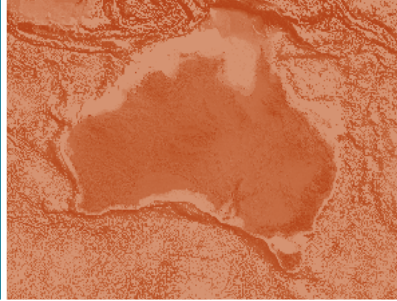




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EDM Height Traversing Levelling Survey Report

Rarotonga, Cook Islands, December 2012

S. J. K. Yates, A. Lal

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GEOSCIENCE AUSTRALIA
RECORD 2014/15

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Australian Government
Geoscience Australia

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Contents

1 Introduction	1
2 The Survey	2
2.1 Bench Mark Locality Diagram	3
2.2 The Cook Islands Datum	3
2.3 Equipment.....	3
2.4 Method	4
2.5 Cook Islands 2012 Reduced Levels	4
2.6 Survey Support	5
2.7 Issues	5
3 Comparisons	6
3.1 Comparisons between 2012 and 2011 EDM Surveys	6
3.2 Combined Comparisons 1993 to 2012	7
3.3 Time Series of Bench Mark Movement relative to Fixed Deep Bench Mark BM27	8
4 Deep Driven Bench Mark Locality Diagrams.....	13
5 Temporary Holding Mark Locality Diagrams	19
6 CKISBM and CKIS Reference Mark Locality Diagram.....	23
7 References	24

1 Introduction

This report outlines the high precision level survey completed between the Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) tide gauge and continuous Global Navigation Satellite System (GNSS) station in Rarotonga, Cook Islands from 5th to 9th December 2012.

Personnel involved in the survey were Steve Yates, Project Officer, Geoscience Australia and Andrick Lal, Surveyor, Secretariat of the Pacific Community (SPC).

The Electronic Distance Measurement (EDM) height traversing levelling technique was employed to observe differences in height between the deep bench mark arrays in Rarotonga, which runs approximately 2.2 km from the Tide Gauge Sensor to the continuous GNSS (CGNSS) antenna. Previous levelling surveys have been conducted along the route using this technique in 2004, 2007, 2008, 2009 and 2011.

In addition, precise differential levelling surveys were performed along the deep bench mark array from 1993 to 2004 by the National Tidal Centre Australia (NTCA) with the survey in 2004 including a comparison between the precise levelling and EDM height traversing technique. This report contains a comparison between the 2012 and 2011 EDM height traversing results as well as a combined comparison since the first levelling survey.

2 The Survey

The EDM height traversing levelling survey was carried out between the SEAFRAME tide gauge sensor benchmark, CGNSS station and the deep driven bench mark array:

BM26	– deep driven benchmark
COO56	– SEAFRAME sensor benchmark
COO10	– Project plaque point
BM18	– local survey department benchmark
BM33	– deep driven bench mark
BM27	– reference deep driven bench mark for the survey
BM34	– deep driven bench mark
BM28	– deep driven bench mark
BM35	– deep driven bench mark
CKISBM	– reference bench mark for the CGNSS pillar

Also included in the survey were:

- Temporary holding marks – COO77, COO102, COO84, COO85, COO103, COO100, COO101 and COO103 which are permanent stainless steel bolt holding marks, drilled in concrete and glued in place.
- CGNSS reference point (CKISBM) and the three CGNSS Reference Marks - RM1, RM2 and RM3.

COO103 was a new holding mark established during the 2012 visit replacing COO92 that was found destroyed.

All the deep bench marks were located and found in good order and undisturbed.

The EDM height traversing levelling technique was performed to the Class L2A specifications (ICSM, Standards and Practices for Control Surveys). After reduction an internal precision of $1\text{mm}\sqrt{K}$ or better was achieved, where K is distance in kilometres. This is well within the project specification of $2\text{mm}\sqrt{K}$. A table of results and comparisons and the 2012 reduced levels are detailed later in this report.

2.1 Bench Mark Locality Diagram



2.2 The Cook Islands Datum

The Datum for the survey is Mean Sea Level (MSL).

All reduced levels for the Rarotonga levelling survey are relative to BM27 fixed at a RL of 4.7407 m. This value was determined by the NTCA in 1998.

2.3 Equipment

- Leica total station model TM30 (Serial No: 361441)
- Leica precision prisms GPH1P (2).
- Leica rigid tripod.
- Stainless steel target poles supported by Leica telescopic bi-poles (2).
- Shortened stainless steel target pole for the SEAFRAME sensor BM connection.
- Leica cast iron change plates (2).
- Kestral 4000 pocket weather tracker

2.4 Method

The “Leap-Frog” EDM height traversing technique was employed for the Rarotonga tide gauge levelling survey. This technique involves setting up a total station (TCA1800L) midway between two target/reflectors (on reflector rods with struts). The targets remain at a particular change point for the back-sight and fore-sight observations. The instrument measures slope distances ($\pm 1\text{mm}$) and vertical angle ($1''$) to derive height differences (between the instrument’s trunnion axis and the reflectors). In support of the slope distance observations, the ambient temperature, pressure and humidity are recorded (Kestral 4000 pocket weather tracker) and input into the instrument to apply the first velocity correction to the observed distances (Rüeger & Brunner, 1982). Four rounds of observations are taken to the back-sight and fore-sight targets from each instrument setup. All levelling runs started and finished with the same reflector and reflector rod, i.e. an even number of setups when the two reflector rod configuration was used. This eliminates any reflector rod zero error. This technique can also be performed using a single set-up / single rod configuration which is particularly useful when levelling between bench marks which are close together e.g. between the CGNSS RMs.

Reduction of the digital data was computed by the Geoscience Australia levelling program “leveling1.exe”. This program computes the height difference between the two reflectors.

2.5 Cook Islands 2012 Reduced Levels

Table 2.1 Rarotonga, Cook Islands– Reduced levels relative to BM27 from 2012 survey

Date: 5 – 9 December 2012

Datum: Mean Sea Level

Point ID	Reduced Level 2012	Type
BM27	4.74074	Stainless Steel Rod in Ground
COO77	4.87097	Stainless Steel Pin in Concrete
COO103	5.19673	Stainless Steel Pin in Concrete
COO100	4.99580	Stainless Steel Pin in Concrete
BM34	4.65339	Stainless Steel Rod in Ground
COO84	3.48512	Stainless Steel Pin in Concrete
BM28	3.19548	Stainless Steel Rod in Ground
BM35	3.36607	Stainless Steel Rod in Ground
COO85	3.75602	Stainless Steel Pin in Concrete
COO101	3.11670	Stainless Steel Pin in Concrete
CKISBM	3.25347	Stainless Steel Pillar Pin
*CKIS	4.5153	Pillar Plate (ARP)
BM33	3.46006	Stainless Steel Rod in Ground
BM18	3.59371	Brass Plaque in Concrete
COO10	1.54535	Project Plaque with Stainless Steel Pin in Concrete
COO56	2.67877	Tide Gauge Stainless Steel Pin
CKISRM1	2.63417	Stainless Steel Rod in Ground

Point ID	Reduced Level 2012	Type
CKISRM2	2.44432	Stainless Steel Rod in Ground
CKISRM3	2.80718	Stainless Steel Rod in Ground

**The RL of the Reference Point CKIS (ARP) is derived from adding the static height difference of 1.2618 m (CKISBM to CKIS) to the levelled RL of CKISBM.*

2.6 Survey Support

The survey team very much appreciated the assistance from Lands and Survey Department (Ministry of Works) and the Meteorological Department.

Personnel consulted during the visit were:

Mr Arona Ngari	Director of the Cook Islands Meteorological Office.
Mr. Keu Mataora	Director, Ministry of Works.
Mr. Timoti Tangiruaiane	Project Officer, Ministry of Works
Mr. Vaipo Matoara	GIS, Ministry of Works.

Both departments have a keen interest in the PSLMP (Pacific Sea Level Monitoring Project) and are always supportive with any associated project matters.

2.7 Issues

Customs clearance of the survey equipment should be arranged prior to the visit to Cook Islands.

It is also essential to arrange access and security passes to the airport area prior to arrival in Cook Islands. This can be done through personnel from Ministry of Works and Meteorological Office.

Unfortunately we were not able to access deep benchmark, BM26, as it is inside the closed compound and the gates were locked.

3 Comparisons

3.1 Comparisons between 2012 and 2011 EDM Surveys

Table 3 Rarotonga, Cook Islands EDM Height Traversing Levelling Comparison 2012 - 2011. BM27 - adopted fixed height of 4.74074m

From	To	Levelled Ht. Diff.	RL 2012	Misclose (mm)	Dist. (km)	1mm√k	RL 2011	Difference (mm) 2012 - 2011
BM27			4.74074					
COO77	COO77	0.13023	4.87097	0.100	0.1855	0.431	4.87071	0.26
COO103	COO103	0.32577	5.19673	0.002	0.1246	0.353	NEW MARK	NEW MARK
COO100	COO100	-0.20094	4.99580	0.100	0.2089	0.457	4.99638	-0.58
BM34	BM34	-0.34241	4.65339	0.050	0.0464	0.215	4.65346	-0.07
COO84	COO84	-1.16826	3.48512	-0.375	0.1911	0.437	3.48561	-0.49
BM28	BM28	-0.28965	3.19548	-0.190	0.1234	0.351	3.19608	-0.60
BM35	BM35	0.17059	3.36607	-0.063	0.1409	0.375	3.3664	-0.33
COO85	COO85	0.38994	3.75602	0.238	0.1709	0.413	3.75672	-0.70
COO101	COO101	-0.63932	3.11670	-0.188	0.1537	0.392	3.11715	-0.45
	CKISBM	0.13678	3.25347	-0.250	0.0761	0.276	3.25284	0.63
BM27			4.74074					
BM33	BM33	-1.28068	3.46006	-0.458	0.2109	0.459	3.46016	-0.10
BM18	BM18	0.13365	3.59371	-0.350	0.2219	0.471	3.59431	-0.60
COO10	COO10	-2.04836	1.54535	0.050	0.0552	0.235	1.54635	-1.00
	COO56	1.13342	2.67877	-0.040	0.0226	0.150	2.68169	-2.92
			Misclose for all bays levelled =	-1.374	1.9319	1.38993		
CKISBM			3.25347					
	CKISRM1	-0.61931	2.63417	0.010	0.0324	0.180	2.63319	0.98
CKISBM			3.25347					
	CKISRM2	-0.80915	2.44432	0.002	0.0253	0.159	2.44348	0.84
CKISBM			3.25347					
	CKISRM3	-0.44629	2.80718	0.000	0.0305	0.175	2.80616	1.02

*The RL of the Reference Point CKIS (ARP) is derived from adding the static height difference of 1.2618 m (CKISBM to CKIS) to the levelled RL of CKISBM.

All levelling was performed within the project specifications of 2√k

3.2 Combined Comparisons 1993 to 2012

Examination of the level survey results (holding BM27 as the fixed reference bench mark) indicate no significant displacement of any of the deep driven bench marks and the CGNSS benchmark, but movement was detected with COO56, the SEAFRAME Sensor Bench Mark.

Table 2 Rarotonga, Cook Islands – bench mark Comparison of the RL's for Precise Differential Levelling (1993 – 2004) and EDM Height Traversing (2004 – 2012).

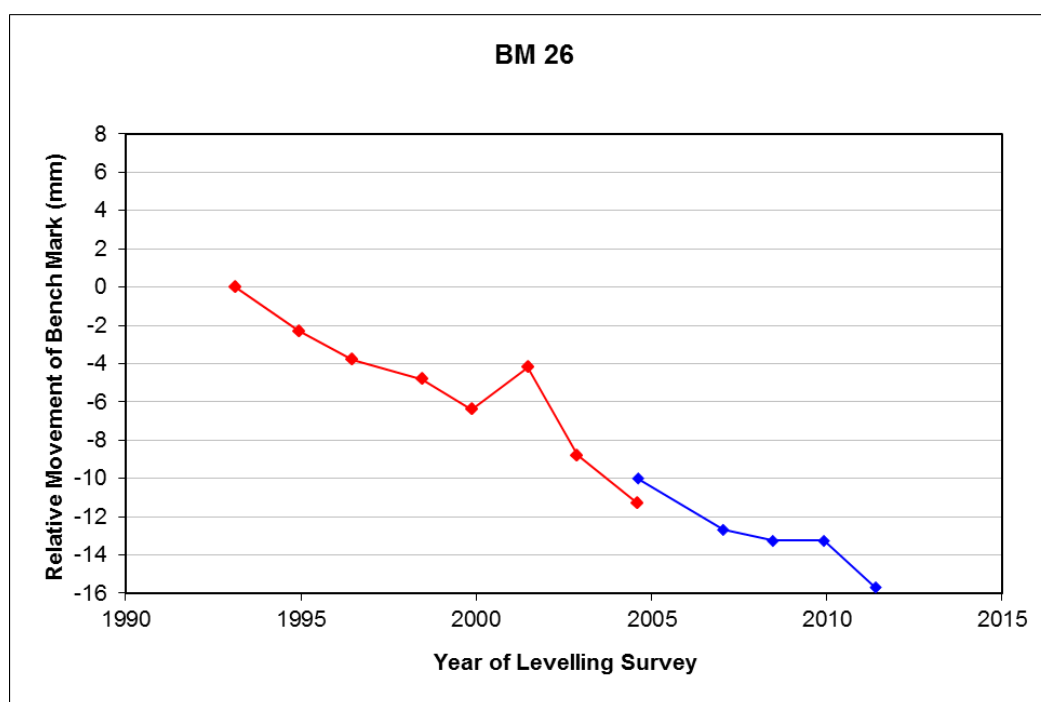
Year	BM 18	BM 26	BM 28	BM 29	BM 33	BM 34	BM 35	COO 10	COO 56	CKISBM
1993.1	3.6180	2.1587	3.1986	2.6141				1.5487		
1994.9	3.6170	2.1564	3.1973	2.6121				1.5484		
1996.5	3.6156	2.1549	3.1980	2.6132				1.5481		
1998.5	3.6155	2.1539	3.1978	2.6133				1.5489	2.6843	
1999.9	3.6147	2.1523	3.1974	2.6121				1.5484	2.6844	
2001.5	3.6181	2.1545	3.1976	2.6134	3.4606	4.6542	3.3664	1.5518	2.6904	
2002.9	3.6147	2.1499	3.1984	2.6131	3.4615	4.6555	3.3680	1.5485	2.6867	3.2560
2004.6	3.6131	2.1474	3.1971		3.4615	4.6555	3.3680	1.5472	2.6855	3.2547

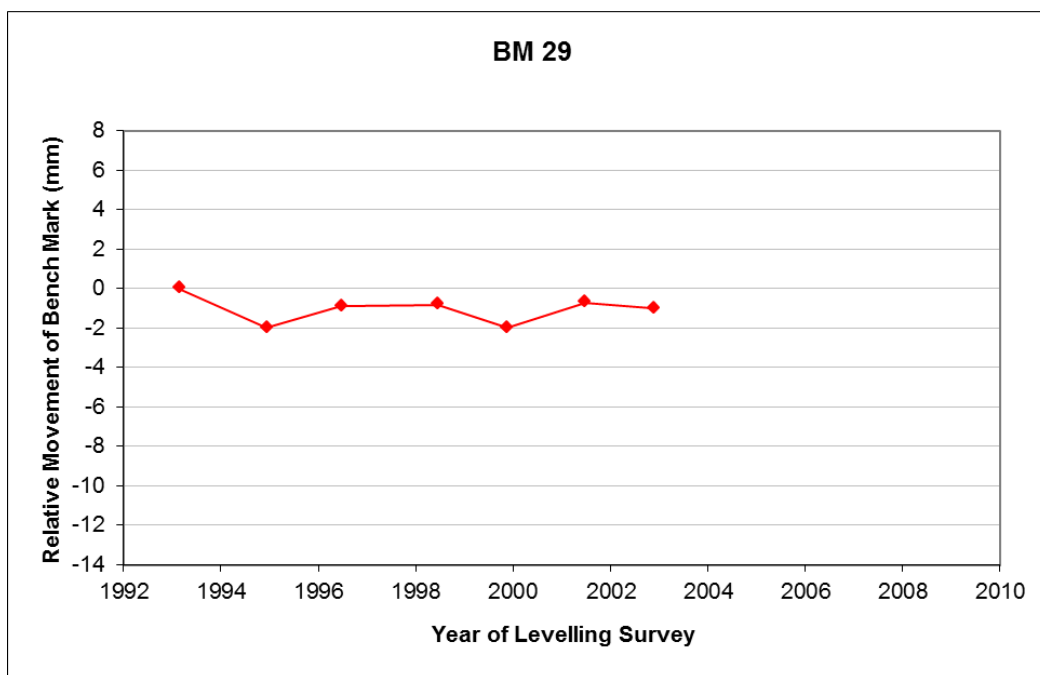
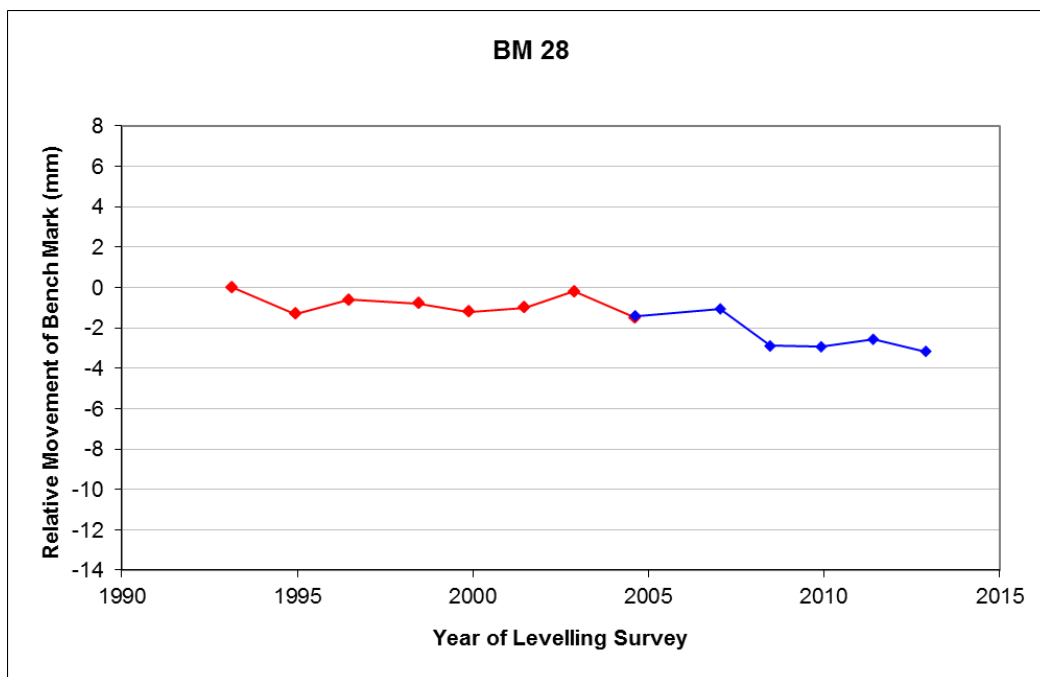
Year	BM 18	BM 26	BM 28	BM 29	BM 33	BM 34	BM 35	COO 10	COO 56	CKISBM
2004.6		2.1487	3.1972		3.4609	4.6546	3.3671	1.5481	2.6864	3.2562
2007.1	3.6101	2.1461	3.1976		3.4603	4.6543	3.3677	1.5473	2.6831	3.2561
2008.5	3.5965	2.1455	3.1958		3.4606	4.6525	3.3656	1.5474	2.6820	3.2535
2009.9	3.5965	2.1455	3.1957		3.4603	4.6534	3.3657	1.5472	2.6819	3.2521
2011.4	3.5943	2.1431	3.1961		3.4602	4.6535	3.3664	1.5464	2.6817	3.2528
2012.9	3.5937		3.1955		3.4601	4.6534	3.3661	1.5454	2.6788	3.2535

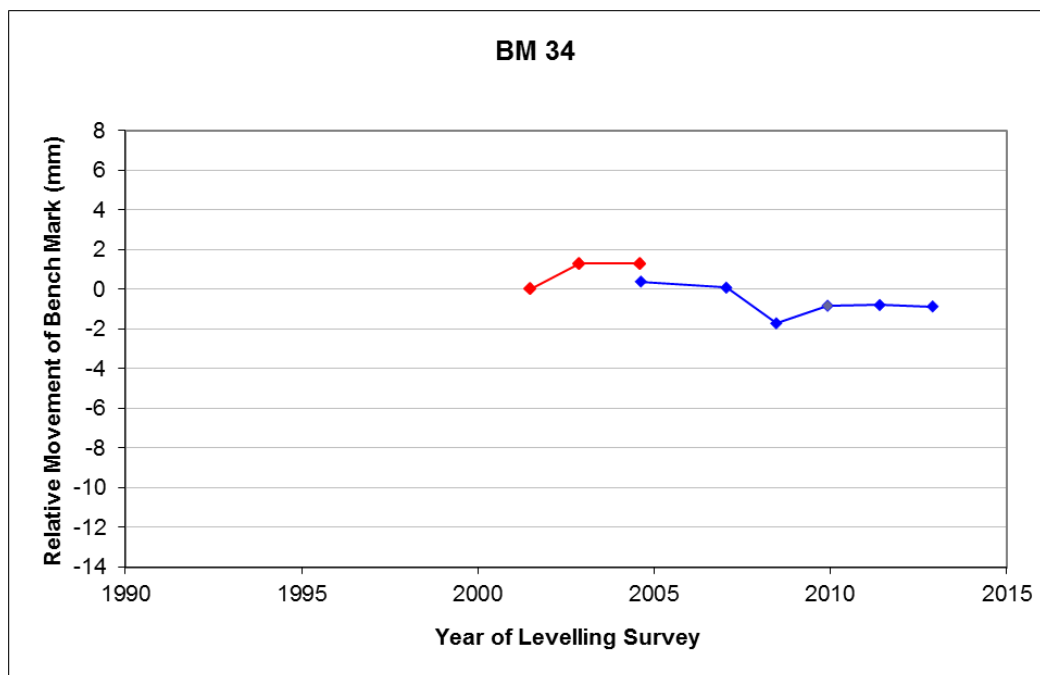
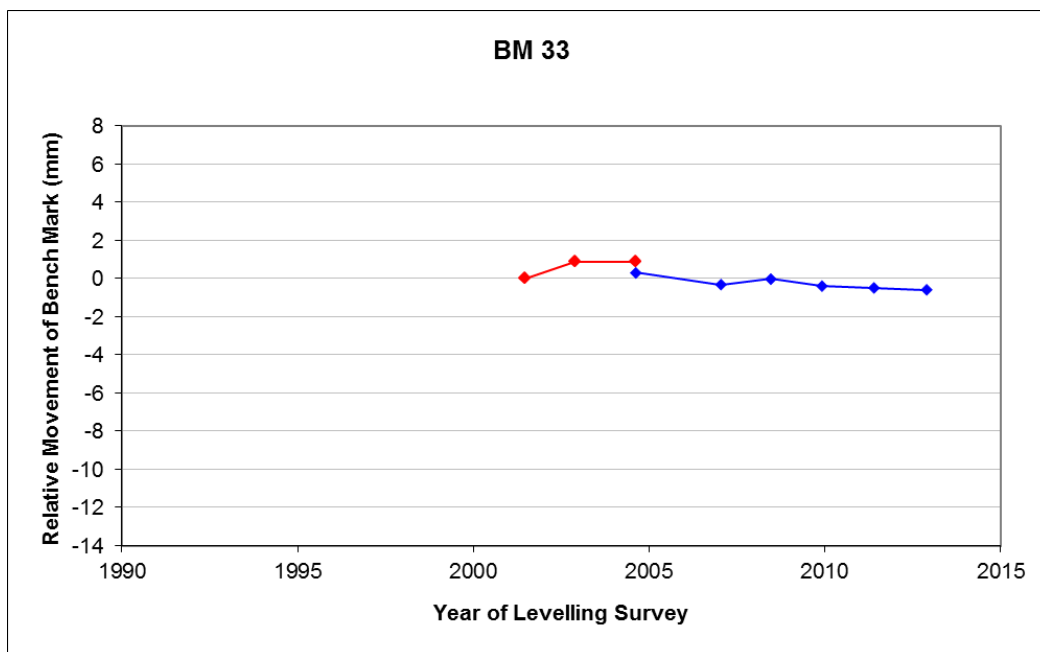
3.3 Time Series of Bench Mark Movement relative to Fixed Deep Bench Mark BM27

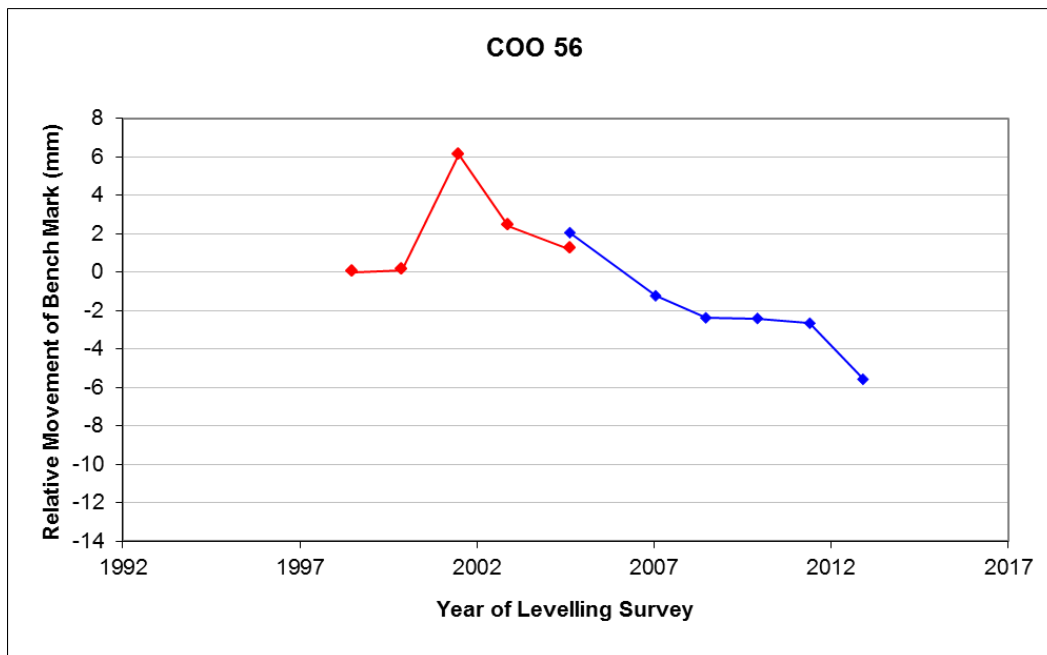
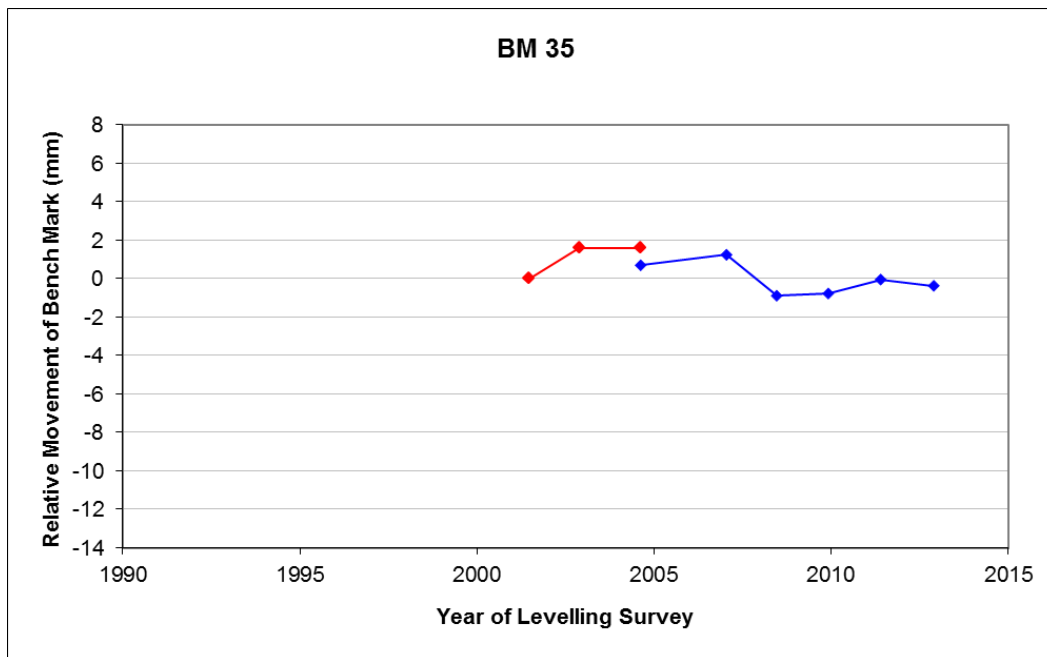
Precise Differential Levelling: 1993 - 2004 ◆ — ◆
EDM Height Traversing: 2004 onwards ◆ — ◆

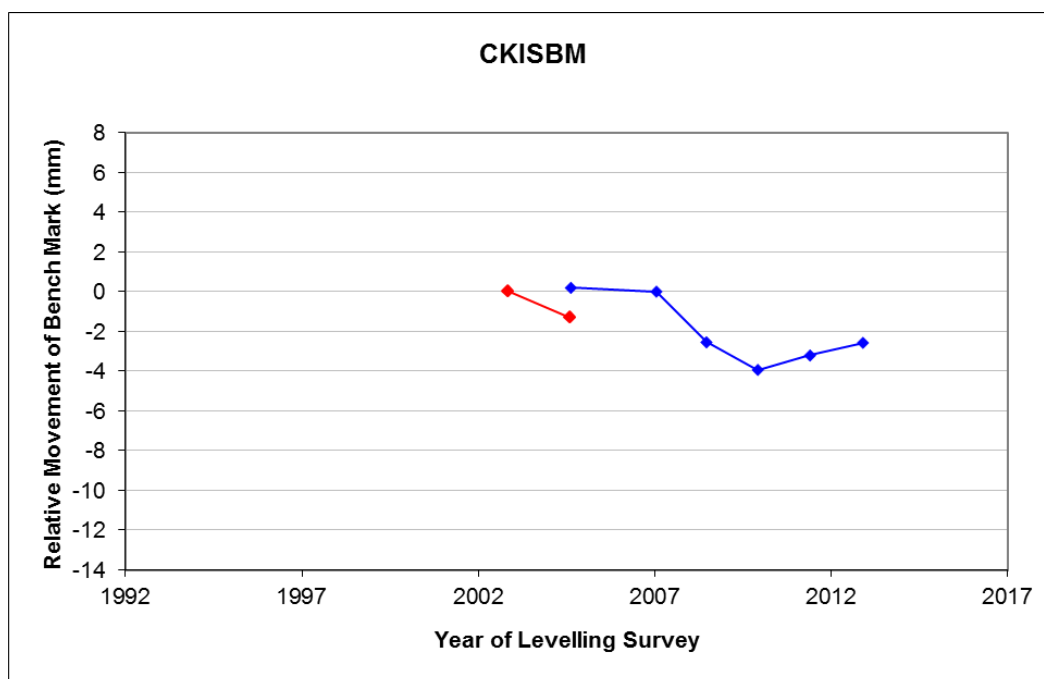
According to the 2012 survey, the SEAFRAME Sensor Benchmark, COO56, moved by -2.92mm (dropped); whereas all the other benchmarks showing insignificant movement. This indicates that COO56 at the tide gauge may have been disturbed.











4 Deep Driven Bench Mark Locality Diagrams



**SOUTH PACIFIC SEA LEVEL
&
CLIMATE MONITORING PROJECT**



Survey Bench Mark Record

Bench Mark Number: BM26

Original Bench Mark Established by:
National Tidal Centre Australia, Oceanographic Services,
Bureau of Meteorology, 25 College Rd. Kent Town, SA.

Date: 03-12-91

Existing Bench Mark Established by:

Date:

Notes / References: Deep Survey Benchmark
This survey mark is in a good locality for GPS occupation.

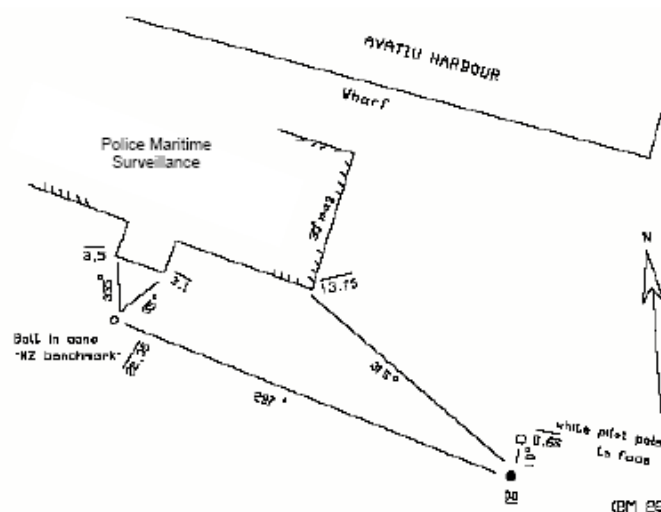
Country: Cook Islands
Island: Rarotonga

City: Avatiu

Marking and locality sketch

Bench Mark: 11.0m of 19mm diameter stainless steel capped rod driven to refusal.
Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.6m. Top of mark 0.2m below ground level.

Locality sketch: Mark approximately 50m from the tide gauge station.



Not to scale

Distances in Metres

Magnetic bearings

Approved by: Geoscience Australia / SOPAC

Date: January 2007

c:\users\andrick\sps\comp\locality\diagrams\cooks



**SOUTH PACIFIC SEA LEVEL
&
CLIMATE MONITORING PROJECT**



Survey Bench Mark Record

Bench Mark Number: BM28

<i>Original Bench Mark Established by:</i> National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 College Rd, Kent Town, SA.	<i>Date:</i> 03-12-91
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
--	--------------

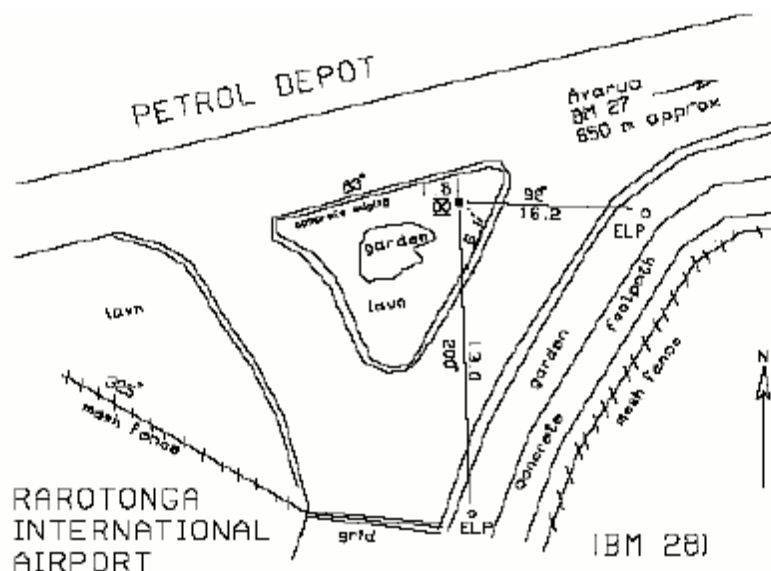
Notes / References: Deep Survey Benchmark
 This survey mark is in a good locality for GPS occupation.

<i>Country:</i> Cook Islands <i>Island:</i> Rarotonga	<i>City:</i> Avatiu
--	---------------------

Marking and locality sketch

Bench Mark: 2.6m of 19mm diameter stainless steel capped rod driven to refusal.
 Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for
 0.5m. Top of mark 0.2m below ground level. ROD NOT DRIVEN TO
 REFUSAL

Locality sketch: Mark approximately 1400m from the tide gauge station.



Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC	Date: January 2007
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c:\users\landrick\sp\comp\localitydiagrams\cooks



**SOUTH PACIFIC SEA LEVEL
&
CLIMATE MONITORING PROJECT**



Survey Bench Mark Record

Bench Mark Number: BM33

<i>Original Bench Mark Established by:</i> National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 College Rd, Kent Town, SA.	<i>Date:</i> 18-11-02
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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<i>Notes / References:</i> Deep Survey Benchmark This survey mark is in a good locality for GPS occupation.
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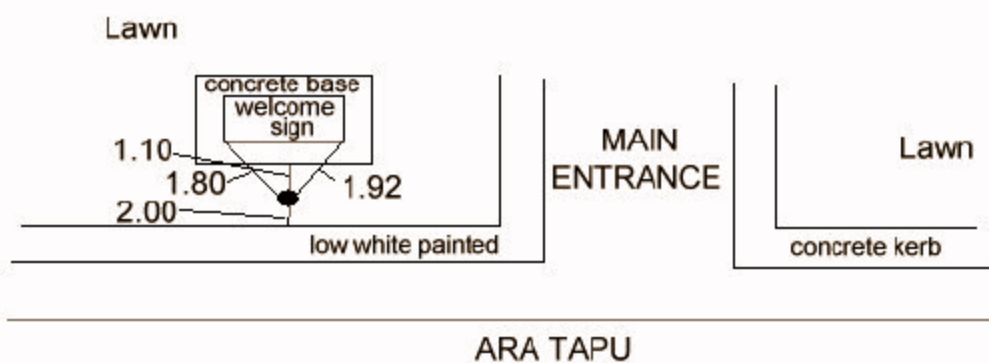
<i>Country:</i> Cook Islands <i>Island:</i> Rarotonga	<i>City:</i> Avatiu
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Marking and locality sketch

Bench Mark: 19mm diameter stainless steel capped rod driven to refusal.
 Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m. Top of mark 0.2m below ground level.

Locality sketch: Mark approximately 480m from the tide gauge station.

**CHURCH OF JESUS CHRIST
OF LATTER-DAY SAINTS**



Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC

Date: January 2007

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**SOUTH PACIFIC SEA LEVEL
&
CLIMATE MONITORING PROJECT**



Survey Bench Mark Record

Bench Mark Number: BM34

<i>Original Bench Mark Established by:</i> National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 College Rd, Kent Town, SA.	<i>Date:</i> 18-11-02
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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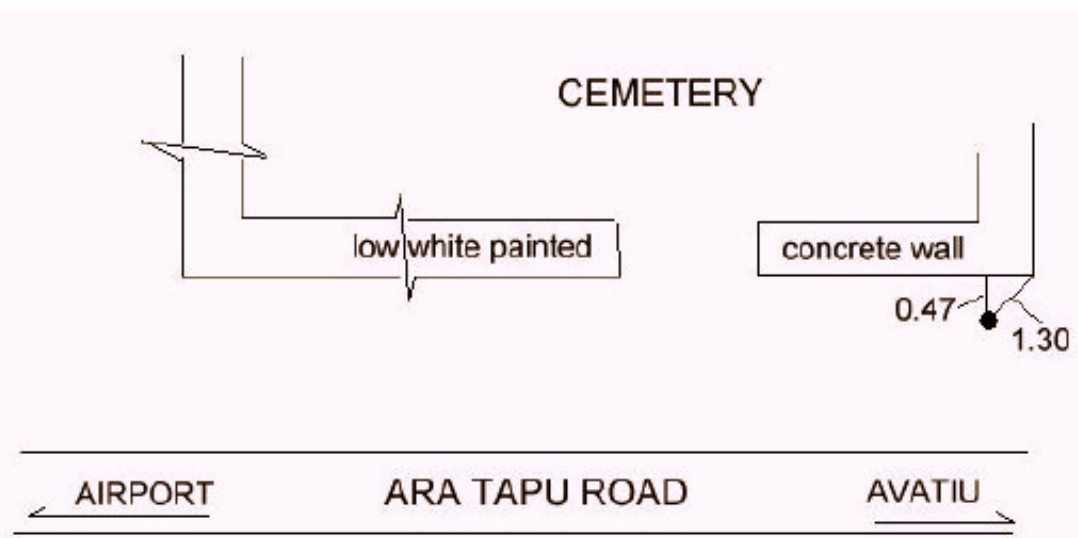
<i>Notes / References:</i> Deep Survey Benchmark This survey mark is in a good locality for GPS occupation.
--

<i>Country:</i> Cook Islands <i>Island:</i> Rarotonga	<i>City:</i> Avatiu
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Marking and locality sketch

Bench Mark: 19mm diameter stainless steel capped rod driven to refusal.
 Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m. Top of mark 0.2m below ground level.

Locality sketch: Mark approximately 1200m from the tide gauge station.



Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC	Date: January 2007
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**SOUTH PACIFIC SEA LEVEL
&
CLIMATE MONITORING PROJECT**



Survey Bench Mark Record

Bench Mark Number: BM35

<i>Original Bench Mark Established by:</i> National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 College Rd, Kent Town, SA.	<i>Date:</i> 18-11-02
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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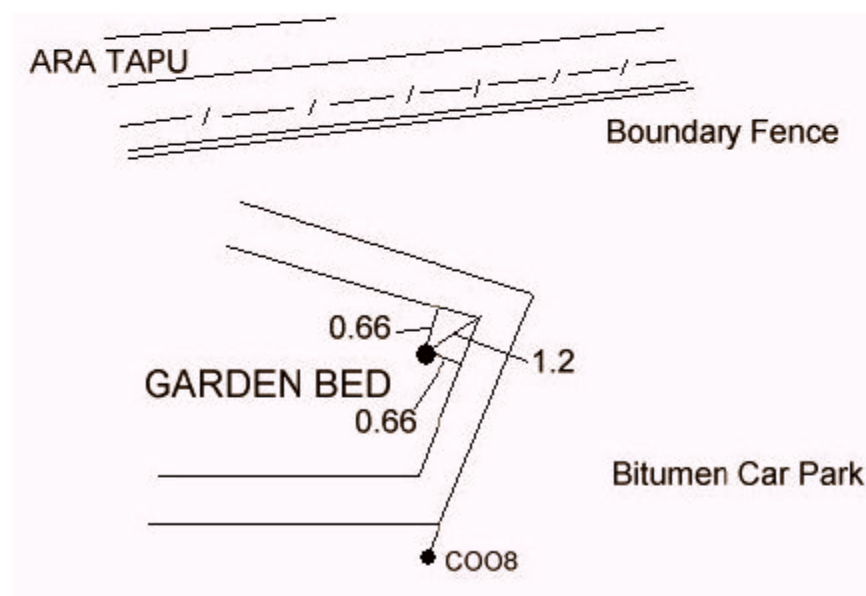
<i>Notes / References:</i> Deep Survey Benchmark This survey mark is in a good locality for GPS occupation.
--

<i>Country:</i> Cook Islands <i>Island:</i> Rarotonga	<i>City:</i> Avatiu
--	---------------------

Marking and locality sketch

Bench Mark: 19mm diameter stainless steel capped rod driven to refusal.
 Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m. Top of mark 0.2m below ground level.

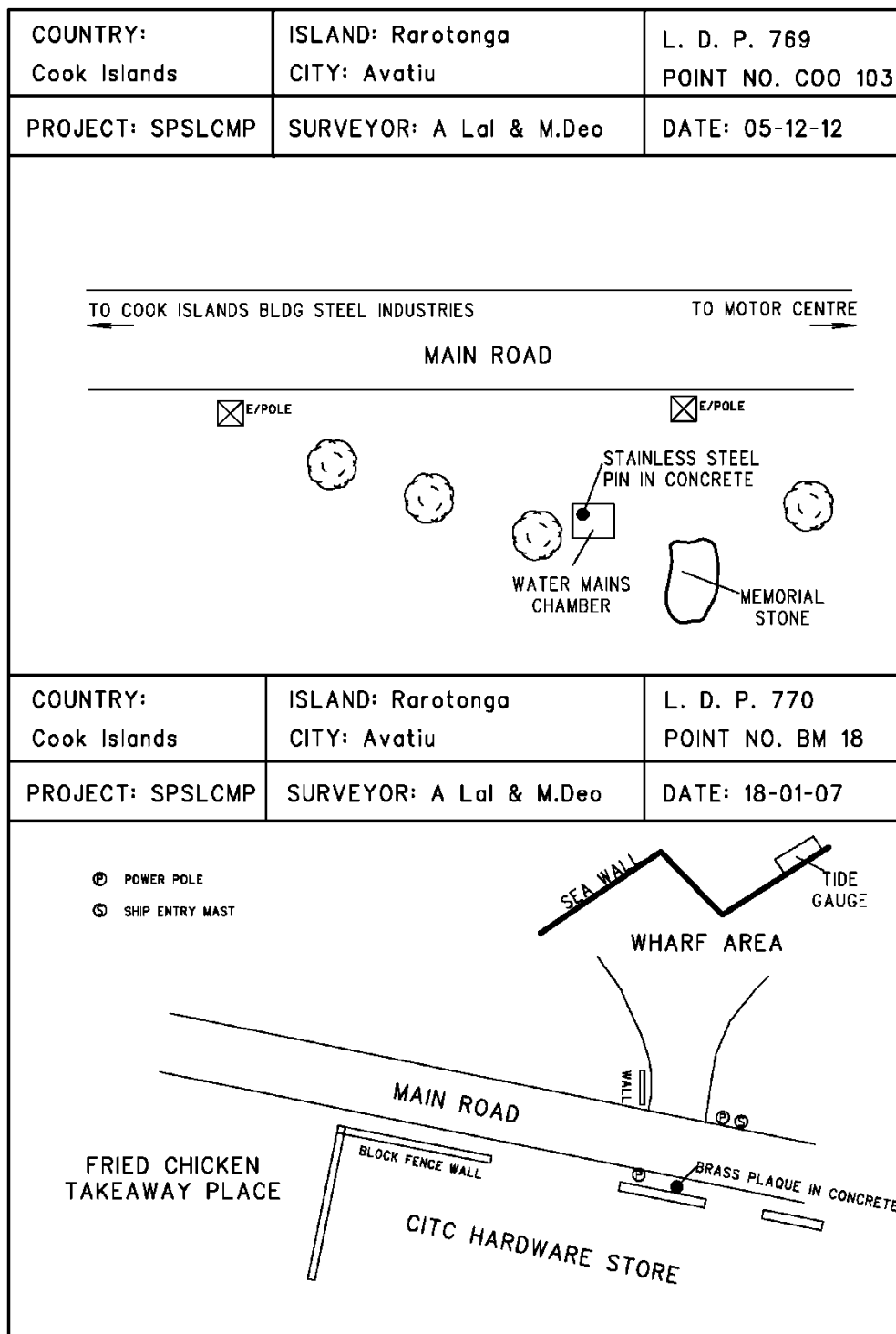
Locality sketch: Mark approximately 1500m from the tide gauge station.



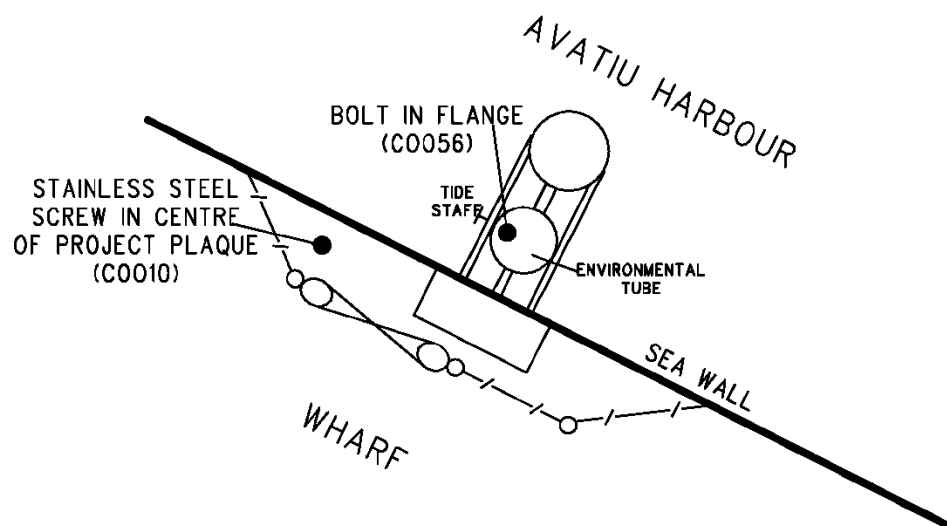
Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC	Date: January 2007 c:\users\landrick\ps\comp\locality\diagrams\cooks
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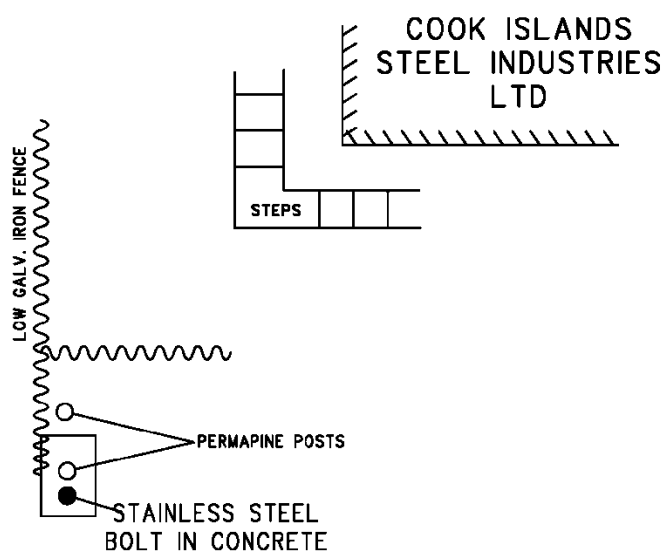
5 Temporary Holding Mark Locality Diagrams



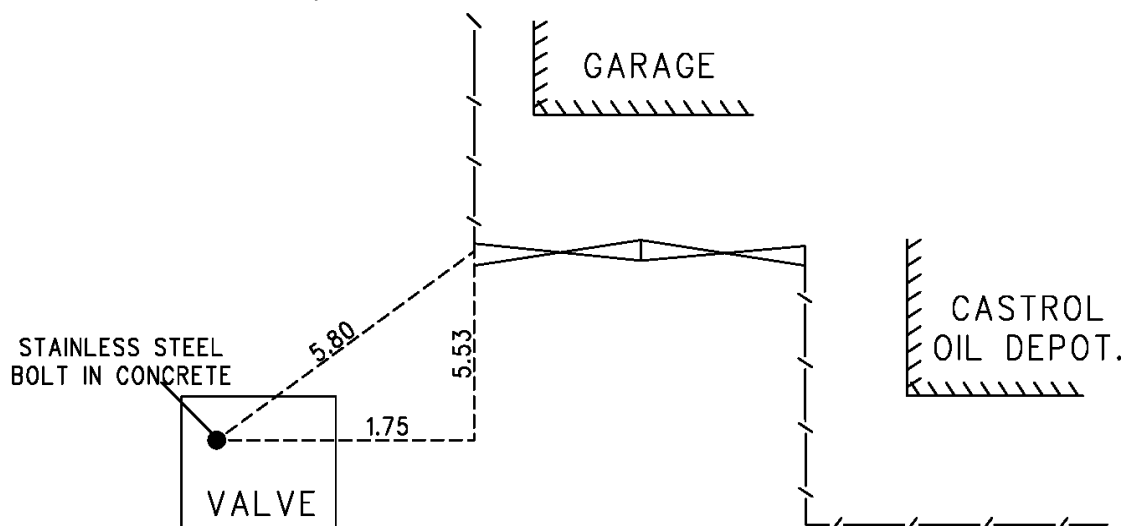
COUNTRY: Cook Islands	ISLAND: Rarotonga CITY: Avatiu	L. D. P. 771 POINT NO. C00 10 & 56
PROJECT: SPSLCMP	SURVEYOR: S M Turner	DATE: 11-02-93



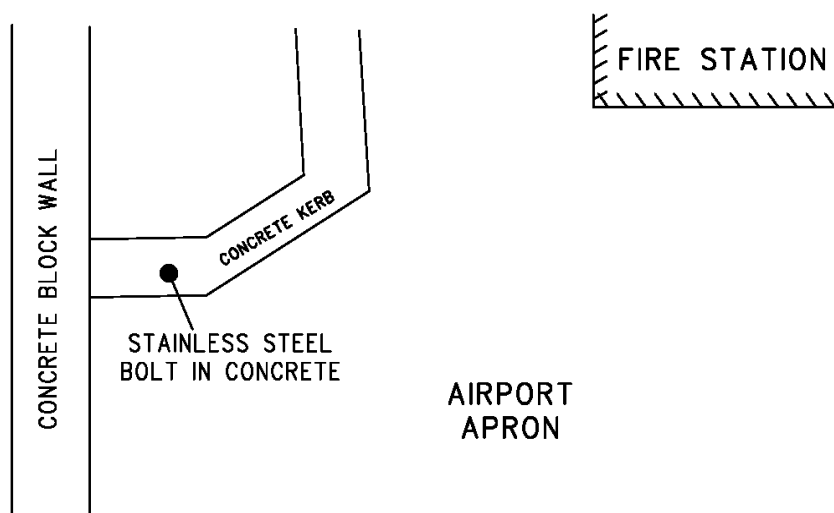
COUNTRY: Cook Islands	ISLAND: Rarotonga CITY: Avatiu	L. D. P. 772 POINT NO. C00 77
PROJECT: SPSLCMP	SURVEYOR: S M Turner	DATE: 16-11-02

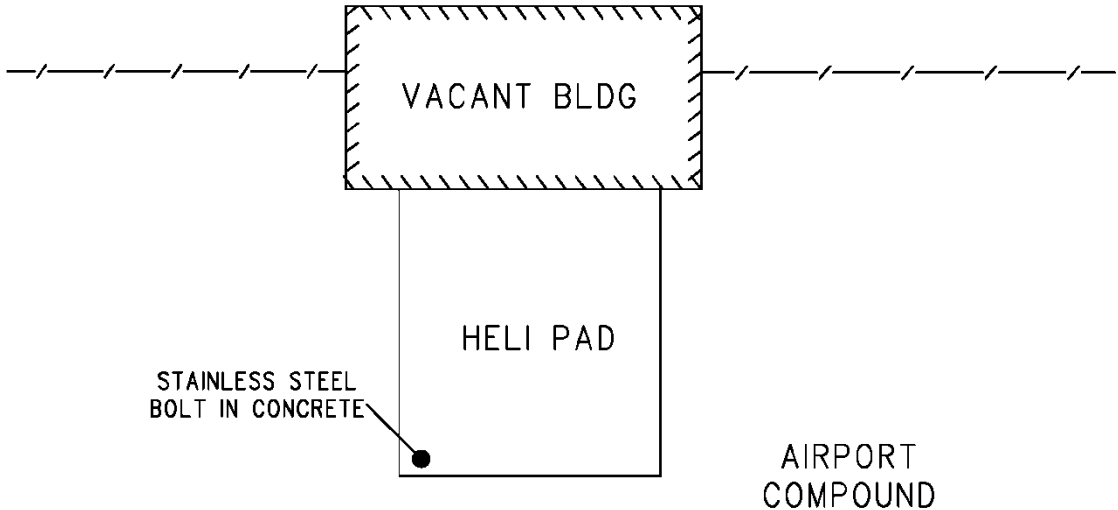
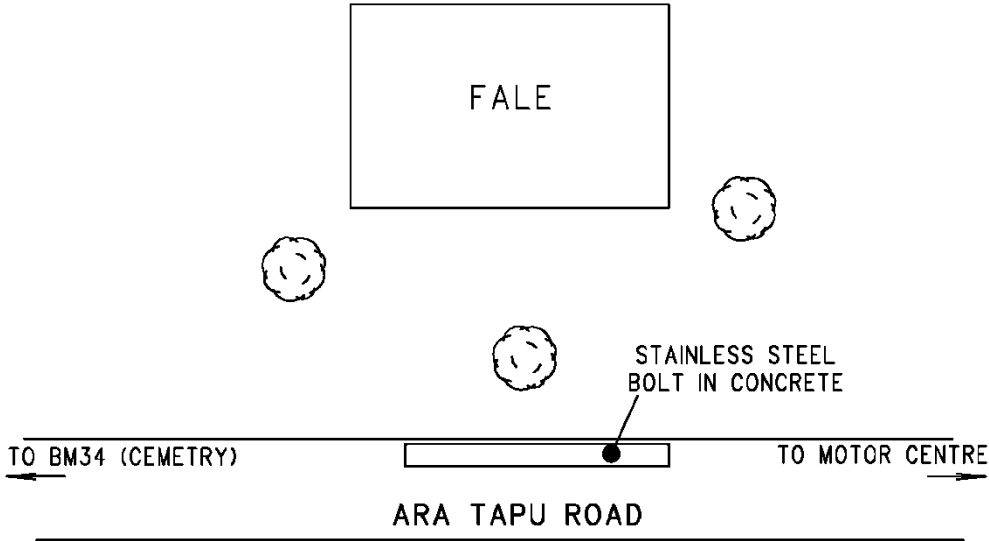


COUNTRY: Cook Islands	ISLAND: Rarotonga CITY: Avatiu	L. D. P. 773 POINT NO. COO 84
PROJECT: SPSLCMP	SURVEYOR: S M Turner	DATE: 16-11-02



COUNTRY: Cook Islands	ISLAND: Rarotonga CITY: Avatiu	L. D. P. 774 POINT NO. COO 85
PROJECT: SPSLCMP	SURVEYOR: S M Turner	DATE: 16-11-02



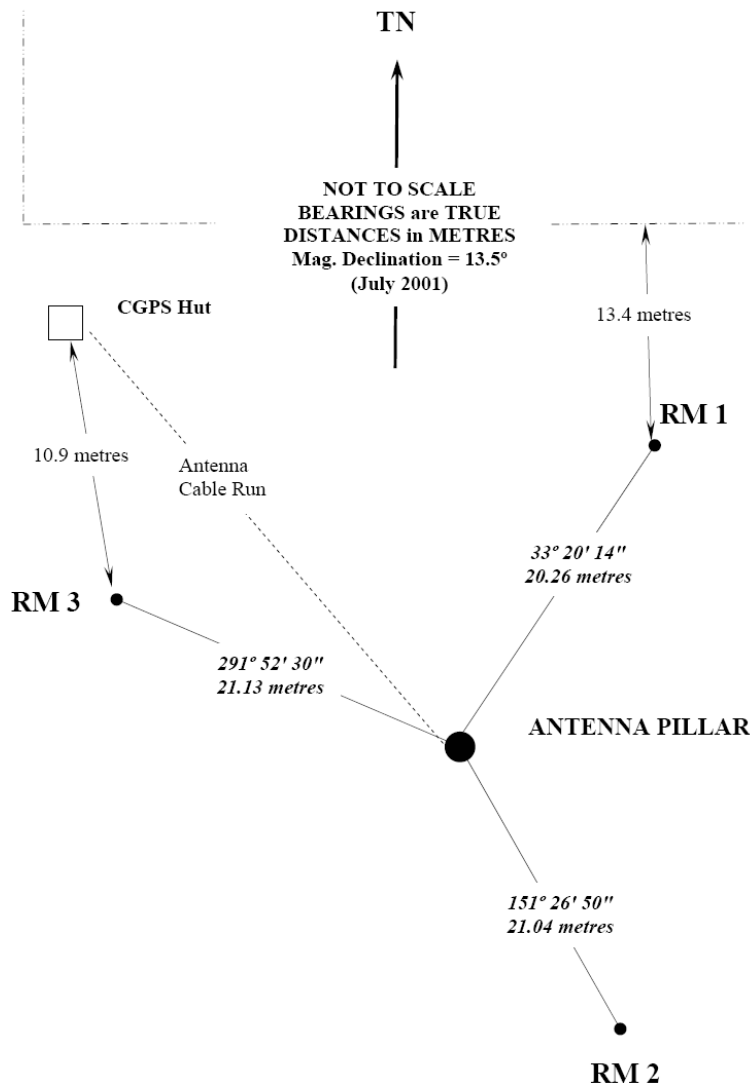
COUNTRY: Cook Islands	ISLAND: Rarotonga CITY: Avatiu	L. D. P. 775 POINT NO. C00 101
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 16-06-08
 The diagram shows a rectangular area labeled 'AIRPORT COMPOUND'. Inside, there is a hatched rectangle labeled 'VACANT BLDG'. Below it is a solid rectangle labeled 'HELI PAD'. A dot on the left side of the heli pad is labeled 'STAINLESS STEEL BOLT IN CONCRETE' with a leader line. Dashed lines extend horizontally from the sides of the vacant building.		
COUNTRY: Cook Islands	ISLAND: Rarotonga CITY: Avatiu	L. D. P. 776 POINT NO. C00 100
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 16-06-08
 The diagram shows a rectangular area labeled 'FALE'. Below it is a horizontal line labeled 'ARA TAPU ROAD'. A dot on the road is labeled 'STAINLESS STEEL BOLT IN CONCRETE' with a leader line. Arrows point left and right from the road, labeled 'TO BM34 (CEMETRY)' and 'TO MOTOR CENTRE' respectively. There are three cloud-like symbols: one to the left of the road, one to the right of the road, and one above the road near the bolt.		

6 CKISBM and CKIS Reference Mark Locality Diagram

COOK CGPS Station, Rarotonga – Reference Marks

REFERENCE MARKS

All RM's are capped 20 mm stainless steel rods driven to refusal and protected by 150 mm PVC pipe within circular poly carbonate valve boxes. The valve box lids are approximately 200mm below ground level.



7 References

- Rüeger, J.M. & Brunner, F.K. 1982, 'EDM Height Traversing versus Geodetic Levelling', The Canadian Surveyor, vol. 36, no. 1, pp. 69-87.
- Inter-Government Committee on Surveying and Mapping (ICSM) 2002, Standards and Practices for Control Surveys, SP1, Ver. 1.5, May 2002.