Bonriki Inundation Vulnerability Assessment

Single Beam Survey

Salesh Kumar, Jens Kruger, Zulfikar Begg, Aseri Baleilevuka

Australian Government

SPC Secretariat of the Pacific Community

Australian Aid

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SPC
Secretariat of the Pacific Community

Original text: English

Secretariat of the Pacific Community Cataloguing-in-publication data

SPC Technical Report SPC00004

March 2015

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This report has been produced with the financial assistance from the Secretariat of the Pacific Community.

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Acknowledgements

The BIVA project is part of the Australian Government's Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP), within the International Climate Change Adaptation Initiative. The project was developed by the Secretariat of the Pacific Community's (SPC) Geoscience Division (GSD) in partnership with the Australian Government and the Government of Kiribati (GoK).

Key GoK stakeholders that contributed to the implementation of the project were:

- Ministry of Public Works and Utilities (MPWU), in particular the Water Engineering Unit with the MPWU
- The Public Utilities Board (PUB), in particular the Water and Sanitation Division and the Customer Relations Division within the PUB
- The Office of the President, in particular the Disaster Management Office
- The Ministry of Environment, Lands and Agricultural Development (MELAD) Lands Division
- The Ministry of Fisheries and Marine Resources Development (MFMRD) Minerals Division
- Members of the Kiribati National Expert Group on climate change and disaster risk management (KNEG)

The Bonriki Village community members also played a key role in the implementation of the project. Community members participated in the school water science and mapping program, assisted with construction of new piezometers and data collection for the groundwater component, and shared their knowledge and experiences with regards to historical inundation events and coastal processes.

Key technical advisors involved with implementation of the project included:

- Flinders University, Adelaide, Australia
- University of Western Australia, Perth, Australia
- The University of Auckland, Auckland, New Zealand
- United Nations Educational, Scientific and Cultural Organization, Institute for Water Education (UNESCO-IHE), Delft, the Netherlands
- Technical advisors Tony Falkland and Ian White

List of Abbreviations

°C	degrees Celsius
ASCII	American Standard Code for Information Interchange
cm	centimetre
CTD	conductivity, temperature and depth
dbar	decibar
GPS	global positioning system
kHz	kilohertz
m	metre
ppm	parts per million
RMS	root mean square
SBES	single beam echosounder
UTM	universal transverse mercator
WGS	world geodetic system

1. Introduction

1.1. Background

The Bonriki Inundation Vulnerability Assessment (BIVA) project is part of the Australian government's Pacific–Australia Climate Change Science and Adaptation Planning Program (PACCSAP), within the International Climate Change Adaptation Initiative. The objectives of PACCSAP are to:

- improve scientific understanding of climate change in the Pacific;
- increase awareness of climate science, impacts and adaptation options; and
- improve adaptation planning to build resilience to climate change impacts.

The BIVA project was developed by the Geoscience Division (GSD) of the Secretariat of the Pacific Community (SPC) in partnership with the Australian government and the Government of Kiribati (GoK).

1.1.1. Project objective and outcomes

The BIVA project aims to improve our understanding of the vulnerability of the Bonriki freshwater reserve to coastal hazards and climate variability and change. Improving our knowledge of risks to this freshwater resource will enable better adaptation planning by the GoK.

More specifically, the project has sought to use this knowledge to support adaptation planning through the following outcomes:

- Improved understanding and ability to model the role of reef systems in the dissipation of ocean surface waves and the generation of longer-period motions that contribute to coastal hazards.
- Improved understanding of freshwater lens systems in atoll environments with respect to seawater overtopping and infiltration, as well as current and future abstraction demands, recharge scenarios and land-use activities.
- Enhanced data to inform a risk-based approach in the design, construction and protection of the Bonriki water reserve.
- Increased knowledge provided to the GoK and the community of the risks associated with the impact of coastal hazards on freshwater resources in response to climate change, variability and sea-level rise.

1.1.2. Context

The Republic of Kiribati is located in the Central Pacific and comprises 33 atolls in three principal island groups. The islands are scattered within an area of about 5 million square kilometres. The BIVA project focuses on the Kiribati National Water Reserve of Bonriki. Bonriki is located on Tarawa atoll within the Gilbert group of islands in Western Kiribati (**Error! Reference source not found.**). South Tarawa is the main urban area in Kiribati, with the 2010 census recording 50,182 people of the more than 103,058 total population (KNSO and SPC 2012). Impacts to the Bonriki water resource from climate change, inundation, abstraction and other anthropogenic influences have potential for severe impacts on people's livelihood of South Tarawa. The Bonriki water reserve is used as the primary raw water supply for the Public Utilities Board (PUB) reticulated water system. PUB water is the source of potable water use by at least 67% of the more than 50,182 people of South Tarawa (KNSO and SPC 2012). Key infrastructure including the PUB Water Treatment Plant and Bonriki International Airport and residential houses are also located on Bonriki, above the freshwater lens, making it an important economic, social and cultural area for the Republic of Kiribati.

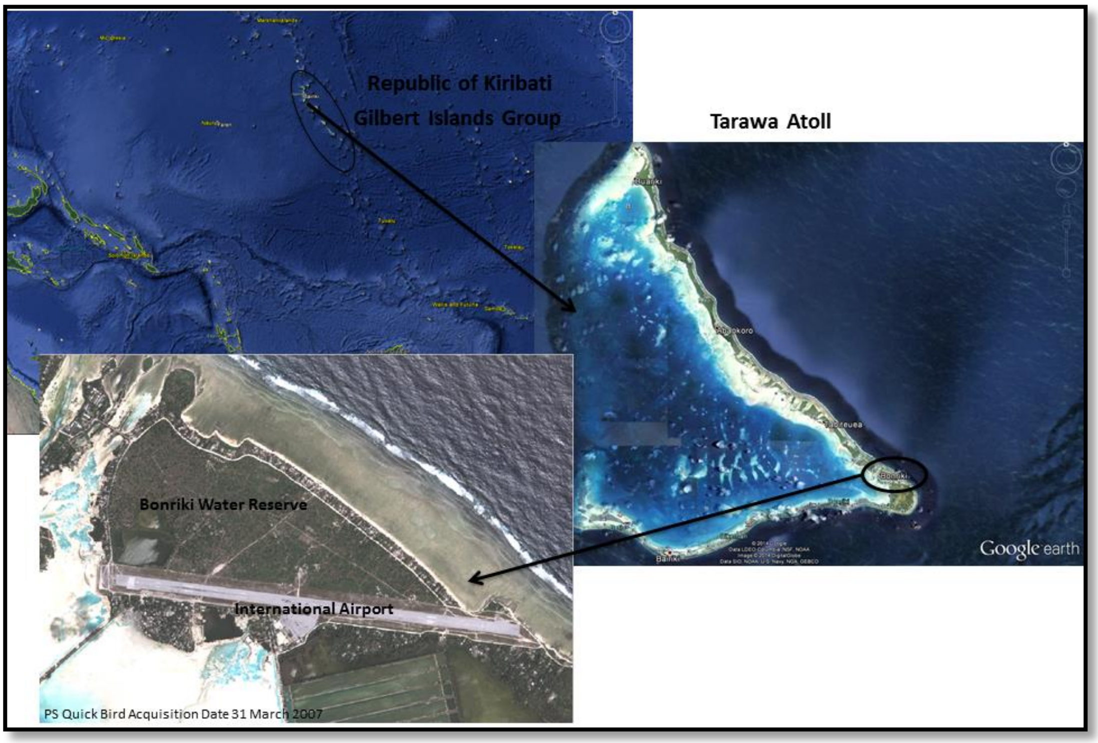


Figure 1. *Bonriki Water Reserve Location*

1.2. Purpose of this report

This report provides a summary of the bathymetric survey activities undertaken as part of the coastal component of the BIVA project. As illustrated in Figure 2, the project consisted of three interlinked components: stakeholder engagement, groundwater investigations and analysis, and coastal investigations and analysis. The single beam survey to collect bathymetric data, providing information on the depth and morphology of the seafloor, as well as the shape and size of submarine features, was designed as an input into the coastal component. This contributed to the development of a seamless coastal terrain model used in the running of the hydrodynamic inundation model.

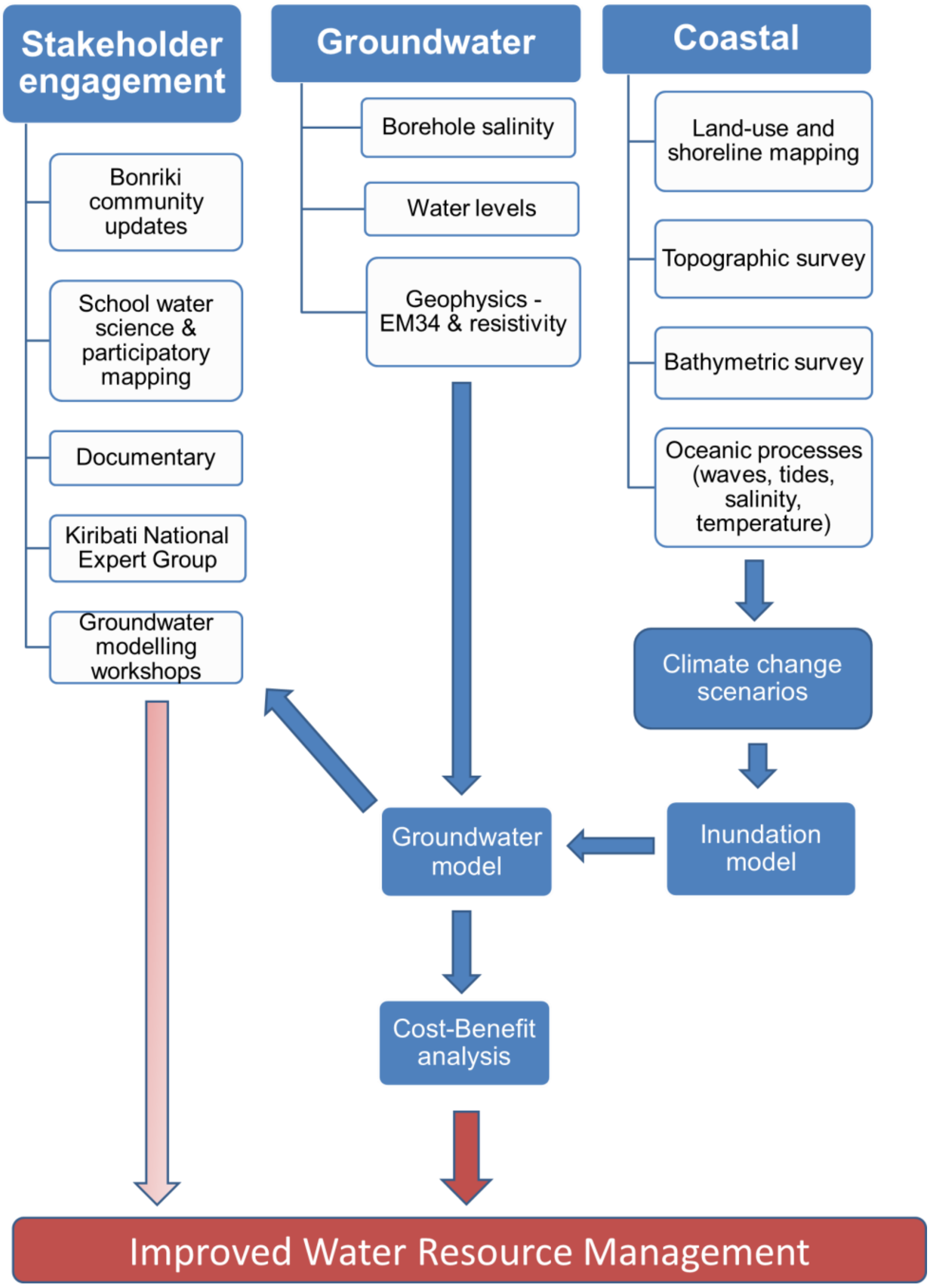


Figure 2. *Bonriki Inundation Vulnerability Assessment project components*

1.3. Scope of this report

The depth and shape of the seafloor significantly influences the way that waves interact with the shoreline. A good knowledge of the bathymetry is therefore essential in the approach taken in this study, which uses a hydrodynamic model to investigate the potential of coastal inundation. This report details the bathymetry survey as per the report structure below:

- Section 2 provides the methodology and the details on the data acquisition and processing
- Section 3 provides the results from the bathymetry survey
- Section 4 contains a conclusion

2. Data acquisition and processing

2.1. Fieldwork summary

Four different areas of Tarawa atoll in Kiribati (Figure 3) were surveyed with a single beam echosounder (SBES) between 25 November, 2013 and 8 December, 2013. These are shown in Figure 3 below.

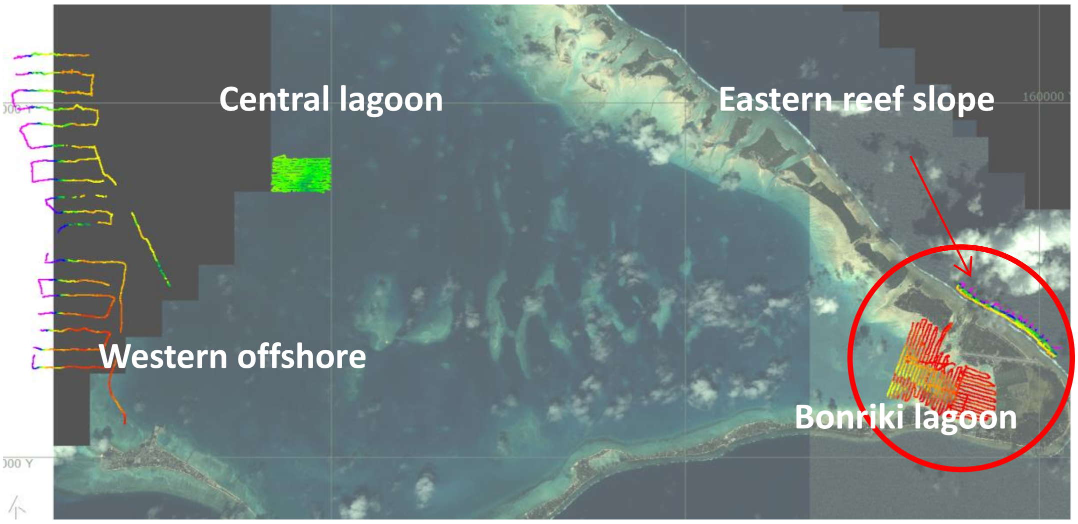


Figure 3. *SBES survey areas in Tarawa atoll*

Three of SPC's Geoscience Division (GSD) staff surveyed the areas, assisted by the owner of a 4.5 m aluminium punt.

Table 1. *Field personnel*

GSD	
Salesh Kumar	Hydrographic Surveyor
Zulfikar Begg	Senior Technical Asistant
Aseri Baleilevuka	Coastal Mapping Assistant
Vessel	
Keannatu	Captain

2.2. Single beam echo sounder

An Odom Echotrac CVM SBES was temporarily installed on a small aluminium boat (Figure 4), and used to provide single point soundings. A SBES provides information about the water depth. The equipment was powered by two 12V batteries in parallel with an AC inverter.

Positioning during the survey was by differential GPS, using a Trimble SPS 852 Global Navigation Satellite System (GNSS) with a horizontal accuracy of 0.25 m +1 ppm RMS, and a vertical accuracy of 0.50 m +1 ppm RMS.

A good satellite constellation status was observed throughout the survey.

Figure 4. *Survey boat*

The main instrumental and operating parameters are listed below.

Table 2. *Single beam echo sounder - main instrumental parameters*

Instrumentation	
Single beam echosounder	Echotrac CVM
Transducer mount	Port side, pole mounted
Positioning	Trimble SPS 852 GNSS (independent system with Fugro G2 signal)
Sound velocity probe at transducer	Not applicable. Conductivity, temperature and depth casts were used to determine sound velocity

Table 3. *Single beam echo sounder - main operating parameters*

Operating parameters	
Transducer frequency	200 kHz
General water depth	1-100 m
Average ship's speed	3 knots
Transmit power	Variable
Pulse length	Auto pulse length
Ping rate	Variable

Table 4. *Single beam echo sounder - offset calibration parameters*

Offset calibration	
Transducer draft	0.23 m
GPS latency correction	0.00
GPS antenna	–1.20 m

2.3. Tidal information

Observed soundings from the SBES were reduced to the chart datum using six-minute sea level data from the tide gauge in Betio, Tarawa, through the South Pacific Sea Level and Climate Monitoring Project.[1]

A secondary tide station – a free-standing tide pole next to the old jetty at the survey area in Bonriki Lagoon – was established to provide redundancy. Tidal data were recorded for 25 hours at the tide pole, for comparison with tidal data from the sea level tide gauge (Appendix A).

A levelling run used a Leica spirit level from benchmark PTP25 located on the old jetty, to the tide pole (Appendix B) was done to connect the tide readings to a known bench mark on the land.

2.4. Geodetic reference system

The geodetic reference data in the table below were used to map the survey results.

Table 5. *Geodetic reference data*

Geodetic datum	WGS84	
Ellipsoid	WGS84	
	semi-major axis (a)	6378137
	semi-major axis (b)	6356752
	inverse flattening (1/f)	298.2572
	eccentricity sq. (e2)	0.006694
Projection	UTM Zone59 North	
	projection type	transverse mercator
	origin latitude	00°00'00.000" North
	origin longitude	168°00'00.000" East
	origin false easting	500000
	origin false northing	0
	scale factor	0.9996
	grid unit	metres
Geodetic transformation from WGS84 (GPS satellite datum) to UTM 59 North		
	source coordinate system	WGS84
	target coordinate system	UTM 59 North
	Transformation parameters	
	dX	0
	dY	0
	dZ	0
	rX	0
	rY	0
	rZ	0
	scale	0

[1] http://www.bom.gov.au/pacificsealevel/index.shtml

2.5. Speed-of-sound profiling

The accuracy of depth soundings depend in part on the variation of the speed of sound with water depth. This is because the acoustic beams pass through a water column that has varying properties, causing refraction of the beam. The sound speed structure of the water column is determined from measurements of temperature, salinity and depth with conductivity, temperature and depth (CTD) sensor. The main instrumental, operational and processing parameters are listed below.

Table 6. *Speed-of-sound profiling - main instrumental parameters*

CTD instrumentation	
Make	SeaBird Electronics
Model	SeaCat 19+ (self-powered, self-contained)
Serial number	2795
Depth rating	3000 m

Table 7. *Speed-of-sound profiling – main operating parameters*

Operating parameters	
Sample rate	1 scan every 0.5 s
Maximum depth	Limited to 100 m due to rope length
Data recorded	Profiles of conductivity, temperature and pressure

Table 8. *Speed-of-sound profiling – main processing parameters*

Data processing	
Positioning	The profile position was taken at the GPS antenna near the start of the downcast. Vessel drift may have been significant (~50 m) over the duration of the profile
Data conversion	Converted raw data (.hex) to a .cnv file. Values output from the recorded data are:
	• pressure (dbar)
	• depth (m) (derived using salt water at local latitude)
	• temperature (°C) (ITS-90)
	• salinity (psu) (derived)
	• density (kg m-3) (derived)
	• sound velocity (m s-1) (derived using Chen and Millero, 1977)
Bin average	Averaged data into 1 m depth bins. No filtering was applied
Output	Processed data were saved in ASCII text format with the file name date_location_bin.cnv.

The CTD profile details are listed below. The summaries of the CTD profile data in graphical form are shown in Appendix C, and a map of the CTD locations is shown in Figure 5. All dates and times are given in the local Kiribati time zone.

Table 9. *CTD profile details*

Profile location	Date	Time	Easting	Northing	Depth (m)
Bonriki Lagoon	3/11/2013	14:20	736891.1	152054.2	7
Bonriki Lagoon west	2/12/2013	13:36	718838.7	157821.9	20
Offshore east	8/12/2013	12:48	740409.3	152980.9	70
Offshore east	8/12/2013	13:06	738786.5	154140.4	30
Bonriki Lagoon	3/12/2013	14:35	735886.4	151875.9	10
Bonriki Lagoon	3/12/2013	14:40	737114.6	152654.9	3
Bonriki Lagoon	3/12/2013	15:47	736613.3	152690.2	1

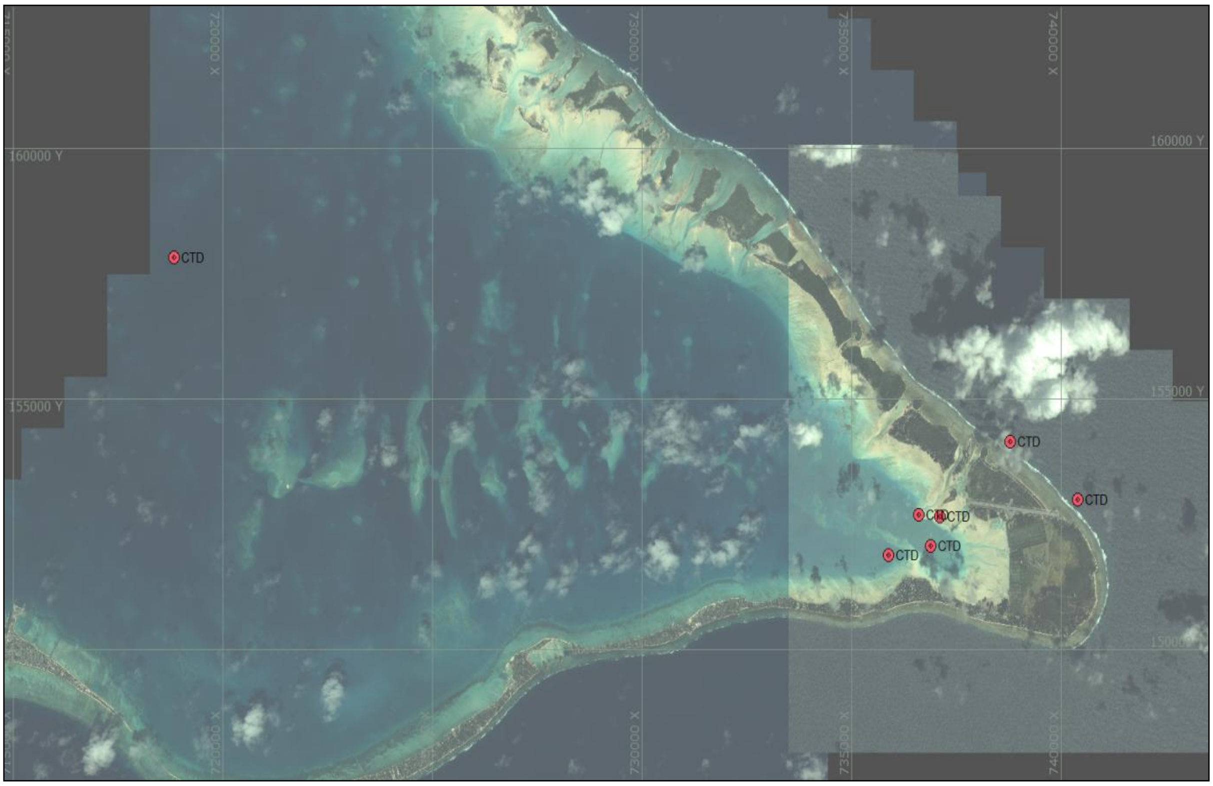


Figure 5. *Map showing the location of CTD casts*

2.6. Single beam echo sounder data processing

A Windows XP laptop running HYPACK 2013 was used for continuous online data logging and computation of positioning and digital bathymetry. The online operator continuously monitored a range of quality control parameters.

On return to the SPC office in Suva, HYPACK 2013a software was used to post-process the survey data. Post-processing is a form of data reduction, which involves checking, calibration, cleaning and preparation necessary to convert raw measurements into a form suitable for analysis, application and presentation. Post-processing produces ASCII listings of gridded easting, northing and depth (XYZ) points. The processing and chart production sequences are listed below.

Table 10. *Post-processing and chart production sequences*

Post-processing sequence	
Phase 1	Apply tidal, draft and sound velocity corrections
Phase 2	Filter to remove poor-quality beams and spikes. Edit manually to remove outliers from individual survey lines
XYZ output	ASCII XYZ files (easting, northing, depth) are in the project coordinate system. The final output consisted of a file that includes all post-processed sounding points

3. Results

Around 176 line kilometres of seabed were mapped using the SBES during this survey (Figures 6–9). The survey lines were spaced at 100 meter intervals in eastern Bonriki Lagoon, 50 meter intervals in the centre of the lagoon, 200 meter intervals in the eastern offshore area and 500 meter intervals in the western offshore area. Water depths ranged from 1 to 6 meters in the eastern Bonriki lagoon, 1 to 8 meters in the centre of the lagoon, 5 to 50 meters in the eastern offshore areas and 5 to 100 meters in the western offshore areas.

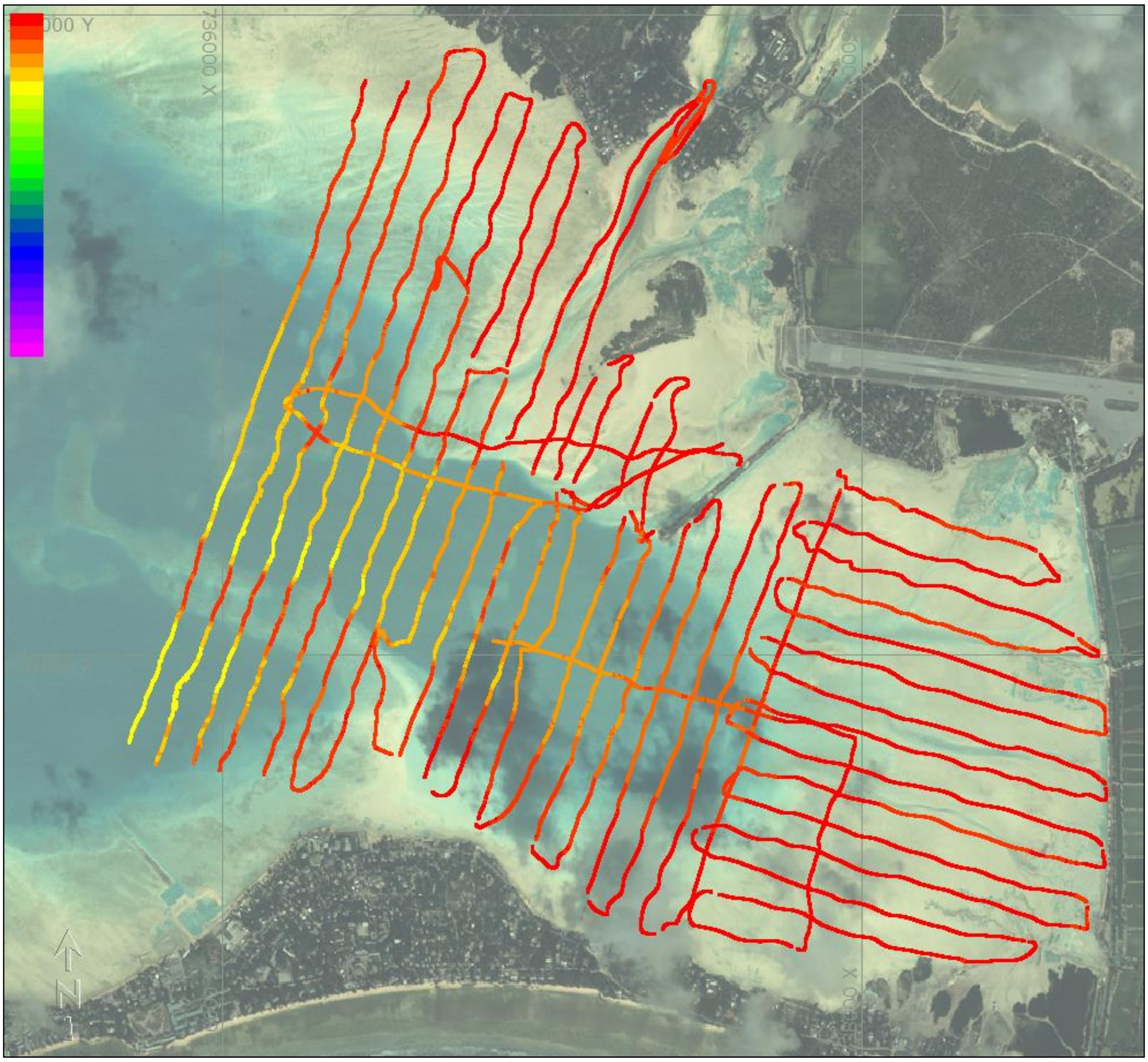


Figure 6. *SBES survey coverage – eastern Bonriki Lagoon, from shallow to deep (red to purple as shown by the colour scale)*

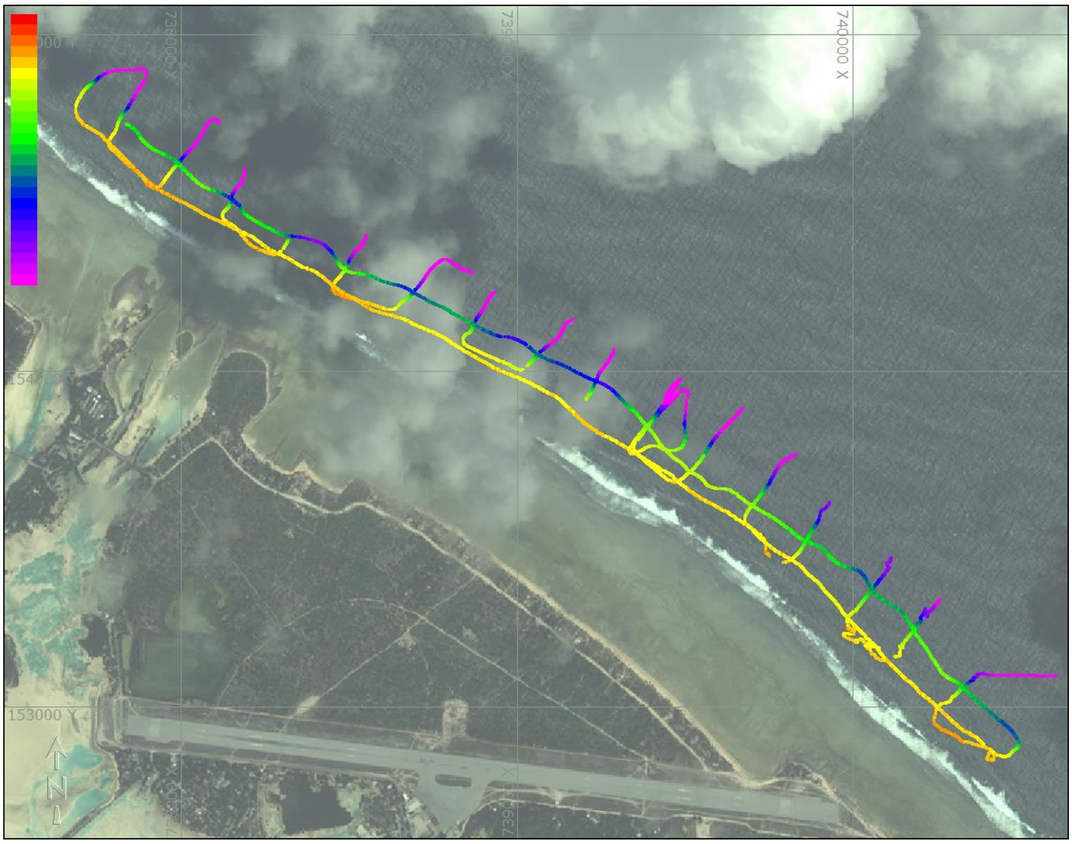


Figure 7. *SBES coverage – eastern offshore area*

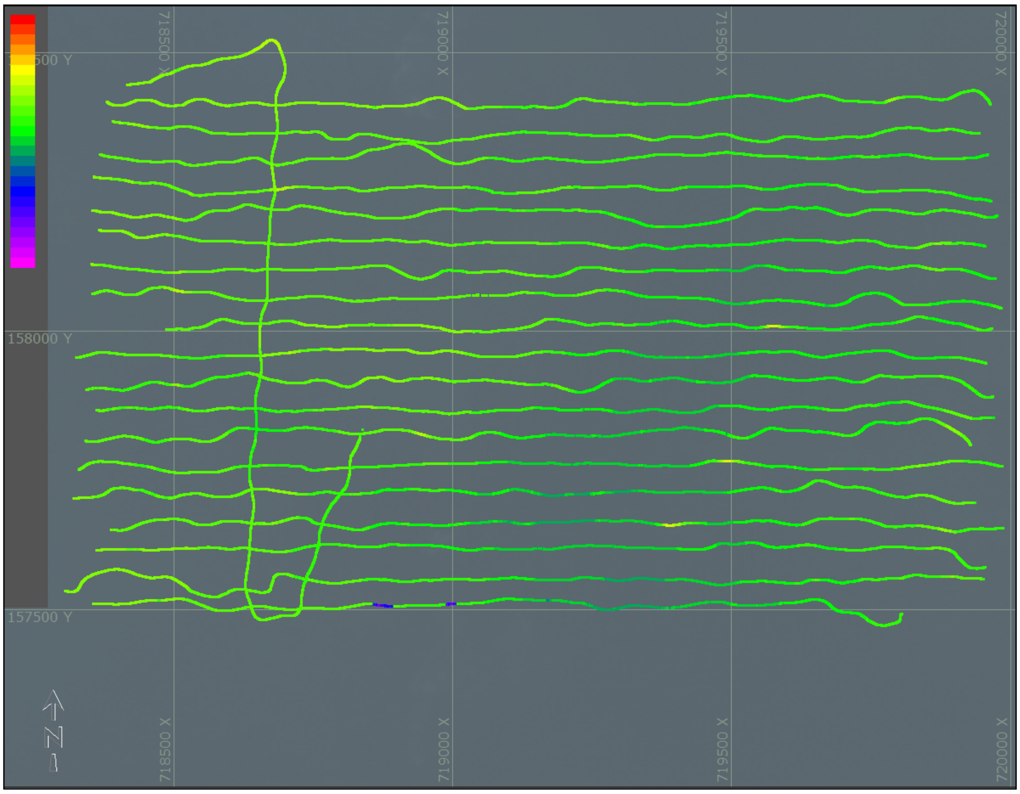


Figure 8. *SBES coverage – central lagoon*

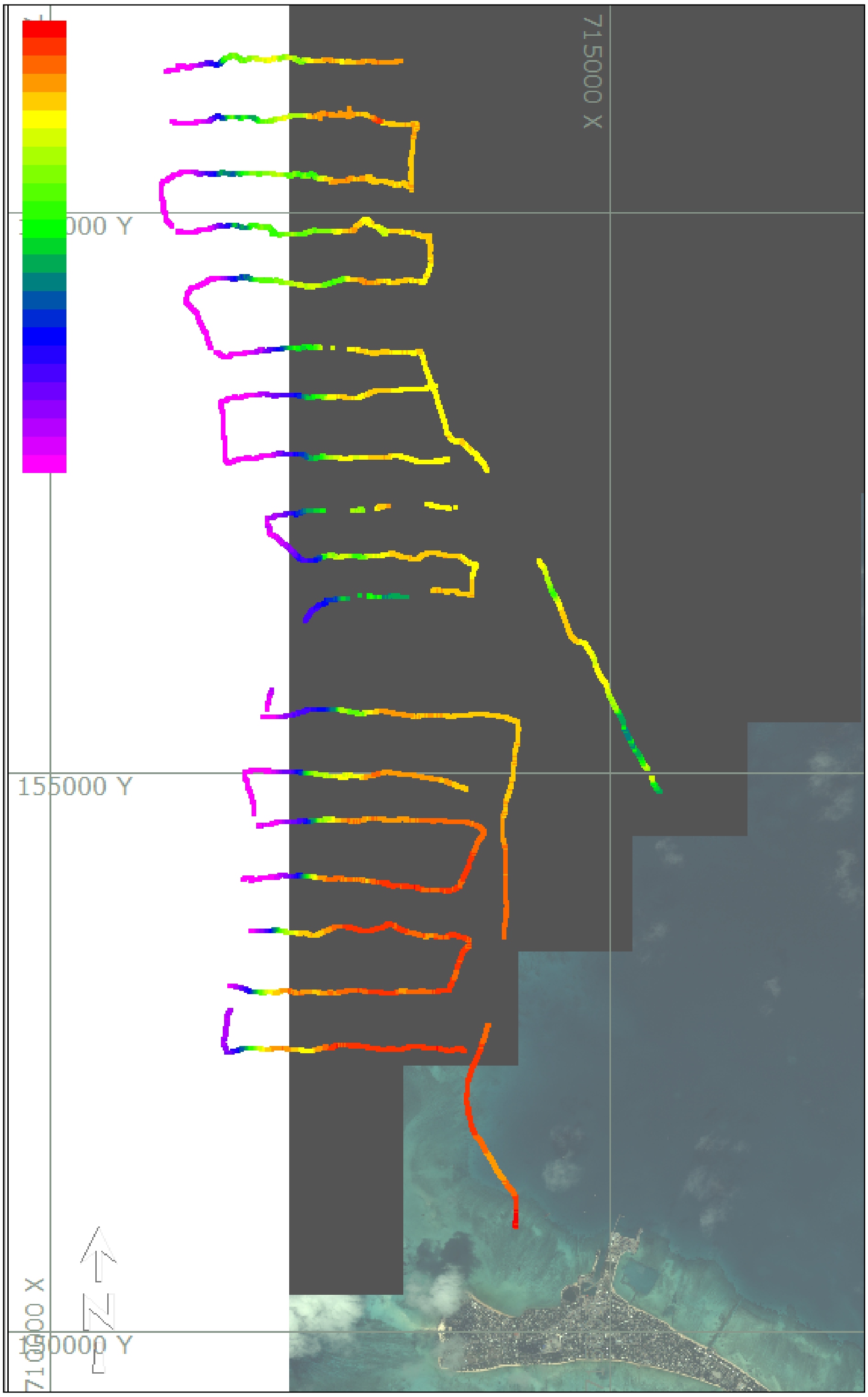


Figure 9. *SBES coverage – western lagoon*

4. Conclusion

Overall, good-quality data were collected during the survey; however, the coverage – and thus data quality – achieved in the eastern offshore area and the western lagoon was constrained by poor weather conditions. The SBES data acquired from this bathymetric survey will complement data from the other components of the BIVA project to derive a digital terrain model.

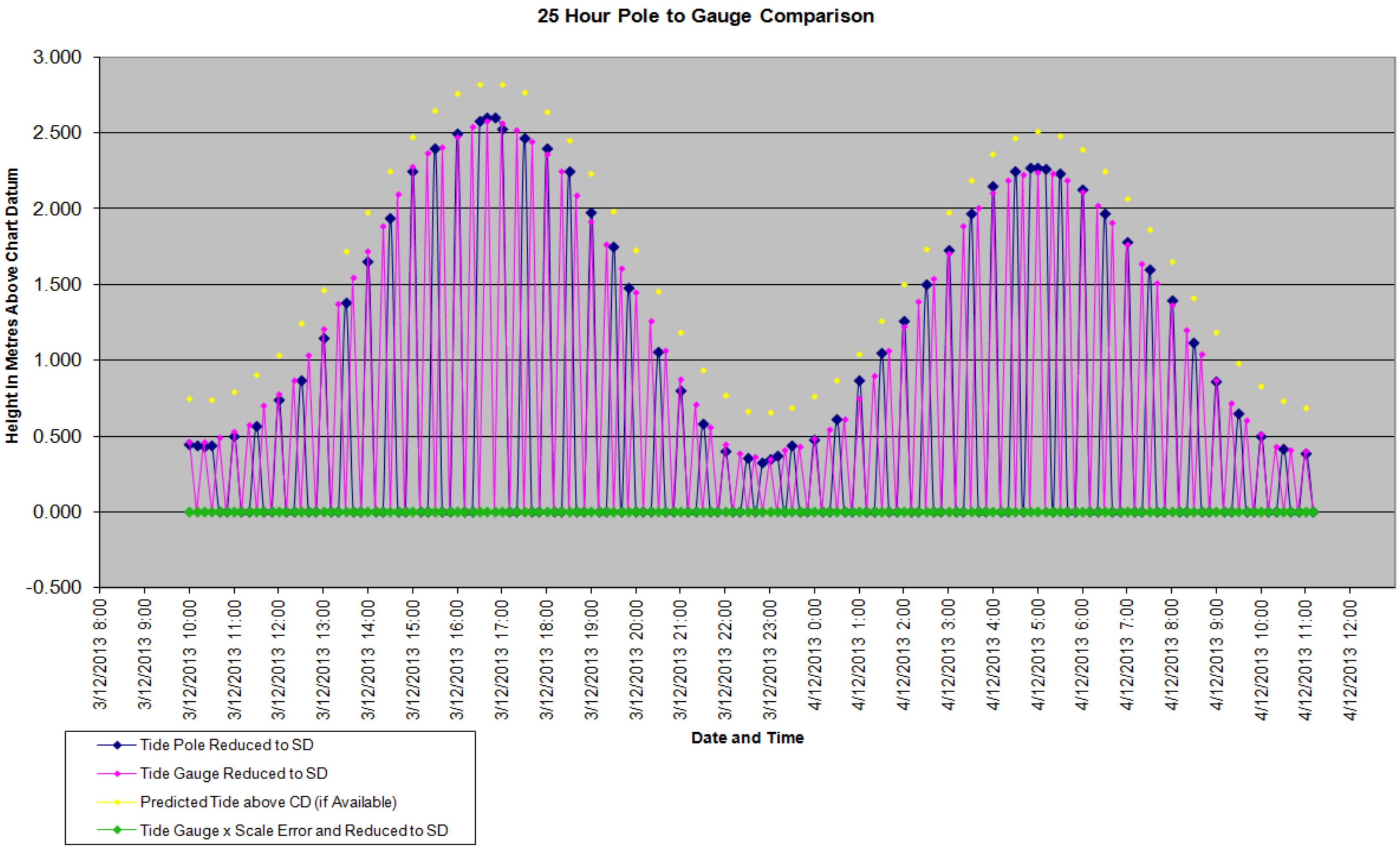
5. References

Chen, C.T. and Millero, F.J. 1977. Speed of sound in seawater at high pressure. Journal of the Acoustic Society of America 62(5):1129–1135.

KNSO and SPC 2012, Kiribati 2010 census. Volume 2, Analytical report. Kiribati National Statistics Office and the Secretariat of the Pacific Community Statistics for Development Program.

6. Appendices

6.1. Appendix A – Comparison of tide pole data with tide gauge data in Bonriki Lagoon



6.1.1. 25 hour tide gauge observations, Bonriki Lagoon, December, 2013

Tide gauge type	TWR 2050		
Tide pole zero relative to sounding datum (SD) (+ above and – below):		Tide gauge zero relative to SD (+ above and – below) :	**–4.228**
Uncorrected tide gauge multiplication factor from scatter plot graph (gradient):		Raw tide gauge constant from scatter plot graph (intercept):	

Time dd/mm hh:mm	Uncorrected observed tide pole	Observed tide pole reduced to SD	Uncorrected recorded tide gauge	Tide pole red. to SD **minus** uncorrected recorded gauge	Recorded tide gauge reduced to SD using value in cell K6 (mean diff. tide pole reduced to SD **minus** uncorrected gauge reading).	Recorded tide gauge × scale error formula & reduced to SD	Tide gauge direct red. to SD **minus** tide gauge × scale error & red. to SD	Predicted tide (above chart datum)
3/12 10:00	0.45	0.450	4.69	–4.244	0.466	0.000	0.466	0.75
3/12 10:10	0.44	0.440						
3/12 10:20	0.43	0.430	4.69	–4.263	0.465	0.000	0.465	
3/12 10:30	0.44	0.440						0.74
3/12 10:40			4.72		0.491	0.000	0.491	
3/12 10:50								
3/12 11:00	0.50	0.500	4.76	–4.261	0.533	0.000	0.533	0.79
3/12 11:10								
3/12 11:20			4.81		0.579	0.000	0.579	
3/12 11:30	0.57	0.570						0.91
3/12 11:40			4.93		0.700	0.000	0.700	
3/12 11:50								
3/12 12:00	0.74	0.740	5.01	–4.270	0.782	0.000	0.782	1.04
3/12 12:10								
3/12 12:20			5.09		0.866	0.000	0.866	

3/12 12:30	0.87	0.870							1.24
3/12 12:40			5.27		1.037	0.000	1.037		
3/12 12:50									
3/12 13:00	1.15	1.150	5.44	−4.290	1.212	0.000	1.212		1.46
3/12 13:10									
3/12 13:20			5.60		1.371	0.000	1.371		
3/12 13:30	1.38	1.380							1.72
3/12 13:40			5.77		1.544	0.000	1.544		
3/12 13:50									
3/12 14:00	1.65	1.650	5.95	−4.298	1.720	0.000	1.720		1.98
3/12 14:10									
3/12 14:20			6.12		1.890	0.000	1.890		
3/12 14:30	1.94	1.940							2.25
3/12 14:40			6.33		2.098	0.000	2.098		
3/12 14:50									
3/12 15:00	2.25	2.250	6.51	−4.255	2.277	0.000	2.277		2.47
3/12 15:10									
3/12 15:20			6.60		2.367	0.000	2.367		
3/12 15:30	2.40	2.400							2.65
3/12 15:40			6.63		2.406	0.000	2.406		
3/12 15:50									
3/12 16:00	2.50	2.500	6.70	−4.200	2.472	0.000	2.472		2.76
3/12 16:10									
3/12 16:20			6.77		2.541	0.000	2.541		
3/12 16:30	2.58	2.580							2.82
3/12 16:40	2.60	2.600	6.81	−4.206	2.578	0.000	2.578		
3/12 16:50	2.60	2.600							
3/12 17:00	2.53	2.530	6.79	−4.261	2.563	0.000	2.563		2.82

3/12 17:10									
3/12 17:20			6.75		2.519	0.000	2.519		
3/12 17:30	2.47	2.470							2.76
3/12 17:40			6.67		2.442	0.000	2.442		
3/12 17:50									
3/12 18:00	2.40	2.400	6.59	–4.186	2.358	0.000	2.358		2.64
3/12 18:10									
3/12 18:20			6.47		2.246	0.000	2.246		
3/12 18:30	2.25	2.250							2.46
3/12 18:40			6.32		2.092	0.000	2.092		
3/12 18:50									
3/12 19:00	1.98	1.980	6.15	–4.167	1.919	0.000	1.919		2.24
3/12 19:10									
3/12 19:20			5.99		1.762	0.000	1.762		
3/12 19:30	1.75	1.750							1.98
3/12 19:40			5.84		1.608	0.000	1.608		
3/12 19:50	1.48	1.480							
3/12 20:00			5.68		1.452	0.000	1.452		1.73
3/12 20:10									
3/12 20:20			5.49		1.260	0.000	1.260		
3/12 20:30	1.06	1.060							1.45
3/12 20:40			5.29		1.063	0.000	1.063		
3/12 20:50									
3/12 21:00	0.80	0.800	5.11	–4.307	0.879	0.000	0.879		1.18
3/12 21:10									
3/12 21:20			4.94		0.709	0.000	0.709		
3/12 21:30	0.58	0.580							0.94
3/12 21:40			4.79		0.559	0.000	0.559		

3/12 21:50								
3/12 22:00	0.40	0.400	4.68	–4.275	0.447	0.000	0.447	0.77
3/12 22:10								
3/12 22:20			4.62		0.390	0.000	0.390	
3/12 22:30	0.36	0.360						0.67
3/12 22:40			4.59		0.362	0.000	0.362	
3/12 22:50	0.33	0.330						
3/12 23:00	0.35	0.350	4.58	–4.231	0.353	0.000	0.353	0.66
3/12 23:10	0.37	0.370						
3/12 23:20			4.64		0.413	0.000	0.413	
3/12 23:30	0.44	0.440						0.69
3/12 23:40			4.660		0.432	0.000	0.432	
3/12 23:50								
4/12 0:00	0.48	0.480	4.712	–4.232	0.484	0.000	0.484	0.76
4/12 0:10								
4/12 0:20			4.770		0.542	0.000	0.542	
4/12 0:30	0.61	0.610						0.87
4/12 0:40			4.838		0.610	0.000	0.610	
4/12 0:50								
4/12 1:00	0.87	0.870	4.973	–4.103	0.745	0.000	0.745	1.05
4/12 1:10								
4/12 1:20			5.130		0.902	0.000	0.902	
4/12 1:30	1.05	1.050						1.26
4/12 1:40			5.290		1.062	0.000	1.062	
4/12 1:50								
4/12 2:00	1.26	1.260	5.450	–4.190	1.222	0.000	1.222	1.50
4/12 2:10								
4/12 2:20			5.616		1.388	0.000	1.388	

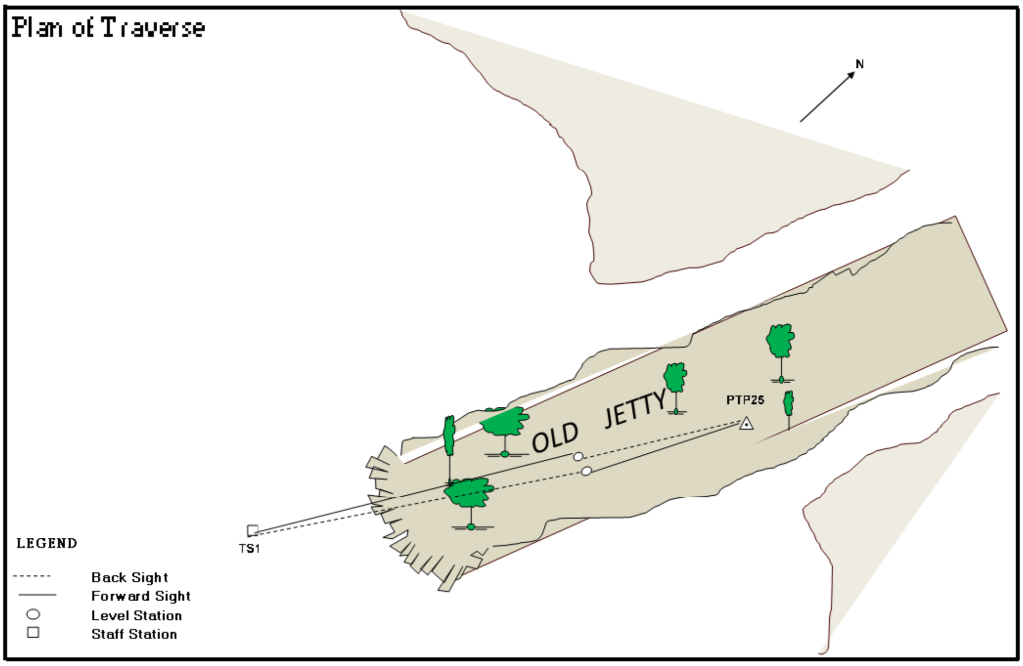
4/12 2:30	1.50	1.500						1.74
4/12 2:40			5.770		1.542	0.000	1.542	
4/12 2:50								
4/12 3:00	1.73	1.730	5.930	–4.200	1.702	0.000	1.702	1.98
4/12 3:10								
4/12 3:20			6.111		1.883	0.000	1.883	
4/12 3:30	1.97	1.970						2.19
4/12 3:40			6.238		2.010	0.000	2.010	
4/12 3:50								
4/12 4:00	2.15	2.150	6.334	–4.184	2.106	0.000	2.106	2.36
4/12 4:10								
4/12 4:20			6.418		2.190	0.000	2.190	
4/12 4:30	2.25	2.250						2.47
4/12 4:40			6.452		2.224	0.000	2.224	
4/12 4:50	2.27	2.270						
4/12 5:00	2.27	2.270	6.466	–4.196	2.238	0.000	2.238	2.51
4/12 5:10	2.26	2.260						
4/12 5:20			6.460		2.232	0.000	2.232	
4/12 5:30	2.23	2.230						2.48
4/12 5:40			6.416		2.188	0.000	2.188	
4/12 5:50								
4/12 6:00	2.13	2.130	6.340	–4.210	2.112	0.000	2.112	2.39
4/12 6:10								
4/12 6:20			6.250		2.022	0.000	2.022	
4/12 6:30	1.97	1.970						2.25
4/12 6:40			6.135		1.907	0.000	1.907	
4/12 6:50								
4/12 7:00	1.78	1.780	5.994	–4.214	1.766	0.000	1.766	2.07

4/12 7:10								
4/12 7:20			5.866		1.638	0.000	1.638	
4/12 7:30	1.60	1.600						1.87
4/12 7:40			5.738		1.510	0.000	1.510	
4/12 7:50								
4/12 8:00	1.40	1.400	5.596	–4.196	1.368	0.000	1.368	1.65
4/12 8:10								
4/12 8:20			5.432		1.204	0.000	1.204	
4/12 8:30	1.12	1.120						1.41
4/12 8:40			5.272		1.044	0.000	1.044	
4/12 8:50								
4/12 9:00	0.86	0.860	5.094	–4.234	0.866	0.000	0.866	1.18
4/12 9:10								
4/12 9:20			4.948		0.720	0.000	0.720	
4/12 9:30	0.65	0.650						0.98
4/12 9:40			4.837		0.609	0.000	0.609	
4/12 9:50								
4/12 10:00	0.50	0.500	4.740	–4.240	0.512	0.000	0.512	0.83
4/12 10:10								
4/12 10:20			4.659		0.431	0.000	0.431	
4/12 10:30	0.42	0.420						0.73
4/12 10:40			4.639		0.411	0.000	0.411	
4/12 10:50								
4/12 11:00	0.39	0.390	4.632	–4.242	0.404	0.000	0.404	0.69
4/12 11:10								
		Mean diff:		-4.228	Mean diff:		1.369	
		Std. Dev:		0.045	Std. Dev:		0.736	

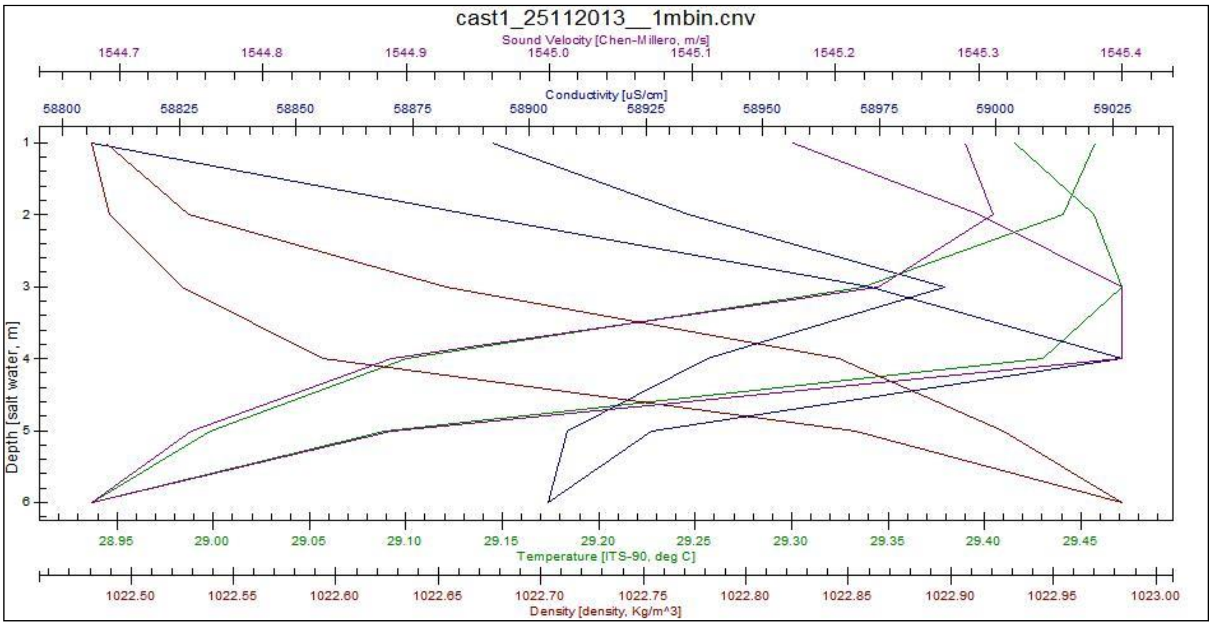
6.2. Appendix B – Levelling observations

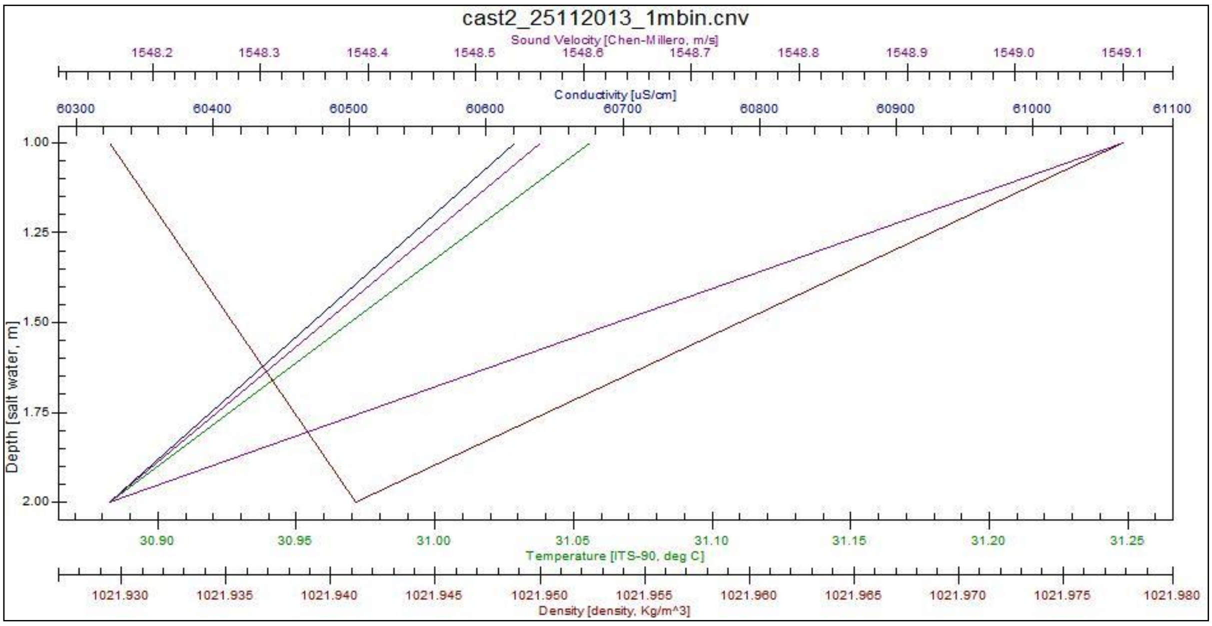
Survey	BONRIKI	Date	4-Dec-13	Observer	Zulfikar Begg
Ship	SOPAC	Time	11.00AM LOCAL TIME	Recorder	Zulfikar Begg
Locality	BONRIKI CAUSEWAY	Weather	Fine , Wind: NE 10kts , Cloud: 1/8 , Temp: 27.0°C, Pres: 1018.6hPa	Inst No	5324253
Bench Marks	PTP25, TS1	Map		Staff No	Page 1 of 1

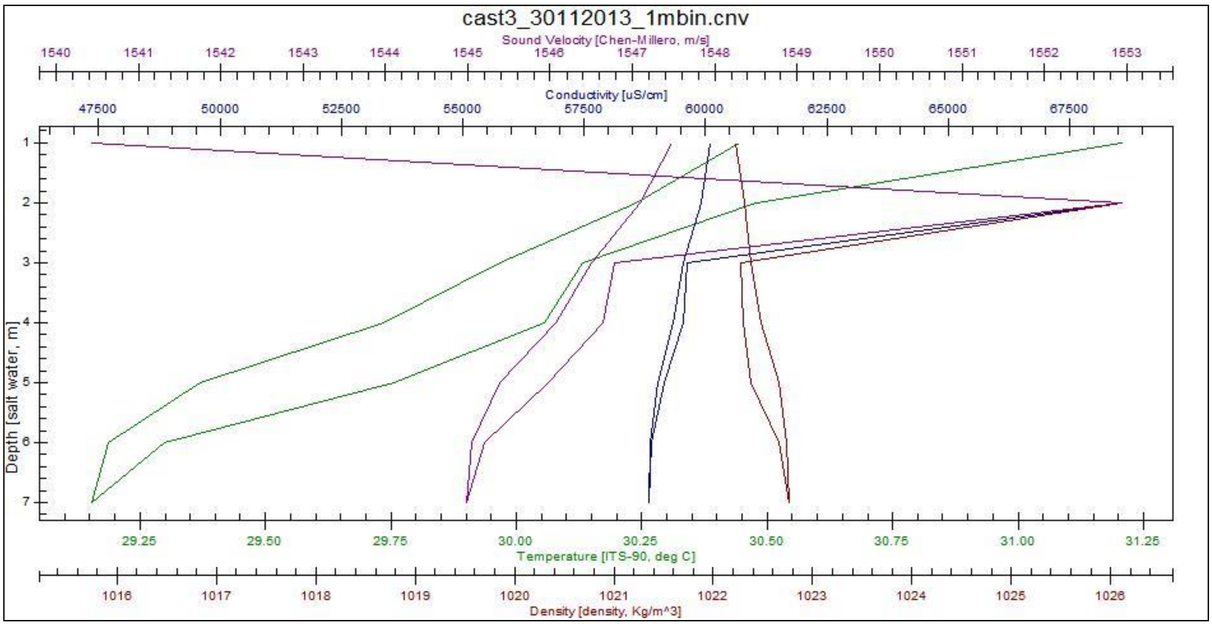
Staff Station	Distance (m)	Stadia Wire	Back Reading	Inter Reading		Forward Reading	Rise	Fall	Reduced Level	Remarks
PTP25		T	1.300	0.102						PTP25 IS A STAINLESS STEEL PIN SET IN CONCRETE MARKED"PTP25' (3.266 ABOVE MSL)
		M	1.198						3.266	
	20.8	B	1.092	0.106						
TS1	44.7	T	4.900	0.221	0.226	4.878				
		M	4.679			4.652		3.454	-0.188	
	44.5	B	4.455	0.224	0.221	4.431				
PTP25	20.0	T			0.108	1.309				
		M				1.201	3.478		3.290	
		B			0.092	1.109				
		T								
		M								
		B								
		T								
		M								
		B								
		T								PTP25
		M								
		B								
		T								
		M								3.478M
		B								
		T								
		M								TS1
		B								
		T								THEREFORE PTP25 LIES 3.481 METRES ABOVE TS1 (TIDE POLE ZERO IS 0.212 M ABOVE MSL)
		M								
		B								
Check Totals	130.0		5.877	0.653	0.647	5.853	3.478	3.454		Traverse Length (Kms) 0.13 Km; Allowable Misclosure (12√DIST in KM) 4 mm
				1.300						Reduced by: SALESH KUMAR
Height						0.024		0.024	-3.266	Checked by; Actual Misclosure 24 mm


Plan of Traverse
N
OLD JETTY
PTP25
TS1
LEGEND
Back Sight
Forward Sight
Level Station
Staff Station

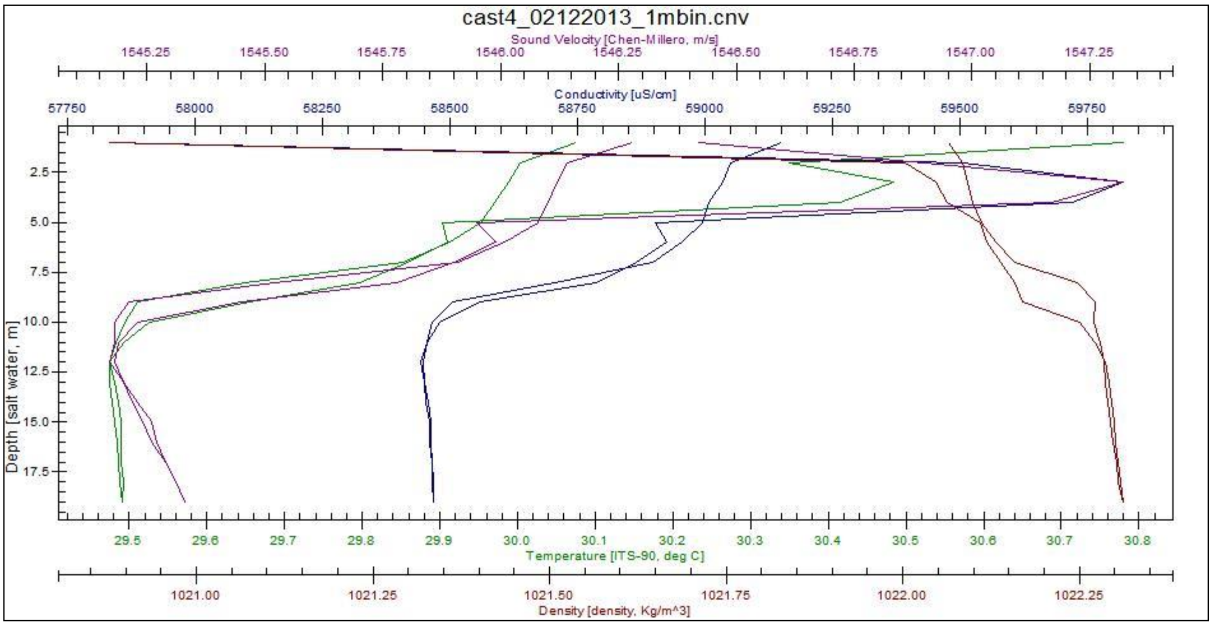
6.3. Appendix C – CTD profiles



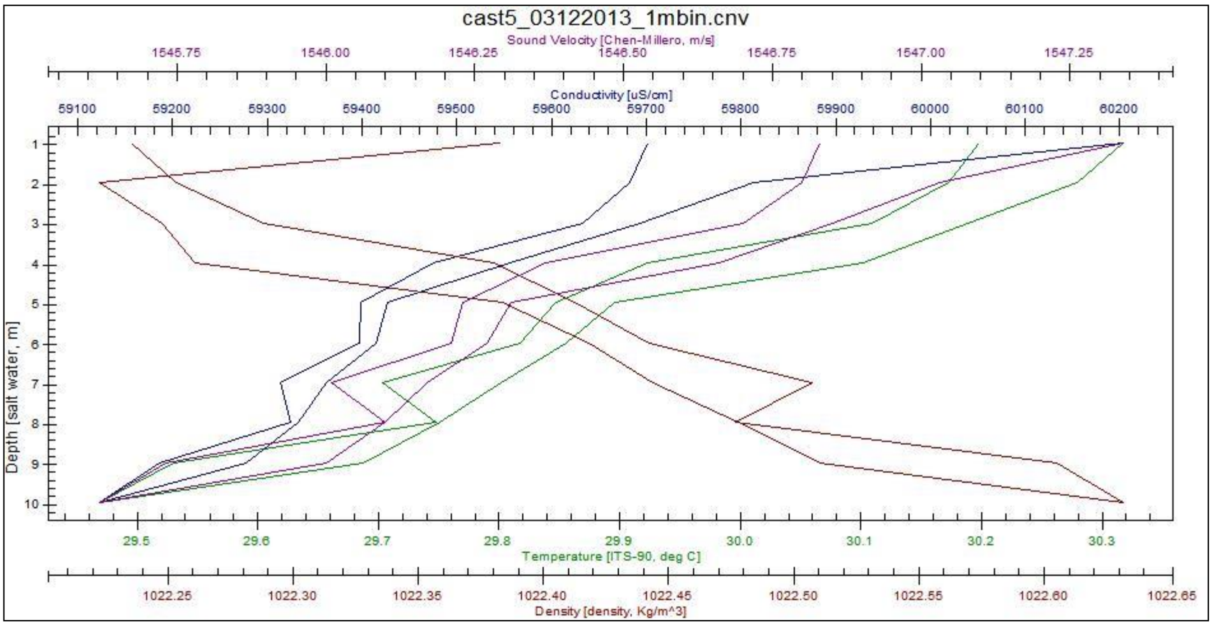


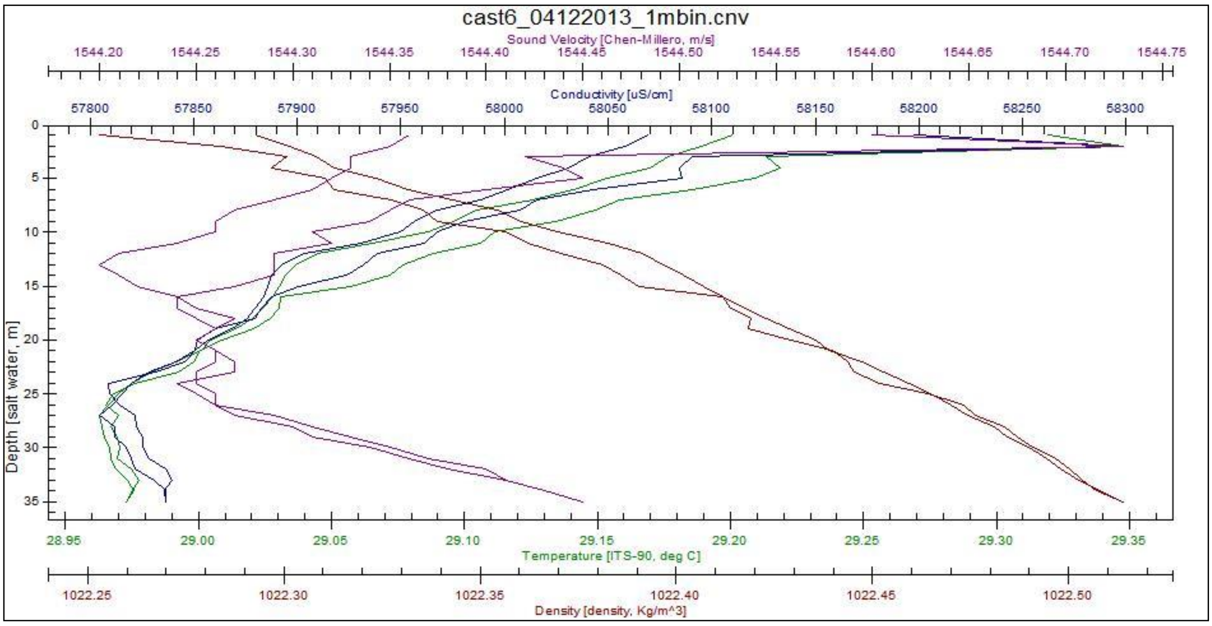


cast3_30112013_1mbin.cnv
Sound Velocity [Chen-Millero, m/s]
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
Conductivity [uS/cm]
47500
50000
52500
55000
57500
60000
62500
65000
67500
Depth [salt water, m]
1
2
3
4
5
6
7
29.25
29.50
29.75
30.00
30.25
30.50
30.75
31.00
31.25
Temperature [ITS-90, deg C]
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
Density [density, Kg/m^3]



cast4_02122013_1mbin.cnv
Sound Velocity [Chen-Millero, m/s]
1545.25
1545.50
1545.75
1546.00
1546.25
1546.50
1546.75
1547.00
1547.25
Conductivity [uS/cm]
57750
58000
58250
58500
58750
59000
59250
59500
59750
Depth [salt water, m]
2.5
5.0
7.5
10.0
12.5
15.0
17.5
29.5
29.6
29.7
29.8
29.9
30.0
30.1
30.2
30.3
30.4
30.5
30.6
30.7
30.8
Temperature [ITS-90, deg C]
1021.00
1021.25
1021.50
1021.75
1022.00
1022.25
Density [density, Kg/m^3]


cast5_03122013_1mbin.cnv
Sound Velocity [Chen-Millero, m/s]
1545.75
1546.00
1546.25
1546.50
1546.75
1547.00
1547.25
Conductivity [uS/cm]
59100
59200
59300
59400
59500
59600
59700
59800
59900
60000
60100
60200
Depth [salt water, m]
Temperature [ITS-90, deg C]
29.5
29.6
29.7
29.8
29.9
30.0
30.1
30.2
30.3
Density [density, Kg/m^3]
1022.25
1022.30
1022.35
1022.40
1022.45
1022.50
1022.55
1022.60
1022.65


cast6_04122013_1mbin.cnv
Sound Velocity [Chen-Millero, m/s]
1544.20
1544.25
1544.30
1544.35
1544.40
1544.45
1544.50
1544.55
1544.60
1544.65
1544.70
1544.75
Conductivity [uS/cm]
57800
57850
57900
57950
58000
58050
58100
58150
58200
58250
58300
Depth [salt water, m]
Temperature [ITS-90, deg C]
28.95
29.00
29.05
29.10
29.15
29.20
29.25
29.30
29.35
Density [density, Kg/m^3]
1022.25
1022.30
1022.35
1022.40
1022.45
1022.50

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