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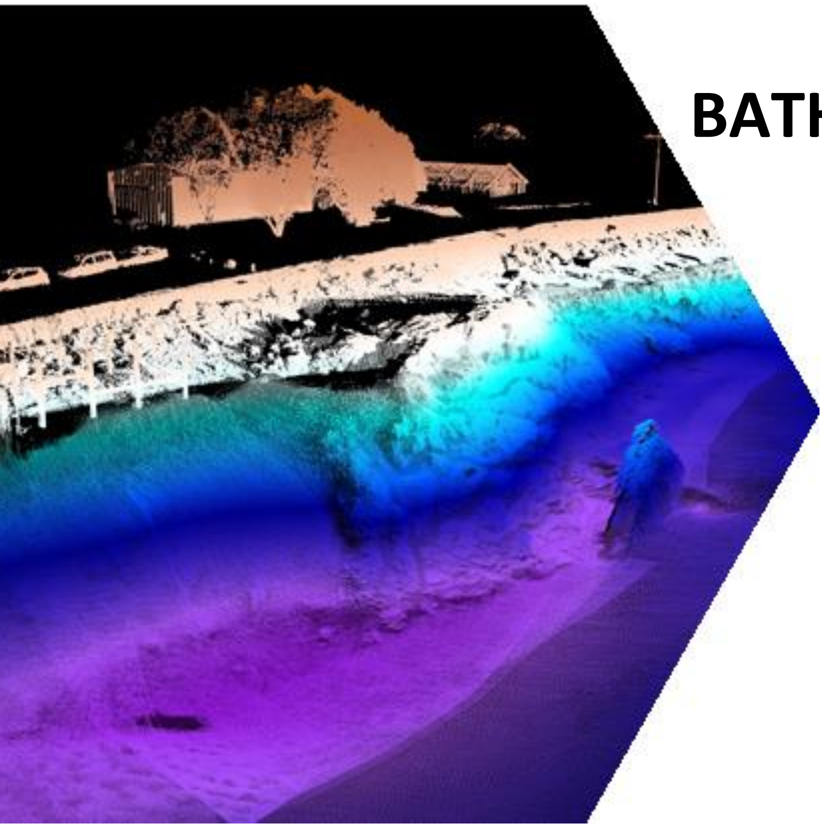


PORIRUA HARBOUR BATHYMETRIC SURVEY 2019: REPORT OF SURVEY

CLIENT: Greater Wellington Regional Council
PROJECT: Porirua Bathymetric Survey 2019

greater WELLINGTON REGIONAL COUNCIL Te Pane Matua Taiao

www.dmlsurveys.co.nz

DML DISCOVERY MARINE LTD

Reference: 1902

17 July 2019

Dr Megan Oliver
Greater Wellington Regional Council
Shed 39, 2 Fryatt Quay
Pipitea, Wellington 6011

Dear Megan

Report of Survey – Porirua Harbour Bathymetric Survey

1. Survey Requirement

Greater Wellington Regional Council (GWRC) requested DML (Discovery Marine Limited) undertake a bathymetric survey of Porirua Harbour, to provide a dataset for comparison against similar surveys conducted in 2014 and 2009. The results of the survey and comparisons are used to monitor the harbour bed for sediment movement, accretion or erosion.

2. Survey Location

The location for this survey was Te Awarua-o-Porirua Harbour in the Wellington region. The natural inlet opens into two shallow arms, Onepoto Arm to the south and Pauatahanui Arm to the north-east.

Figure 1: Porirua Harbour Survey Area

3. Survey Dates

Field work for the 2019 survey was conducted between Monday 20 May and Friday 24 May 2019. Data processing and reporting was progressed through June and July 2019.

4. Weather & Sea Conditions

The survey was completed during late Autumn. The weather was settled and fine for most of the survey except for 22 May which was wet with 10-15 knot winds from the north. Harbour conditions were generally flat with minimal sea state. Due to the shallow nature of the harbour arms, survey operations were conducted around high tides to allow safe navigation in shallower areas.

5. Survey Vessel

This survey was undertaken using DML's 5.6m Stabicraft survey vessel PELICAN, fitted with equipment as described below. The vessel is operated under the Maritime New Zealand MOSS safety system.

6. Horizontal Datum

Positions are in terms of the New Zealand Geodetic Datum 2000 (NZGD2000) and Transverse Mercator Projection (NZTM).

The following control marks were used during the survey:

Table 1: Survey Control Benchmarks for the 2019 Survey

Mark	Easting (m)	Northing (m)	Elevation Chart Datum (m)	Elevation NZVD16 (m)	Comments
A2GC	1757035.00	5448015.20	5.69	4.503	LINZ. Origin of NZVD16 heights
BB4C	1756984.74	5449009.31	4.31	3.143	LINZ
TG Bolt	1756821.30	5448475.94	2.54	1.34	Position by DML
C1K1_DML	1756787.10	5448512.31	2.55	1.35	Position by DML. Origin of CD from LINZ
DML1	1756824.56	5448534.14	3.21		DML
DML2	1756671.29	5448867.02	6.64		DML
DML3	1756693.28	5448521.78	3.00		Original position found disturbed due to erosion/earthquake
DML3 (Disturbed)	1756693.28	5448521.73	2.95	1.77	New position of DML3 (unsuitable for future surveys)

7. Vertical Datum

All final depth data is referenced to Porirua Sounding Datum (SD) which is linked to Porirua Chart Datum (CD), defined as 2.55m below LINZ steel pin C1K1 at the Mana Cruising Clubrooms. A connection was also made to the New Zealand Vertical Datum 2016 (NZVD16) using LINZ survey benchmarks marks A2GC and BB4C.

The 2019 bathymetric data was reduced directly to NZVD16 in real time by combining the echo sounded depth with GNSS (Global Navigation Survey System) heights for the SBES (Single Beam Echo Sounder) transducer. The data was further reduced to SD, by applying a separation model or difference model between NZVD16 and SD. Previous surveys in 2009 and 2014 were reduced to SD using tide / water level measurements from the GWRC tide gauge inside Mana marina and applying a co-tidal model for the two harbour arms. The factors for the co-tidal model were originally derived from a tidal study in 2009 and outlined in both the 2009 and 2014 reports of survey.

The separation model was derived by reducing the 2019 dataset using the tide method and comparing the bathymetric data against the same data set reduced to NZVD16. The separation between the two data sets was modelled and spatially represents the gradual vertical changes between SD and NZVD16 across the survey area. The separation model was applied to the NZVD16 reduced data and has resulted in final bathymetric data set that matches the co-tide reduced data for 2019. Verification of the model and methodology was undertaken by spot checking depth differences between the final data set and tide reduced data sets, with an average difference of approximately 2cm. Further in field verification was undertaken on the Mana marina tide gauge and tide pole by recording daily comparisons between the pole and gauge against the GNSS survey system. The three sources water level were generally in good agreement, with the range of difference typically less than 1.5cm.

The separation model and RTK GNSS method was developed for this survey to safeguard any future surveys against unexpected movement of the tide gauge (from earthquake or damage) or uncalibrated tide gauge data. Future surveys could apply the separation model in real time during data acquisition, resulting in depth referenced to SD without the need to tide gauge reductions. Alternatively, the original tide method could be used if the Mana tide gauge remains in good working order.

8. Equipment

The following equipment was used:

Echo Sounder

Type:	Tritech PA500
Depth Acquisition:	8 – 10 soundings per second
Frequency:	500 kHz
Beam width:	6°
Rated Accuracy:	+/- 1cm

Positioning System

A Trimble SPS881/882 GNSS RTK system, consisting of a base station receiver setup over local benchmarks DML3 and A2GC and rover receiver mounted on the vessel was used for the duration of the survey. Corrections were provided from the base station via UHF radio link. The New Zealand Geoid 2016 (NZGeoid2016) was used to correct the ellipsoidal heights to NZVD16.

GNSS System Accuracy: Horizontal uncertainty of +/-0.02m and vertical uncertainty of +/- 0.03m.

9. Software

The following software was used to produce the deliverables.

Acquisition:	QPS QINSy v8.18.2
Data Processing:	QPS Qimera v1.7.5
Data Quality Control and Rendering:	Trimble Terramodel v10.61

Data Quality Control:	Trimble Terramodel v10.61
Volume Calculation:	QPS QINSy v8.18.2
Data Rendering:	QPS QINSy v8.18.2

10. Conduct of Survey

Sounding operations were undertaken using standard hydrographic principles. To closely replicate the 2009 and 2014 survey methodology, vessel navigation lines from previous surveys were loaded into the acquisition software to enable direct comparisons. Cross lines or check lines were sounded perpendicular to mainlines to provide data overlaps for internal checking and Quality Assurance (QA) requirements.

11. Coverage Achieved

The SBES coverage achieved during the 2019 survey is depicted in Figure 2 below. This coverage is considered comparable to the 2014 data set, which is depicted in Figure 3 below. Some transects from 2014 were realigned during the 2019 survey to better reflect the direction of channels or natural boundaries.

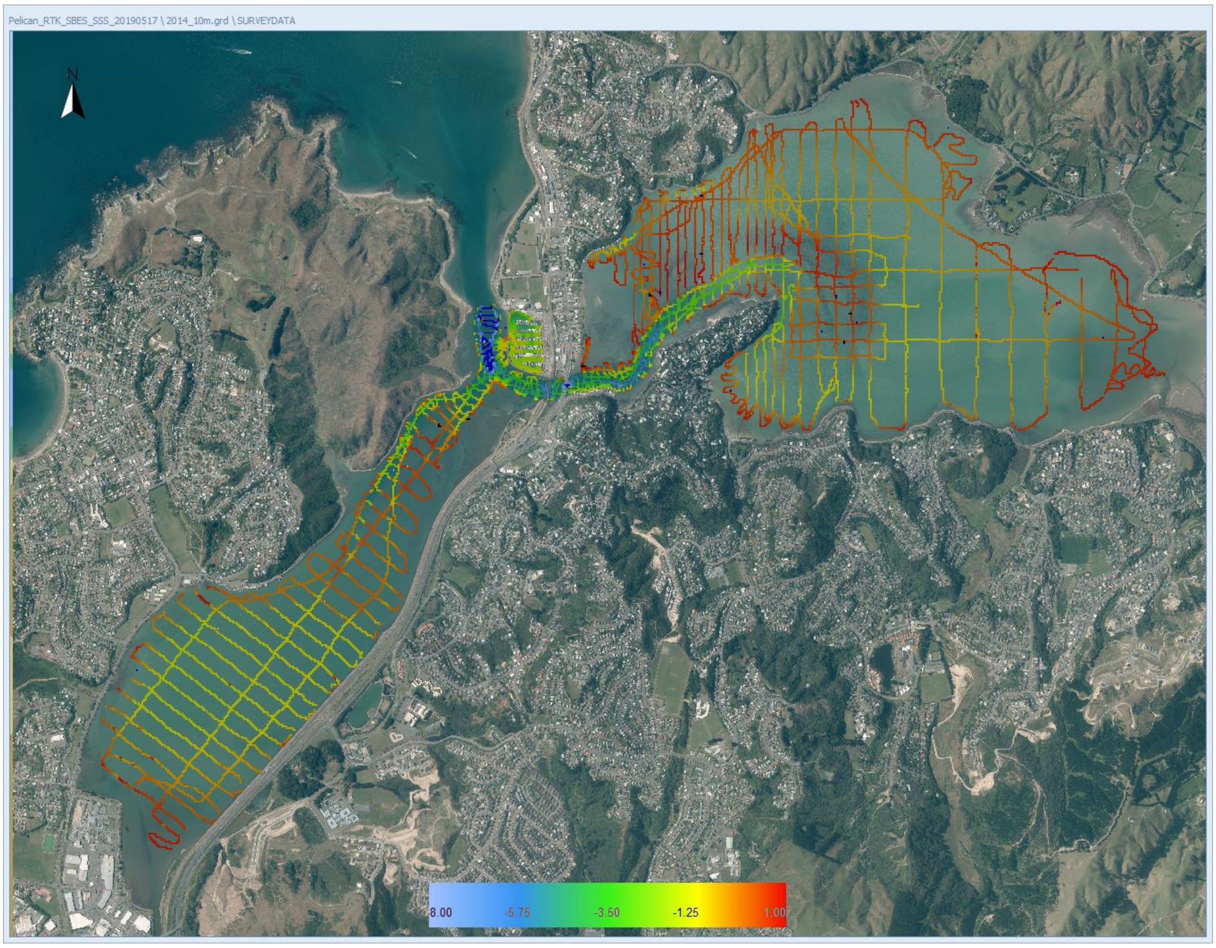


Figure 2: 2019 Bathymetric Survey Coverage by SBES

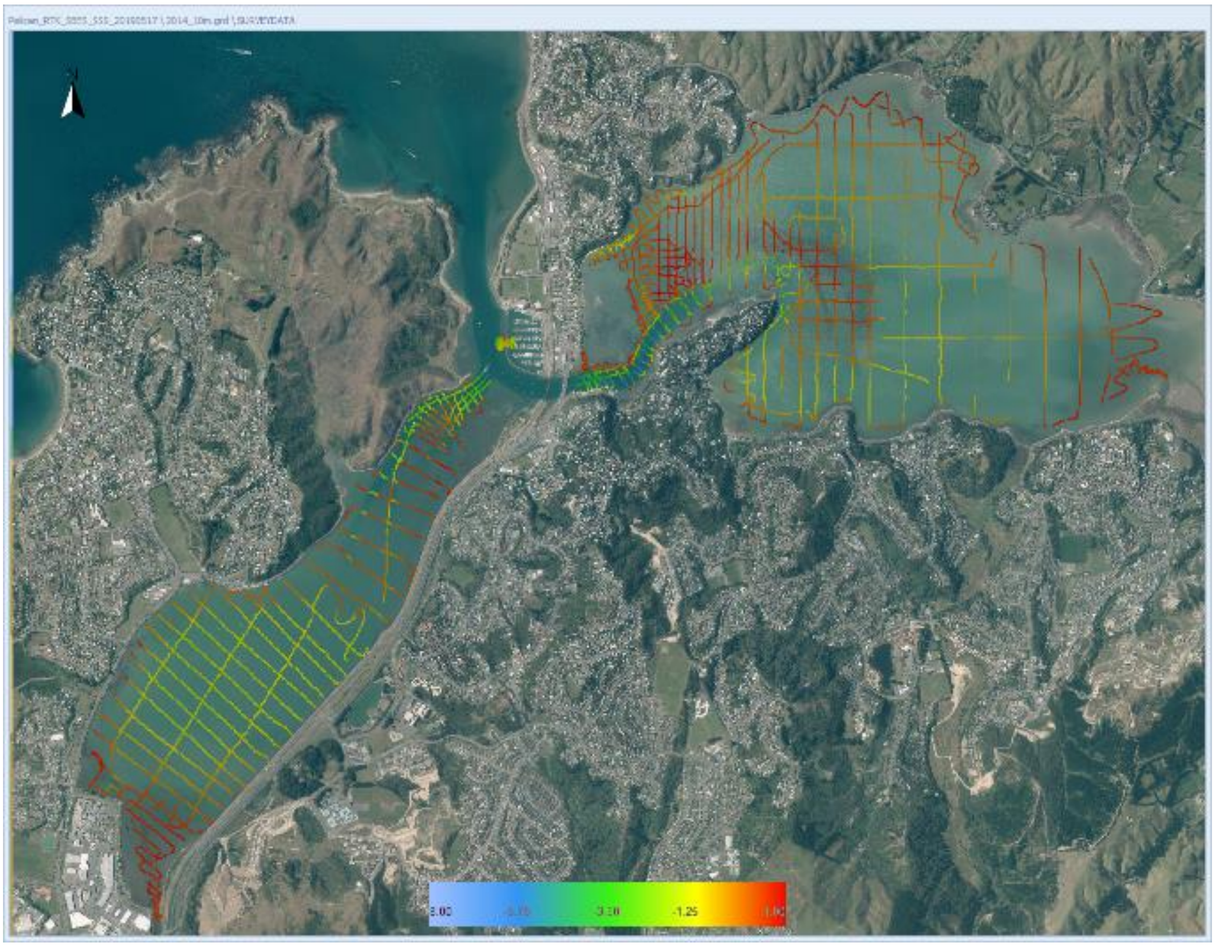


Figure 3: 2014 Bathymetric Survey Coverage by SBES

12. Data Editing and Processing

The following steps outline the general processing workflow used to transition the raw depth data to a Digital Terrain/Triangulation Model (DTM) and gridded 10m data set for volume calculations and cross section visualisation.

- Raw data reprocess in QINSy to apply the NZVD16 to SD separation model,
- Open raw data files in QIMERA for 3D visualisation and data processing/cleaning,
- Export processed data to XYZ and import into Terramodel,
- Create 10m gridded DTM from the RAW data for both 2019 and 2014 data sets,
- Export DTMs to XYZ and import into SURFER and QINSy
- Calculate volumes constrained to specific areas in SURFER and QINSy
- Create cross sections for visualisation in QINSy

13. Estimated Vertical Uncertainty

The description of Vertical Uncertainty below is cited from the International Hydrographic Organisation (IHO) Special Publication 44 (5E) and describes how vertical uncertainty (previously referred to as depth accuracy) is attributed to depth data. The TVU calculation method is also used in the LINZ Contract Specifications for Hydrographic Surveys v1.3, to define the LINZ standards for depth data.

> *"Vertical uncertainty is to be understood as the uncertainty of the reduced depths. In determining the vertical uncertainty, the sources of individual uncertainties need to be quantified. All uncertainties should be combined statistically to obtain a Total Vertical Uncertainty (TVU).*
>
> *The maximum allowable vertical uncertainty for reduced depths specifies the uncertainties to be achieved to meet each order of survey. Uncertainty related to the 95% confidence level refers to the estimation of error from the combined contribution of random errors and residuals from the correction of systematic errors. The capability of the survey system is demonstrated by the TVU calculation.*
>
> *Recognising that there are both depth independent and depth dependent errors that affect the uncertainty of the depths, the formula below is to be used to compute, at the 95% confidence level, the maximum allowable TVU. The parameters "a" and "b" for each order, as given in Table 1, together with the depth "d" have to be introduced into the formula in order to calculate the maximum allowable TVU for a specific depth:*
>
> $TVU = [a^2 + (bd)^2]$
>
> *Where: **a** represents that portion of the uncertainty that does not vary with depth, **b** is a coefficient which represents that portion of the uncertainty that varies with depth and **d** is the depth, **b x d** represents that portion of the uncertainty that varies with depth."*

The A Posteriori TVU at the 95% confidence level for the 2019 survey is tabulated below, along with the LINZ Special and IHO Special Order maximum allowable TVU, for a given depth.

Table 2: TVU Calculation

A POSTERIORI ESTIMATE OF DEPTH UNCERTAINTY							
PROJECT: Porirua Harbour Bathymetric Survey 2019							
SURVEY VESSEL: Pelican SBES							
				Note	Depth (m)	Depth (m)	Depth (m)
Source of Error	**Depth Independent Error**		**Depth Dependent Error**		**2**	**5**	**10**
Vessel Offset Measurments	0.02			a	0.02	0.02	0.02
Variation in NZVD16 - SD Separation Model	0.02			b	0.02	0.02	0.02
Vessel Settlement and Squat	0.00			c	0.00	0.00	0.00
Tritech PA500 Instrument Accuracy	0.01	±	0.20% d	d	0.01	0.01	0.02
Roll Error	0.01		0.0000 d	e	0.01	0.01	0.01
Sound Velocity Measurement			0.0010 d	f	0.00	0.01	0.01
Sound Velocity Spatial Variation			0.0013 d	g	0.00	0.01	0.01
Sound Velocity Temporal Variation			0.0013 d	h	0.00	0.01	0.01
Vertical Uncertainty in GNSS	0.03			i	0.03	0.03	0.03
Co-Tidal Corrections	0.00			j	0.00	0.00	0.00
Combined Total	**0.04**	±	**0.0029 d**		0.04	0.05	0.05
LINZ Special Requirement @ Depth	**0.25**	±	**0.0075 d**		**0.25**	**0.25**	**0.26**
IHO Special Order Requirement @ Depth	**0.25**	±	**0.0075 d**		**0.25**	**0.25**	**0.26**
Standard Met					YES	YES	YES

Cross line comparisons form the 2019 survey indicate a relative accuracy of approximately +/-0.040m. The A Posterori Total Propagated Uncertainty (TPU) of final depths for this survey is assessed as +/-0.050m. The TVU calculation indicates the 2019 meets both the LINZ Special and IHO Special Order standard.

14. Comments, Results & Comparisons

In 2016 central New Zealand experienced a magnitude 7.8 earthquake and subsequent aftershocks, centred near Kaikoura. Effects of the violent shaking were evident throughout the region with significant damage to buildings and port infrastructure in Wellington City. DML contacted the Senior Geodetic Surveyor at Land Information New Zealand (LINZ) to establish whether this event had caused any movement in the Porirua area that might impact the results of this survey. LINZ's advice was that post earthquake there was *1cm or less* change to heights of the local survey benchmarks in the area, although there was significant movement recorded during the event. While the final positions of the LINZ benchmarks have not moved significantly, it is difficult establish with any certainty that differences with the previous Porirua Harbour survey are caused by natural processes or the earthquake. Checks on DML's internal benchmarks were generally consistent with the LINZ feedback, although one benchmark on the Mana Marina breakwater moved vertically by -3cm, which is most likely as a result of localised surface erosion and slumping of soft sand in the area caused by the earthquake. This mark was re surveyed and a new coordinate established prior to use as a GNSS base station during the 2019 survey.

Survey Plans and Difference Plots

Due to the wide spaced survey lines and irregular shaped seabed, some gridding artefact can be seen in the final DTM (Digital Terrain Model). The DTM artefact is most evident in areas where there are changes in the bathymetry that are not modelled well by the DTM, or along the outer edges of the survey area. Figures 4 and 6 below depicted the colour gradient imagery for the two arms of the harbour. In Figure 4 and area of DTM artefact can be seen along the northern channel, where it appears there are ridges in the channel. These are not real features, but DTM linking issues due to the survey line spacing across the narrow channel. In Figure 6, a similar artefact can be seen along the southern edge of the survey area, and in some flat areas some raised unnatural features can be seen.

Figures 5 and 7 below depict colour gradient difference plots for each harbour arm, generated by comparing the 2019 10m DTM surface and the 2014 10m DTM surface then calculating the difference between the two where they overlap. The impact of the DTM artefact can been seen in the surface difference images, but both images still indicate general harbour erosion (blue) or sedimentation (red) over the last five years. Figure 5 indicates general shoaling across the main Onepoto basin, but generally little change along the shallow banks at the northern entrance. Figure 7 indicates general shoaling of the southern side of the Pauatahanui arm and some possible erosion or deepening on the northern side.

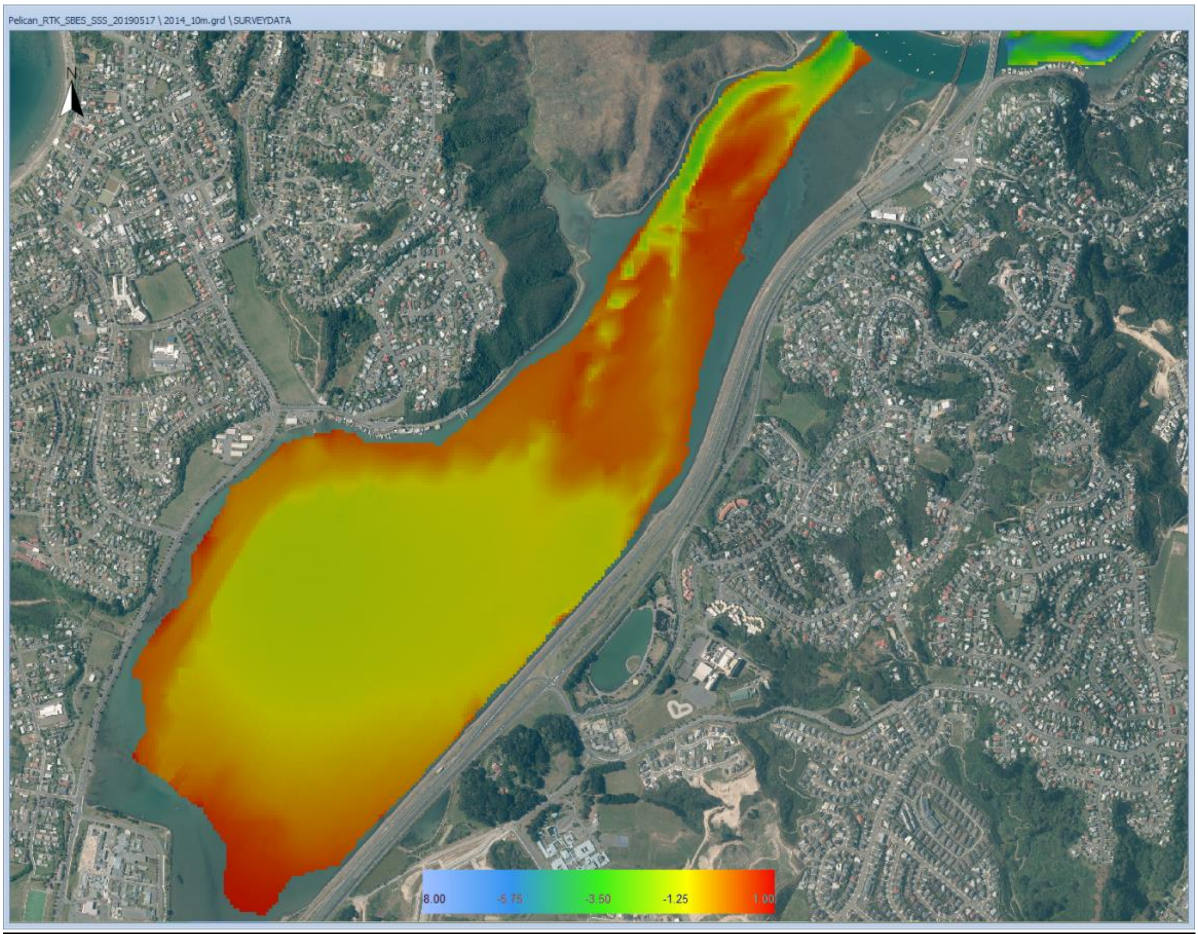


Figure 4: Plan view of Porirua Harbour, Onepoto Arm – 2019 Survey

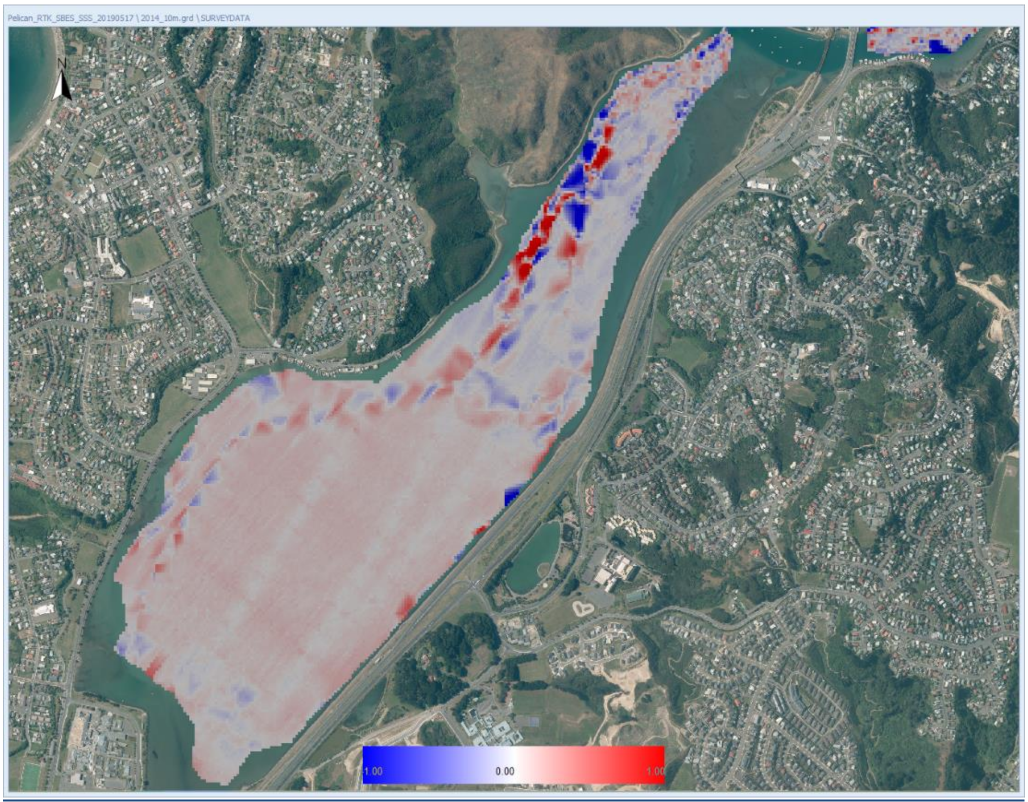


Figure 5: Plan view of Porirua Harbour, Onepoto Arm – 2019 versus 2014 Difference Plot

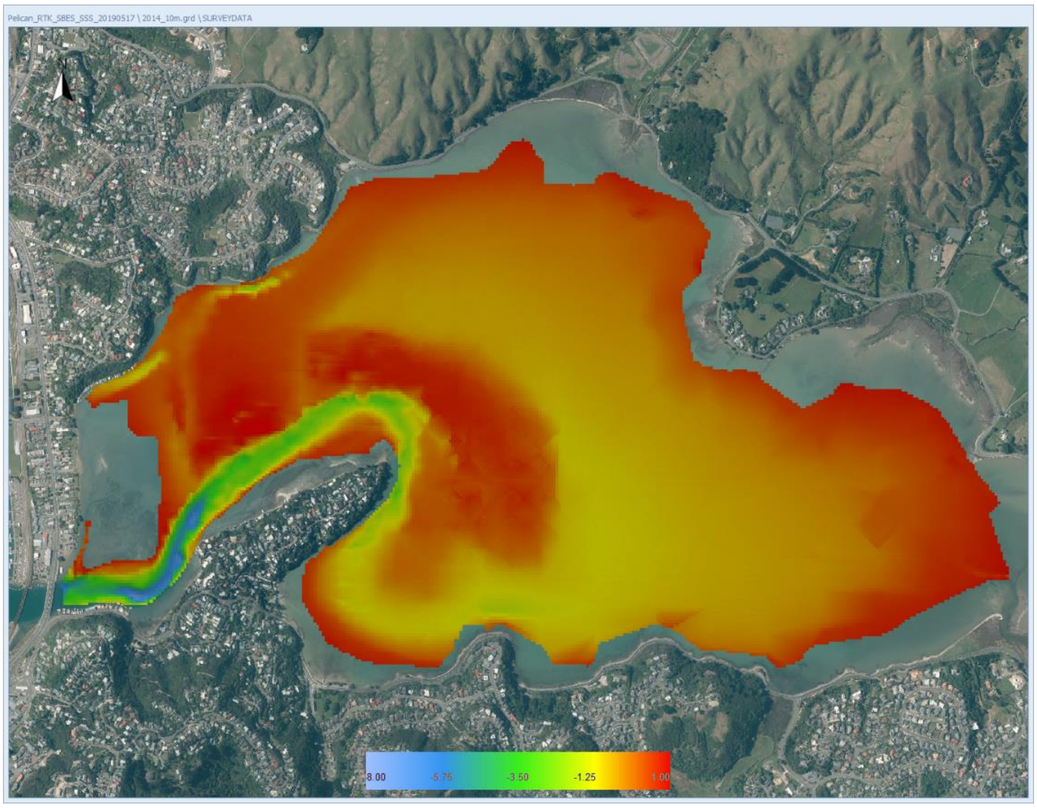


Figure 6: Plan view of Porirua Harbour, Pauatahanui Arm – 2019 Survey

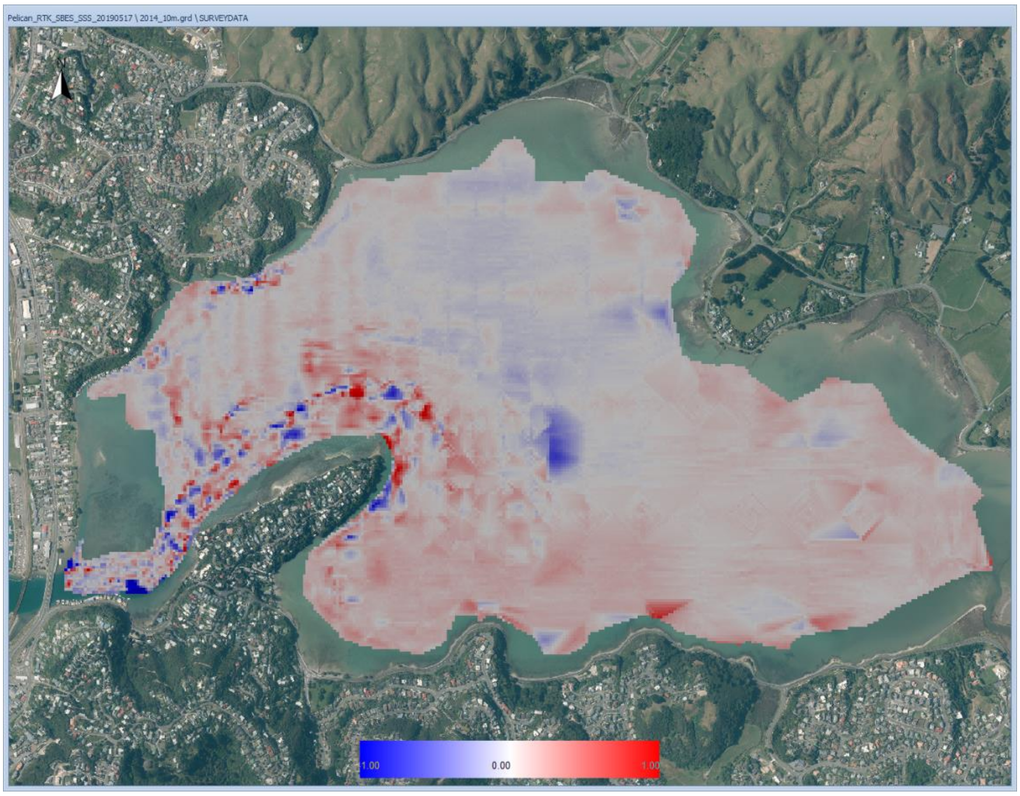


Figure 7: Plan view of Porirua Harbour, Pauatahanui Arm – 2019 versus 2014 Difference Plot

Volume Calculations

Volume calculations between the 2019 survey and previous surveys in 2014 and 2009 are tabulated below and indicate volumetric change between overlapping gridded surfaces. Each volume calculation was constrained to the boundaries depicted in Figure 8 below. The volume boundaries for the 2019 survey have been defined to better reflect the natural areas within each arm. For completeness, volume calculation for the 2014 and 2009 surveys have been included in the new format using the 2019 methodology. Results between each year, for each area are tabulated below. Each table lists the amount of cut/erosion and fill/accretion for each area, the used surface area of the volume calculation, the average area cut or fill and the annual rate of cut or fill.

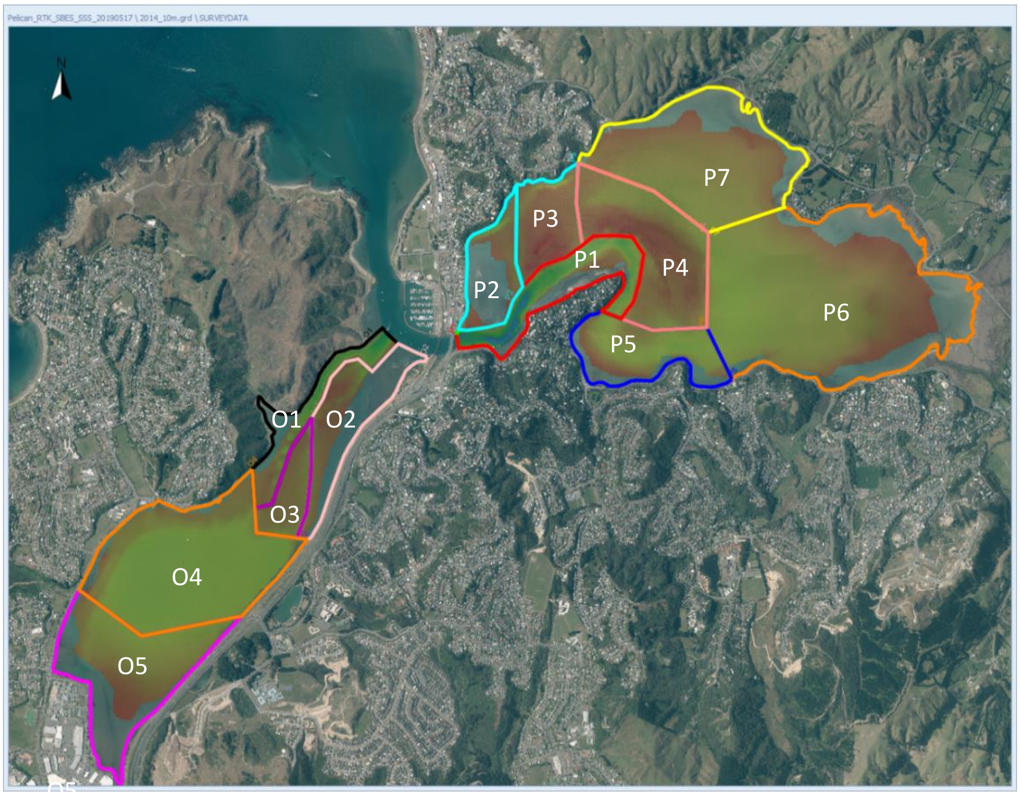


Figure 8: 2019 Volume Areas for Porirua Harbour

2019 vs 2014 Volume Calculation

Table 3: 2019 vs 2014 Pauatahanui Arm Volume Calculation

PAUATAHANUI ARM					
Area	**2019 vs 2014**		Used Area (m²)	Average Area of Cut/Fill (mm)	Average per Year*
	Cut (m³)	Fill (m³)			
P1		11348.65	260732.68	50	10
P2		1880.18	101594.99	20	4
P3		11902.56	254528.06	50	10
P4		38259.54	604298.53	60	12
P5		35391.11	287518.64	130	26
P6		75816.01	1350315.6	60	12
P7	-7502.61		681860.81	-10	-2
Total	167,095		3,540,849	47	

**Calculated average sedimentation per year during 5 year period between surveys*

Table 4: 2019 vs 2014 Onepoto Arm Volume Calculation

ONEPOTO ARM					
Area	**2019 vs 2014**		Used Area (m²)	Average Area of Cut/Fill (mm)	Average per Year*
	Cut (m³)	Fill (m³)			
O1		7828.67	152924.31	50	10
O2	-7113.72		174657.2	-40	-8
O3	-1265.32		163261.16	-10	-2
O4		65149.62	914791.52	70	14
O5		28036.56	428192.59	70	14
Total	92,636		1,833,827	51	

**Calculated average sedimentation per year during 5 year period between surveys*

2019 vs 2009 Volume Calculation

Table 5: 2019 vs 2009 Pauatahanui Arm Volume Calculation

PAUATAHANUI ARM					
Area	2019 vs 2009		Used Area (m^2)	Average Area of Cut/Fill (mm)	Average per Year**
	Cut (m^3)	Fill (m^3)			
P1		8,491	260,733	30	3
P2	-2,235		101,595	-20	-2
P3		3,882	254,528	20	2
P4		47,065	604,299	80	8
P5		14,993	287,519	60	6
P6		81,084	1,350,316	60	6
P7		33,713	681,861	50	5
Total	186,992		3,540,849	53	

***Calculated average sedimentation per year during 10 year period between surveys*

Table 6: 2019 vs 2009 Onepoto Arm Volume Calculation

ONEPOTO ARM					
Area	2019 vs 2009		Used Area (m^2)	Average Area of Cut/Fill (mm)	Average per Year**
	Cut (m^3)	Fill (m^3)			
O1		14,650	152,924	100	10
O2	-5,674		174,657	-30	-3
O3		186	163,261	0	0
O4		50,470	914,792	60	6
O5		21,377	428,193	50	5
Total	81,011		1,833,827	44	

***Calculated average sedimentation per year during 10 year period between surveys*

2014 vs 2009 Volume Calculation

Table 7: 2014 vs 2009 Pauatahanui Arm Volume Calculation

PAUATAHANUI ARM					
Area	2014 vs 2009		Used Area (m^2)	Average Area of Cut/Fill (mm)	Average per Year*
	Cut (m^3)	Fill (m^3)			
P1	-12,432		269,331	-50	-10
P2	-6,044		109,146	-60	-12
P3	-7,856		255,166	-30	-6
P4		8,773	605,181	10	2
P5	-19,915		281,559	-70	-14
P6		5,280	1,398,455	0	0
P7		39,325	754,632	50	10
Total	7,131		3,673,469	2	

**Calculated average sedimentation per year during 5 year period between surveys*

Table 8: 2014 vs 2009 Onepoto Arm Volume Calculation

ONEPOTO ARM					
Area	2014 vs 2009		Used Area (m^2)	Average Area of Cut/Fill (mm)	Average per Year*
	Cut (m^3)	Fill (m^3)			
O1		7,051	169,580	40	8
O2		2,329	252,274	10	2
O3		1,452.	163,261	10	2
O4	-14,611		933,280	-20	-4
O5	-6,249		562,872	-10	-2
Total	-10,029		2,081,267	-5	

**Calculated average sedimentation per year during 5 year period between surveys*

Annual Sedimentation Rate Comparison

The annual sedimentation rates for each of the volume areas are tabulated below and depicted graphically in Figure 9. The values below indicate a positive trend in almost all areas, with some significant changes to rate of accretion when compared to the previous survey. It is possible that some of the variation can be attributed to the repeatability of the survey methodology, which is discussed in Section 13 above and considered to be in the order of 5cm between surveys.

Table 9: 2014 vs 2009 Onepoto Arm Volume Calculation

	Sedimentation per year (mm)		
Area	**2019 - 2014**	**2014 - 2009**	***2019 - 2009***
P1	10	-10	*3*
P2	4	-12	*-2*
P3	10	-6	*2*
P4	12	2	*8*
P5	26	-14	*6*
P6	12	0	*6*
P7	-2	10	*5*
O1	10	8	10
O2	-8	2	-3
O3	-2	2	0
O4	14	-4	6
O5	14	-2	5

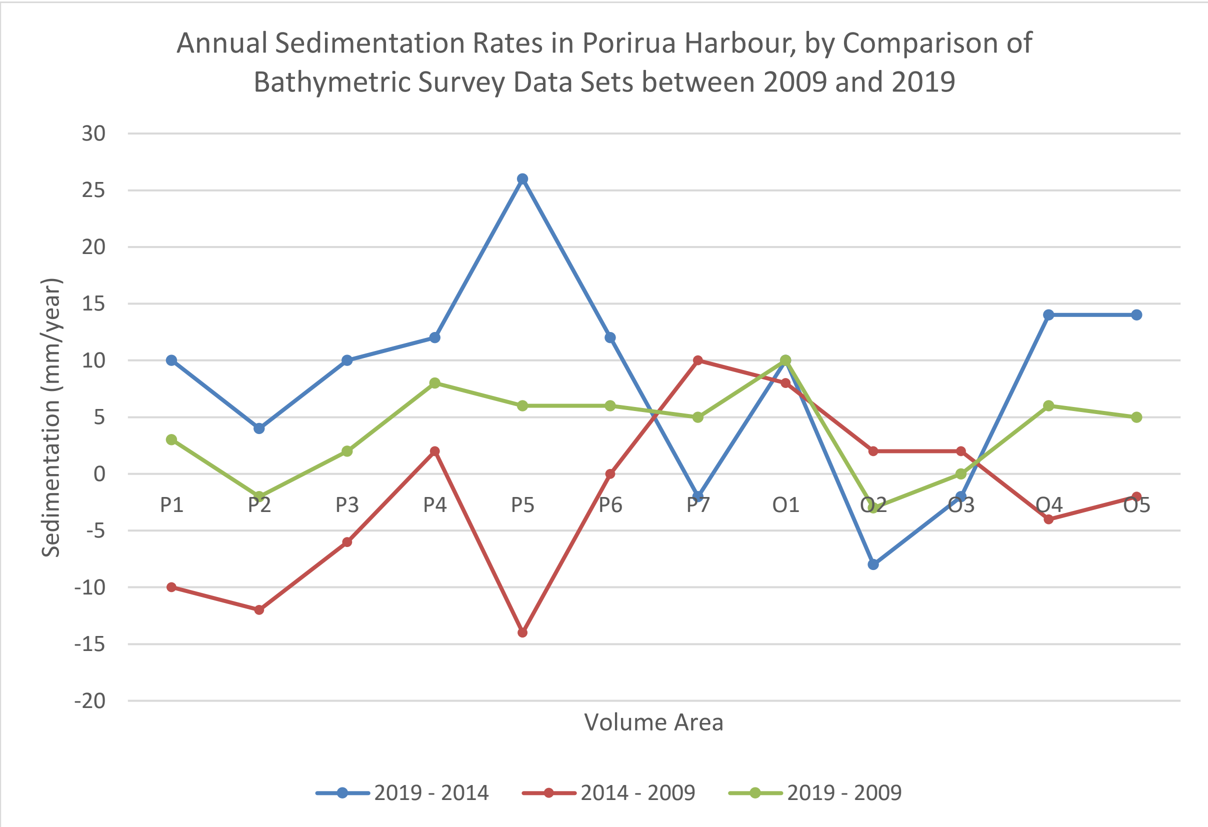


Figure 9: Annual Sedimetation Rates by Comparison of Bathymetric Survey Data

Cross Sections

To visually assess changes between surveys, profiles through the data set have been created comparing the 2019 dataset against 2014 and 2009 datasets. The datasets were re gridded at 2m intervals to show a smoother profile line. The profiles have been aligned to reflect the actual transects run in the field. The profiles and profile layout are depicted in Figures 9 to Figure 18 below. Two separate PDF documents containing the profiles accompany this report of survey in the folder of digital deliverables.

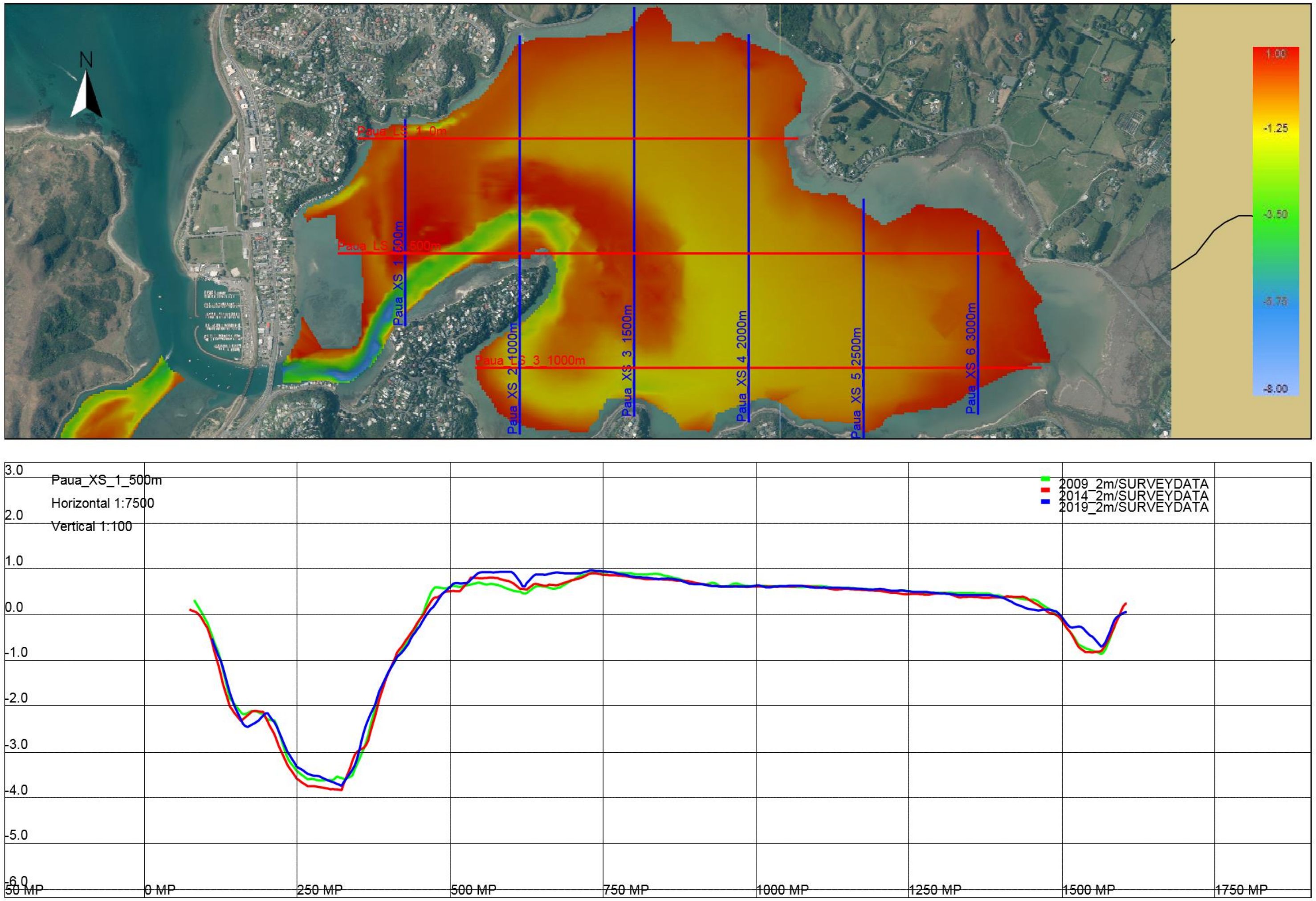


Figure 10: Porirua Harbour, Pauatahanui Arm – Profiles Page 1

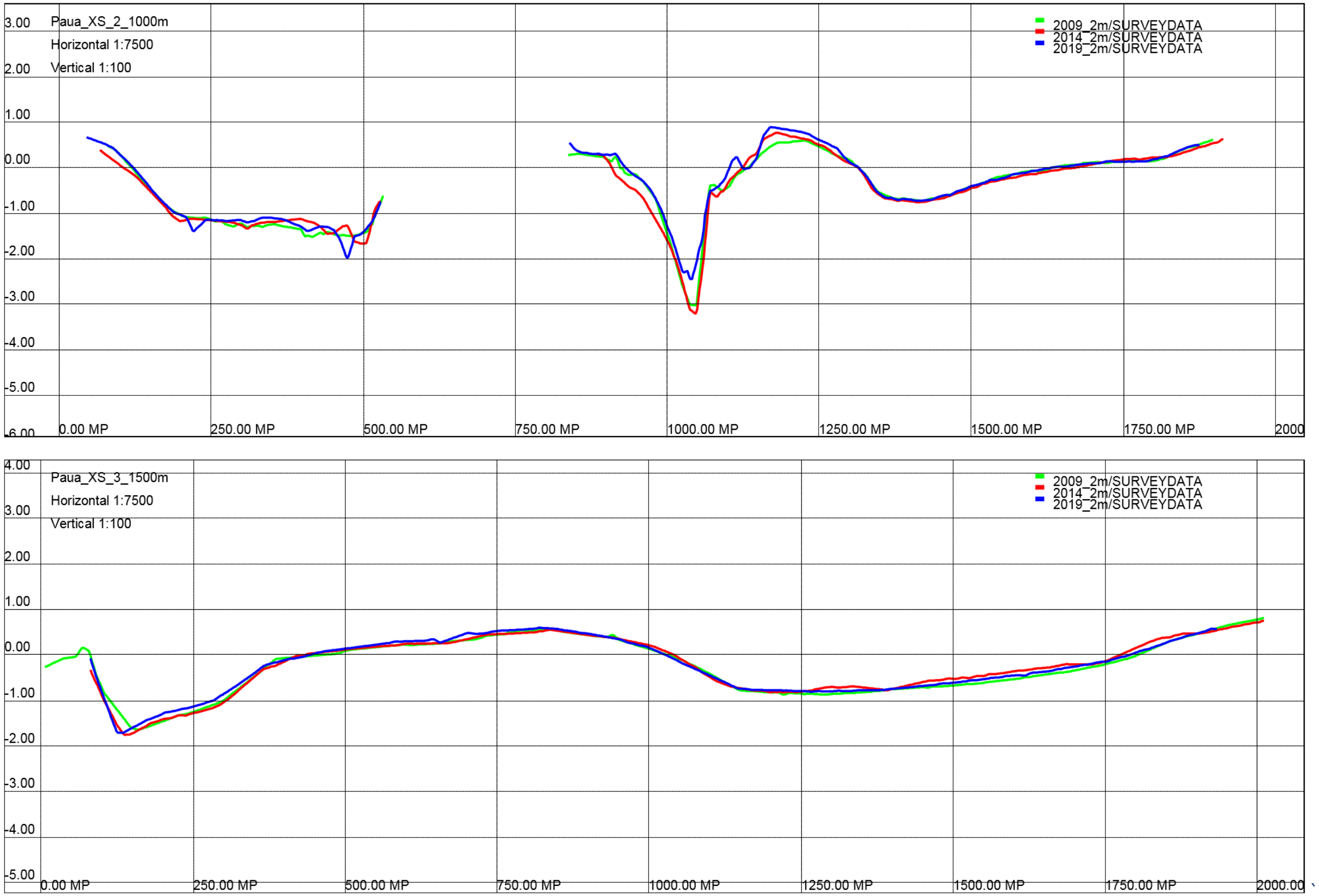
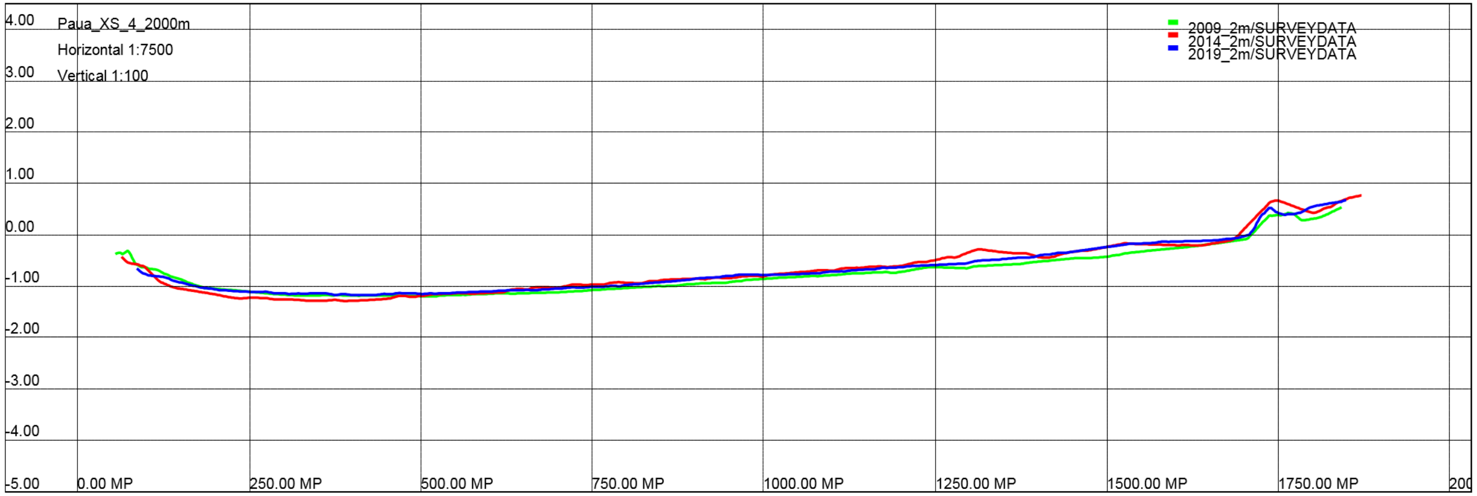


Figure 11: Porirua Harbour, Pauatahanui Arm – Profiles Page 2



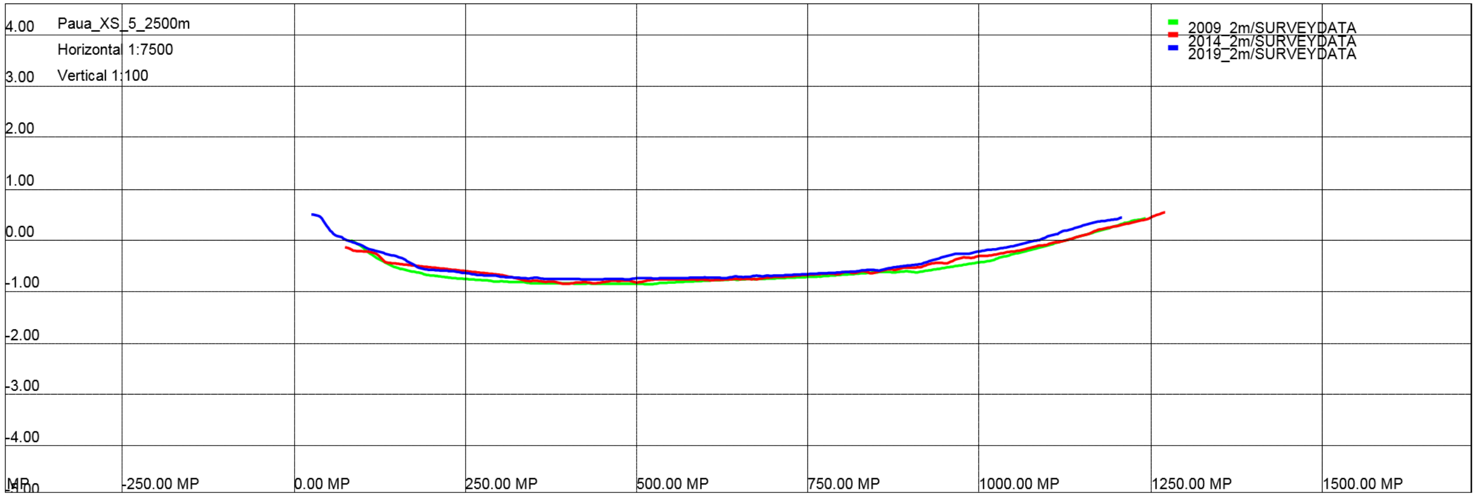
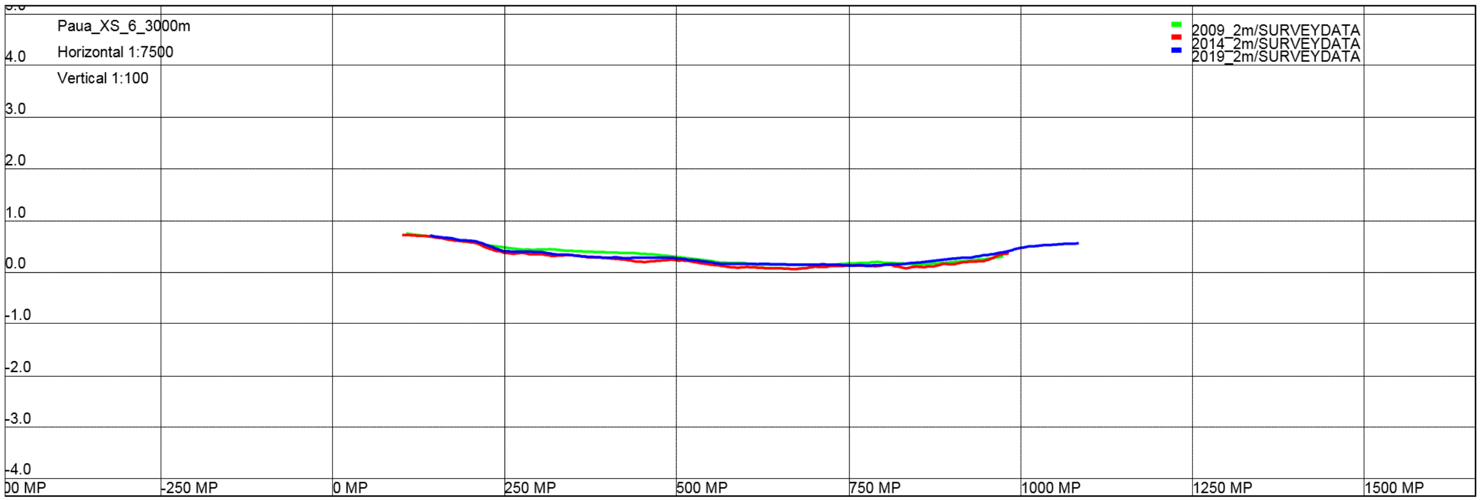


Figure 12: Porirua Harbour, Pauatahanui Arm – Profiles Page 3



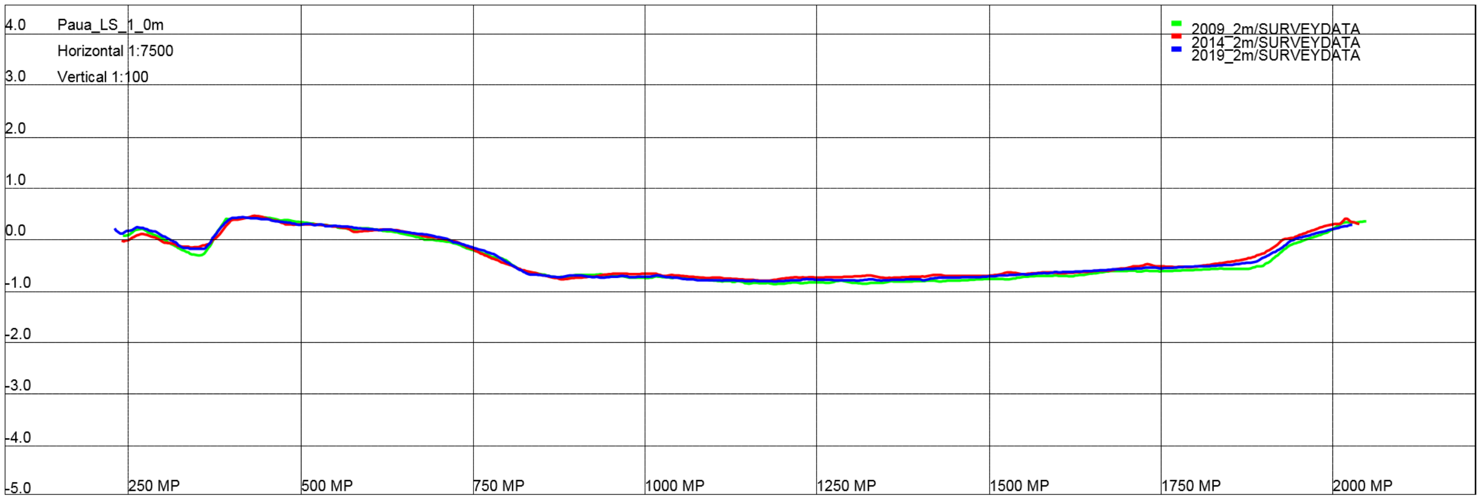
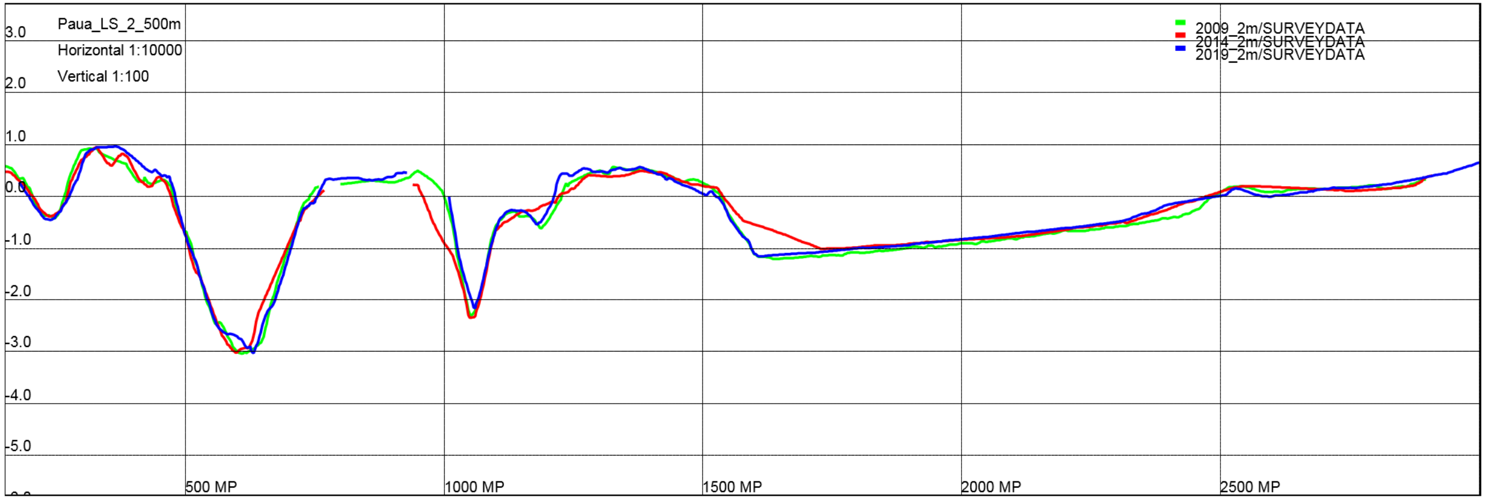


Figure 13: Porirua Harbour, Pauatahanui Arm – Profiles Page 4



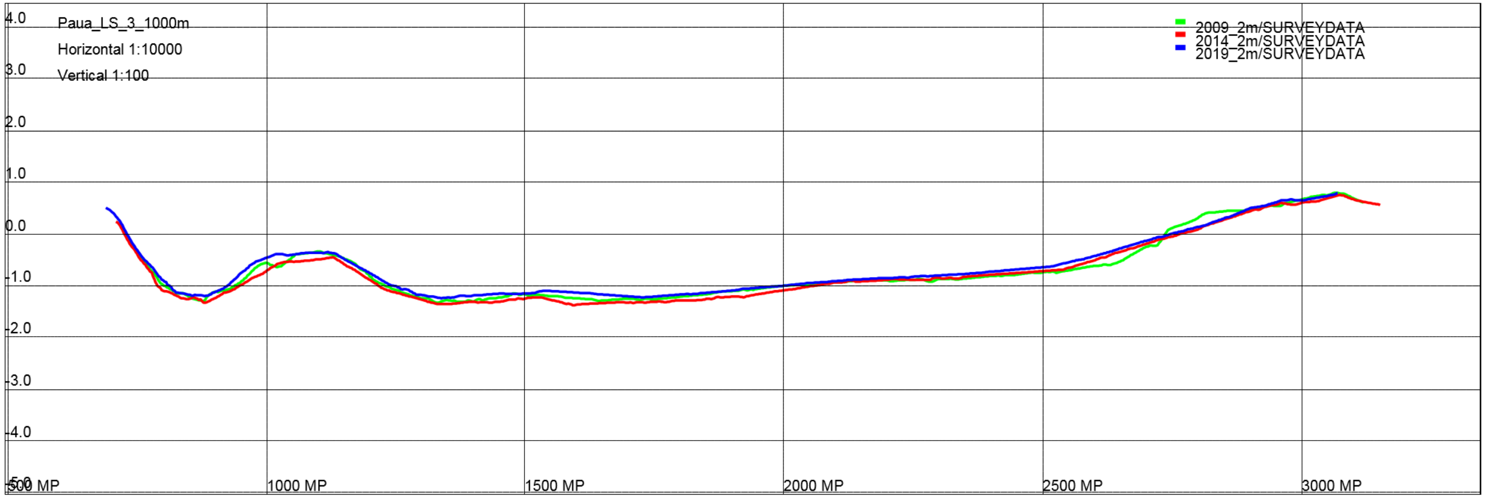
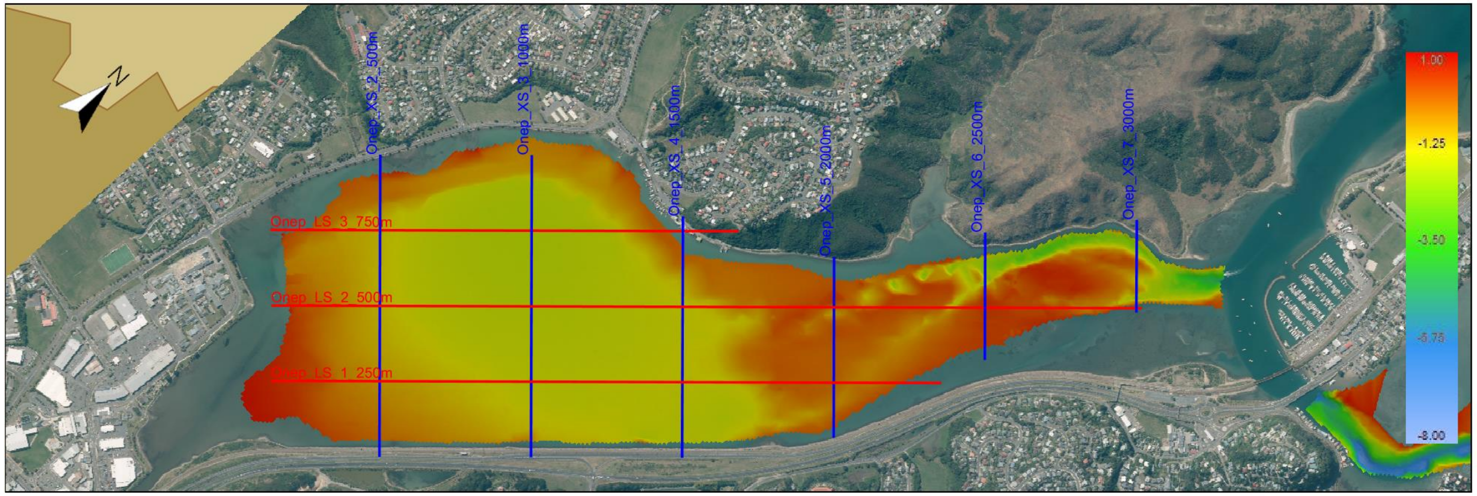


Figure 14: Porirua Harbour, Pauatahanui Arm – Profiles Page 5



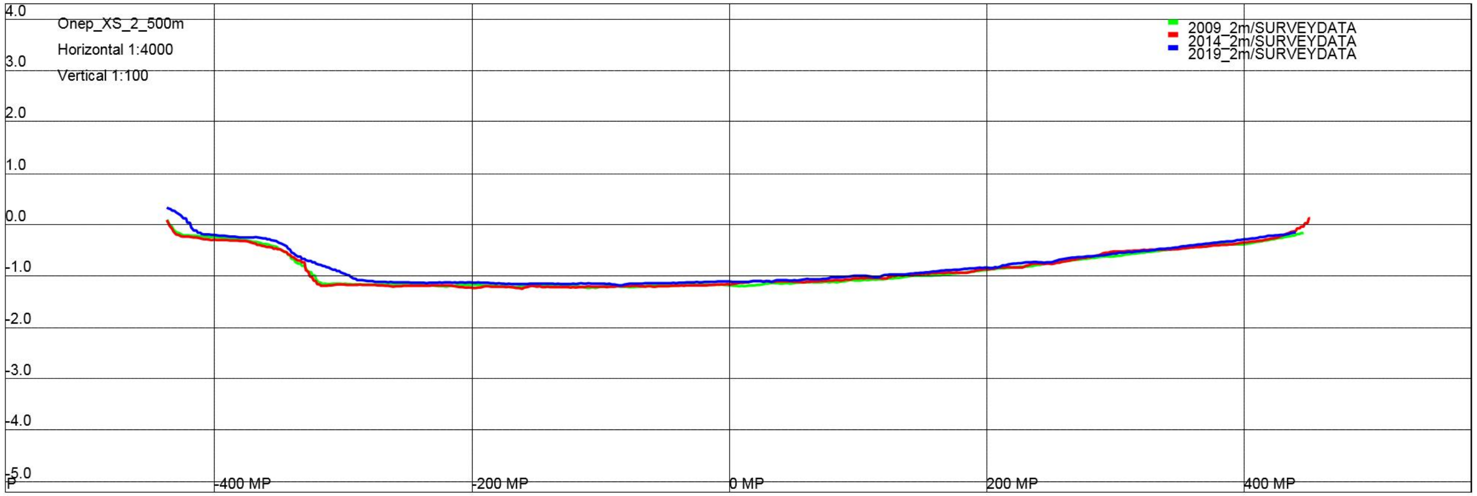
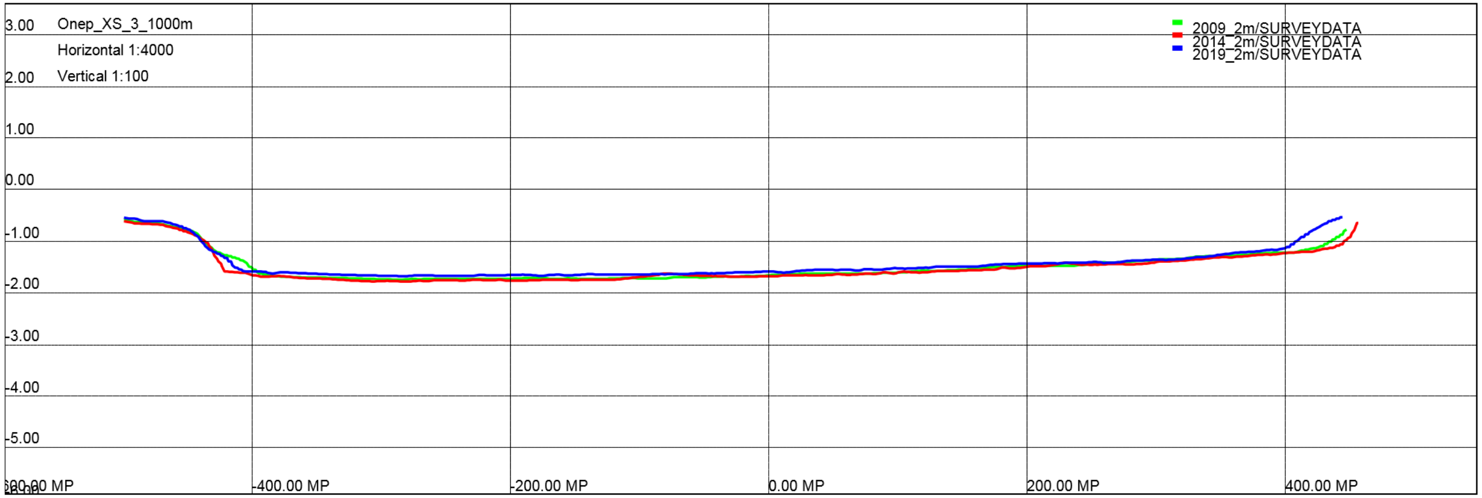


Figure 15: Porirua Harbour, Onepoto Arm – Profiles Page 1



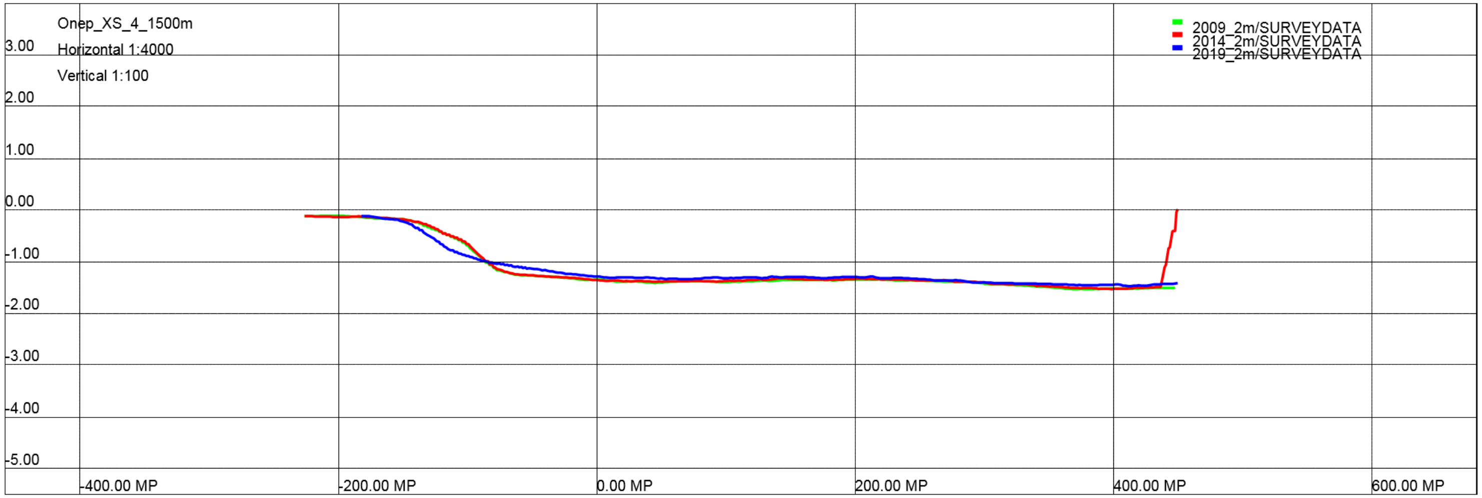
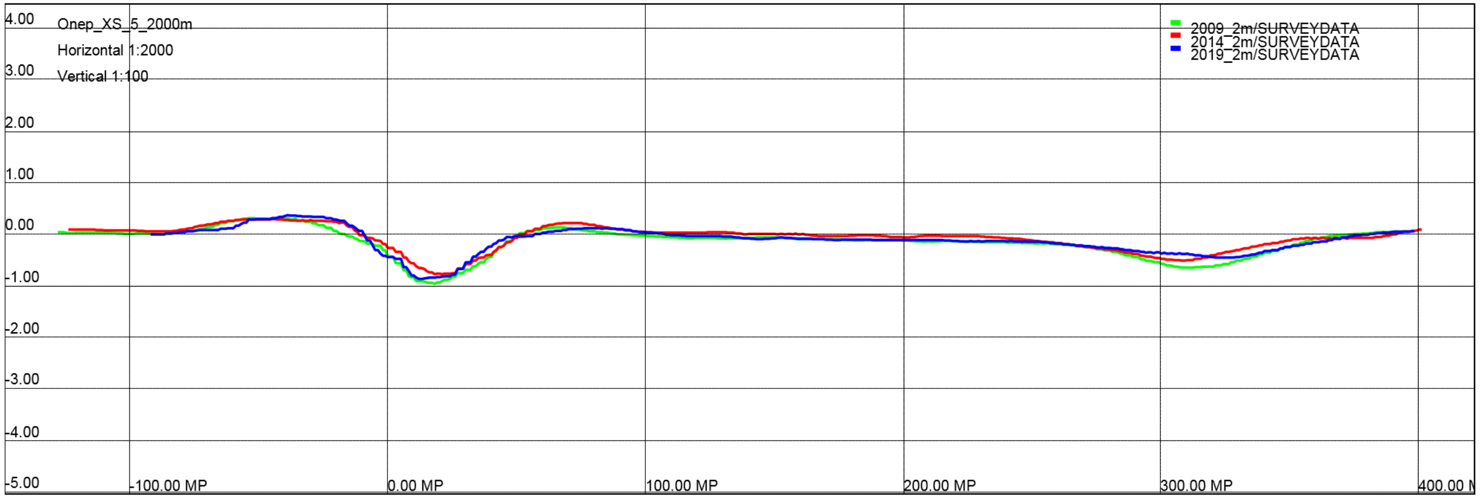


Figure 16: Porirua Harbour, Onepoto Arm – Profiles Page 2



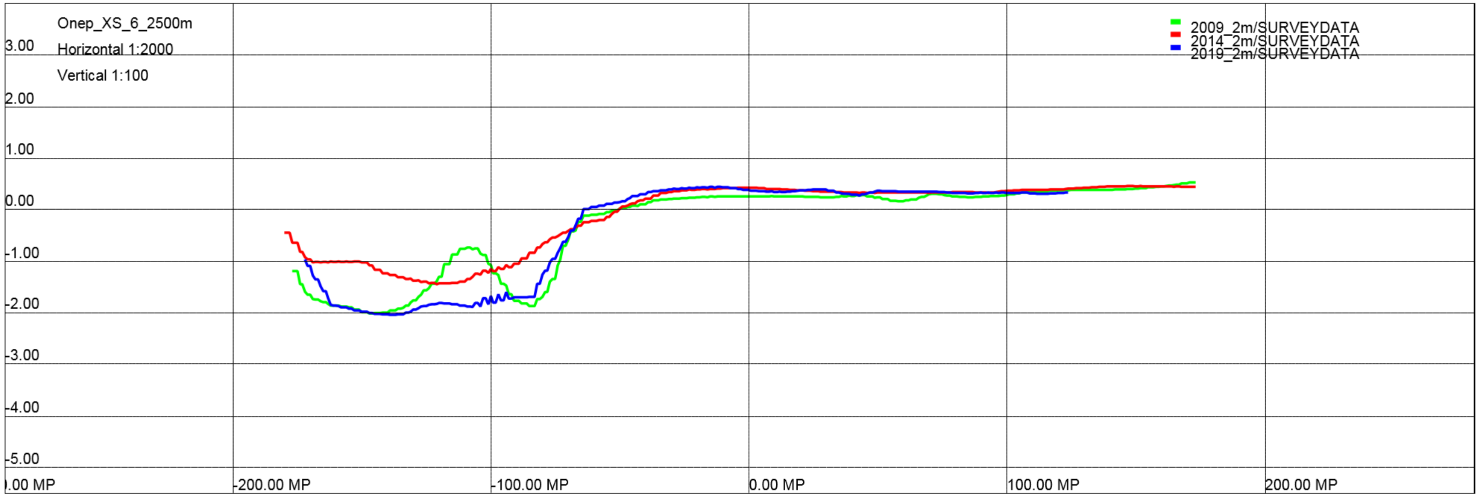
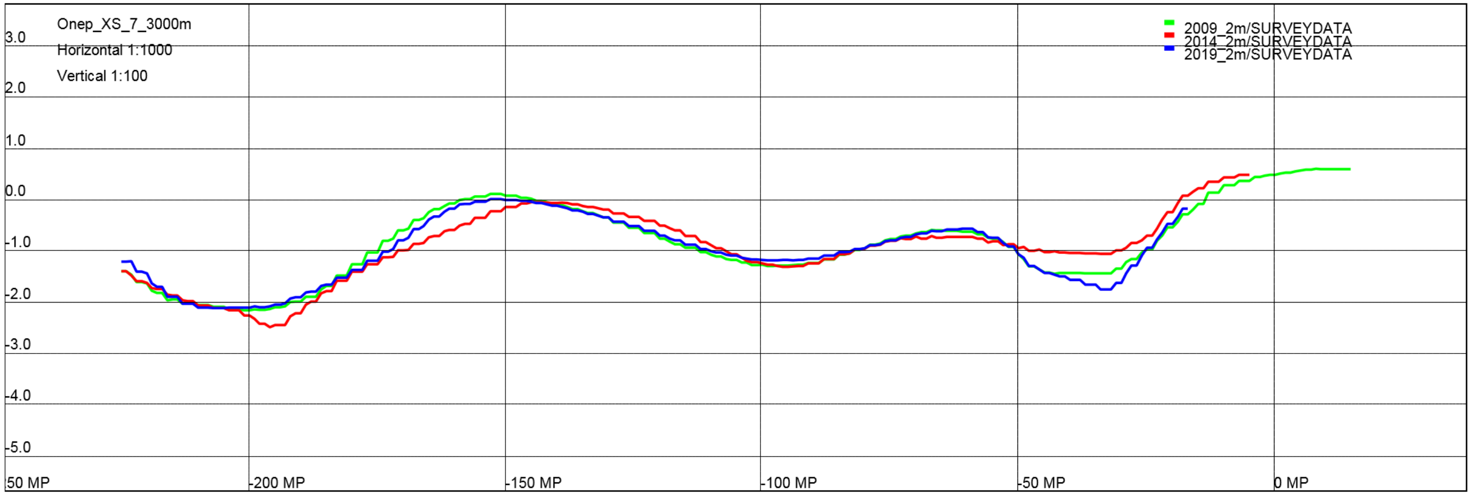


Figure 17: Porirua Harbour, Onepoto Arm – Profiles Page 3



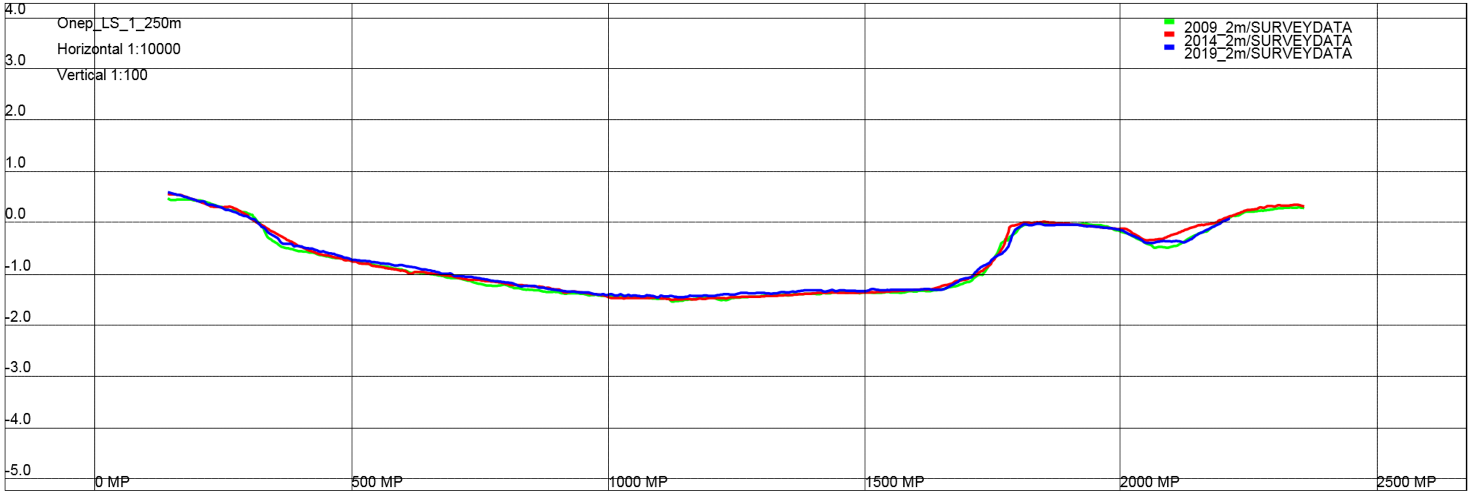
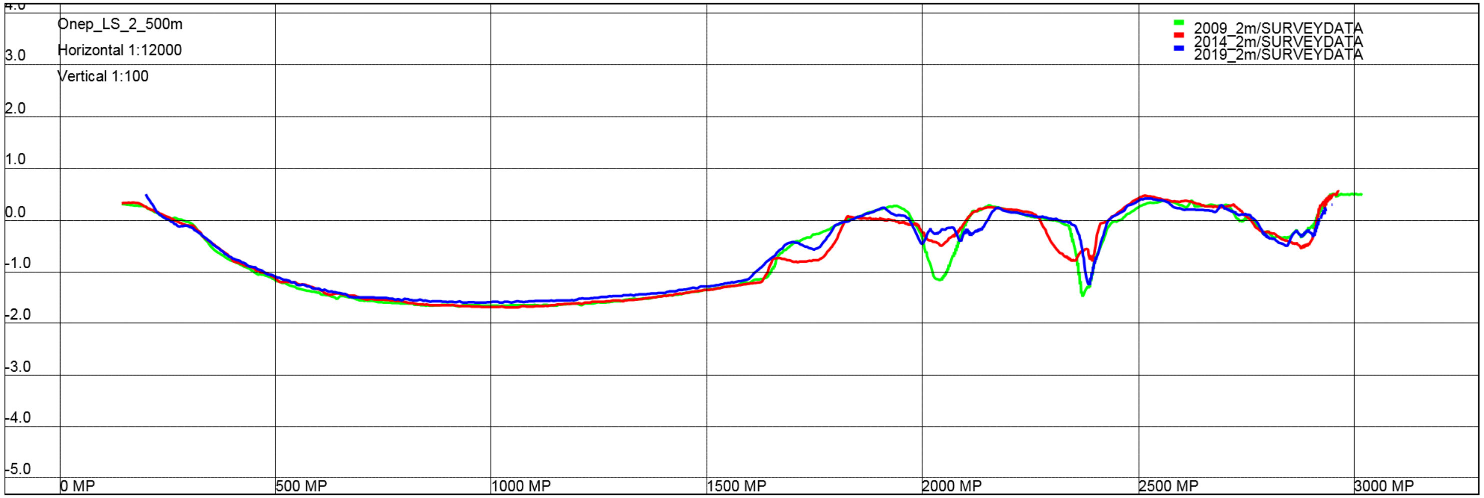


Figure 18: Porirua Harbour, Onepoto Arm – Profiles Page 4



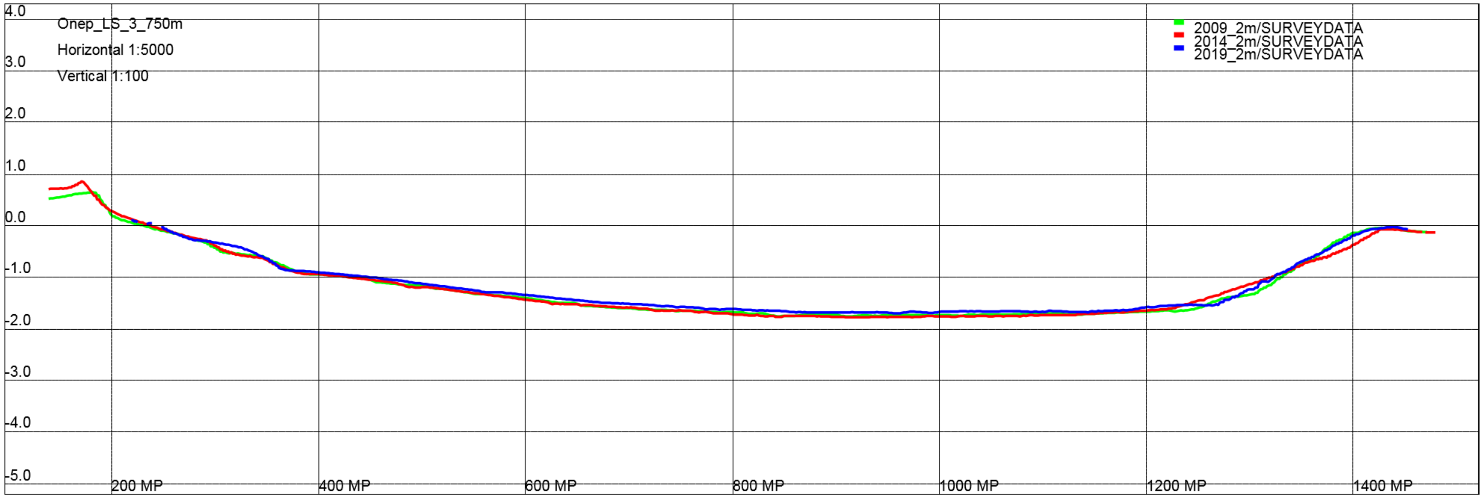


Figure 19: Porirua Harbour, Onepoto Arm – Profiles Page 5

15. Retention of Data

DML will retain copies of the project deliverables, including source data files, on its servers for a period of 12 months from completion of the project. The data will then be archived to a digital medium and retained for 7 years. After the initial 12 month period client requests to access and supply project data will incur a fee.

DML wishes to thank GWRC for the opportunity to undertake this project and looks forward to working with GWRC again in the future.

For Discovery Marine Ltd

Authored by		Date: 19 July 2019
	Bevan Waller	Senior Surveyor
Approved by		Date: 19 July 2019
	Declan Stubbing	Survey Manager

Enclosures:

A. Report of Survey
B. Profile Images
C. Survey Data (xyz point file)