COASTAL MANAGEMENT CONSULTANCY LIMITED

ADDENDUM TO C.R. 2009/1

SEDIMENTATION ZONES AND RATES WITHIN PAUATAHANUI INLET AND THE ONEPOTO ARM OF PORIRUA HARBOUR

by

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CONSULTANCY REPORT PREPARED FOR GREATER WELLINGTON REGIONAL COUNCIL

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SEDIMENTATION ZONES AND RATES WITHIN PAUATAHANUI INLET AND THE ONEPOTO ARM OF PORIRUA HARBOUR

1. INTRODUCTION

On 26 May 2011, Coastal Management Consultancy Ltd (CMCL) were commissioned by Greater Wellington Regional Council (GWRC), to derive average sedimentation rates within eleven zones in the arms of Porirua Harbour. CMCL commissioned Greg Cox, Managing Director, Discovery Marine Ltd (DML), to calculate sedimentation rates for the various zones using the same hydrographic survey data used in the 2009 study (C.R.2009/1). The hydrographic survey data files for the 2009 study are held by DML.

As part of this addendum, a report by DML is attached which summarises the methods used to determine rates, plus rate calculations with uncertainty values. These data were used here to finalise sedimentation rates with uncertainties for the 11 sedimentation zones within Porirua Harbour.

2. SEDIMENTATION ZONES

Following a workshop on Porirua Harbour at the GWRC offices late April, sedimentation zones were broadly defined by Dr Malcolm Green, Principal Scientist, NIWA, and Dr Jeremy Gibb, Managing Director, CMCL, together in early May. The zones were defined on the basis of existing bathymetric data in C.R. 2009, the findings of that study, and the proximity of each zone to major sediment supply sources. Basic features of these zones (Figs. 1 & 2) are summarised in Table 1 (Pauatahanui Inlet) and Table 2 (Onepoto Arm).

2.1. Pauatahanui Inlet

Table 1 and Figure 1 reveal that the largest sedimentation zone is the central mud basin (Zone 2) which is fed by mixed suspended sediment from all streams discharging into the Pauatahanui Inlet during floods. Next in size is the flood-tide delta (Zone 1) fed mostly by bedload supplied from the ebb-tide delta during flood tides. The remaining 5 zones are mostly locally supplied by both bedload and suspended load from an adjacent stream (Table 1).

Table 1: Sedimentation zones in Pauatahanui Inlet including inferred major sediment supply sources.

ZONES	AREA (m^2)	PERCENTAGE OF INLET	DEFINITION	MAJOR SEDIMENT SOURCE
1	1,171,437	25.4	Flood-tide delta	Ebb-tide delta
2	1,746,993	37.9	Central mud basin	All streams
3	482,226	10.5	Kakaho tidal flats	Kakaho Stream
4	317,345	6.9	Horokiri tidal flats	Horokiri Stream
5	520,382	11.3	Pauatahanui tidal flats	Pauatahanui Stream
6	104,575	2.3	Browns Bay tidal flats	Browns Bay Stream
7	264,806	5.7	Browns Bay mud basin	Browns Bay Stream
TOTAL AREA: 4,607,764 m^2				

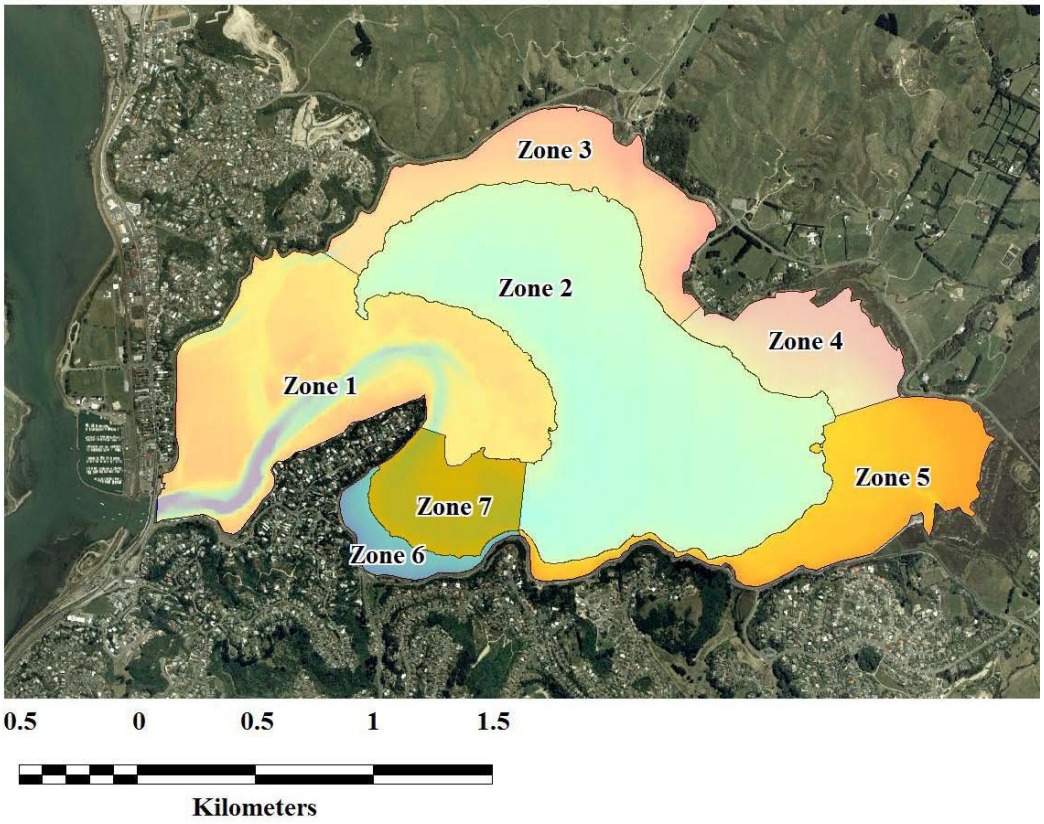


Figure 1: Location of 7 sedimentation zones defined here for the Pauatahanui Inlet.

2.2. Onepoto Arm

Table 2 and Figure 2 reveal that like Pauatahanui Inlet, the largest sedimentation zone within the Onepoto Arm is the central mud basin (Zone 2), fed mostly by suspended sediment from the Porirua Stream. This zone is followed by the flood-tide delta (Zone 1) fed mostly by bedload supplied from the ebb-tide delta. The Porirua Stream delta (Zone 3) has been truncated significantly by reclamations to the east and west as have the tidal flats to the west (Zone 4), which are locally supplied by streams and coastal erosion.

Table 2: Sedimentation zones in the Onepoto Arm of Porirua Harbour plus inferred major sediment supply sources.

ZONES	AREA (m^2)	PERCENTAGE OF ARM	DEFINITION	MAJOR SEDIMENT SOURCE
1	741,166	30.6	Flood-tide delta	Ebb-tide delta
2	1,313,441	54.2	Central mud basin	All streams
3	239,600	9.9	Porirua tidal flats	Porirua Stream
4	129,483	5.3	Western tidal flats	Western streams
TOTAL AREA: 2,423,690 m^2				

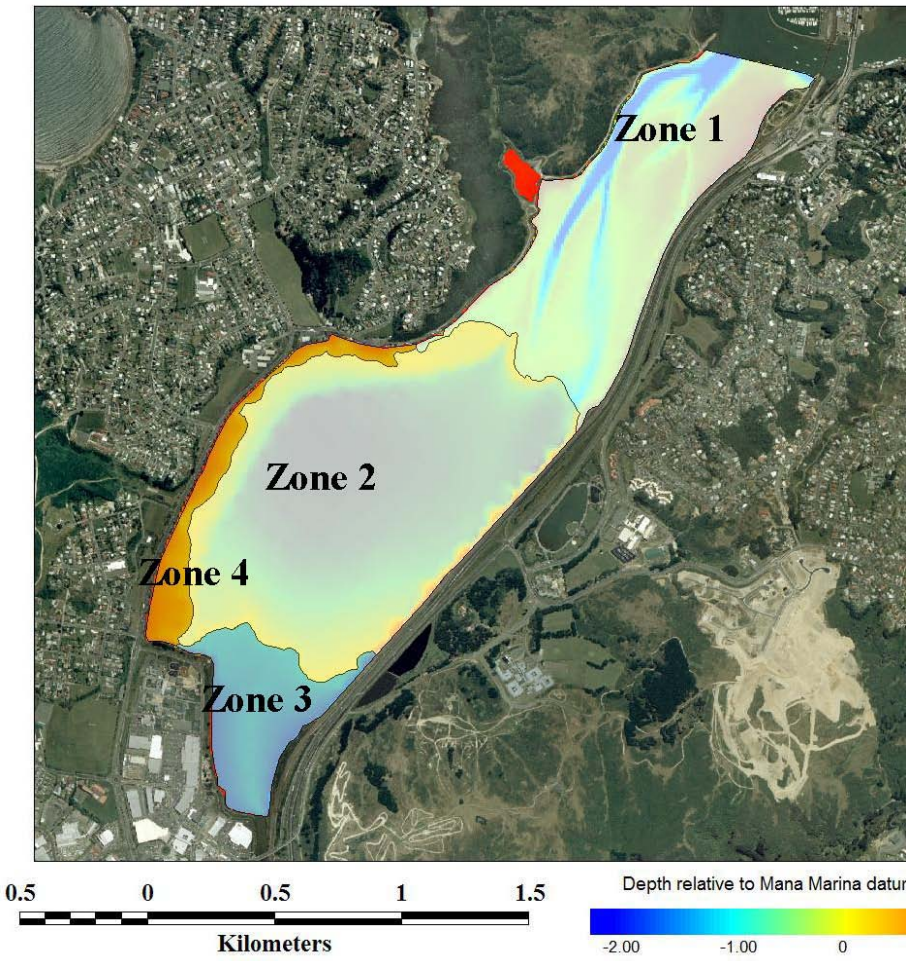


Figure 2: Location of 4 sedimentation zones defined here for the Onepoto Arm.

3. SEDIMENTATION RATES

For each of the 11 sedimentation zones (Tables 1 & 2), average rates were calculated by DML in May 2011 by comparing sounding surveys made in1974 and 2009. In addition, these rates were supplemented in this study by spot sounding comparisons in C.R.2009/1 (Appendix B) for the periods 1950-1974, 1974-2009, 1950-2009 (Pauatahanui Inlet) and 1974-1991, 1991-2009, 1974-2009 (Onepoto Arm). Note that although the 1974 and 2009 surveys cover both arms of the harbour, the 1950 survey only covered Pauatahanui Inlet. Although covering both arms, the 1991 survey was found to be only reliable for the Onepoto Arm.

All rates have been adjusted for an inferred sea-level rise of 1.95mm/year at Porirua Harbour since 1950, (after C.R.2009/1). Tectonic stability, including zero vertical deformation of Porirua Harbour from 1974-2009 is also assumed (after C.R.2009/1). Sedimentation rates are summarised in Table 3 (Pauatahanui Inlet) and Table 4 (Onepoto Arm).

3.1. Uncertainties

DML (2011) have determined a relatively high Composite Survey Error (CSE) for the 1974 and 2009 hydrographic surveys of ±0.141m. For all 11 sedimentation zones, the survey error equates to a rate error of ±4.1mm/year over the 34.44-year survey period. In addition, CMCL have determined a Survey Coverage Factor (SCF) for each of the 11 zones thereby increasing

uncertainty values further. The SCF ranges from 100% survey coverage (SCF1.0) to about 30% coverage (SCF 1.7) for a given zone. To determine a final uncertainty value for each sedimentation zone, the CSE of ±4.1mm/year was multiplied by the SCF (see Tables 3 & 4).

3.2. Pauatahanui Inlet Rates

Table 3 reveals that from 1974-2009, sedimentation rates have ranged from a relatively low 7.0±4.1mm/year on the flood tide delta (Zone 1) up to a relatively high 15.2±4.1mm/year within the Browns Bay mud basin (Zone 7). Both zones have 100% survey coverage hence relatively low uncertainties (±4.1mm/year). The adjacent Browns Bay tidal flat (Zone 6) also has a relatively high deposition rate of 14.2±6.1mm/year followed by the central mud basin (Zone 2) of 10.7±4.1mm/year (Table 3).

Table 3: Average sedimentation rates (1974-2009) for the 7 sedimentation zones (Fig.1) within Pauatahanui Inlet. Deposition rates have been adjusted for SLR of 1.95mm/year since 1974.

ZONE	AREA	DEPOSITION RATES		SCF	UNCERTAINTIES	
	(m^2)	(m^3/year)	(mm/y)		(±m^3/year)	(±mm/y)
1	1,171,437	8,200	7.0	1.0	4,796	4.1
2	1,746,993	18,693	10.7	1.0	7,153	4.1
3	482,226	3,810	7.9	1.3	2,566	5.3
4	317,345	2,570	8.1	1.7	2,208	7.0
5	520,382	4,111	7.9	1.7	3,623	7.0
6	104,575	1,485	14.2	1.5	642	6.1
7	264,806	4,025	15.2	1.0	1,084	4.1

In contrast, the relatively low rates with high uncertainties (Table 3) for the tidal flats between the Kakaho and Pauatahanui Streams (Zones 3-5), probably reflect the fact that the 1974 survey coverage is limited to the seaward edge of the flats and only covers an estimated 30-70% of each zone. For the tidal flats, deposition rates range from 7.9±5.3mm/year (Zone 3), up to 8.1±7.0mm/year (Zone 4).

In terms of spot soundings, only Zones 1 & 2 (Figure 1) are covered by surveys made in 1950, 1974 & 2009 (Appendix B, Fig.B-2, Table B-4, C.R.2009/1). For the western portion of the flood-tide delta (Zone 1), spot rates at 6 stations (Mana transect) ranged from 15.29mm/year to -18.88mm/year from 1950-1974, reducing to 2.23mm/year to -11.77mm/year from 1974-2009. Over the 59-year period, spot rates ranged from 2.97mm/year to -7.20mm/year averaging net erosion at -4.38mm/year over all 6 stations (Table B-4).

For the mid portion of the flood-tide delta (Zone 1), spot rates at 6 stations (Cambourne transect) ranged from 6.13mm/year to -6.38mm/year from 1950-1974, increasing to 10.51mm/year to -11.20mm/year from 1974-2009. Over the 59-year period, spot rates ranged from 8.73mm/year to -5.85mm/year, averaging net deposition at 0.31mm/year over all 6 stations (Table B-4).

For the eastern portion of the flood-tide delta (Zone 1) which is composed of a mostly sub-tidal re-curved spit, spot rates at 3 stations (Cambourne transect) along the crest ranged from 1.96mm/year to -2.21mm/year from 1950-1974, increasing to 3.37mm/year to -5.20mm/year

(1974-2009), averaging net erosion at -0.08mm/year (1950-2009) over all 3 stations. At the distal end of the re-curved spit (Zone 1), spot rates at 3 stations (Browns Bay transect) ranged from 6.13mm/year to -10.54mm/year from 1950-1974, increasing to 11.37mm/year to -10.34mm/year (1974-2009), averaging net deposition at 1.16mm/year (1950-2009) over all 3 stations (Table B-4).

For the central mud basin (Zone 2), spot rates at 7 stations (Motukaraka Point & Browns Bay transects) ranged from 109.04mm/year to -10.13mm/year (1950-1974), decreasing to 14.80mm/year to -29.49mm/year (1974-2009), averaging net deposition at 5.39mm/year (1950-2009) over all 7 stations (Table B-4).

3.3. Onepoto Arm Rates

Table 4 reveals average deposition rates ranging from a relatively low 3.4±7.0mm/year (Zone 3) up to a relatively high 7.8±4.5mm/year (Zone 2) from 1974-2009. The relatively higher rates occur in the central mud basin (Zone 2) and are followed by an equally high rate of 6.4±4.9mm/year in Zone 4 along the western tidal flats that lie adjacent to Zone 2. Next is the flood tide delta (Zone 1) with a deposition rate of 5.7±4.1mm/year from marine sand supplied from the ebb-tide delta. The lowest deposition rate with the highest uncertainty (3.4±7.0mm/year) is the Porirua Stream delta which is largely the result of inadequate coverage from the 1974 survey (30%) limited to the distal end.

Table 4: Average sedimentation rates (1974-2009) for the 4 sedimentation zones within Onepoto Arm of Porirua Harbour. Deposition rates have been adjusted for SLR of 1.95mm/year since 1974.

ZONE	AREA	DEPOSITION RATES		SCF	UNCERTAINTIES	
	(m^2)	(m^3/year)	(mm/year)		(±m^3/year)	(±mm/y)
1	741,166	4,225	5.7	1.0	3,035	4.1
2	1,313,441	10,245	7.8	1.1	5,916	4.5
3	239,600	815	3.4	1.7	1667	7.0
4	129,483	833	6.4	1.2	636	4.9

Spot soundings in Table B-3, Appendix B, C.R.2009/1, are limited to Zones 1 & 2 and are available along 3 transects from surveys made in 1974, 1991 and 2009. For the central mud basin (Zone 2), spot rates at 4 stations (South transect), ranged from 13.71mm/year to -3.94mm/year (1974-1991), decreasing to 3.06mm/year to -6.39mm/year (1991-2009), averaging net deposition at 1.58mm/year (1974-2009) over all 4 stations (Table B-3).

For the northern part of the flood-tide delta (Zone 1), spot rates at 6 stations (North transect), also ranged from 13.71mm/year to -3.94mm.year (1974-1991), increasing to 46.39mm/year to -40.83mm/year (1991-2009), averaging net deposition at 5.37mm/year (1974-2009) over al 6 stations. Across the southern distal end of the delta (Zone 1), spot rates at 4 stations (Mid transect), also ranged from 13.71mm/year to -3.94mm/year (1974-1991), increasing to 18.61mm/year to -5.28mm/year (1991-2009), averaging net deposition at 2.25mm/year (1974-2009) over all 4 stations (Table B-3).

4. CONCLUSIONS

i. Both arms of Porirua Harbour are silting up at relatively rapid rates, with deposition rates in Pauatahanui Inlet being approximately double those within the Onepoto Arm as a result of more streams discharging sediment into the former.

ii. Between 1974 and 2009 the highest average deposition rates occurred in the mud basins within both arms, ranging from 10.7±4.5mm/year to 15.2±4.1 mm/year within Pauatahanui Inlet, to 7.8±4.5mm/year within the Onepoto Arm. Within the central mud basin of Pauatahanui Inlet, deposition rates of 10.3-13.8mm/year occurred between 8645±330 to 8953±340 Cal.years B.P. (Table 4, C.R.2009/1).

iii. Deposition rates along the tidal flats and deltas of streams discharging into both arms are severely constrained by a lack of soundings from the 1974 survey with coverage ranging from an estimate 30% to 80%, resulting in relatively high rate uncertainties of ±4.9mm/year to ±7.0mm/year.

iv. Spot rates derived from 30 stations in Pauatahanui Inlet from soundings made in 1950, 1974 & 2009, reveal a large variation in rates ranging from rapid deposition at 109.04mm/year (1950-1974), to equally rapid erosion at -29.49mm/year (1974-2009).

v. For the Onepoto Arm, spot rates derived from 13 stations from soundings made in 1974, 1991 & 2009 reveal equally large rate variations, ranging from rapid deposition at 46.39mm/year (1991-2009) to rapid erosion at -40.83mm/year (1991-2009).

vi. Assuming representative sedimentation rates for Porirua Harbour from one or a handful of stations (soundings, cores, discs, etc.) is likely to be completely misleading. A more reliable method is to compare high quality, comprehensive surveys of the seafloor such as the 2009 survey to derive average rates across the sedimentation zones within both arms of the Harbour.

PORIRUA HARBOUR

CALCULATION OF RATES OF SEDIMENTATION WITHIN PAUATAHANUI INLET AND ONEPOTO ARM

Report Prepared by:

DISCOVERY MARINE LIMITED

Hydrographic & Coastal Management Services
NEW ZEALAND
www.dmlsurveys.co.nz

Report Prepared for Coastal Management Consultancy Ltd

25 May 2011

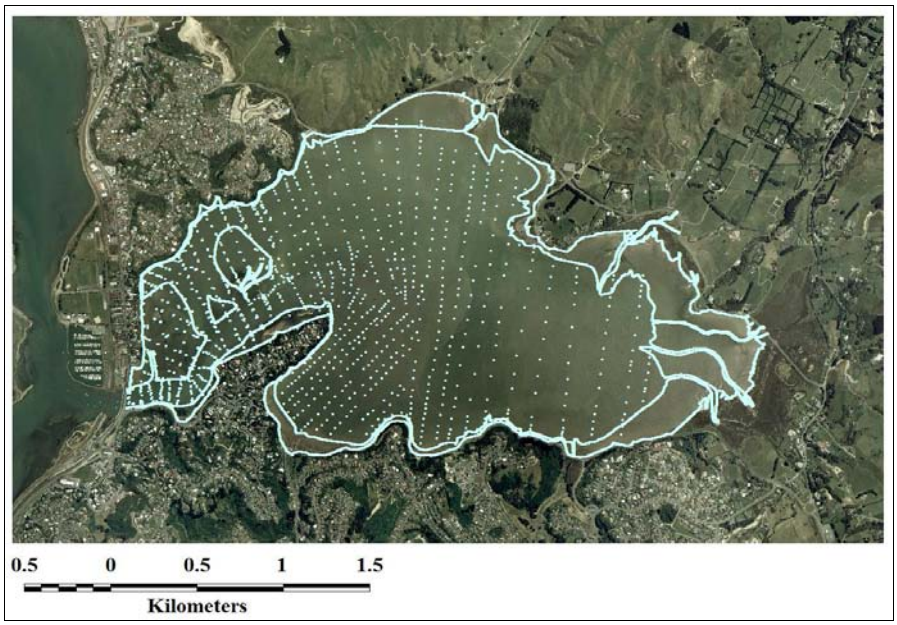
PORIRUA HARBOUR

CALCULATION OF RATES OF SEDIMENTATION WITHIN PAUATAHANUI INLET AND ONEPOTO ARM

Reference: DML Report of Survey – dated 25 June 2009

1 PAUATAHANUI INLET

Sounding data sets from the RNZN 1974 and DML 2009 hydrographic surveys have been imported into Surfer8 Contouring and Surface Mapping software. Data was gridded at 5m intervals using the Kriging geostatistical gridding method. Figures 1 and 2 below illustrate the survey density derived from each survey.



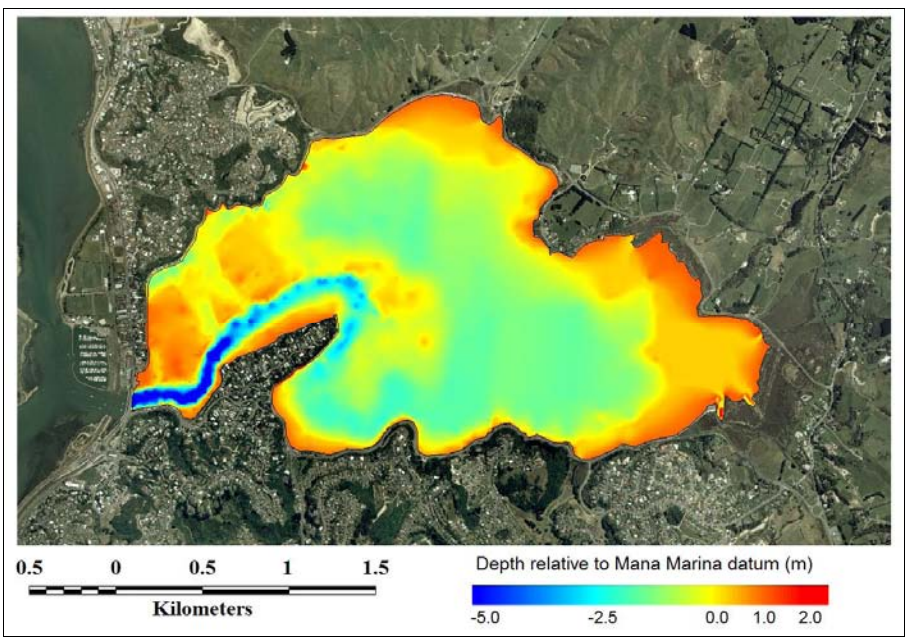
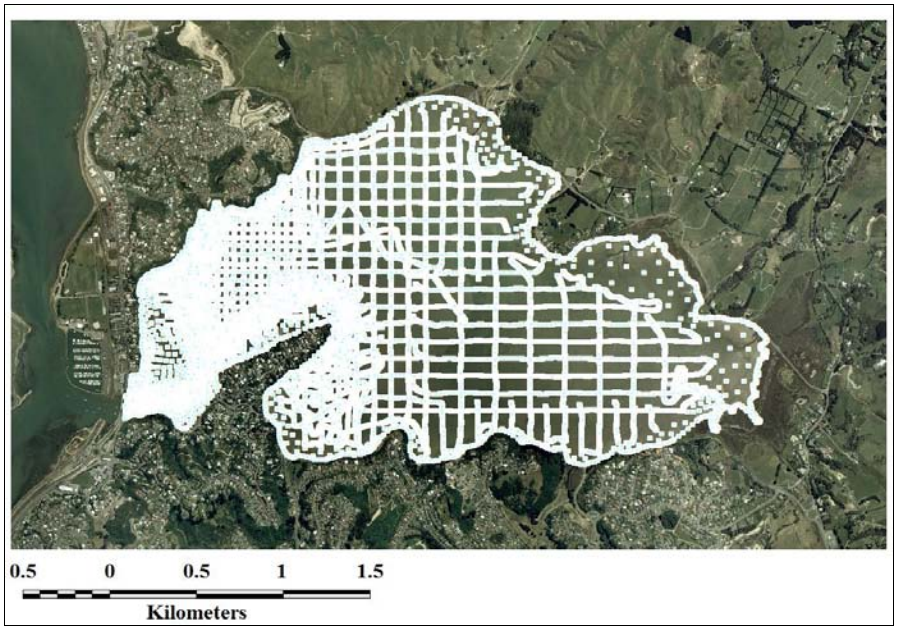


Figure 1 - 1974 coverage and bathy



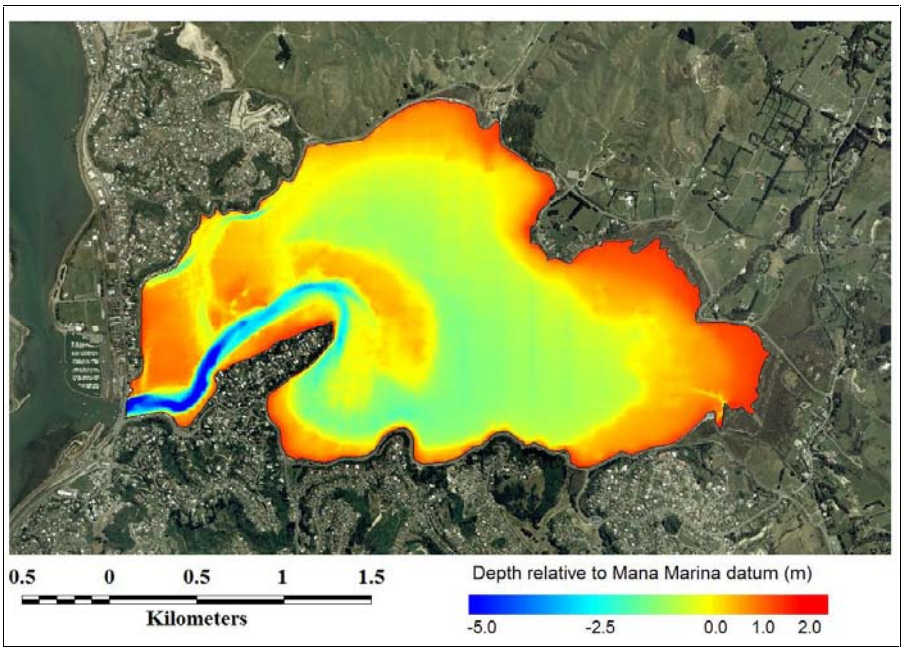


Figure 2 - 2009 coverage and bathy

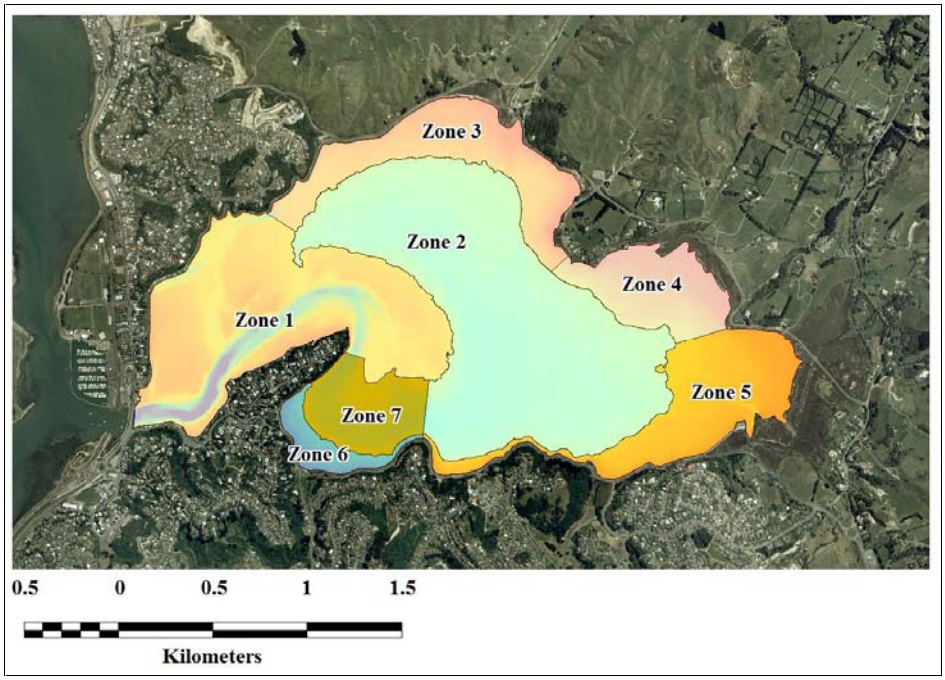


Figure 3 – Calculation Zones

Errors

The composite error between the differences of the two surveys is given as:

$$RMS_{errorDifference} = \sqrt{\sigma^2_{(RandomErrorSurvey1)} + \sigma^2_{(RandomErrorSurvey2)}}$$

Accordingly, the error in the difference between two hydrographic surveys is estimated to be $\pm$ 0.141 m for comparisons between surveys (i.e. 0.1 m error for both the 1974 and 2009 survey).

Table 1. Sedimentation rates (determined between the dates of the surveys, i.e. Oct/Nov 1974 and March / April 2009). In all areas the average trend is for sediment accretion. The SCE value is derived by estimation of data overlap between surveys (source: Dr. Jeremy Gibb).

Zone	**Area**	**Survey Coverage Error (SCE)**	**Accretion rate m3 per year**		**Accretion rate mm per year**	
	Area (m^2)	Factor	$m^3.yr^{-1}$	Error (±) $m^3.yr^{-1}$	$mm.yr^{-1}$	Error (±) $mm.yr^{-1}$
Zone 1	1171436.5	1.0	10481	4796	9	4
Zone 2	1746993.3	1.0	22103	7153	13	4
Zone 3	482225.62	1.3	4756	2566	10	5
Zone 4	317345.02	1.7	3199	2208	10	7
Zone 5	520382.47	1.7	5121	3623	10	7
Zone 6	104575.35	1.5	1691	642	16	6
Zone 7	264806.02	1.0	4531	1084	17	4

Volumes for zones 3, 4, 5 and 6 are based on very limited data relative to the 1974 survey and should be used with caution. These zones have therefore been assigned a higher error value.

Errors

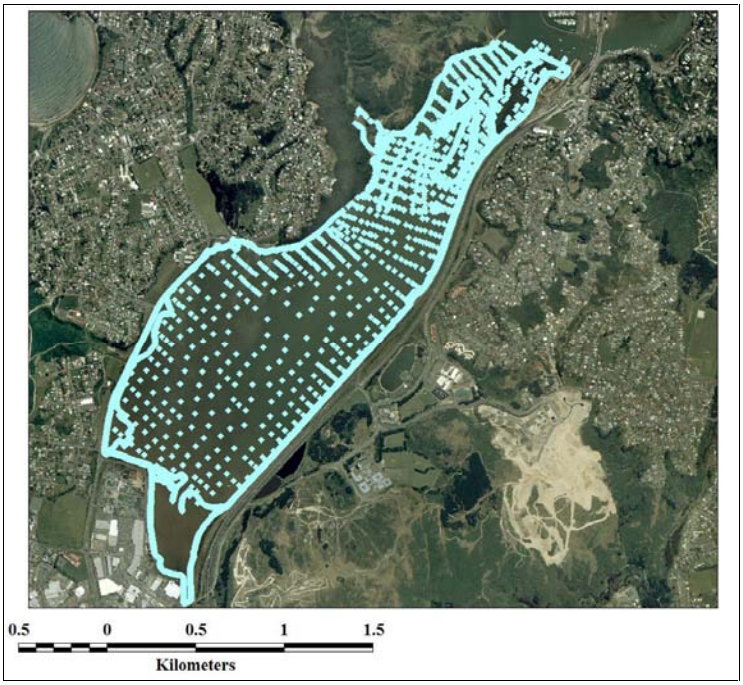
The composite error between the differences of the two surveys is given as:

$$RMS_{errorDifference} = \sqrt{\sigma^2{}_{(RandomErrorSurvey1)} + \sigma^2{}_{(RandomErrorSurvey2)}}$$

Accordingly, the error in the difference between two hydrographic surveys is estimated to be ± 0.141 m for comparisons between surveys (i.e. 0.1 m error for both the 1974 and 2009 survey).

2 ONEPOTO ARM

Sounding data sets from the RNZN 1974 and DML 2009 surveys have been imported into Surfer8 Contouring and Surface Mapping software. Data was gridded at 10m intervals using the Kriging geostatistical gridding method. Figures 4 and 5 below illustrate the survey density derived from each survey.



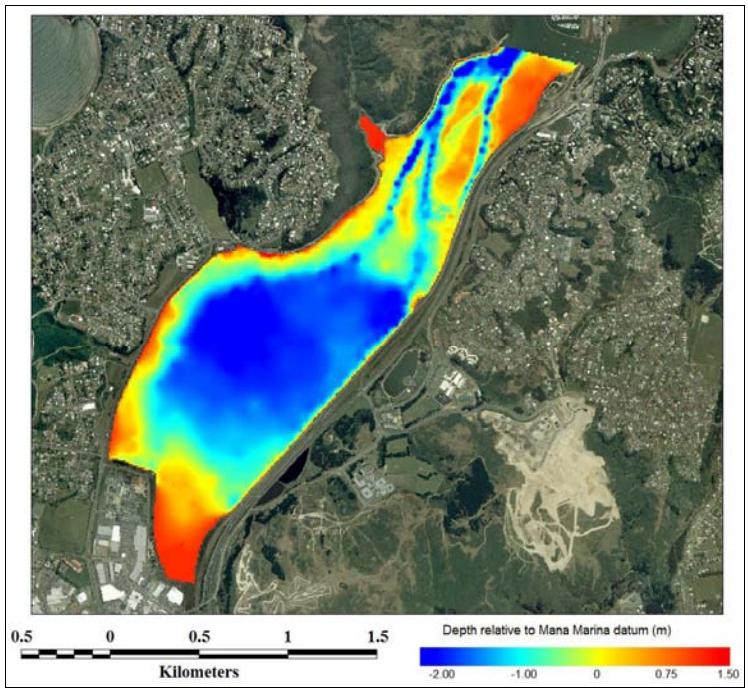
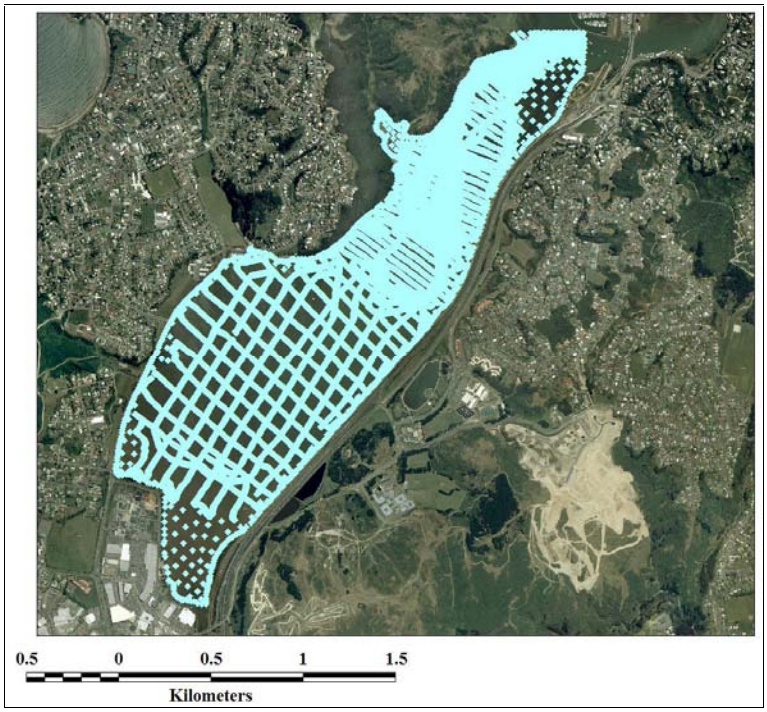


Figure 4 - 1974 coverage and bathy



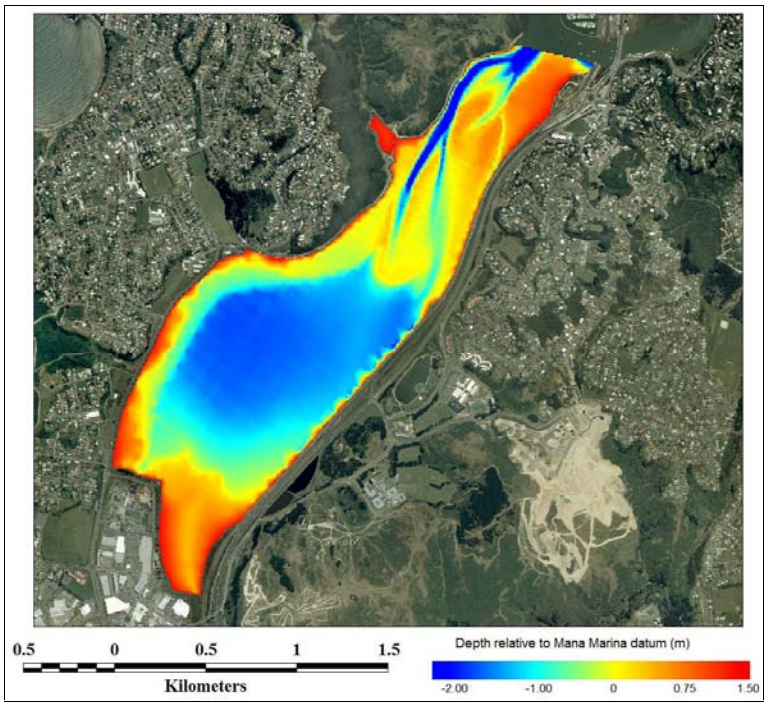


Figure 5 - 2009 coverage and bathy

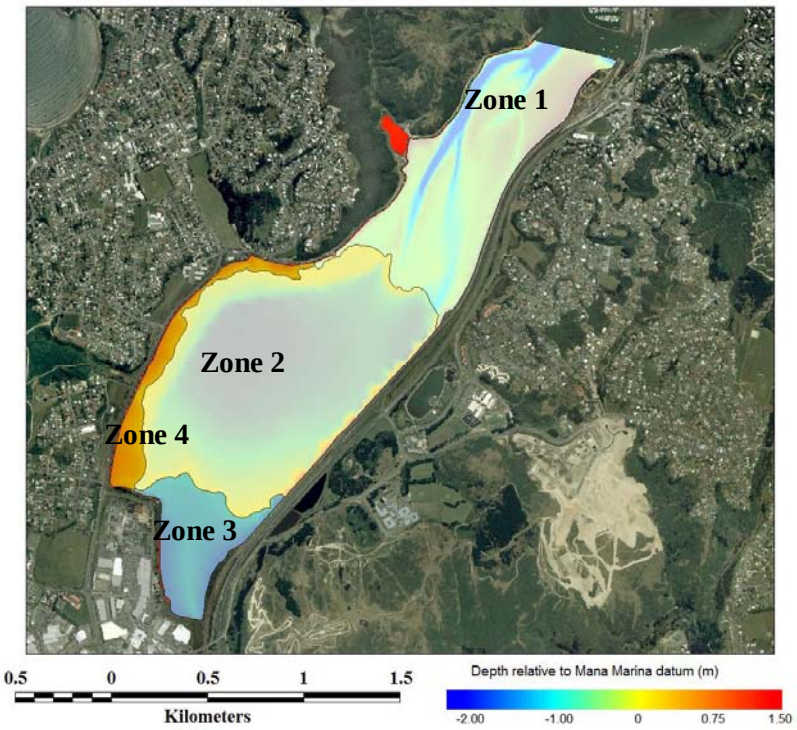


Figure 6 – Calculation Zones

Errors

The composite error between the differences of the two surveys is given as:

$$RMS_{errorDifference} = \sqrt{\sigma^2_{(RandomError\,Survey1)} + \sigma^2_{(RandomError\,Survey2)}}$$

Accordingly, the error in the difference between two hydrographic surveys is estimated to be ± 0.141 m for comparisons between surveys (i.e. 0.1 m error for both the 1974 and 2009 survey).

Table 2. Sedimentation rates (determined between the dates of the surveys, i.e. Oct/Nov 1974 and March / April 2009). In all areas the average trend is for sediment accretion.

Zone	**Area**	**Survey Coverage Error (SCE)**	**Accretion rate m3 per year**		**Accretion rate mm per year**	
	Area (m^2)	Factor	$m^3.yr^{-1}$	Error (±) $m^3.yr^{-1}$	$mm.yr^{-1}$	Error (±) $mm.yr^{-1}$
Zone 1	741166	1.0	5635	3035	8	4
Zone 2	1313441	1.1	12738	5916	10	4
Zone 3	239600	1.7	1271	1667	5	7
Zone 4	129483	1.2	1086	636	8	5

The survey coverage of the 1974 data is relatively sparse, particularly for Zone 3, relative to the 2009 survey data. Hence there has been considerable interpolation of the 1974 data in order to derive volume differences and care using the values should be taken accordingly.

Errors

The composite error between the differences of the two surveys is given as:

$$RMS_{errorDifference} = \sqrt{\sigma^2_{(RandomErrorSurvey1)} + \sigma^2_{(RandomErrorSurvey2)}}$$

Accordingly, the error in the difference between two hydrographic surveys is estimated to be $\pm$ 0.141 m for comparisons between surveys (i.e. 0.1 m error for both the 1974 and 2009 survey).

SUMMARY

Table 3 below summarises accretion estimates for both Pauatahanui Inlet and Onepoto Arms. Based on Sea Level Rise (SLR) adoption of 1.9mm per year over the last 35 years (value provided by Dr. Jeremy Gibb), the annual accretion value has been further adjusted to reflect the effect of SLR over the time span between surveys. The error value for some zones is very high, due to lack of data within the 1974 data set.

Location	**Raw Accretion Rate** $mm.yr^{-1}$	**Accretion Rate (adjusted for SLR)** $mm.yr^{-1}$	**Estimated Error (±)** mm.yr-1
Pauatahanui Inlet			
Zone 1	9	7.0	4.1
Zone 2	13	10.8	4.1
Zone 3	10	8.0	5.3
Zone 4	10	8.2	7.0
Zone 5	10	7.9	7.0
Zone 6	16	14.3	6.1
Zone 7	17	15.2	4.1
Onepoto Arm			
Zone 1	8	5.7	4.1
Zone 2	10	7.8	4.5
Zone 3	5	3.4	7.0
Zone 4	8	6.5	4.9

Limitations and Disclaimer:

It must be emphasised that all calculations are derived from only two survey data sets, with the historical 1974 data being of inferior density and completeness. As such, DML takes no responsibility for the accuracy of the 1974 RNZN survey data, and consequently, the accuracy of the accretion rates provided. The margin of error is high due to the level of uncertainty when comparing data sets over a large timeframe. Accurate sedimentation estimates can only be derived by comparing recent and repeat surveys using modern digital equipment and techniques and similar levels of data coverage.

Initial calculations by Brett Beamsley, Met Ocean Ltd.
Final Calculations and report compiled by G.J. Cox, Discovery Marine Ltd.

G.J. COX
Managing Director