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High-Resolution Multibeam Surveys at the Sydney Ports Corporation

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ABSTRACT

The recent introduction of a high-resolution multibeam echosounder in the Sydney Ports Corporation Survey Services Department has provided full seafloor coverage of our ports for the first time. Results from these surveys have continually proven to meet the manufacturer's stated accuracy and repeatability. The multibeam echosounder system was more recently utilised during the construction of the Port Botany Expansion project to survey the scour rock placed to protect the quay wall from erosion. The Port Botany Expansion contract design stipulated minimum depths for the scour rock, as well as a minimum thickness of the placed rock. The contractor's resultant hydrographic surveys produced quite different results to the checking surveys conducted by Sydney Ports' hydrographic survey team. This paper presents some of the changes in equipment and procedures since the adoption of multibeam technology, and also the processes used by Sydney Ports' Survey Department to validate the reliability and the accuracy of the scour rock hydrographic surveys.

KEYWORDS: *Sydney Ports, Port Botany Expansion, hydrographic, multibeam echosounder, accuracy.*

1 INTRODUCTION

Sydney Ports Corporation Survey Services Department provides hydrographic survey information to mariners and engineers. Coverage areas include all navigation channels utilised by commercial traffic within Sydney Harbour and Port Botany (Figure 1). In the past, this information was gathered using singlebeam echosounder and side-scan sonar technology. In 2009, Sydney Ports Corporation (SPC) introduced a High Resolution Multibeam Echosounder (MBES) survey system.

The MBES system has greatly improved the efficiency of the survey section as well as increasing the seafloor coverage of Sydney Ports charting. Results from these surveys have continually proven to meet the manufacturer's stated accuracy and repeatability.

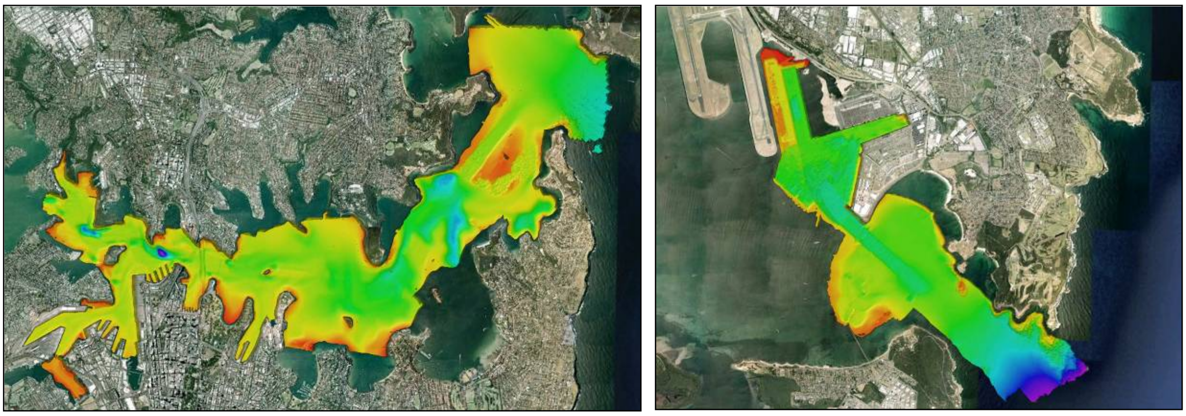

Figure 1: Sydney Ports Corporation hydrographic survey coverage areas, i.e. Sydney Harbour (left) and Port Botany (right).

2 SYDNEY PORTS SURVEY REQUIREMENTS

SPC hydrographic surveys are carried out in accordance with the Ports Australia Principles for Gathering and Processing Hydrographic Information in Australian Ports (Ports Australia, 2008). These principles are primarily intended for (but not limited to) use in Australian ports where shipping regularly or on occasions operates with restrictions on Under Keel Clearance (UKC) and are intended for use in ports, supplementing the International Hydrographic Organization (IHO) SP44 Standards for Hydrographic Surveys (Table 1). IHO Special Order Survey specifications are used as nominal standards for all hydrographic surveys performed by SPC.

Table 1: IHO S-44 Standards for hydrographic surveys (International Hydrographic Bureau, 2008).

ORDER	Special	1	2	3
Examples of typical areas	Harbours, berthing areas, and associated critical channels	Harbours, approaches, recommended tracks and some coastal areas with depths up to 100m	Areas not described in Special Order and Order 1, or areas up to 200m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal accuracy (95% confidence level)	2m	5m + 5% of depth	20m + 5% of depth	150m + 5% of depth
Depth accuracy for reduced depths (95% confidence level)†	a = 0.25m b = 0.0075	a = 0.5m b = 0.013	a = 1.0m b = 0.023	Same as Order 2
100% bottom search	Compulsory	Required in selected areas	May be required in selected areas	N/A
System detection capability	Cubic features >1m	Cubic features >2m in depths up to 40m; 10% of depth beyond 40m.	Same as Order 1	N/A
Maximum line spacing	N/A	3x average depth or 25m, whichever is greater	3-4x average depth or 200m, whichever is greater	4x average depth

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

where:

a = constant depth error, i.e. sum of all constant errors
$b \times d$ = depth dependent error, i.e. the sum of all depth dependent errors
b = factor of depth dependent error
d = depth

2.1 Achieving Survey Requirements before MBES

Prior to the purchase and installation of the new MBES system, SPC met the IHO Special Order survey specifications through the use of singlebeam echosounder (SBES) and side-scan sonar (SSS). Depth soundings were measured using the SBES, with the SSS enabling the compulsory 100% bottom search and identification of features and/or targets larger than 1 m^3 which would then be re-surveyed using the SBES and possibly removed by divers at a later date.

The SBES used by SPC was the ATLAS DESO 25 with a dual-frequency transducer (33 kHz and 210 kHz). At the higher frequency the echosounder measured the minimum seabed depth within the eight-degree transducer beamwidth, with an approximate footprint diameter of 1.4 m at 10.0 m depth, and 2.1 m at 15.0 m depth. Because of the size of this transducer footprint the true position of the measured depth can never be known with certainty.

The SSS used was a Klein 3000, with a maximum across-track range of 600 m at 100 kHz and 150 m at 500 kHz operating frequency. However, line spacing never exceeded 150 m, as SBES line spacing was run at 2 m within berth boxes, up to a maximum of 20 m in deeper channel areas. The SSS was generally run at 50 m range setting, allowing for at least 200% seafloor ensonification (total coverage of survey area that is acoustically imaged in the course of a sonar survey) in all areas. The SSS along-track beam width was 0.7° at 100 kHz, or 0.21° at 500 kHz, enabling multiple strikes on a 1 m^3 target at a vessel speed of 5 knots.

Trimble HydroPro® software was used for the online acquisition of the SBES data, and SonarPro® for the SSS. Office-based processing of SBES data was also completed using Trimble HydroPro® software, and SSS data in CARIS SIPS®.

Horizontal accuracy requirements were met through the use of Real Time Kinematic (RTK) GPS, which SPC has adopted since 1995.

SPC owns and operates two GNSS base stations, located at Sydney Harbour and Port Botany. These SPC base stations are coordinated:

- Horizontally in Map Grid of Australia 1994 (MGA94) coordinates, which is the Universal Transverse Mercator (UTM) projection based on the Geocentric Datum of Australia 1994 (GDA94, see ICSM, 2006).
- Vertically in the chart datum, Zero Fort Denison Tide Gauge (ZFDTG), i.e. 0.925 m below the Australian Height Datum 1971 (AHD71, see Roelse et al., 1971).

Differentially adjusted values measured the height of the antenna on the vessel. Combined with its fixed offset to the transducer and the depth measured by the echosounder, a reduced value for each sounding could be determined. The general survey vessel setup for a SBES survey is shown in Figure 2.

Bar checks were carried out before and after the survey to ensure the SBES was performing effectively and taking into consideration daily metocean conditions such as water temperature and salinity which in turn alter the speed of sound through water. The bar check is carried out by lowering a bar underneath the SBES transducer. This bar is attached to wire rope that has accurate metre markings and is held at various interval depths to calibrate and check the accuracy of the echo sounder measurements. The process is essentially the same as checking an Electronic Distance Measuring (EDM) instrument over a known baseline. Repeatability, however, was difficult to assess with singlebeam as coverage of the seafloor is actually quite sparse. Survey cross-lines were run at 50-metre spacing over the site. Comparisons were carried out between subsequent surveys using contour comparisons to assess changes to the seabed.

This equipment, as well as SPC's well founded methodology, achieved the Special Order survey standard requirements, set by IHO in SP44 (International Hydrographic Bureau, 2008).

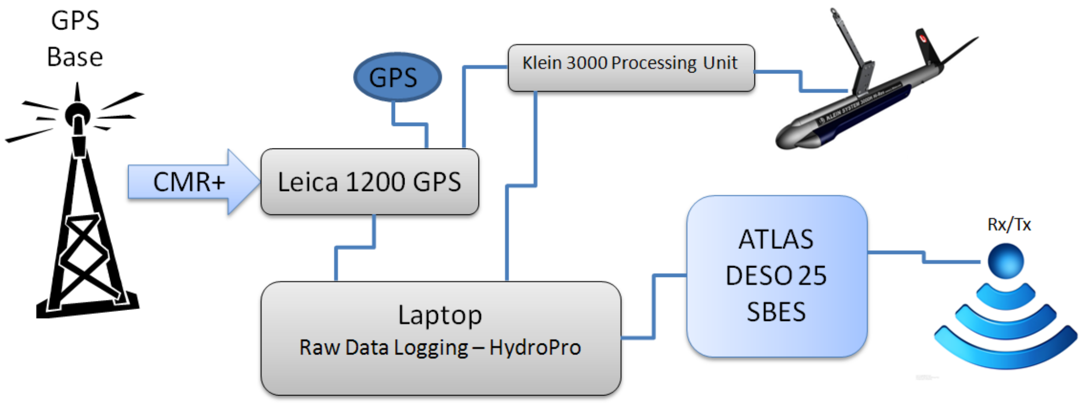

Figure 2: General survey setup for SBES surveys on SPC vessels.

2.2 Achieving Survey Requirements with MBES

In August 2009, SPC invested in a Reson 7125 SV MBES system. The Reson 7125 is a multibeam system with 256 beams, with individual beam widths of 1° along track and 0.5° across track. Using advanced beam-forming algorithms, this can be increased to 512 beams and can "ping" at up to 50 Hz. The swath width is 128°, allowing for across-track coverage of up to four times the water depth. The MBES system also records backscatter data (intensity data for each beam), enabling the creation of mosaics as previously created with the SSS and allowing for seabed classification and improved target identification.

The MBES system receives the vessel position and attitude data from an Applanix® Position & Orientation Solution for Marine Vessels (POSMV 320), an inertially-aided RTK system. The POSMV is capable of measuring vessel roll and pitch to 0.01°, yaw to 0.02° and heave to 0.05 m. The general survey vessel setup for a MBES survey is shown in Figure 3.

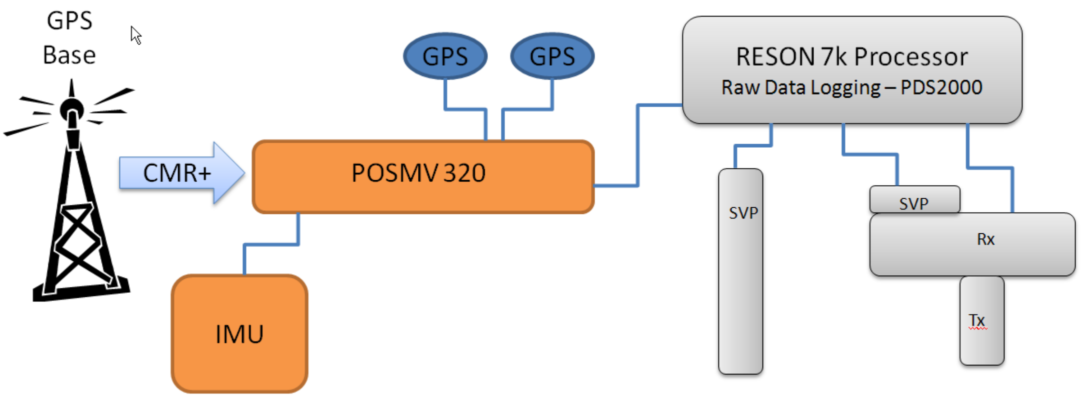

Figure 3: General survey setup for MBES surveys on SPC vessels.

Horizontal and vertical datum and all project geodesy remain the same as with previous SBES surveys, though with Applanix® POSPac software it is now also possible to calculate an inertially-aided, post-processed kinematic solution back in the office and reapply this to the sounding data during processing. This is ideal for periods of RTK drop-outs whilst acquiring data in the field, and allows for more rigorous quality control (QC) of positioning data applied to finally reduced soundings.

The MBES setup onboard the vessel is regularly and periodically calibrated to ensure calibration values are valid for the vessel and that final data quality meets survey requirements. This is done in order to calculate alignment offsets between the motion sensor and gyro (in SPC's case the POSMV) and the Reson 7125 sonar head, plus any latency within the system setup. The patch test routine which SPC follows is a very well documented procedure, more details regarding these calibration tests can be found in the Caris HIPS/SIPS User Manual (Godin, 2003).

Field procedures for MBES surveys include real-time comparisons of RTK tidal values against measured tide gauge data, line planning to ensure at least 200% seabed coverage and ensuring that target detection criteria are met (three soundings across-track and three soundings along-track on a 1 m^3 target). With the implementation of MBES comes the requirement for increased measurements of the speed of sound through the water column, both spatially and temporally, within the survey area using a calibrated Sound Velocity Profiler SVP.

Office-based data processing of the MBES data involves the QC of all position and attitude data, sound velocity data and the merging of this data with the raw soundings from the echosounder. Once this is complete, a point cloud of all reduced data is created (much like terrestrial LiDAR and/or laser scanner data). Various filters, such as spike filters and removal of outer beams can be run automatically before the manual data analysis, data cleaning and data QC is carried out by one of the SPC hydrographic surveyors. The entire processing procedure adopted by SPC involves many different steps, though the process is fairly standard to all MBES surveys irrespective of equipment and/or processing software. This office-based data processing procedure is illustrated in Figure 4.

This equipment and methodology has continually proven to achieve the Special Order survey standard requirements, set by IHO in SP44 (International Hydrographic Bureau, 2008).

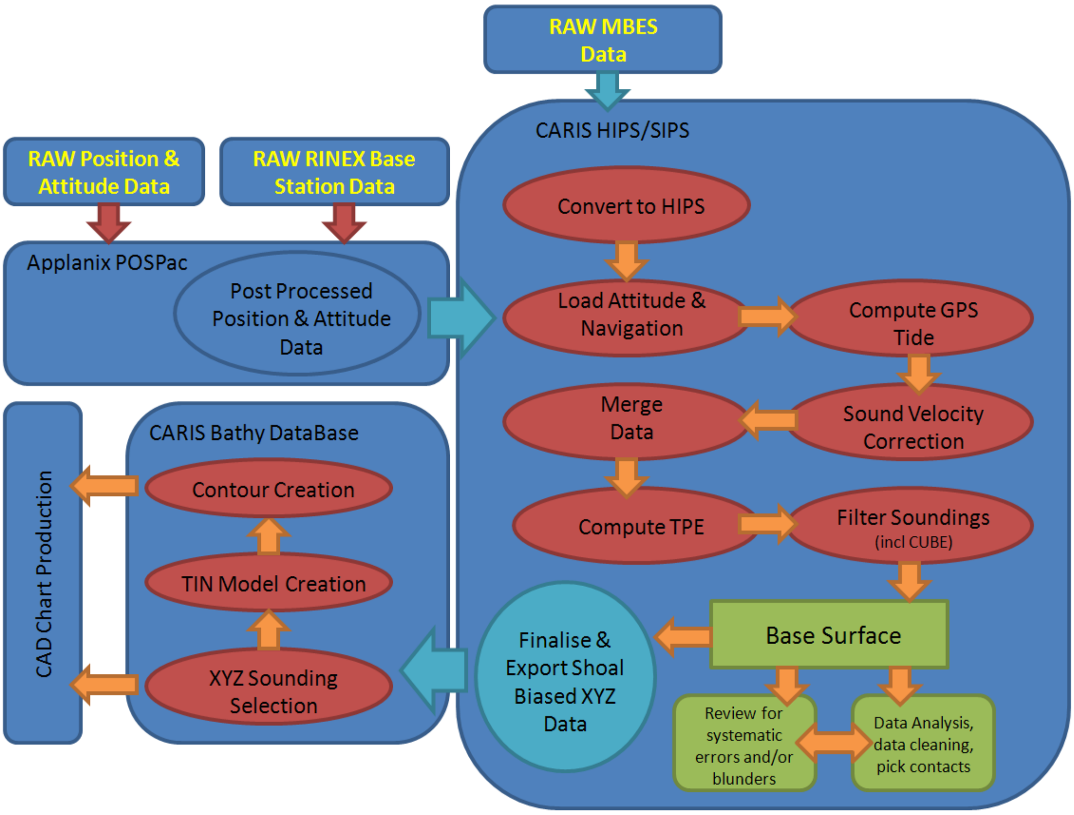

Figure 4: Office-based data processing procedure for MBES surveys at SPC.

2.3 Benefits of MBES to SPC

Whilst the adoption of multibeam technology has meant an overhaul of SPC's hydrographic survey procedures, and a massive increase in data storage requirements, there are many benefits to its implementation. These include:

- Real-Time digital terrain model (DTM) view of data, allowing for more rapid identification of hazards to navigation.
- 100% seabed bathymetry, allowing for increased coverage and less acquisition time in the field. However, office-based processing times have increased.
- Improved target detection capabilities, especially with regards to those posing potential hazards to navigation. More reliable detection and identification of smaller targets allows for more informed decisions on whether diver inspections and/or target removals are required.
- Improved quality of wreck investigation surveys, for archaeological purposes, as well as safety of navigation. This is due to higher density, more accurate soundings, allowing higher definition imagery of objects found on the port bed.
- Improved quality of coastal engineering surveys, such as quay wall inspections, bridge foundation monitoring and general scour monitoring surveys. This is achieved because of the ability to measure more accurately and densely all underwater structures, then enabling comparison of their position of over various surveys.
- More accurate volume calculation for all aspects of proposed and ongoing dredging projects.
- The ability to bid competitively for hydrographic survey contracts, as most survey specifications usually state a requirement for MBES.

- 3D interactive visualisations for engineering works and ease of interpretation of hydrographic data.
- More accurate temporal comparisons between successive surveys, allowing for better monitoring of erosion and deposition of seabed sediments.

3 ACCURACY AND PRECISION OF MBES DATA

The primary purpose of SPC's hydrographic data is safety of navigation, and hence it is important to quantify accuracy (closeness to the true depth) and precision (repeatability of depth sounding) of acquired data.

The increased density of the sounding data acquired with MBES also allows a better statistical analysis of the reduced soundings, specifically with regards to the accuracy and precision of the data with respect to survey standards and specifications. Standards used within this paper for the assessment of hydrographic data precision accuracy will be referred to IHO S44 Special Order survey tolerance values (International Hydrographic Bureau, 2008).

During 2011, SPC completed several surveys adjacent to the new Port Botany Expansion (PBE) over areas of scour protection rock. This scour rock was placed by the engineering contractor in the newly constructed berthing areas adjacent to the dock. The purpose of these surveys was to ensure that the construction of the berths had been completed within project design specifications, specifically minimum scour rock layer thickness and minimum berth depth clearance with respect to the chart datum.

SPC MBES data from these surveys were compared with as-constructed survey data as supplied by the PBE construction engineering contractor. Analysis of these datasets revealed some discrepancies between surveys which needed to be quantified before the work could be signed off. Of most interest were individual scour rock targets, which were showing as above the design depth in SPC surveys, but often not shown in the contractor's surveys.

In order to quantify the accuracy and precision of MBES survey data, a reference surface is created from the survey data and then subsequent survey line data is statistically analysed against this surface. The area chosen for the reference surface would usually be an area of relatively benign seabed which has been ground-truthed in some way.

The reference surface for this study was created using survey data collected over the scour pad area and produced with a bin size roughly equivalent to the average diameter of the scour rock boulders, i.e. about 0.50 m. Results of this analysis are shown in Table 2.

Table 2: SPC and contractor MBES survey stats over SPC scour rock reference surface.

Survey Method	SPC MBES Survey	Contractor MBES Survey
Number of points in comparison	945,449	364,425
Mean Difference from Reference (m)	-0.005	0.008
Standard Deviation (m)	0.062	0.100
95% confidence interval (m) [mean + (2 x standard deviation)]	0.129	0.208
IHO Special Order error limit	0.270	0.270
IHO Special Order survey	ACCEPTED	ACCEPTED

The data shows that, statistically, both the SPC surveys and the contractor surveys are within IHO Special Order specifications, although SPC data shows a closer fit with the reference data. However, many isolated scour rock targets were evident above the design level (-16.5 m) in the SPC survey, but not in the contractor surveys (Figure 5).

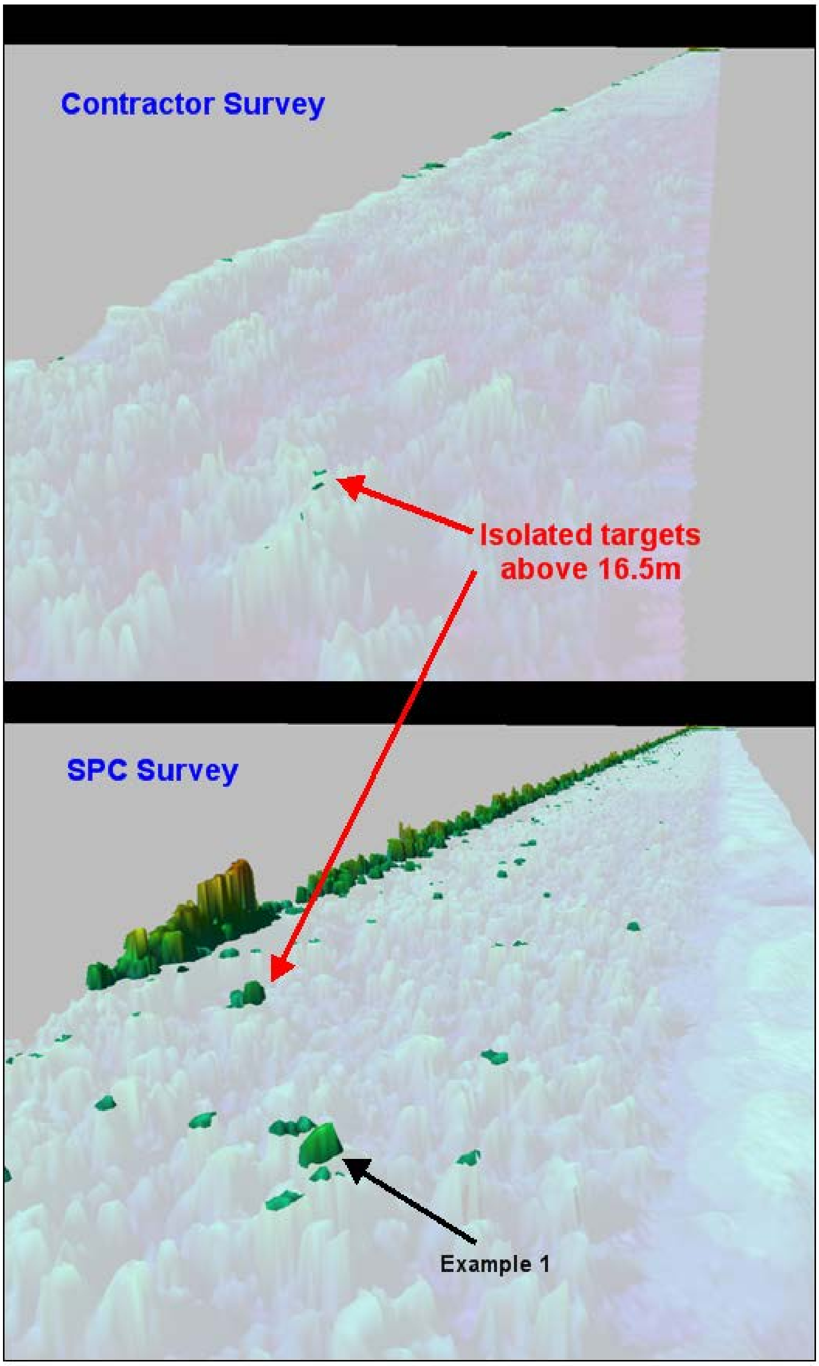

Figure 5: Targets remaining above 16.5 m depth in contractor and SPC MBES surveys.

To ensure that these shoal depths were 'real' SPC carried out repeated surveys on consecutive days (and also from differing vessel surface position/heading) to confirm repeatability. Because the contractor's equipment was not identifying these individual rock shoals with any consistency, it was their position that the shoals were in fact 'phantoms'. Repeated MBES surveys of the same areas indeed showed that many, if not all, of the targets shown in the data definitely existed (Figure 6).

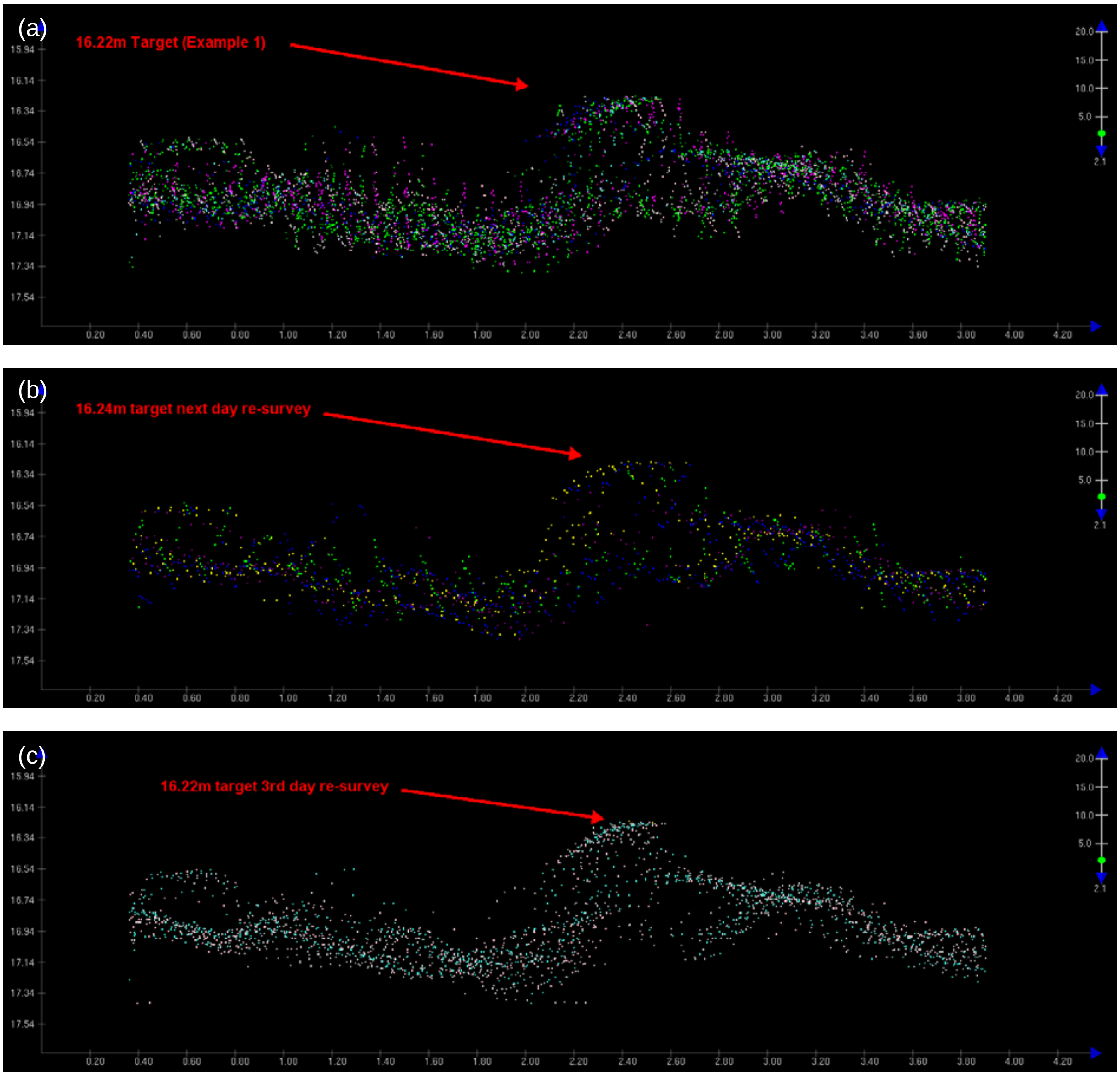

Figure 6: Example target surveyed by SPC on (a) 1 August, (b) 3 August and (c) 4 August 2011.

The contractor was using a Kongsberg EM3002 MBES system with 254 beams at 1.5° by 1.5° beamwidth, whereas SPC uses a Reson 7125 SV with 256 beams at 0.5° by 1° beamwidth. The higher resolution SPC Reson 7125 MBES data showed the targets much clearer, and with more defined shoal points than the contractor data (Figure 7).

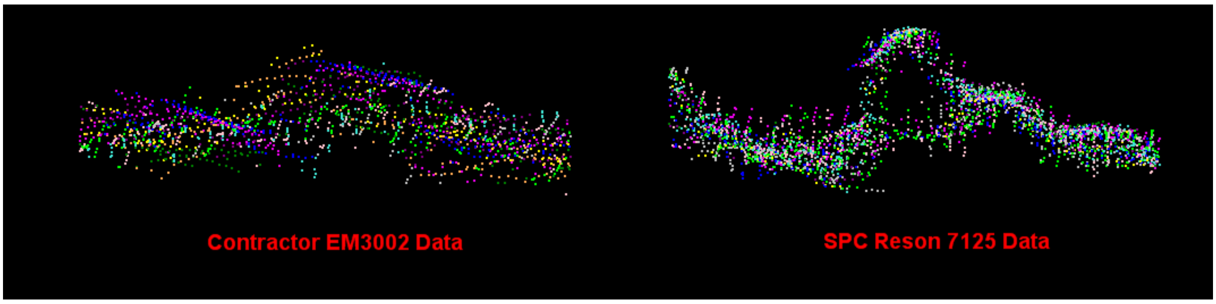

Figure 7: Comparison of contractor and SPC point cloud data over an example target.

After showing that the precision of the SPC Reson 7125 data was not in question, it was then required that the absolute accuracy of the SPC data be ground-truthed in order to resolve the conflicting survey (least depth) results over these isolated targets.

Firstly, the RTK-derived tidal reductions used by SPC were compared with the Port Botany tide gauge. Results showed that the RTK-derived tidal adjustments applied to the data were within 0.03 m of the Port Botany tide gauge. This is part of regular SPC survey checks and procedures, and hence was never considered a real source of error.

SPC then performed SBES surveys over the selected shoal targets in order to verify the minimum depths recorded by the MBES system. A bar check was performed for SBES calibration, and a statistical analysis of SBES data compared with a MBES reference surface over an area of relatively flat, benign seabed was carried out. The results of this comparison are shown in Table 3.

Table 3: Comparison between SPC SBES survey and MBES reference surface.

Survey Method	**SBES**
Number of points in comparison	869
Mean Difference from Reference (m)	-0.033
Standard Deviation (m)	0.089
95% confidence interval (m) [mean + (2 x standard deviation)]	0.212
IHO Special Order error limit	0.260
IHO Special Order survey	ACCEPTED

The SPC Deso 25 SBES has a beamwidth of 8°, i.e. the footprint at 16.5 m depth is 2.30 m in diameter. As a result, it was seen that the SBES gave more consistent results with the MBES data over isolated targets in the middle of the berth box, rather than on the berth fender line, where shoal soundings from behind the fender line are identified. This means that a shoal target surveyed as adjacent to the berth fender line by SBES could in fact have its true position up to 1 metre behind the fender line.

SBES surveys over the isolated shoal targets identified by MBES generally showed a good depth correlation, generally within ±0.15 m. Due to the much higher data density of the MBES data, and the relatively large beamwidth of the SBES, there is no benefit in running any statistical analysis of the depths of the isolated targets when surveyed with MBES against SBES, as the inherent discrepancies in horizontal positioning produce incorrect depth comparisons. Instead, it is best to investigate each target separately (Figure 8).

At this time the contractor was still disputing the survey results and conducting their own soundings using a dipping pole and land survey techniques in order to establish the true depth over the shoal point in dispute. The results of the contractor's dipping pole surveys are shown in Table 4. As can be seen, when compared statistically to both the SPC and contractor MBES surveys over the same area, the dipping pole surveys are shown to be outside of IHO Special Order survey tolerances. This may be due to the non-verticality of the pole, causing errors in horizontal positioning of the bottom of the pole, and hence recorded depth.

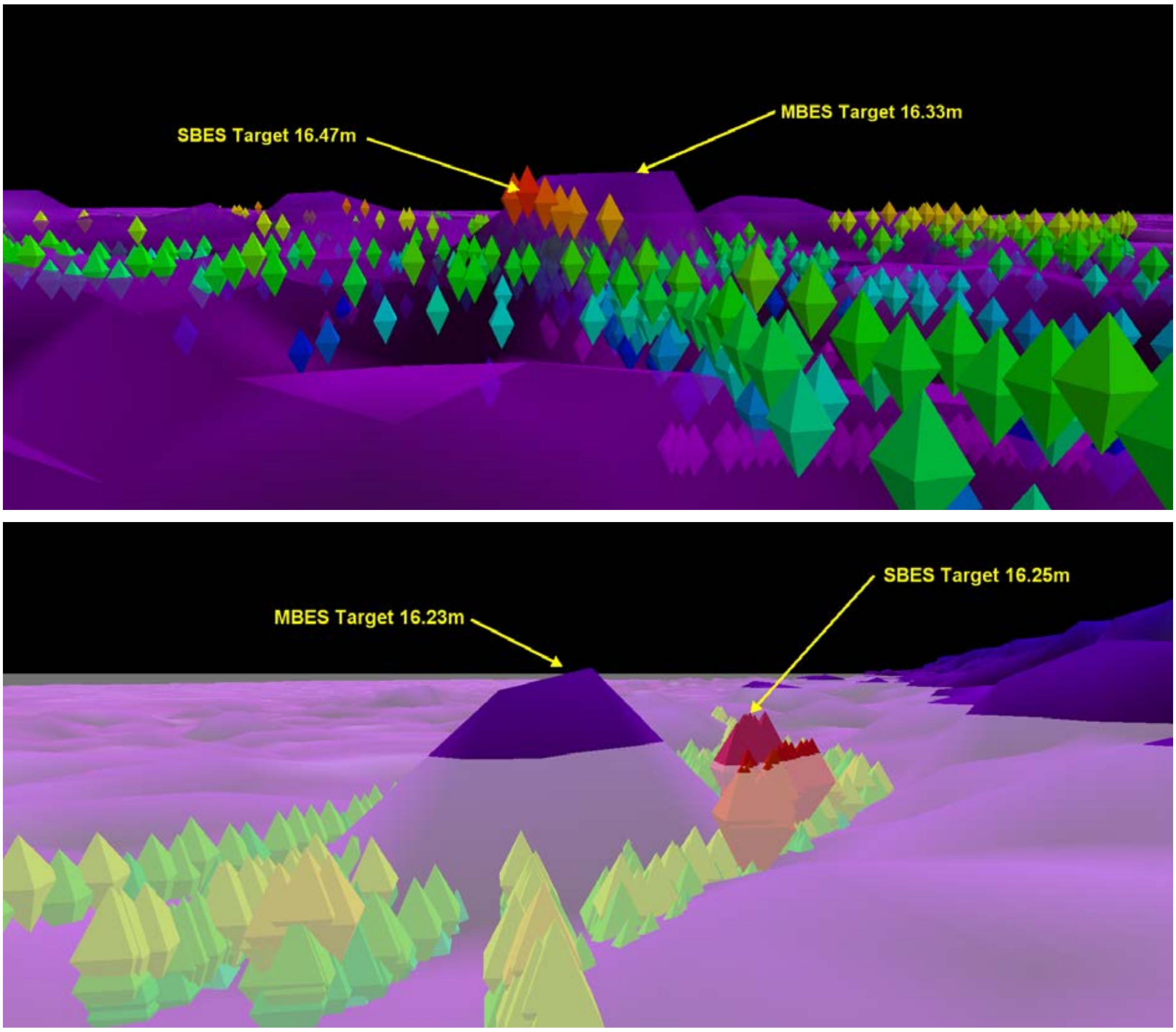

Figure 8: Comparisons of MBES and SBES soundings over isolated shoal targets.

Table 4: Comparison between the dipping pole survey and the SPC/contractor MBES surveys.

Survey Method	**SPC MBES Survey 14/04/2011**	**Contractor MBES Survey 30/03/2011**
Number of points in comparison	209	207
Mean Difference from Reference (m)	0.203	0.223
Standard Deviation (m)	0.162	0.149
95% confidence interval (m) [mean + (2 x standard deviation)]	0.526	0.521
IHO Special Order error limit	0.280	0.280
IHO Special Order survey	REJECTED	REJECTED

Further comparisons and verifications of the MBES data were carried out using a calibrated pressure sensor. The sensor has a quoted pressure accuracy of 0.001% (i.e. 0.0165 m at 16.5 m depth). Final depth calculations using the UNESCO standard formula for converting pressure to depth were tested by SPC and found to be within 0.02 m of the actual depth when lowered to different depths on a calibrated steel wire. Following this calibration, the pressure sensor was held on location above selected shoal targets by divers. Soundings were reduced by noting the time of measurement and subtracting the tidal value recorded at the Port Botany tide gauge. Results of these pressure soundings are shown in Tables 5 and 6.

Table 5: Pressure gauge survey results.

PBE - Pressure Gauge Soundings						
Target Number	MBES Depth (SPC)	SVP Depth (SPC)	SPC MBES - SPC SVP	MBES Depth (contractor)	SPC - Contractor MBES	Contractor MBES - SPC SVP
1	16.18	16.42	-0.24	16.70	-0.52	0.28
2	16.23	16.19	0.03	16.65	-0.42	0.46
3	16.18	16.17	0.01	16.78	-0.60	0.61
4	16.30	16.31	-0.01	16.82	-0.52	0.51
5	16.29	16.30	-0.02	16.51	-0.22	0.21
6	16.33	16.36	-0.04	16.52	-0.20	0.16
		Mean	**-0.042**		**Mean**	**0.372**
		StDev	**0.100**		**StDev**	**0.181**

Table 6: Pressure gauge survey comparison with SPC and contractor MBES surveys.

Survey Method	**SPC MBES Survey**	**Contractor MBES Survey**
Number of points in comparison	6	6
Mean Difference from Reference (m)	-0.042	0.372
Standard Deviation (m)	0.100	0.181
95% confidence interval (m) [mean + (2 x standard deviation)]	0.242	0.732
IHO Special Order error limit	0.280	0.280
IHO Special Order survey	ACCEPTED	REJECTED

The results of the pressure test show that the derived soundings are within survey tolerance specifications when compared with the SPC survey, but not with the contractor survey. It should be noted that this is a very small data sample for statistical analysis and so may be distorted and must be treated with caution.

4 CONCLUDING REMARKS

With the adoption of MBES technology and increasing amounts of hydrographic data being logged comes the necessity for more complex processing procedures and the need for extra attention to quality control of data throughout the process, from the field right through to the finished product.

It has been shown that by using MBES, SPC has increased the amount of hydrographic data collected, the quality of that data and also the number of uses for which this data can be put towards. Differing survey methods, such as using different equipment and/or different procedures, may provide differing survey results, yet with both being technically and statistically “within specification”.

This may become a sticking point, especially in areas whereby a specified minimum depth requirement has been defined and is required to be ascertained over a specific survey area. One of the main issues is that realistic and obtainable survey accuracy and precision capabilities are rarely taken into account during the design stages of such coastal engineering works. Factors affecting the precision and accuracy of survey results include the choice of survey equipment, the acoustic environment within which the survey is to be carried out and differing survey procedures – both during the data acquisition and data processing stages.

Often the survey equipment best suited for the job and the equipment available are two very different things. However, the equipment setup used for the job should always be assessed by its fitness for purpose for each individual project and its results eligible for statistical evaluation for precision and accuracy.

REFERENCES

Godin A. (2003) CARIS HIPS/SIPS 5.3 user manual, CARIS, Fredericton, Canada.

ICSM (2006) Geocentric Datum of Australia technical manual, version 2.3, http://www.icsm.gov.au/icsm/gda/gdatm/index.html (accessed Feb 2012).

International Hydrographic Bureau (2008) *IHO standards for hydrographic surveys SP44* (5th edition), http://www.iho.int/iho_pubs/standard/S-44_5E.pdf (accessed Feb 2012).

Ports Australia (2008) Principles for gathering and processing hydrographic information, http://www.portsaustralia.com.au (accessed Feb 2012).

Roelse A., Granger H.W. and Graham J.W. (1971) The adjustment of the Australian levelling survey 1970-1971, *Technical Report 12*, Division of National Mapping, Canberra, Australia, 81pp.