a ‘convergence of solution’. This technique uses the initial lever arm offset values (centre of mass (COM) to sonar centre XYZ) acquired during hardstand survey as a starting point, and uses the large volume of GNSS data acquired over the course of a survey day to validate and refine these values. Due to the large volume of data, the converged solution is expected to be a more representative value for the port–starboard GNSS offset than the physically derived value, as it is acquired under ‘survey’ conditions when the vessel and its reference frame are moving. This technique also provides a means to test the separation value between the port and starboard GPS antennas and port antenna to vessel reference point (0, 0, 0) to millimetres on a day-to-day basis. Once the GNSS based solution is resolved, these Lever Arm values can be applied to all surveys until such time as the next changes to the POS system or sonar installation occur.

2.4.4 Ancillary equipment

A range of ancillary equipment and associated software is required when operating multibeam systems.

Surface sound velocity

Both setups on RV *Bombora* and RV *Sea Scan* employ a Valeport sound velocity sensor (SVS) that constantly measures sound velocity (to 1 decimal place; e.g. 1520.1 metres/second) at the sonar heads. The SVS is mounted adjacent to the sonar heads and records the in-water surface sound velocity at a rate of 1 metre/second using a beam of light. Data are recorded in real-time and are retained within the system as raw data (*hsx). SVS files can be observed in Hypack software packages as part of Phase 1 processing or can be extracted and exported separately if required.

(i) 

(ii) 

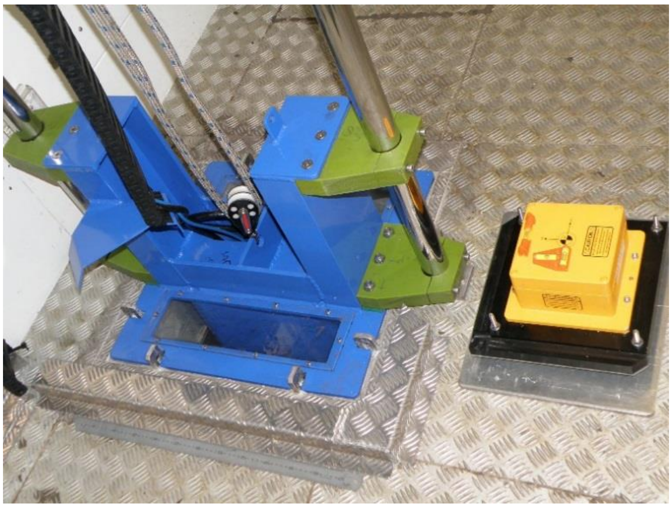
(iii) 

Figure 2.8 (i) Trailer-able survey vessel RV *Sea Scan*, (ii) retracted through-hull moonpool mount for R2Sonic, and (iii) deployed position. Photos: S Holtznagel/OEH

Water column sound velocity

OEH also owns a suite of SeaBird (Seabird, USA) profiling CTDs that are used onboard for collecting sound velocity profile information (SBE25, SBE19+ and SBE9+). These instruments measure vertical changes in sound velocity within the water column. Data is collected at a rate of 2–4 scans per second as the CTDs are dropped through the water column (descent rate of <0.5 metres/second). Files are processed using the SBE data processing program and Integrated Marine Observing System profiling CTD manual protocols (IMOS.org.au) with an additional output variable of sound-velocity selected (using the UNESCO Chen Millero equation – Chen and Millero, 1977). The protocol was written specifically for application to coastal water CTD profile data using downcast-only values binned at 1 metre depth intervals. OEH SeaBird CTD sensors are calibrated annually using the CSIRO calibration facility in Hobart. An instrument drift of <0.002 for salinity and <0.001 °C/year^{-1} for temperature is routinely observed. Dual-sensor checks are also achieved by cross-referencing the surface values with the calibrated onboard flow-through system.

The Odom Digibar Pro (Teledyne, USA) is another sound instrument that uses a beam of light to measure the speed of sound within the water column. Once activated the instrument is dropped through the water column where it records at a rate of approximately 1 metre/second. Data are downloaded and uploaded into the Hypack survey project onboard. While the probe itself is not calibrated regularly, surface values are checked against the SVS values prior to casting for validation. Values routinely vary between the SVP and SVS by <2 metres/second.

Other equipment

RV *Bombora* also possesses a range of other navigational and oceanographic data acquisition systems that value-add to seabed mapping, providing additional data sources or cross-check values for mapping instrumentation. These include:

- Furuno NavNet GPS system for operation by the master of the vessel for long range navigation and C-Map charting. The Furuno also has anemometers, thermometers and a depth sounder for managing operations at sea.
- A Sea-Bird SBE32 (using SBE9+ or 19+ CTD system) onboard rosette for ocean water sampling and real-time water column profiling. Sound velocity profiles can be calculated from the CTD output and water samples obtained for lab cross-checks.
- Sea-Bird SBE23 Thermosalinograph (conductivity–temperature) with turbidity, chl-a and CDOM fluorometers for in-progress surface water sampling. This is a pumped flow-through conductivity–temperature (CT) system that records physical surface water variables. When the system is operational the flow-through computes sound velocity from pressure–temperature–conductivity values, providing a real-time quality control (QC) check on the behaviour of the sonar SVS.
- Workhorse Sentinel ADCPs (300, 600 and 1200 kilohertz) measure water column current speed and direction using water column backscatter. These instruments have a heading and tilt sensors, bottom tracking function and a transducer head temperature sensor.

2.5 Patch testing

Patch testing occurs on a bi-annual to quarterly basis, following a re-installation of the sonar heads and/or change in physical equipment positioning or setup. The patch test site has historically been near Lilli Pilli in the upper basin of Port Hacking, RV *Bombora*'s home port. Ideally, patch tests are repeated over the same area to build a reference surface and system QC over time.

Patch tests have been completed elsewhere in Port Stephens and Sydney Harbour when operations have required the vessel to be further afield. A patch test area:

- is in a protected location that is largely removed from motion inducing effects of swell and/or sea
- has reliable satellite and/or base station corrections available (DGPS, RTK)
- is over both an area of relatively flat seafloor (roll correction) as well as a significant seabed feature (latency, pitch, yaw), and
- is in water depths 20–25 metres that are representative of the average survey depths across study areas (note: the greater the water depth the greater the effective swath width and the more data available for deriving patch test offsets).

The R2Sonic derived patch test values for roll typically varied by <0.1° between tests. Pitch and yaw are also important as they can have implications for roll crosstalk. Patch test results for pitch and yaw were more variable however values were typically <0.5° between tests.

Details of patch test dates and locations for the R2Sonic are provided in Table 2.3.

Table 2.3 R2Sonic multibeam system patch test dates

Date d/m/y	System	POS system quality	Patch test site	Roll (P/S)	Pitch	Yaw
17/5/17	R2Sonic 2022 200–400 kHz	Real-time G2 equivalent RTK with Single-Base Station 48 hour RINEX via SmartNet	Lilli Pilli, Port Hacking	0.70	2.90	1.45
1/6/17				0.70	2.41	1.95
11/1/18				0.75	2.47	2.08
23/2/18				0.75	2.30	2.20

2.6 Planning

Field surveys require a level of planning and consideration for geographical area and weather conditions and for equipment capabilities/limitations and management of data both in the field and in the office.

2.6.1 Survey blocks

Field survey planning is predominantly conducted using Hypack. The sections of coast to be surveyed as part of the SeaBed NSW program are tens of square kilometres in size and take days to months to complete. Generally, survey transects are run parallel to contours to maintain consistent sonar settings and swath width so as to maximise survey efficiency. When moving from the office to the field, however, weather conditions and/or site factors may cause plans to change and operators need to be adaptive in their planning approach.

To manage the expected data flow during acquisition, each sediment compartment area is divided into manageable survey blocks of around 10–12 square kilometres. Limiting survey block size and surveying in a concentrated section-by-section manner is preferable to running long transect lines because it:

- constrains the operational area for ease of data management in post-processing
- optimises field survey efficiency and logistics, i.e. completeness of blocks may facilitate multivessel operations (one multibeaming while the other is ground-truthing)
- better manages sound velocity spatial and temporal variability.

To date, field acquisition blocks are coded A, B, C, in Hypack and then altered for post-processing with a 2-digit (row and column) naming convention (Figure 2.9). The dual naming system provides a means by which the level of processing (either raw or processed) can be ascertained at a glance from the filename. This is critical when there are large numbers of files, multiple subsections within compartments, and large data volumes sometimes limited by software and/or hardware constraints. For example: the various software programs used when processing backscatter data are limited in the number of files that can be loaded at any given time.

Figure 2.9 Block area naming convention (processing) for the Wollongong sediment compartment

Surveying is conducted by either:

- producing a series of equidistant planning lines (i.e. @ 25 or 50 metre line spacings) in the survey software (Hypack) for each survey block. The line that is selected to 'drive-to' is determined based on 1) the active swath coverage being achieved at the start of the new survey line while at survey speed, and 2) considering the 'average' swath width that was achieved on the previous/adjacent line that is to be 'overlapped'. Factors including seabed hardness, system variability, vessel speed, absorption coefficient settings, water column, weather, and terrain can also impact upon transect spacing and the width of a swath
- using a real-time 'painting' option for surveying where sonar coverage of the seafloor during acquisition is 'retained' within a saveable matrix. A new feature of Hypack 2017 is the ability to space the 'next' survey line at a nominated distance based on the vessel track of the previous survey line. Although painting is operationally efficient, complexity of seafloor terrain promotes an increasingly sinusoidal course for navigation. This can have implications for the backscatter end product. By using the painting option, the vessel track tends to follow contours more closely. Small variations in seabed hardness associated with depth may become more difficult to discern, compared to straight line navigation, specifically when trying to align day-to-day changes in frequency or power settings during mosaicing.

Despite the best planning efforts, a survey needs to be adaptive. Conditions on the day and preferences of the survey crew will dictate the most appropriate method.

A planned overlap of between 25 and 50% with adjacent swaths is the objective for SeaBed NSW surveys.

2.6.2 Line spacing, ping length and resolution

Swath widths achieved using the single-head R2Sonic are typically around four times the water depth. The horizontal range is dependent on water depth, seabed hardness, sonar settings/performance as well as environmental variables. Generally, transects are run as series of parallel lines, with ping length adjusted to ensure a 25–50% overlap and no less than 1.5 pings per square metre along-track. This provides a minimum ping rate of ~4–5 soundings for every 2 x 2 metre area across the seafloor. For example, at 30 metre water depth on hard-bottom substrate the R2Sonic might achieve a swath width of 110–120 metres (60 metres per side). In this case the next transect would theoretically be run at ~90–100 metres from the centreline of the previous transect.

Overlap provides data redundancy and works as a safeguard when swath width is reduced due to unexpected changes in seafloor type or during a rapid change in vessel direction (resulting in a data gap). Transect overlap also provides additional quality control for each survey day and valuable overlap for the outer beams where across-track data coverage can deteriorate. It also provides a mechanism for checking that roll offsets are correct.

At the end of a survey day, a line running perpendicular and across the day's transects is recommended and considered best-practice to provide additional data for QC checks. Results of cross-validation lines (where completed) are provided in OEH rigour statements and published online with accompanying datasets.

2.6.3 Sound velocity

Surface sound velocity (SVS) is recorded continuously by sound velocity sensors (Valeport, UK) mounted next to the sonar head and on the sonar mount. Data are recorded, time-stamped and logged as part of the raw R2Sonic sonar file (1 per second).

During multibeam surveys, sound velocity profiles (SVP) should typically be collected at a minimum of twice daily, once in the morning and once in the afternoon. This is adequate in locations where little to no stratification of the water column is present; however, across certain sections of the coast (e.g. adjacent to estuaries, depths of >20–25 metres, and/or in summer), stratification can be significant enough to alter the speed of sound by >2–4 metres/second. For example, when operating at a survey depth of 100–110 metres, a 4 metres/second change in sound velocity would induce a 0.26 metre change in the depth detected by the sonar. In locations along the NSW coastline where stratification is present, surface sound velocities are monitored during surveys and additional SVPs are collected to account for potential changes in density with depth.

The operator of the SVP sensor must also understand how the sensor operates, considering surface ‘soak’ times and sampling rates to ensure that adequate representation of the water column structure is recorded for each profile. Throwing the SVP sensor in the water column and profiling immediately and/or allowing the sensor to fall through the water column at speed under gravity will not produce reliable SVPs and may result in damaged equipment. SeaBird sensors require 2–3 minutes surface soak time before accurate and reliable sensor readings are achieved. Note: The SeaBird calculates sound velocity based on a combination of temperature, conductivity and pressure using the Chen–Millero equation (see SeaBird manual).

2.6.4 Weather and field

Since NSW OEH survey operations are conducted from relatively small research vessels (<12 metres), weather conditions are a strong determinant of the quality and success/failure of multibeam surveys. In NSW coastal waters, surveying with RV *Bombora* is generally conducted when swell conditions are <2 metres, seas <1–1.5 metres and winds <12–15 knots. Beyond these conditions, generally, data quality starts to decline.

Weather forecasts are examined in the days leading up to a survey and the team mobilised once conditions appear favourable for at least several days. The R2Sonic system performs best under low wave and swell conditions but can continue to acquire high resolution bathymetry data with reasonable accuracy when conditions are marginal. As conditions deteriorate, the vessel begins to roll and pitch at greater angles. The sea surface can become aerated and air bubbles will interfere with sonar sound waves reaching the seafloor. Under these conditions a survey is likely to be abandoned.

Water conditions can also play a role in determining the success or failure of surveys. In some survey areas (e.g. adjacent to the entrances of estuaries) the density of the water column can vary significantly over the course of a survey day due to tidal flows. The operator must monitor the changing surface velocity through the sound velocity sensor and identify when a threshold has been exceeded (i.e. >2–4 metres/second). In these areas additional sound-velocity profiles must be collected in order to characterise horizontal and vertical variability. Cold-water intrusions from the continental shelf and/or significant reef or headlands may deflect water masses. These can introduce significant changes in sound velocity speeds over the course of a survey day and must be accounted for.

Turbidity is another factor to consider when surveying around river and estuary entrances. Sound attenuates with increased suspended material in the water column and will reduce effective swath width. Seafloor composition can also affect survey outcomes. Softer unconsolidated sediments absorb rather than reflect sonar energy, resulting in lower reflectance and narrower swath widths. The operator should ensure that adjacent transects are spaced closer together to accommodate the reduced range in both scenarios.

3. Acquisition

This section is intended to provide a general overview of the techniques and settings applied by OEH during multibeam surveys and not a step-by-step account of how to run the equipment from start to finish. It is expected that our multibeam operators and other readers of this document have either familiarised themselves with the manuals for both equipment and software used or have access to them, as well as having undergone some training and/or supervision around their operation. A simplified workflow for multibeam acquisition is provided in Figure 3.1.

Offsets determined from installation and calibration procedures are entered into acquisition software interface(s) and once survey planning is complete the survey can commence. Calibration information is retained within each of the project files and offsets applied for roll/pitch/heave are translated into processed data files. Once mobilised, the survey vessel setup remains in place and system offsets need only be recalculated if the sonar heads are moved or if an issue arises with the installation; e.g. a noticeable artefact indicates a component of the reference frame has changed.

Surveys conducted for the SeaBed NSW project are focused on mapping seabed heterogeneity and not specifically for hydrographic charting or target detection. Surveys are generally conducted to achieve an International Hydrographic Organisation (IHO) order 1B standard for level of accuracy for bathymetry. This level is for non-charting purposes (see Section 4.2). It is expected that sounding densities for characterising seabed hardness (backscatter) patterns are relatively lower and thus both are achieved with this order specification (Lurton & Lemarche 2015).

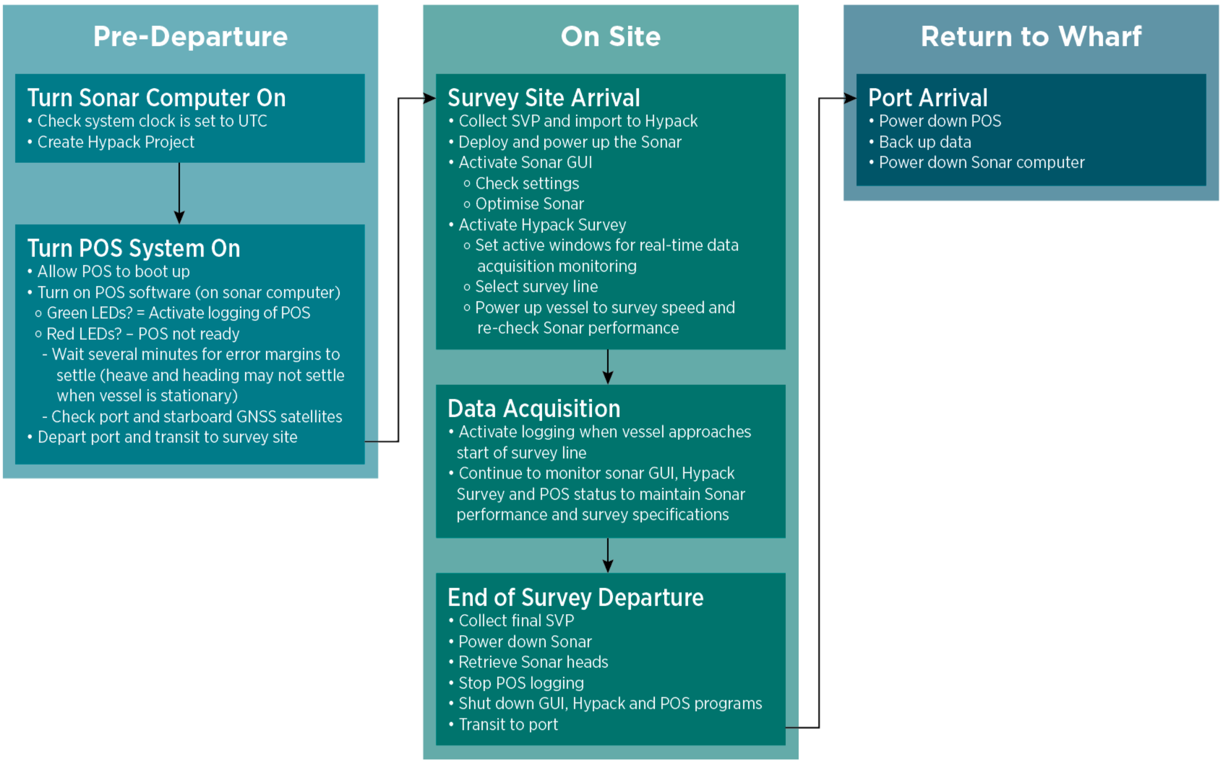


Figure 3.1 Multibeam data acquisition workflow

3.1 Pre-survey settings and considerations

3.1.1 System timing and POS setup

All onboard systems operate and record in Coordinated Universal Time (UTC) (Casablanca) with time-stamping provided by POS. The POS timing is updated constantly through a pulse per second (PPS) signal delivered through the satellite network.

Logging of POS data occurs in POSView and must be activated by the operator at the start of the survey day via an ethernet connection to the survey computer. Active logging is initiated by the survey operator once incoming GNSS (G2) and IMU data values in POSView are within allocated tolerances, i.e. LED indicator lights are green (LED indicators will be red when these conditions are not met). Data are logged until the vessel returns to port to ensure that Start and End points are within 20km of a SmartNet base station. POS data files should be coded with a 3-letter prefix for the sediment cell location (i.e. WLN for Wollongong) and then the date (yyyymmddUTC) at the start of the survey day in UTC.

Survey operations using G2 satellite corrections default to differential GPS in times of G2 signal drop out. With this setup, drop outs do not affect the final SBET. This is because updated base station RINEX files are downloaded from SmartNet post survey and processed in POSPac using a single base solution (SBS) module.

3.1.2 File naming conventions

Hypack projects are created for each survey day with the following UTC day naming protocol, yyyymmddUTC_location, e.g. 20170317UTC_Wollongong. These projects contain the planned lines and survey block matrices for use in the survey.

Three separate raw data files, single-beam sounding (.RAW), multibeam soundings (.HSX) and backscatter information (.R2S) are recorded by Hypack using the Canadian Hydrographic Service (CHS) file naming protocol with the survey block as a prefix. This protocol is as follows: surveyblock_yyyyBOjjjhhmm, where surveyblock is as outlined above, yyyy is year, BO is a boat designator, jjj is day since beginning of the year, hhmm is hour and minute (UTC) of start of file. An example from survey block A off Wollongong from 25 May 2017 starting at 21:28 is nsw02203_A_2017BO1452128. Data files are auto split by Hypack at 10-minute time intervals to better manage files in post-processing.

3.1.3 Sound velocity

During the course of a survey day, SVS variability can be monitored either by regular checking of the SVS window (Hypack) or alternatively by setting software threshold alarms. Both the R2Sonic graphical user interface or Hypack have options to set an SVS alarm that will notify the operator when the sound velocity at the heads exceeds the threshold value.

When approaching the survey location, the operator should select a site for an SVP profile. Ideally, this should be a site that is close to the start of the first sonar transect but ~5–10 metres deeper than the depths expected across the targeted area for the day. This is to ensure that sound velocity values are acquired across all depths expected to be surveyed that day and to avoid any potential damage to the SVP sensor from its coming into contact with the seabed while profiling.

Once on-site the SVP sensor will be deployed either using the onboard winch system (SeaBird deployed using the winch and A-frame) or by attaching a 'tether' or marked rope line (smaller SVP sensors, e.g. Digibar) and deploying it over the side. While conducting the surface soak, details such as sounder depth, time, position, sound velocity (from the flow-through system) can be entered manually in field log sheets. Alternatively, the position can be recorded as a ‘target’ (using the F5 hotkey function) in Hypack and then the name and additional information on the profile entered into the target by using right-click-edit options.

Once an adequate surface soak time is complete, the SVP sensor is lowered through the water column at a slow and steady pace accommodating the sensor’s sampling rate. Ideally, to get the best representation of water column structure at a site, the SVP sensor should be recording multiple samples across each 1–2 metre depth bin through the water column.

Once the SVP sensor is retrieved, data can be downloaded and the sensor washed and/or stored appropriately and securely. Downloaded raw SVPs can be viewed, edited and exported and either applied to the sonar data during acquisition or be left until later during post-processing.

3.2 Commencement of survey

Hypack is used to undertake surveying with the R2Sonic, including navigation, management of survey lines, logging targets and ‘painting’ of predefined matrices with gridded real-time depth values (Figure 3.2). Once Hypack is activated and a project created, the program receives the data from the R2Sonic and POS and manages all aspects of the data collection including data synchronisation, storage and file creation.

Once at the survey site, a location for an SVP cast should be identified, the SVP instrument deployed and a profile acquired. Once completed the operator then downloads the SVP data using the proprietary software. A target, to log SVP position and time, is recorded in Hypack using the F5 function key. SVPs are then processed, inspected for data quality, and uploaded into the active Hypack project for use in real-time.

Once the R2Sonic is deployed, the graphical user interface (GUI) is activated. Although Hypack software provides an interface for managing data from the R2Sonic system, the GUI is also required to be active as it contains several control functions that can only be accessed within its window (Figure 3.2).

3.2.1 Sonar settings

The R2Sonic GUI interface provides controls over various settings including power, gain, ocean absorption, sector coverage, and filters including depth, angle and auto range tracking. Details on how these settings affect data acquisition are in the user manual and are not discussed further here. Generally, frequency and power settings are expected to be ‘optimised’, applied and retained to ensure consistency within and between survey days. A significant change to the water depth within the area of operation, however, may result in over saturation of the return signal and indicate the need to change frequency/power settings and re-optimise. For the general mapping surveys conducted as part of the SeaBed NSW program:

- ocean absorption values should be set daily based on the water temperature and the frequency being used by the sonar. A quick reference table of absorption values is kept onboard the survey vessel
- gain settings must always be retained at 1
- ping length (µs) must be maintained to ensure that along-track ping density stays at specification.

(Note: Changes such as moving from equiangle to equidistant spacing and/or beam steering might be required when moving from general mapping to wreck and infrastructure type surveys).

Once the R2Sonic is optimised and the GUI sonar acquisition window has stabilised, the filter gates and range tracking can be enabled and data acquisition is ready to commence. Hypack Survey is then activated.

3.2.2 Real-time monitoring

In Hypack Survey, the operator chooses a line for the master to navigate along. As the vessel approaches the start of the line or edge of the matrix, data logging is activated for the nominated line/transect.

As the survey progresses and transects are surveyed, the active Hypack matrix is 'painted' with corrected depths in real-time using the data from the R2Sonic, and positioning and altitude from the POS. This allows the surveyor and master to control and monitor survey coverage. To further ensure sufficient overlap between transects, offset limits are set so that real-time display, including the real-time depth matrix, show approximately 10 metres less than the full swath width on each side of the vessel. Note that this does not affect the data logging, all soundings are logged by Hypack.

Other real-time checks on the incoming data include monitoring R2Sonic data via a waterfall plot and display in the R2Sonic control software, alarms to warn of large (>2 metres/second) deviations of the surface sound velocity compared to the SVP in use, and roll-pitch-yaw-heave values displayed by Hypack.

Saturation levels should also be monitored through the R2Sonic GUI software's saturation window once the sonar is actively pinging the bottom, and to ensure the power level is optimised.

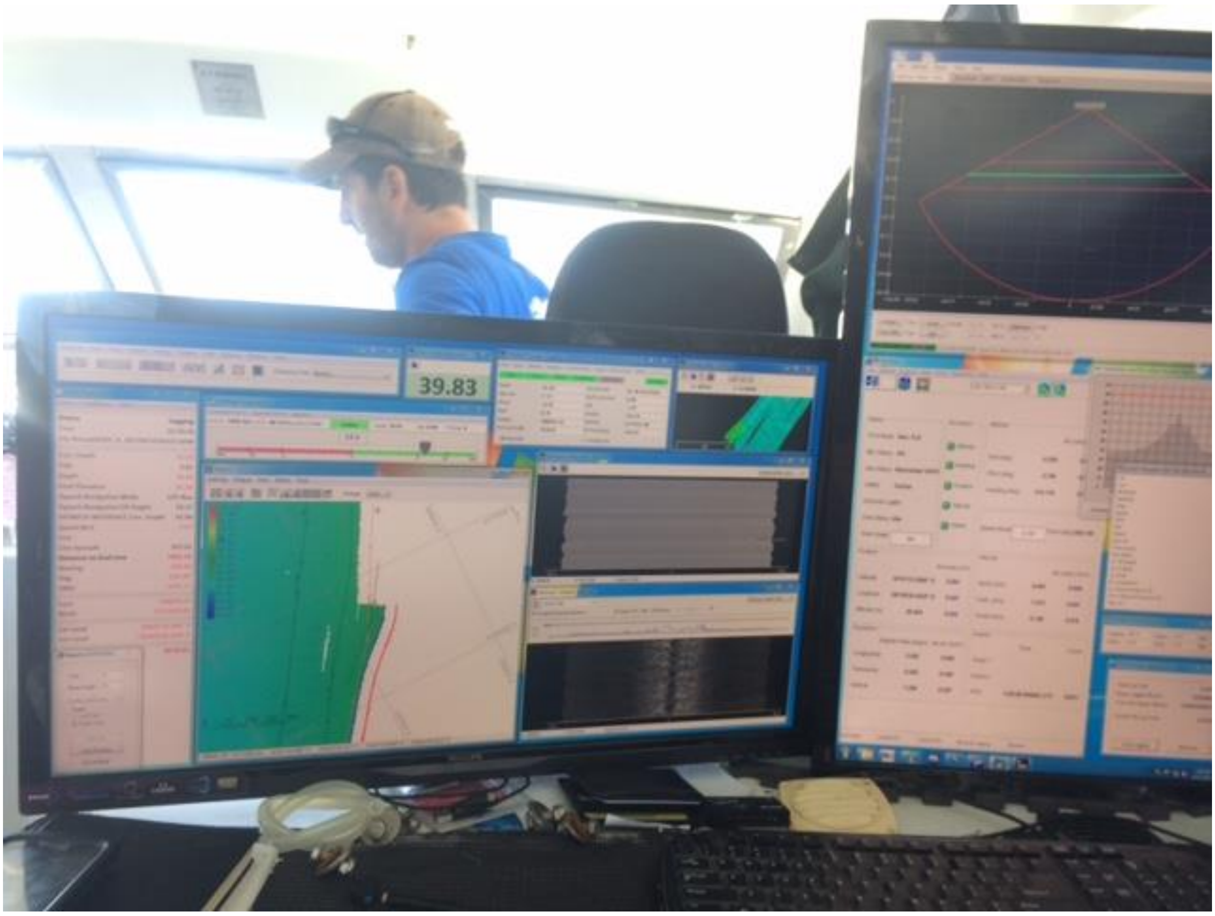


Figure 3.2 Onboard setup of Hypack, POSView and R2Sonic interface. Photo: T Ingleton/OEH

4. Processing

Data processing R2Sonic surveys involves a multistep procedure summarised in Figure 4.1. Phase 1 editing involves basic filtering and QC checks of R2Sonic data in Hypack MBMax before exporting relevant files. Phase 2 editing makes use of QPS software Fledermaus (Netherlands) in an effort to improve the quality of hydrographic outputs. Phase 2 of cleaning and editing uses a method called the Combined Uncertainty Bathymetric Estimator (CUBE) to identify erroneous data and provide quality control information on the soundings relative to industry standards.

A summarised version of the workflow (Figure 4.1) and procedures applied for R2Sonic data processing are provided below.

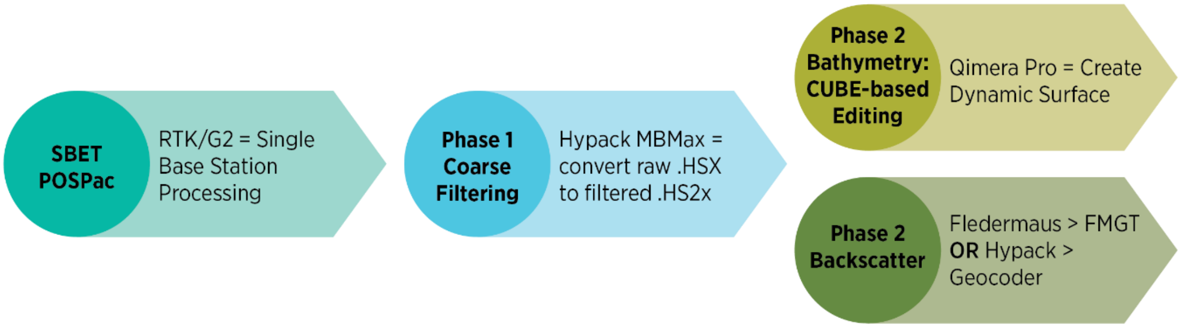


Figure 4.1 Generic workflow steps and software used for post-processing of multibeam

4.1 R2Sonic

4.1.1 POS processing for SBET

POS data is imported into POSPac and processed using SBS processing (Applanix POSPac manual) which incorporates improved satellite positioning data (48-hour ephemeris), base station RINEX data (from SmartNet) and the vessel motion (IMU) data. The result is an improved smoothed best estimate of trajectory (SBET) for the vessel. XYZ RMS accuracies are generally <0.025 metres.

4.1.2 Phase 1

R2Sonic data is processed in Hypack using the multibeam editor (MBMAX 64) to convert raw data files (.HSX) to processed (.HS2x) files.

Sound velocity profiles (one or more) are imported into MBMAX and then inspected for erroneous values. These cleaned SVP files are linked to the relevant raw .HSX based on a location and time-stamp. SBETs are also imported and will be applied to the data during processing, replacing real-time trajectory (positioning, elevation, pitch and roll, and heading) with new 'smoothed' values. The following auto filters are generally applied once processing commences:

- corrected depth – nominally 0 metres minimum and 60 metres maximum, however the maximum depth filter is adjusted for each survey day based on the known maximum depth of the survey
- speed over ground – minimum 0 knots, maximum 12 knots
- beam angle limits – both port and starboard set to minimum 0 degrees and maximum 60 degrees

- over/under filter – removes soundings that either overhang or undercut the previous or next beam
- median filter – filters data in a set of areas (defined by number of pings and number of beams) by removing soundings that deviate from the median by more than the gate value. Gate size 1.0 metre, # Pings 3 and # Beams 5.

The use of these auto filters allows the process to be operator independent and repeatable, whilst removing the majority of grossly erroneous soundings. Filtered soundings are written into .HS2x extension files for use in Phase 2 processing. Note: No changes are made to the raw data files.

4.1.3 Phase 2 data processing

For bathymetric data, a second stage of processing is applied using Qimera QPS software. (Note: Processing prior to September 2016 was conducted using Point Editing suite functions in Fledermaus). For backscatter (mean amplitude return or snippets backscatter timeseries), files were mosaiced in either FMGT or Hypack using Geocoder.

Bathymetry

Processed Point files (.HS2x) (produced in Hypack) for each survey are brought into Qimera to generate QPD files, and a corresponding Dynamic Surface. QPD files represent all soundings from the original Processed Point files and are accessed and updated whenever a cleaning task is performed on a Dynamic Surface.

An automated first pass clean is run on the entire Dynamic Surface using a Very Weak QPD spline filter. This spline filter draws upon an algorithm to fit a surface through noisy soundings (i.e. it determines a well-fitting seabed bottom) and removes footprints that lie too far from this surface.

The spline filtered data is then used to produce a CUBE surface model that filters soundings to recommended international hydrographic organisation (IHO) standards. The remaining soundings within the CUBE surface generate multiple depth solutions (hypotheses) based on a normal distribution and 95% confidence interval. Individual soundings are then selectively accepted or rejected (by the user) on the basis of survey objectives to produce a draft cleaned-sounding dataset. This dataset is used to create a 2-metre grid surface for further detailed inspection. If outliers are still present, cleaning and sounding removal continues in Qimera. Once all errors are accounted for, a final CUBE surface is recalculated and then cleaned soundings are exported as ascii XYZ files. This process is repeated for each survey block within any given sediment compartment. Details on error assessment for surfaces created using Qimera are provided below in Section 4.2.

Each ascii XYZ file created using the above method is brought into DMagic and combined to produce gridded surfaces (using a weighted moving average grid type). The grids depict the entire mapped extent of each sediment compartment at grid cell resolutions of 2 metres, 5 metres and 10 metres. These gridded surfaces form base layers for production of a series of sediment compartment maps, and for undertaking geomorphometric analyses and seabed classification modelling.

Backscatter

R2Sonic backscatter data are mosaiced in either Fledermaus FMGT or Hypack Geocoder. Note: Both programs have limitations on the number of files that can be loaded for any given mosaic.

In FMGT, combined bathymetry and backscatter timeseries (snippets) data are first exported as a single GSF file using Hypack's MBMAX. Data files are then brought into a new FMGT project where backscatter data is automatically extracted as files are loaded. Once loaded, navigation lines are displayed in the project manager window along with information on extents, acquisition time period, and other file information.

Processing options are adjusted within the processing parameters window as follows: Transmit/receive, Power Gain Correction, and Apply Beam Pattern Correction options are selected, a 60° beam angle cut-off is entered and backscatter range is left as 'calibrated'. In the Sonar Defaults tab, system options are set to automatic and R2Sonic 2022 sonar type selected from the drop-down menu with the primary frequency adjusted to the selected operation frequency, which is typically 300000 hertz (300 kilohertz). Surface sound speed is set at 1520 metres/second and angle varied gain (AVG) is set to 'Trend' with a default window size of 300. All other parameters are left as default.

Mosaics are generated using a grid cell size of 2, 5 or 10 metres and using the auto-processing function as a first pass. Where adjacent transects have been acquired using different frequencies, the backscatter adjustment function within the edit tool can be used to adjust line brightness of individual transects and align the backscatter stretch to match.

In Hypack, HS2x files are imported into Geocoder selecting Snippets as the file type for import (this is selected regardless of whether the files contain Snippets or Truepix backscatter amplitude data). Survey lines are examined per survey day and erroneous files identified. Under 'Mosaic Options', the blend nadir option is selected and angle restricted to 0–60°. A pixel size of 2, 5 or 10 metres is entered and boxes Tx/Rx gain, area correction and spherical spreading options selected. AVG is set to Trend.

A histogram of the loaded file(s) is examined by using the 'Histogram' dialog to see the extent of dB values contained in the selected data files. Under 'Calibration Parameters' the reference dB level is left as the default value –45. The dB correction level can be adjusted here for files where power settings may have changed between transects of a survey during acquisition. A change to the dB offset is then applied to a single file or to all loaded files accordingly.

Once completed, the built mosaic is exported as a geotiff and XYZ files to import into Fledermaus. Backscatter image mosaics for each survey day or subset/block area are then re-exported as geotiffs and combined in ArcGIS to produce a completed survey-wide backscatter map.

4.2 Error assessment

To ensure a level of quality control is maintained within the final processed datasets, an analysis of surface uncertainty and sounding density statistics is undertaken on the final version of the cleaned surface in Qimera (see examples in Figures 4.2 and 4.3). The surface uncertainty assessment can be done in two ways depending on whether data editing/ validation was conducted using phase 1 processed sounding data from Hypack (HS2x files) or raw sounding data (HSX files) in Qimera.

The bathymetric grids generated by OEH (for the Seabed NSW project) are not for navigational/charting purposes; however, as a means of maintaining high quality scientific data output, OEH aims to meet IHO Order 1B standards across its products. That is, the uncertainty within each cell or the total vertical uncertainty (TVU) associated with the CUBE nodal depth should fall within a certain threshold and is calculated using the following formula:

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

where:

a = portion of uncertainty that does not vary with depth

b = coefficient representing the portion of uncertainty that varies with depth

d = depth

b * d = portion of uncertainty that varies with depth

The formula calculates, at the 95% confidence level, the maximum allowable uncertainty or TVU for a specific depth. Parameters ‘a’ and ‘b’ for Order 1B, as stipulated in IHO Standards for Hydrographic Surveys 5th Edition (IHO 2008), are a = 0.5 metres and b = 0.013.

To calculate a threshold cell uncertainty or nodal TVU that meets IHO Order 1B standards, these two parameters are substituted into the formula above along with the **mean survey depth value** (d) across each mapped sediment compartment. This threshold is then compared to the 95% confidence interval values for each cell if working with the geospatially-corrected HS2x files or the CUBE uncertainty surface if working with the raw HSX files. A simple RED/GREEN colour palette is applied to each surface to highlight which regions of the survey area (if any) fall outside IHO Order 1B standards (see Figure 4.2).

As an example, the **mean survey depth** in the Wollongong Sediment Compartment is 37.31 metres; therefore, the TVU threshold for this bathymetric dataset is approximately ±0.70 metres, calculated as follows:

$TVU = \sqrt{[0.5^2 + (0.013 * 37.31)^2]}$

$TVU = \sqrt{[0.25 + (0.24)]}$

$TVU = \sqrt{0.49}$

$TVU = \pm 0.70$ m

The reason two different approaches are required is because the total horizontal uncertainty (THU) and TVU values for each sounding aren’t carried through by Hypack to the HS2x format. As such, only estimated THU/TVU values can be applied when building a CUBE surface. The validated CUBE surface can still be used to assist in data cleaning efforts but the TVU value associated with each node isn’t derived directly from the data. As such, the 95% confidence interval attribute associated with each cell better represents the consistency of sounding depths within that cell and hence overall uncertainty.

When working with the raw HSX files in Qimera, the uncertainty associated with each multibeam echo sounder system component (i.e. positioning system, orientation system, multibeam system, sound velocity system, etc.) can be tracked and combined to allocate a ‘true’ THU and TVU value for each sounding. When the Dynamic Surface is created in Qimera using the CUBE model the resulting CUBE surface uncertainty represents the nodal TVU produced from all soundings that are consistent with the validated/accepted node depth. In other words, it is a value representing the depth uncertainty of each final depth estimation node or chosen hypothesis in the CUBE surface. The CUBE uncertainty attribute can be used to determine whether the processed bathymetric surface meets project objectives and/or (if warranted) criteria set by the IHO.

CUBE surface uncertainty typically increases across regions with higher relief (such as coastal reef zones) as soundings within a CUBE node capture radius become more variable. In these more complex zones, it is not unusual for CUBE uncertainty values to fall outside recommended IHO Order 1B standards.

Sounding density statistics may be used in two ways. The first way is to ensure that ‘valid’ statistics are associated with the CUBE model, i.e. a suitable number of soundings are associated with a given node spacing; too few soundings for a selected cell size or node spacing result in invalid statistical measurements. The second way is for estimating feature detection. A common rule-of-thumb for prescribing the likelihood of detecting a feature is for a minimum of three pings and three soundings per ping to fall within a cell representing the feature size. Therefore, a minimum of nine soundings should fall within any cell (see Figure 4.3). Note that it is not uncommon for soundings to deteriorate along the outer edges of the swath; thus, analysing the sounding density across a survey will identify regions where additional mapping may be required.

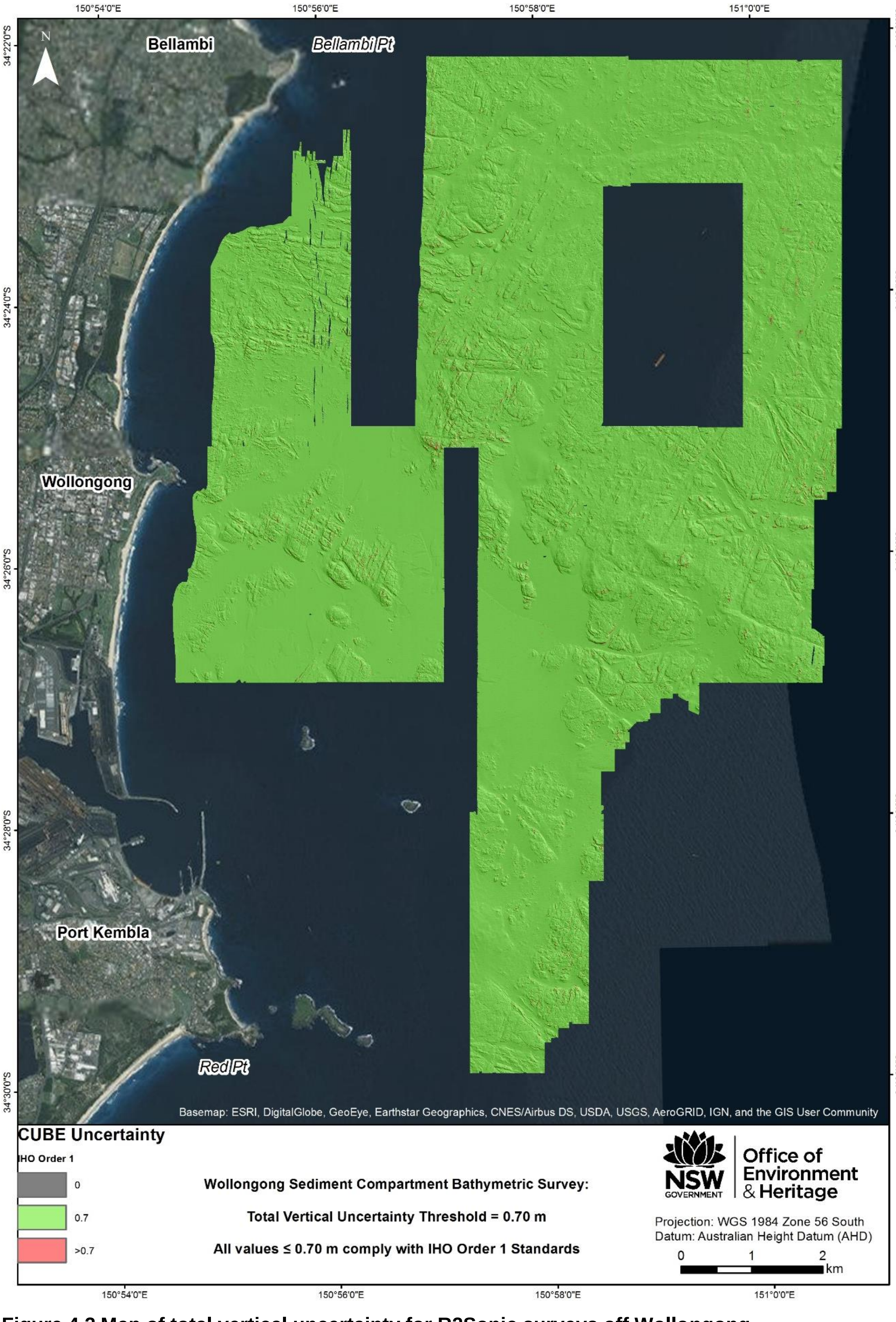


Figure 4.2 Map of total vertical uncertainty for R2Sonic surveys off Wollongong

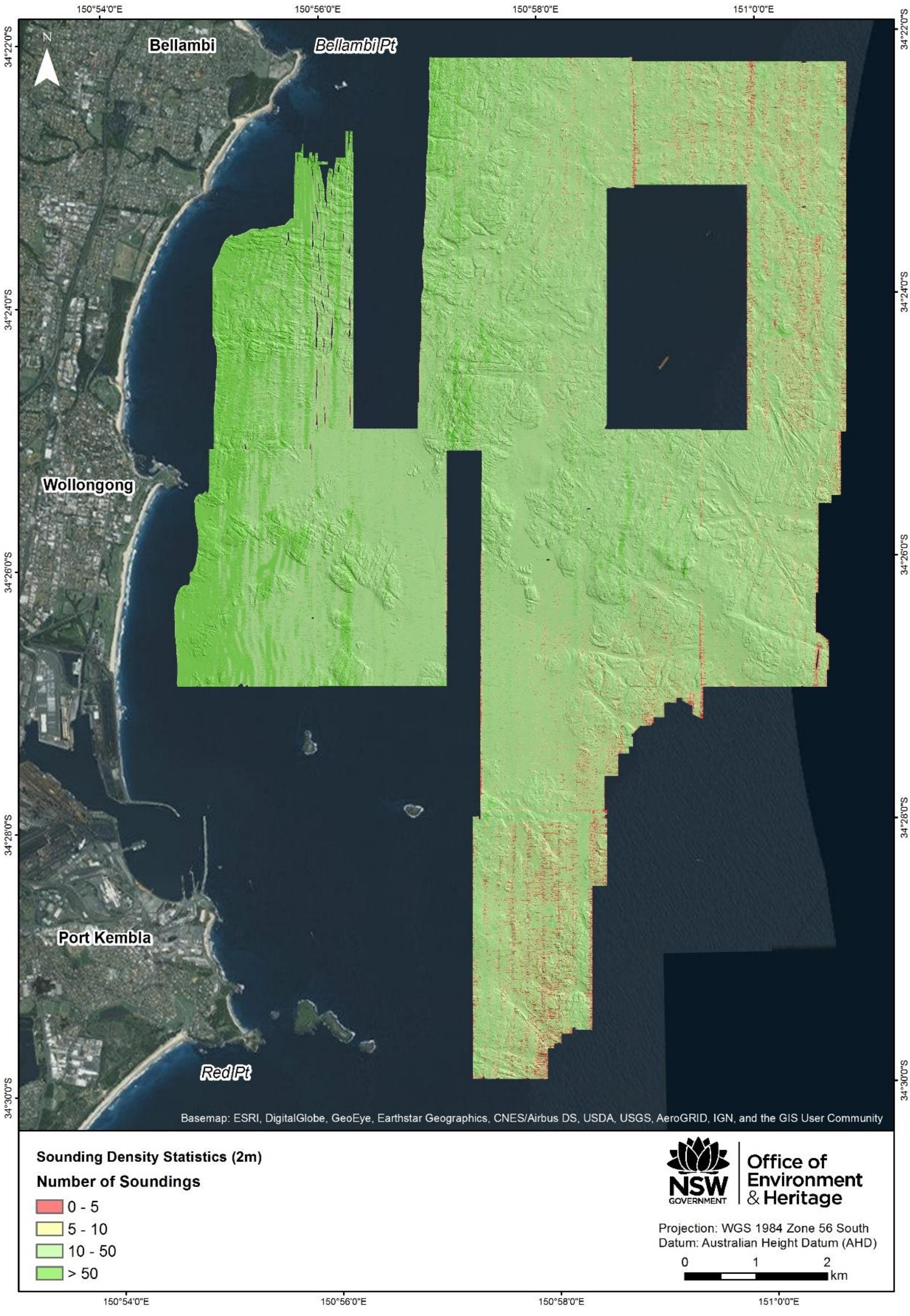


Figure 4.3 Map of population statistics for R2Sonic surveys off Wollongong

4.3 Ground-truthing

To validate sonar data obtained by multibeam systems during the SeaBed NSW program, OEH utilises one or more ground-truthing methods. For bathymetry, high-accuracy single-beam echo sounding systems aboard hydro survey jet-skis are used to provide hydrographic level depth information to cross-check multibeam values. To ground-truth seabed types, sediment samples are collected and analysed for unconsolidated areas and towed video used to validate boundaries and examine hard-substrate variability.

4.3.1 Single-beam echo sounding

Jet-skis fitted with CeeScope (USA) echo sounders are used by OEH for hydrographic surveys of estuaries and beaches in New South Wales (Figure 4.4). Data is acquired using an onboard computer and waterproof dash-mounted screens with either a through-hull or rear-mounted narrow-beam (8 degree) depth transducer (200 kilohertz) and dash or pole-mounted (rear) GNSS antennae. RTK corrections are provided through an NTRIP caster and SmartNet via the 4G mobile phone network.

For the SeaBed NSW statewide mapping program, jet-ski transects are run perpendicular to shore from the edge of the surf zone (<5 metres) to a depth of 40–50 metres offshore at several locations within each sediment compartment. Data will be used to validate depths obtained by multibeam and marine LiDAR surveys.

Figure 4.4 Single-beam jet-ski surveys. Photo: T Ingleton/OEH

4.3.2 Sediment sampling

Ground-truthing of unconsolidated seabed types interpreted from bathymetry and backscatter data is carried out using grab samplers deployed from RV *Bombora*. To identify the safest and most appropriate grab sampler for the program, three types of grabs (a Smith MacIntyre, Shipek and Van Veen) were used to collect samples offshore of Wollongong in August 2017 (Figure 4.5). Based on operational safety, sample integrity and ease of use, the Shipek grab was identified as the grab of choice for future sampling campaigns.

To adequately quantify the range of sediment types across a compartment and validate the seabed interpretation derived from multibeam data, each sampling program must consider obtaining samples that:

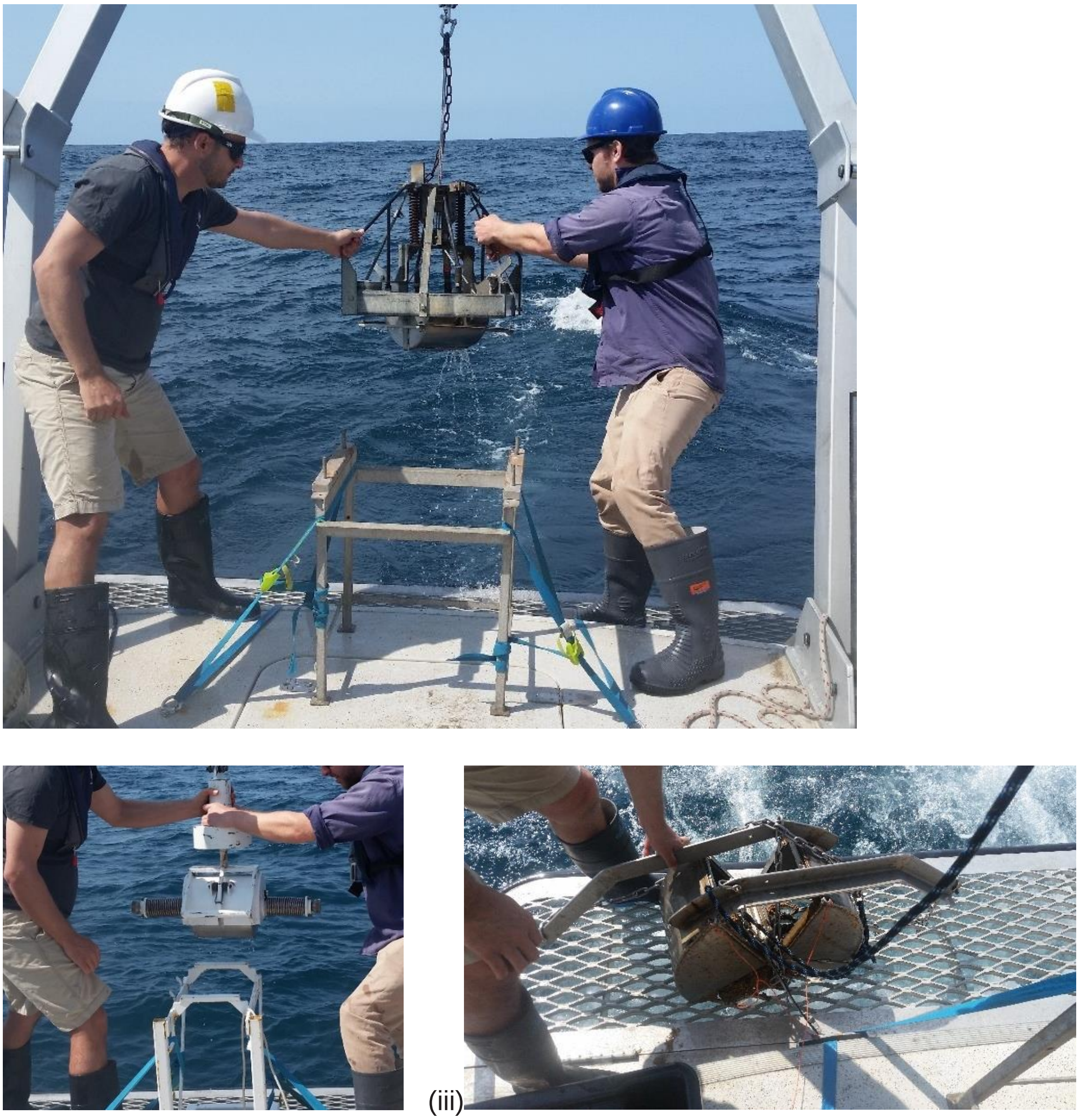
- cover a range of water depths
- cover a range of backscatter types
- include multiples of similar backscatter types (intra-specific variation) within and between different areas
- cover gradational-type areas.

Generally, sediment sampling is conducted in a manner consistent with the National Environmental Science Program (NESP) Marine Biodiversity Hub standard operating procedures (Przeslawski et al. 2018). Triplicate sampling is not achieved at many sites; however, understanding of the small-scale variability (1–5 metres) is supported by acquiring co-located seabed imagery with grab samples by using an underwater camera mounted above the sediment grab.

Accurate positioning of the grab on the seabed is provided using an Ultra-Short Base Length (USBL) 1500 MA Tracklink system (LinkQuest, USA). All positioning and depth information is captured onboard via the Tracklink software, which logs vessel and grab position as time-stamped comma delimited text files. Additional drop video imagery to aid in determination of seabed-type at the site being sampled is obtained using a GoPro (USA) in a waterproof housing (60 metres) and Keldan light (Keldan, Switzerland) attached to the winch block above the grab. Images provide a snapshot of the small-scale variability at a site and provide further evidence to support/reject backscatter-inferred seabed classification. The imagery is also important in areas such as sediment veneered reef or where small-scale variability in sediments exists such as that found between crests and troughs of sand waves.

Once retrieved, grab samples are logged on board for visible character and texture, photographed, and subsampled for laboratory analysis. Duplicate subsamples are collected to analyse for grain size and sorting, carbonate content, mineralogy, plastics and sediment microbes.

For textural analyses, subsamples are characteristically taken from the upper 2 centimetres of undisturbed surface of each grab sample, using plastic spoons, taking care to avoid the outer edges of samples. Approximately 10–20 grams of sediment is obtained for each subsample, varying slightly with the volume and surface area of each grab sample. Samples are stored in zip-lock bags and refrigerated. Where relevant, additional subsamples of notable components (e.g. pebbles, whole shells, other organic matter) are also collected and stored in separate bags. Plastics samples are collected in cleaned polycarbonate jars and refrigerated. Sediment microbe samples are collected by scooping the top <0.5 centimetres using sterile 5 millilitre cryovials, while wearing gloves, and then kept at –80°C for later metagenomic analyses.



(i) (ii) (iii)

Figure 4.5 Grabs types used for seabed sediment sampling in the Wollongong compartment: (i) Smith-MacIntyre, (ii) Shipek, and (iii) Van Veen. Photo: J Miller/OEH

4.3.3 Towed video

Towed underwater video is conducted in a manner consistent with the NESP Marine Biodiversity Hub standard operating procedures (Carroll et al. 2018). Imagery is recorded as video using a GBO Technology 1080 IP camera in an acetal pressure housing (CSIRO, Hobart) mounted at ~30° in an aluminium frame (Figure 4.6). The frame is tethered to a bridle which in turn is connected and data-fed to the surface via a reinforced fibreoptic cable wire. Additional imagery is obtained as downward looking digital stills using a Canon EOS450D (5-second auto-firing) in a waterproof housing (SeaGIS, Adelaide). Forward and down lighting are provided with a combination of Keldan Luna 8 CRI lamps with diffusers and LEDs (SeaGIS). Measurement of seafloor features is enabled through 2 x 5 milliwatt laser pointers (green-light) mounted in parallel with (@100 millimetre separation) and in the field of view of the downward looking still camera only. Laser measurement precision is determined to be <±0.5 centimetres for tow-fish heights of <2 metres (flat-bed test in air).

Figure 4.6 OEH towed video setup with forward looking (30°) video camera providing real-time video feed via fibreoptic cable to the surface and downward looking still cameras with laser pointers for scale. Photo: J Miller/OEH

Positioning of the tow-fish at the seabed is provided using a USBL 1500 MA Tracklink system (LinkQuest, USA). All positioning, depth and image information is managed and captured using onboard software and backed up by USBL Tracklink software, which saves positioning information as time-stamped comma delimited text files.

Tow-fish positioning data are extracted from survey log files into Excel and video footage analysed, scoring presence/absence and/or percent coverage for a series of habitat characteristics. These classifiers and terms are generally compliant with the Collaborative and Annotation Tolls for Analysis of Marine Imagery and Video (CATAMI) (Althaus et al. 2013, Althaus et al. 2015). Text files of analysed video are made available on the Australian Oceanographic Data Network (AODN).

5. Data and products

5.1 Rigour

Once multibeam datasets have been finalised they are subjected to an OEH internal rigour assessment process before being released as a data package. This process and its outcomes are detailed in a rigour statement issued with the final dataset for each compartment grid. The rigour statement is provided to internal/external clients and to the general public with data packages downloaded from the OEH data portal (http://data.environment.nsw.gov.au/), SEED (www.seed.nsw.gov.au) or AODN (https://portal.aodn.org.au/) websites.

The rigour assessment requires a minimum of two OEH scientists familiar with acquisition and processing of multibeam data, as well as the viewing and manipulation of spatial data in various formats and programs.

The rigour statement not only details the relevant metadata but also the results from assessments, various cross-checking, and QC procedures. For example, bathymetry data are compared to previous surveys (where available), where there is overlapping data on different transects, overlapping data on different days, and/or data from different sources. These tests ensure data repeatability and positioning (XY and Z) relative to horizontal and vertical datums. Once finalised the data are issued and the rigour statement signed by the assessors (minimum of two). An example of a rigour statement is provided in Figure 5.1.

5.2 Public data access

Final datasets are made available online at:

- OEH Information Asset Register http://data.environment.nsw.gov.au/
- NSW Government's Environmental data portal SEED www.seed.nsw.gov.au
- Australian Oceanographic Data Network https://portal.aodn.org.au/.

5.3 Output file formats

Once rigour checks have been completed gridded data is output in various generic and proprietary file formats for online delivery and access. Details of file types and software are included in Table 5.1.

Table 5.1 Data available for public access along with associated file types and software programs

Data type	File type	Program
Bathymetry grid	Geo-rectified image (.tiff)	Generic
	ESRI grid	ArcMap v10.4
	Google Earth keyhole mark-up language file (.kml, .kmz)	Google Earth Pro v7.1.4.1529
	Fledermaus object (.sd)	Fledermaus v7.7.4
Depth points	ASCII text tab delimited (.xyz, .xya)	Generic
Survey coverage area	ESRI polygon (.shp) or feature class	ArcMap 10.4

Multi-beam QAQC Metadata sheet

1. Field and Data Processing QAQC

Survey File Name FV00	PTHACKBATEBY20160725_GRD005GSS_WGS84Z56_FLD744_20160914_FV00.XYZ		
Survey Locale/Site Name	Port Hacking Jibbon Royal National Park Offshore Artificial Reef Complex		
Survey Organisation	NSW OEH		
Field Surveyor(s)	1° Tim Ingleton, Skipper Jeff Miller		
Project	Department of Primary Industry (Fisheries)		
Internal contact	David Hanslow		
External Agency Institution and/or Client contact	Ben Doolan DPI (Fisheries)		
Date of Survey	26-27/07/2016	*Horizontal and Vertical Datums*	WGS84Z56 AHD
Survey Equipment Used	11.8m Steber RVBombora with 125kHz Geoswath Interferometric swath system (2003) and POSMV Wavemaster with XYZ 000 as centre of mass at the water line - vertical offset to centre of transducer faces -0.619. Echosunder cross-validation at nadir provided by Tritech, surface sound velocity via Valeport SVS and SV profiles by SeaBird CTD. SURVEYOR: Dr Tim Ingleton, Senior Marine Scientist. Navigation provided in MaxSea and GS+: Total number of survey lines 25 at 50-60 m spacing acquired over 2 half days of surveying with 50-100% overlap. Total coverage of 2.83km².		
Positional System Accuracy	No checks of positioning against state survey marks was conducted. Position was provided as DGPS logged in POSPac. 9-day ephemeris data was acquired for post-processing using In-Fusion Precise Point Positioning for calculating a 3 min forward-backward smooth for improved SBET. Mean SBET positional accuracies were improved to X<0.07, Y<0.10 and Z<0.11.		
Operational Precision	No crossover lines were conducted during the survey. However, a sample of data from overlapping files on the same day (PH20160725UTC_001 and PH20160725UTC_002) gave a mean & sd difference in Z heights for an area of reef of 0.06 and 0.162, respectively.		
Data Processing Officer	Tim Ingleton		
Data Processing	SBETs were applied to Geoswath data before rough processing using amplitude, box, across-track and along-track filters in GS+. GSF files were exported to Fledermaus and then a PFM file and Cube surface created (IHO1) for a first pass filtering. Cube surface areas with more than 2 hypotheses were point edited before re-cubing and then exporting a final clean soundings file. Soundings were then gridded in DMagic at 5m grid scale using weighted averaging. Backscatter were output from GS+ as XTF and then processed in Fledermaus FMGT uncalibrated using 'sidescan solo'.		

2. Processed Dataset QAQC

2° Surveyor Name		Tim Ingleton
Qualitative Check	*Erroneous data removed*	No obvious artefacts associated with variable sound velocity data across deeper sections of the survey were observed. Power supply issue to sonar card meant that some data files were noisy and thus deleted.
	Horizontal and vertical datum check	Data checked and is spatially reasonable proj. as UTMWGS84Z56 relative to other geographic features. Depths are reported as negative in the XYZ.
	Data acquisition QC documented	Additional aspects of acquisition QC can be obtained in the metadata.
Quantitative Precision	*Observable Z differences*	A comparison to a previous survey in 2015 around Jibbon Bombora over areas of unconsolidated seabed indicated a mean, median difference with SD of 0.25, 0.26 and 0.02m, respectively.
FV01 filename		PTHACKBATEBY20160725_GRD005GSS_WGS84Z56_FLD744_20160914_FV01.XYZ

3. Output Products QAQC

3° Surveyor Name		Stephen Holtznagel
Qualitative & continuity check	*Digital Elevation Model + contours*	The DEM and contour plots in Arc/Fledermaus do not show any gross errors or artefacts. A nadir artefact (shallowing <0.5% of the depth) is inherent in the Geoswath dual transducer interferometric system.
	Database	The data have been incorporated in the database for NSW and the Arc Catalogue has been updated. The coverage and datafiles are topologically correct.
FV02 Final Filename		NSWOEH_20160725_PortHackingJibbon_MB_BTYGRD002GSS_W84Z56AHD_FLD744_20160901_FV02.xyz

Authorisations

Name	T Ingleton	T Ingleton	M Linklater
Data checked as	**1° Surveyor**	**2° Processor**	**3° Checker**
Signature			
Date checked	14/09/2016	14/09/2016	15/09/2016

Figure 5.1 OEH rigour statement from the Port Hacking survey 2016

Data files for surveys utilise the naming convention provided with the rigour statement as detailed below in Table 5.2; for example, an XYZ data file containing depth data will have a prefix of 20170622_NSWOEH_Wollongong_MB_AODN.

Table 5.2 Naming conventions for public access data files

Filename code	Meaning	Comments
NSWOEH	Data ownership	6 character name: denotes name of owner/ data custodian – should always be the same
Yyyymmdd	Date of final day of survey	Surveys may be 1 or many days (8 digit)
Aaaaaaaaaaaa	Nominal name of survey location and area	Unlimited character name to denote site and general location combination; upper and lower case; no spaces or underscore
XX	Two characters for data type	MB – multibeam

Additional codes

Filename code	Meaning	Comments
XXXGRDnnnYYY	XXX gridded file output	Bathymetry BTY, backscatter BKS
	GRD gridded product	Generally weighted average of points per cell or CLD cloud of soundings
	NNN grid cell resolution in metres	002 is 2 metres; 010 is 10 metres
	YYY type of multibeam system	GSS is Geoswath 125 kilohertz; R2S is R2Sonic
WnnZnnHHH	Wnn coordinate system	W84 World Geographic Coordinates 1984
	Znn zone in UTM	Z56 zone 57, 56 and 55 cover NSW
	HHH Z height datum	AHD Australian Height Datum or GRY for backscatter
AAAnnn	Software and version used to output the product	FLD Fledermaus v. 744, ARC ArcMap 10.1, FMG770 Fledermaus FMGT Geocoder GTX326 Geotexture, QIM147 for Qimera
Yyyymmdd	Date of product export	The date of producing the final grid or mosaic
FVnn	File version	FV00 gridded output from acquisition software with standard filters applied; FV01 CUBE model filtered and gridded output product draft version non-final, FV02 SBET corrected, CUBE model filtered, accepted soundings only then gridded in Fledermaus DMagic

Appendix A: Survey vessel and equipment timeline

Appendix A provides context for the variability in systems utilised and quality of datasets obtained by OEH using MBES-type systems. A brief timeline of OEH's surveying capacity since 2005 is provided below.

Date	Vessel	Survey system	Detail
Jul 2004	*Glaucus*	Geoswath	NSW Department of Environment and Conservation (now OEH) purchases a Geoswath 125 kHz (GeoAcoustics, UK) swath mapping system to conduct habitat mapping for two proposed new marine parks. The Geoswath is an interferometric swath bathymetry system that collects bathymetry and backscatter (amplitude of reflected signal) information suited to mapping seabed characteristics.
Aug–Nov 2004			Vessel is fitted with an over-the-side pole-mount manufactured at Lidcombe workshop based upon Flinders Ports Authority setup (Adelaide). Ancillary equipment included an Omnistar DGPS system (Fugro, USA), SG Brown gyrocompass for heading (SG Brown, UK), surface sound velocity probe (Valeport, UK) and a DMS-05 TSS motion reference unit (Teledyne, UK) for real-time roll-pitch-yaw-heave corrections at 50 Hz.
Dec 2004			Trials and patch testing, Port Hacking.
Jan 2005			Surveying commenced off Boondelbah and Broughton islands, Port Stephens.
2009	*Sea Scan*	single-beam	Aluminium Marlin Broadbill catamaran, commissioned in 2008 as a trailer-able vessel for Department of Lands – Coastal Branch for single-beam surveying in estuaries, oceanic embayments and the nearshore. *Sea Scan* hydrosurveying utilises RTK corrections through radio-link connections to onshore Leica base stations (co-located on state survey marks) and then later using the mobile phone network (CORSnet).
Jul–Dec 2009	*Bombora*	Geoswath	*Glaucus* decommissioned. Department of Environment and Climate Change takes delivery of RV *Bombora*, an 11.8 m Steber (Taree, NSW) fibreglass mono-hull as the department's new sea-going research vessel. The Geoswath pole-mount was relocated to the new vessel along with the sonar and ancillary equipment. A hardstand survey of the vessel and its equipment was conducted at the time to provide three-dimensional positioning of equipment relative to the vessel frame (mm precision).
2010			Surveying capabilities of Department of Environment and Climate Change and Department of Lands merged.
2011	*Bombora*	Geoswath	Ongoing issues with the DMS-05 (rate-gyro errors) prompted a move to a POS-MV system (Applanix, Canada). POS purchased and installed in early 2011. POS MV is a motion reference system that blends GNSS data with angular rate and acceleration data from an IMU and heading data from GNSS Azimuth Measurement System (GAMS) to produce a robust and accurate full six degrees of freedom position and orientation solution (Applanix, USA).

Date	Vessel	Survey system	Detail
2011	*Sea Scan*	R2Sonic 2022	OEH purchases an R2Sonic 2022 multibeam system (R2Sonic, USA) and modifies *Sea Scan* with a moon-pool to accommodate a through-hull mount. The R2Sonic system operates across a depth range of 0–400 m and frequency range of 200–400 kHz. As a true beam-former, the R2Sonic provides the ability to steer the sonar beams across-track, making it suited to shallow water surveys around shallow reefs, walls, wrecks and infrastructure. The system can be configured to acquire as either equidistant or equiangle. As a single receiver it does not suffer from a paucity of data at nadir like that of dual-transducer systems. RTK is provided through CorsNET and 4G mobile phone network. Hardstand survey (R2Sonic and Geoswath heads) and trials on RV *Bombora* in Port Stephens.
2012			POS Wavemaster 320 system was purchased for *Sea Scan* operations.
2013	*Bombora*	Geoswath	Use of RTK through CorsNET using NTRIP and Hypack. While the system worked well in some areas, reception offshore was often intermittent dropping back to differential level corrections for extended periods. Post-processing was still required to provide the best survey data possible. Due to issues with NTRIP and Windows, use of RTK real-time corrections was abandoned in mid-2015 and operations reverted to using DGPS and PPP post-processed SBET solution.
2014	*Sea Scan*	R2Sonic	Upgrade of the R2Sonic system to enable capture of 'snippets' backscatter timeseries data. Beam-timeseries provides a more even representation of the backscatter return signal resulting in an improved backscatter product that is more reliable for automated seabed classification. Truepix is the R2Sonic version of seabed-return amplitude data which can also be acquired (not simultaneously).
Sept–Nov 2016	*Bombora*	R2Sonic	R2Sonic installed on *Bombora* while major repairs are undertaken on *Sea Scan*. Commence statewide mapping surveys.
Aug 2017			Capital replacement of Geoswath system for *Bombora* confirmed for 2017–18.
Mar 2018	*Bombora*	R2Sonic	Purchase of second R2Sonic 2022 head. Hardstand survey for vessel reference frame and mount.
Dec 20	*Bombora*	R2Sonic	Installation of new pole mount with increase in length of pole arm by 100mm, increased thickness of top hinge plate and installation of locator pin in top hinge plate block. Hardstand survey of new pole mount.

Appendix B: Geoswath survey system

Appendix B provides information about the MBES-type system previously used by OEH to conduct seabed mapping surveys in New South Wales.

Prior to purchasing an R2Sonic multibeam system, OEH operated a 125 kilohertz Geoswath system (GeoAcoustics now Kongsberg) for offshore bathymetry surveying aboard vessels *Glaucus* (2005–2009) and *Bombora* (2009–2016). Geoswath utilises an interferometer or multiphase echo sounder (MPES) to obtain bathymetric information (0–200 metre water depth) and a side-scan to provide data on seabed hardness. The system is user-friendly with simple setup and software and ideal for operations in the 20–100 metre depth range.

Mobilisation and setup

Details on mobilisation and setup for Geoswath prior to 2009 are in Appendix A. Further details can be provided upon request.

Frame of reference and initial lever arm offsets established on RV *Bombora* were obtained while the vessel was on hardstand in 2009 (Steber, Taree) by OEH's hydrosurveyor using a theodolite and laser levelling system. Values were checked again while the vessel was in dry dock at Port Stephens in 2012 with CRKennedy (Sydney) confirming offsets were within 0.005 metres of the original values. The sonic centre to waterline value for the Geoswath installation was determined to be –0.619 metres. Details on lever arm offsets from the initial survey are provided in Section 2.4.1, Figure 2.5 in the main body of this document.

Bathymetric data acquisition

The proprietary software used for acquisition of Geoswath bathymetry data is GS+. Projects are created using the File > New Project option from the drop-down menu. Projects are named using a site (e.g. Wollongong) and year (yyyy) with multiple days of data contained within the same project. XYZ lever arm offsets are imported from previous projects as a Vessel Settings file and patch test offsets as a Calibration File. These are applied in real-time for display only (see Figure B.1 below).

Navigation and survey lines are managed in Hypack with planned survey lines created in a project file named with site (e.g. Wollongong) and year of survey (yyyy) for each new survey area. A backup of vessel positioning is logged by activating file acquisition in Hypack (once sonar acquisition is activated in GS+). All raw sonar data is acquired and time-stamped in GS+. Positioning of SVP can also be recorded in Hypack using the F5 hotkey.

Upon deploying the sonar heads over the side, the sonar is activated by pushing the transmit and receive buttons and surveying is ready to commence.

Sonar settings

Power and gain are generally maintained at 1 for all surveys to ensure a level of consistency in the seabed returns between transects, days and surveys. However, at the start of each day, the ping length (pulse) needs to be adjusted to ensure the soundings being retained are reliable. For this interferometric system, multiple solutions for the seabed will be acquired per 'beam' and displayed for the operator in the Across-Track window in the Acquisition tab of the software. The user can observe multiple soundings as clusters of soundings (at each angle) at the seabed. The operator will also observe an increase in the vertical spread of these soundings with increased distance from nadir (centre-line). The operator must decide on the ping length (a time in µs but in GS+ is displayed as a slant range distance from sonar to seabed) that ensures that data are being acquired up to a point on the seabed where the vertical spread of soundings is no more than ~1–1.5 metres.

As the Geoswath is a dual-transducer system, when one transducer has emitted a ping it must wait for the return signal before pinging again on the alternate side. Generally, for coastal surveys the Geoswath achieves between 4 and 12 pings per second in the along-track direction at a survey speed of 5 knots.

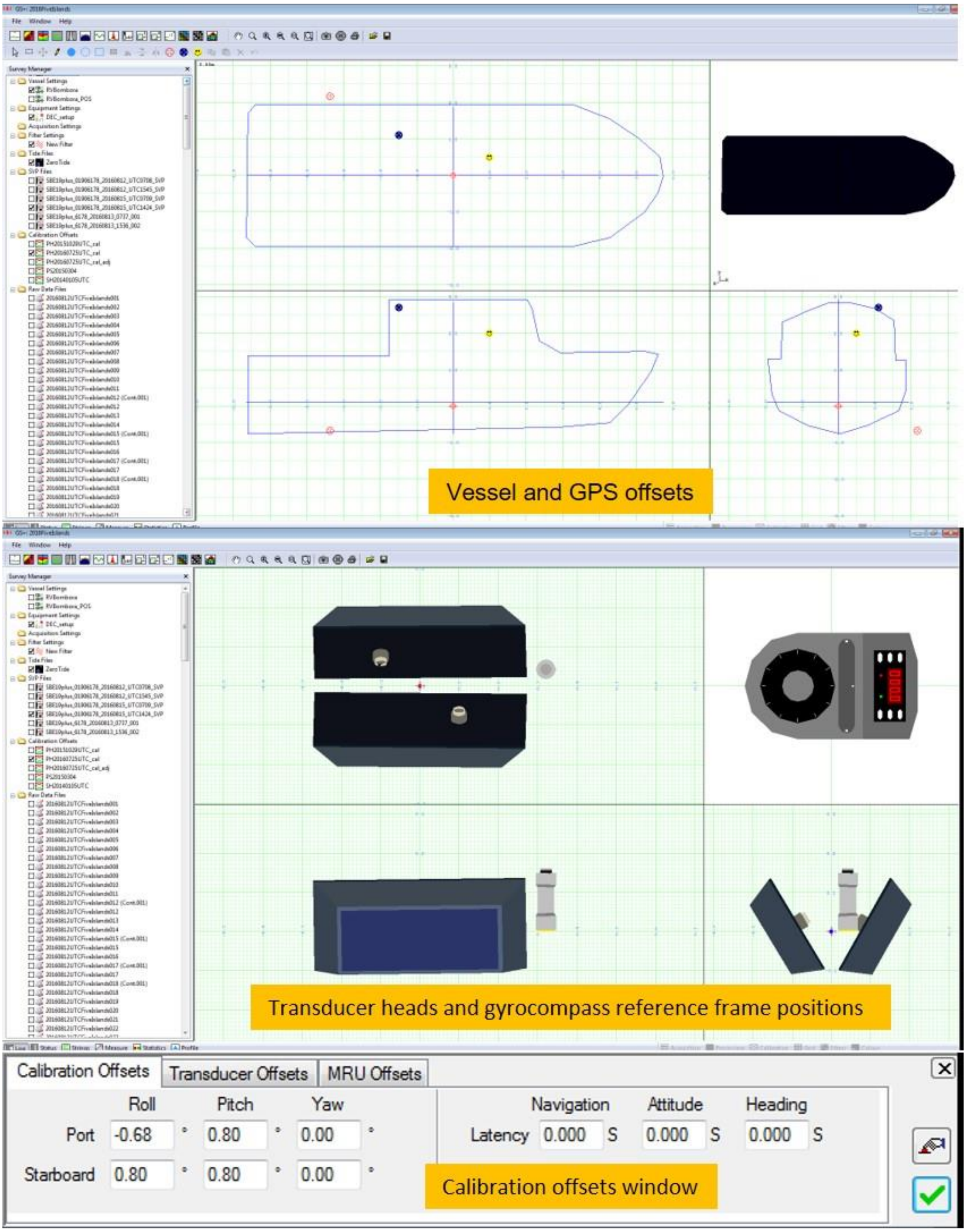


Figure B.1 GS+ Vessel Settings file windows

Filters

All filters except Water Column and Group filters are turned off prior to acquisition so that all soundings are retained and can be filtered in post-processing.

File naming conventions

Raw data files are generally named with a 3-character prefix (ABC) as a site code and then UTC date at the start of the survey day YYYYMMDDUTC followed by 001, 002, 003 for each subsequent file. Data files are auto split at 250MB to better manage files in post-processing.

Real-time monitoring

Surface sound velocity and roll-pitch-yaw-heave windows are monitored in real-time to check for changes in water column speed of sound and to monitor major auxiliary input data outages or errors. POS outputs are monitored using the POSView window to look for POS data outages or accuracy alarms. As the depth, seabed type and/or environmental conditions change, the ping length may need to be adjusted. Generally, the effective swath width is between 4 and 5 times water depth for most surveys using the Geoswath.

Motion and positioning

From 2005–2010 the Geoswath system used a Sokkia differential GPS for positioning (with PPS pulse per second for computer timing), SG Brown Gyrocompass for heading and Teledyne TSS DMS-05 Inertial Motion Unit for 3-D roll, pitch, yaw and heave. Typically, using this setup, DGPS positioning provided XY accuracies of <2 metres and the raw motion solution provided Z accuracies of ~0.75–1 metre. In 2011, improvements to the setup were achieved with the replacement of the IMU/Gyro/DGPS with a POS MV Wavemaster (Applanix, USA) system to provide decimetre level XYZ accuracies.

Operating along the coast and further offshore, Geoswath multibeam surveys relied on DGPS with real-time correction message (RTCM) with POS real-time data collection. POS data were post-processed using POSPac (Applanix, USA) to provide an improved vessel smoothed best estimate of trajectory (SBET). For DGPS level data the precise point positioning (PPP) module in POSPac characteristically provides XYZ accuracies of <0.1–0.15 metres.

Geoswath surveys rely on DGPS for real-time positioning; however, to improve accuracies during post-processing procedures three minutes of 'Good' POS data acquisition (i.e. constant heading and speed) is collected at the beginning and end of the POS data logging period for each survey day. This data is used to perform a three-minute forward-reverse smooth function when calculating the PPP (precise point positioning) SBET (smoothed best estimate of trajectory). When DGPS accuracies are exceeded, the last three minutes of survey are repeated (~100 metres at 6 knots). All accuracy alarms need to have ceased and three minutes of 'good' POS data logging acquired prior to survey recommencement.

Geoswath processing

POS processing for SBET

POS data is imported into POSPac and improved satellite positioning data (21-day final ephemeris) is downloaded online (Applanix POSPac manual). Once uploaded Geoswath real-time POS is processed using PPP with three-minute forward–reverse smoothing. Data is exported in an orthographic WGS84 projection based on the 1997 geoid and output with the sonar centre as the point of reference. XYZ RMS accuracies are generally <0.1 metres.

Phase 1

In GS+ SBET are imported and applied prior to filtering. Vessel lever arms are re-set to XYZ 000 as processing with SBET uses the sonar centre as the point of reference. The water line to sonar offset is accounted for in the GS sonar settings menu (–0.619 metres). Geoswath data are then filtered to remove erroneous points such as water column soundings and noise using a combination of sequential filters including the following:

- amplitude – sets a threshold (%) value for which amplitude values above or below the threshold are filtered out
- box or limits filter – uses horizontal, slant and depth minimum and maximum threshold values to set ‘expected’ limits for sonar returns beyond which points are filtered out. Removes multiples and physically impossible (i.e. above the water) returns
- across-track – a learning filter which uses a percentage of the previous ping to guide filtering on the new ping. The filter adjusts as the bottom changes (greatest concentration of pings – strongest returns) and multiple points in the across-track direction (max. 20) can be set as threshold filters x metres above and below the seabed
- along-track – this filter finds the mean at each step and then defines a depth window box (horizontally and vertically) either side of the mean.

GS+ produces a series of output format files as a result of this process:

- swath GS bathymetry sounding file
- GSF format sounding file (for use in Fledermaus)
- swamp mean backscatter intensity (amplitude) file
- XTF mean backscatter intensity file (for use in FMGT)
- echo sounder file.

Phase 2

Bathymetry

GSF files were imported into Fledermaus and built into a Pure File Magic (PFM) file that provides a 3-D gridded surface to display for editing, while managing the large volume of soundings (clouds) which remain linked but hidden in the background. The PFM is a CUBE modelled surface based on a grid cell size and an International Hydrographic Organisation (IHO) or other hydrographic certifying body standard as defined by the user. OEH surveys typically use a 4-metre grid and adhere to an IHO Order 1B standard for Phase 2 editing.

The PFM surface is projected in 3-D in the main Fledermaus window and a ‘weighted average’ of the grid cell depth values selected for display. The PFM surface is then overlaid with a CUBE ‘uncertainty’ value and areas where there are >2–3 hypotheses highlighted. Smaller subsets of these areas are then ‘extracted’ and the clouds of soundings investigated for that subset using the point editing suite. Here individual soundings can be investigated in detail in a 3-D environment and a decision made to include or exclude individual soundings. Soundings considered bad are then flagged, the CUBE surface recalculated and PFM updated.

Once all editing is completed the entire PFM is re-cubed and then cleaned soundings are exported. Clean soundings files are then imported in DMagic (Fledermaus) where they can be used to generate gridded bathymetry files at the desired resolution.

Uncertainty and population statistics can also be generated to provide measures of QC across the survey area.

Backscatter

Geoswath backscatter ‘swamp’ files are exported from GS+ as XTF and imported to Fledermaus FMGT. Amplitude data is extracted (using side-scan solo mode) and transmit/receive power gain corrections are applied on uncalibrated data between ~0 and 60° using a default reference value of –50 decibels. Transmission loss (absorption coefficient) values are contained within the raw source files and applied. Angle varying gain corrections are applied during filtering over a window of 30 pings using a ‘flat’ algorithm default, with ping statistics calculated in logarithmic space (dB). Mosaicing parameters are set to ‘No Nadir if Possible’ to remove nadir stretching (where there is sufficient overlap of adjacent swaths), ‘dB mean’ is set as the filter type and ‘Filter Gaps with adjacency’ is applied. Sensor configuration values are otherwise set as default. Final mosaics are exported from FMGT as geotiffs, SDs and tab delimited ascii (XYA).

References

Althaus F, Hill NA, Edwards L and Ferrari R 2013, *CAATAMI Classification Scheme for scoring marine biota and substrata in underwater imagery – A pictorial guide to the Collaborative and Annotation Tolls for Analysis of Marine Imagery and Video (CATAMI) classification scheme*, National Environmental Research Program, http://catami.github.io/catami-docs/CATAMI%20class_PDFGuide_V4_20141218.pdf

Althaus F, Hill N, Ferrari R, Edwards L, Przeslawski R, Schönberg CH, Stuart-Smith R, Barrett N, Edgar G, Colquhoun J and Tran M 2015, A standardised vocabulary for identifying benthic biota and substrata from underwater imagery: the CATAMI classification scheme, *PloS one*, vol.10, no.10, p.e0141039.

Carroll A, Althaus F, Beaman R, Friedman A, Ierodiaconou D, Ingleton T, Jordan A, Linklater M, Monk J, Post A, Przeslawski R, Smith J, Stowar M, Tran M and Tyndall A 2018, 'Marine sampling field manual for towed underwater camera systems', in *Field Manuals for Marine Sampling to Monitor Australian Waters*, Przeslawski R, Foster S (eds), National Environmental Science Programme (NESP), pp.131–152.

Chen CT and Millero FJ 1977, Speed of sound in seawater at high pressures, *J. Acoust. Soc. Am*., vol.62, no.5, pp.1129–1135.

IHO 2008, *Standards for Hydrographic Surveys*, (S-44), 5th Edition Feb 2008, Special Publication No. 44, International Hydrographic Organization (IHO), Monaco, www.iho.int/iho_pubs/IHO_Download.htm

Lucieer V, Picard K, Siwabessy J, Jordan A, Tran M and Monk J 2018, 'Seafloor mapping field manual for multibeam sonar', in *Field Manuals for Marine Sampling to Monitor Australian Waters*, Przeslawski R, Foster S (eds), National Environmental Science Programme (NESP), pp.42–64.

Lurton X and Lamarche G (eds) 2015, *Backscatter measurements by seafloor-mapping sonars: Guidelines and Recommendations*, 200pp., http://geohab.org/wp-content/uploads/2013/02/BWSG-REPORT-MAY2015.pdf

Przeslawski R, Berents P, Clark M, Edgar G, Frid C, Hughes L, Ingleton T, Kennedy D, Nichol S and Smith J 2018, 'Marine sampling field manual for grabs and box corers', in *Field Manuals for Marine Sampling to Monitor Australian Waters*, Przeslawski R, Foster S (eds), National Environmental Science Programme (NESP), pp.172–195.