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EDM Height Traversing Levelling Survey Report

Nuku'alofa, Tonga, April 2013

S. J. K. Yates, A. Lal

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GEOSCIENCE AUSTRALIA
RECORD 2014/28

S. J. K. Yates¹, A. Lal²



Australian Government
Geoscience Australia

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1. National Geospatial Reference Systems, Geospatial and Earth Monitoring Division, Geoscience Australia GPO Box 378 Canberra ACT 2601
 2. Secretariat of the Pacific Community (SPC)

Department of Industry

Minister for Industry: The Hon Ian Macfarlane MP

Parliamentary Secretary: The Hon Bob Baldwin MP

Secretary: Ms Glenys Beauchamp PSM

Geoscience Australia

Chief Executive Officer: Dr Chris Pigram

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1 Introduction

This report outlines the high precision level survey completed between the Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) tide gauge and the Continuous Global Navigation Satellite System (CGNSS) station in Nuku'alofa, Tonga from 9th to 16th April 2013.

Personnel involved in the survey were Steve Yates, Project Officer, Geoscience Australia and Andrick Lal, Surveyor, Secretariat of 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 Nuku'alofa, which runs approximately 2 km from the tide gauge sensor to the CGNSS antenna. Previous levelling surveys have been conducted along the route using this technique in 2005, 2007, 2008, 2010 and 2011.

In addition, precise differential levelling surveys were performed along the deep bench mark array from 1993 to 2005 by the National Tidal Centre Australia (NTCA) with the survey in 2005 including a comparison between the precise levelling and EDM height traversing technique. This report contains a comparison between the 2013 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, the CGNSS station and the deep driven bench mark array:

TON15	– project plaque point
TON16	– SEAFRAME sensor benchmark
TON1	– deep driven bench mark
TON60	– deep driven bench mark
TON61	– deep driven bench mark
TON62	– deep driven bench mark
TON2	– deep driven bench mark
TON3	– deep driven bench mark
TONGBM	– Levelling reference bench mark for the CGNSS pillar

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

The temporary holding marks TON67 and TON101 was found to be destroyed and was replaced with TON109 and TON108 respectively. Also included in the survey were the holding marks TON100 and TON102 – 107.

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 2011 reduced levels are detailed later in this report.

2.1 Bench Mark Locality Diagram



2.2 The Tonga Datum

The Datum for the survey is Mean Sea Level (1990).

Reduction of the data has been calculated holding TON1 fixed at 1.118552 metres, this value was determined by the National Tidal Centre Australia in October 1993 by:

Adopting the height of BM41

RL = 1.619 m MSL

Adopting the height of TON1 as derived from the 1993 survey

RL = 1.118552 metres.

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 Nuku’alofa 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 Tonga 2013 Reduced Levels

Table 2.1 Nuku’alofa, Tonga – Reduced levels and heights difference relative to TON1

Date: 9 to 16 April 2013

Datum: Mean Sea Level (1990)

Point ID	2013 Reduced Level	Type
TON1	1.11855	Stainless Steel Rod in Ground
TON103	1.16440	Stainless Steel Pin in Concrete
TON102	1.95456	Stainless Steel Pin in Concrete
TON108	1.57005	Stainless Steel Pin in Concrete
TON100	1.45682	Stainless Steel Pin in Concrete
TON15	2.27119	Stainless Steel Pin in Concrete
TON16	3.88896	Stainless Steel Pin
TON60	1.44120	Stainless Steel Rod in Ground
TON104	1.66906	Stainless Steel Pin in Concrete
TON61	1.09140	Stainless Steel Rod in Ground
TON109	1.37715	Stainless Steel Pin in Concrete
TON62	1.11994	Stainless Steel Rod in Ground
TON105	1.37567	Stainless Steel Pin in Concrete
TON2	0.79853	Stainless Steel Rod in Ground

Point ID	2013 Reduced Level	Type
TON107	1.67415	Stainless Steel Pin in Bitumen
TON106	5.75891	Stainless Steel Pin in Concrete
TON3	7.62395	Stainless Steel Rod in Ground
TONGBM	1.98194	Stainless Steel Pillar Pin
*TONG	2.94814	Pillar Plate (ARP)
TONG RM1	0.74281	Stainless Steel Rod in Ground
TONG RM2	0.80713	Stainless Steel Rod in Ground
TONG RM3	0.89941	Stainless Steel Rod in Ground

**The RL of the Reference Point TONG (ARP) is derived from adding the static height difference of 0.9662 m (TONGBM to TONG) to the levelled RL of TONGBM.*

2.6 Survey Support

The survey team very much appreciated the assistance from Lands and Survey Department.

In particular Mr Aleki Pongi, to make clearance arrangements of the survey equipment from the Customs Authority; Mr Viliami Pahulu and Mr Tahi Kato, from the Geodetic Section.

We also contacted the primary contact of the project Mr Richard Kautoke of the GIS section.

2.7 Issues

Whilst setting up or using the deep driven benchmark, TON60, which is out the front of the ANZ building, one must be aware that it is impossible to setup a telescopic tripod over the mark only the bipod can be levelled over the mark; the fence wall is very close to the benchmark.

Prior arrangements with the local counterpart should be made for the clearance of the survey equipment from the Customs Authority when it is shipped across.

3 Comparisons

3.1 Comparisons between 2013 and 2011 EDM Survey

Table 3.1 Results of Nuku'alofa, Tonga 2013 EDM Height Traversing Comparison 2013 – 2011. TON1 - adopted fixed height of 1.11855 m

From	To	Levelled Ht. Diff.	RL 2013	Misclose (mm)	Dist. (km)	1mm√k	RL 2011	Difference (mm) 2013 - 2011
TON1			1.11855					
TON103	TON103	0.04585	1.16440	-0.050	0.138	0.372	1.16473	-0.33
TON102	TON102	0.79016	1.95456	0.079	0.101	0.318	1.95498	-0.42
TON108	TON108	-0.38450	1.57005	0.150	0.056	0.237	1.56984	0.21
TON100	TON100	-0.11323	1.45682	-0.004	0.085	0.292	1.45712	-0.30
TON15	TON15	0.81437	2.27119	0.050	0.063	0.250	2.27063	0.56
	TON16	1.61778	3.88896	-0.110	0.045	0.213	3.88840	0.56
TON1			1.11855					
TON60	TON60	0.32265	1.44120	-0.052	0.031	0.176	1.44156	-0.356
TON104	TON104	0.22786	1.66906	-0.263	0.154	0.393	1.66993	-0.870
TON61	TON61	-0.57766	1.09140	-0.173	0.176	0.420	1.09278	-1.383
TON109	TON109	0.28576	1.37715	0.063	0.129	0.358	New Mark	New Mark
TON62	TON62	-0.25722	1.11994	-0.350	0.155	0.393	1.12155	-1.614
	TONGBM	0.86200	1.98194	0.013	0.070	0.264	1.98371	-1.772
TON109			1.37715				New Mark	New Mark
TON105	TON105	-0.00148	1.37567	-0.388	0.204	0.451	1.37897	-3.301
TON2	TON2	-0.57715	0.79853	0.108	0.032	0.178	0.80068	-2.154
TON107	TON107	0.87562	1.67415	0.050	0.203	0.451	1.69119	-17.041
TON106	TON106	4.08476	5.75891	0.438	0.189	0.434	5.76213	-3.222
	TON3	1.86504	7.62395	-0.354	0.166	0.407	7.62718	-3.230
			Misclose for all bays levelled =	-0.793	1.995	5.607		
TONGBM			1.98194					
	RM1	-1.23913	0.74281	-0.033	0.039	0.198	0.74461	-1.797
TONGBM			1.98194					
	RM2	-1.17481	0.80713	-0.042	0.029	0.170	0.80888	-1.754
TONGBM			1.98194					
	RM3	-1.08253	0.89941	-0.017	0.052	0.228	0.90139	-1.977

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

3.2 Combined Comparisons 1993 to 2013

Table 3.2 Nuku'alofa, Tonga - Comparison of the RL's for Precise Differential Levelling (1993 - 2005) and EDM Height Traversing (2005 - 2013).

Year	TON1	TON2	TON3	TON60	TON61	TON62	TONGBM	TON15	TON16
1993.79	1.1186	0.7978	7.6217					2.2710	3.8964
1994.71	1.1186	0.7981	7.6224					2.2707	3.8951
1995.88	1.1186	0.7973	7.6212					2.2716	3.8989
1997.46	1.1186	0.7974	7.6217					2.2701	3.8896
1998.88	1.1186	0.7979	7.6223					2.2698	3.8901
2000.38	1.1186	0.7968	7.6211					2.2695	3.8900
2002.13	1.1186	0.7981	7.6227	1.4504	1.0914	1.1198	1.9826	2.2703	3.8896
2003.46	1.1186	0.7978	7.6229	1.4500	1.0913	1.1194	1.9818	2.2700	3.8887
2005.46	1.1186	0.7981	7.6228	1.4497	1.0913	1.1196	1.9821	2.2699	3.8891

Year	TON1	TON2	TON3	TON60	TON61	TON62	TONGBM	TON15	TON16
2005.46	1.1186	0.7984	7.6232	1.4497	1.0921	1.1203	1.9828	2.2692	3.8882
2007.21	1.1186	0.7985	7.6239	1.4427	1.0920	1.1208	1.9832	2.2723	3.8960
2008.83	1.1186	0.7985	7.6237	1.4421	1.0918	1.1207	1.983	2.2714	3.8565
2010.30	1.1186	0.7994	7.6251	1.4418	1.0921	1.1208	1.9830	2.2718	3.8910
2011.40	1.1186	0.8009	7.6274	1.4418	1.0930	1.1218	1.9839	2.2706	3.8933
2013.27	1.1186	0.7985	7.6240	1.4412	1.0914	1.1199	1.9819	2.2712	3.8890

3.3 Time Series of Bench Mark Movement relative to Fixed Deep Bench Mark TON1

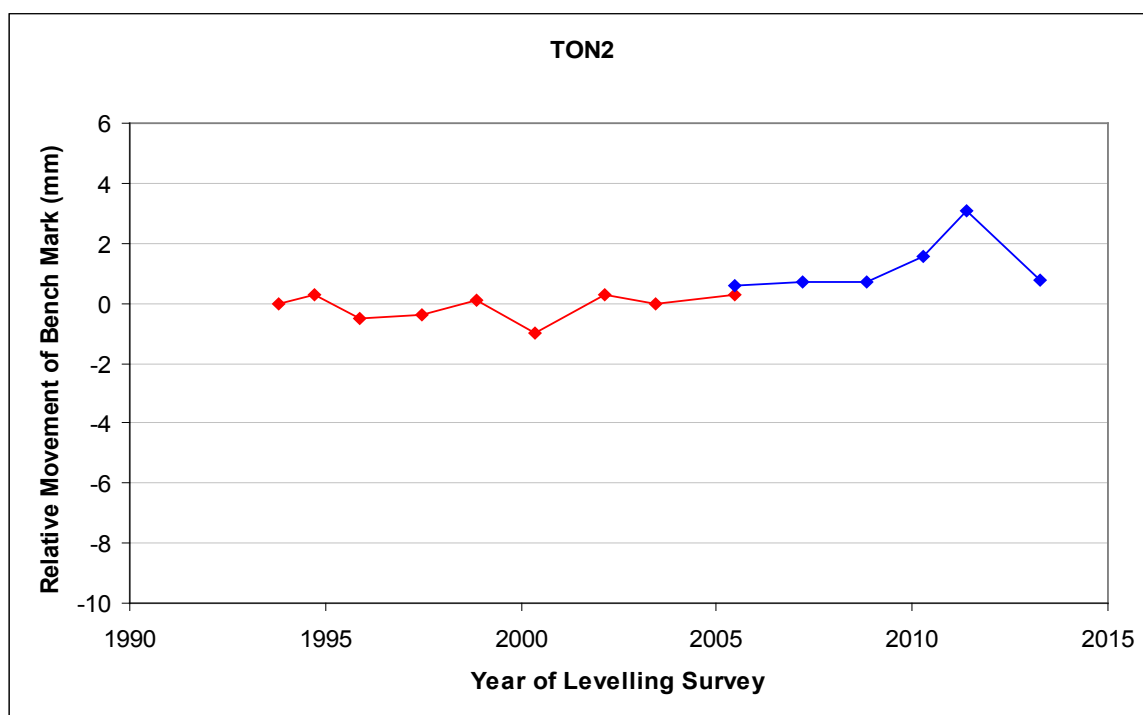
The majority of the deep driven benchmarks only show minor variability when compared with previous surveys; however, there are a couple which require further discussion and investigation.

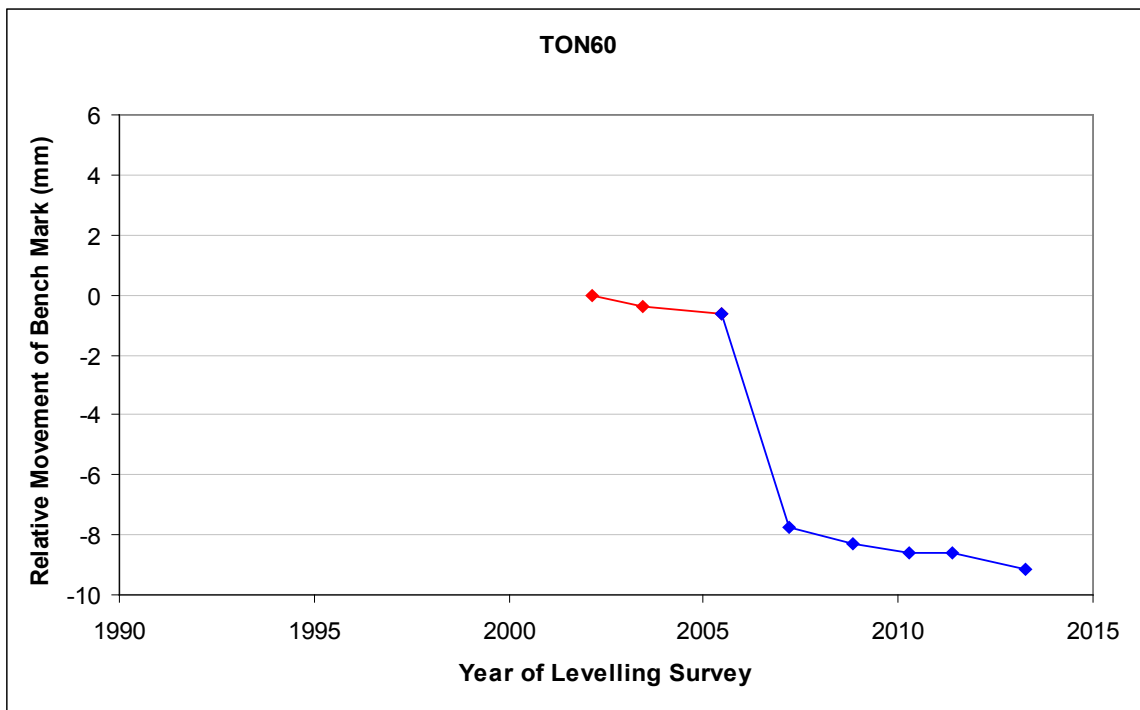
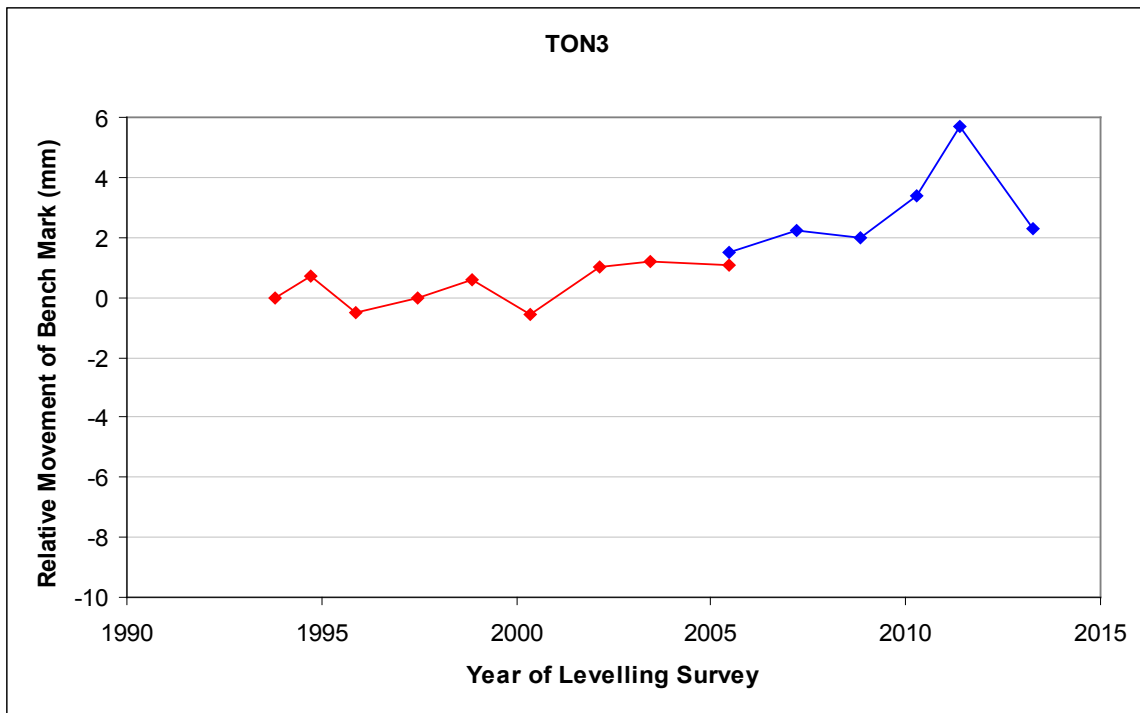
Firstly, the time series of TON16 (SEAFRAME sensor benchmark) shows the knock it received between early 2007 and late 2008 causing a ~40 mm drop in the height of the tide gauge and the results of the most recent survey show the height increase by ~35 mm after the tide gauge was straightened following the knock.

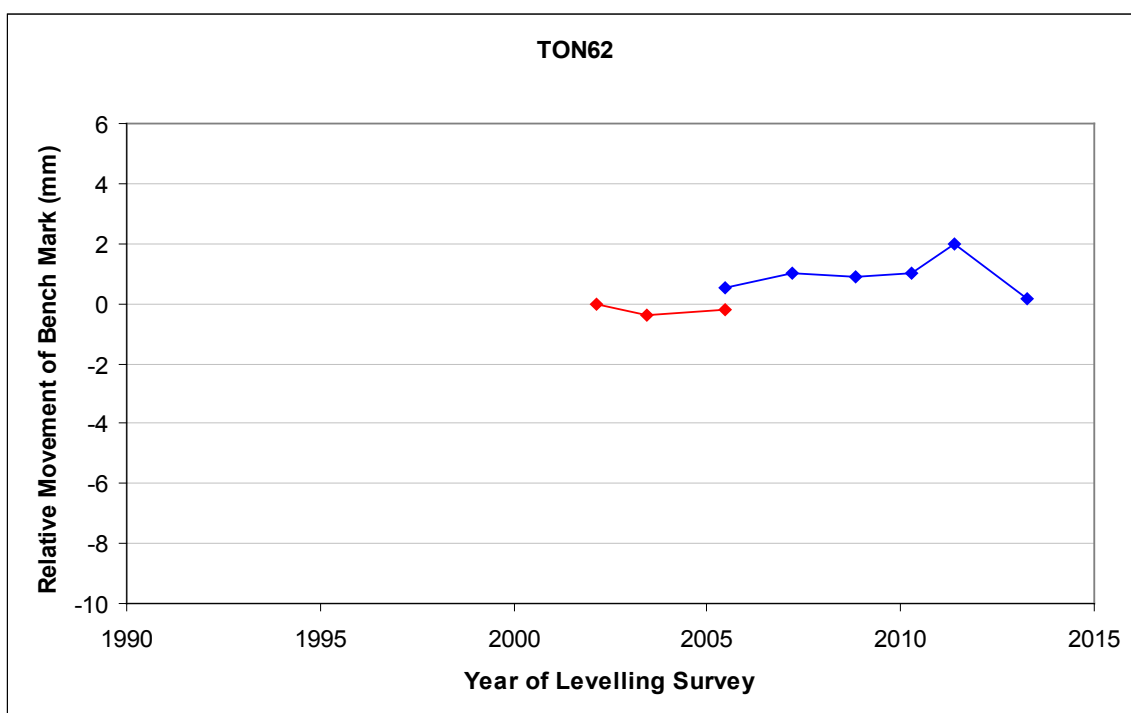
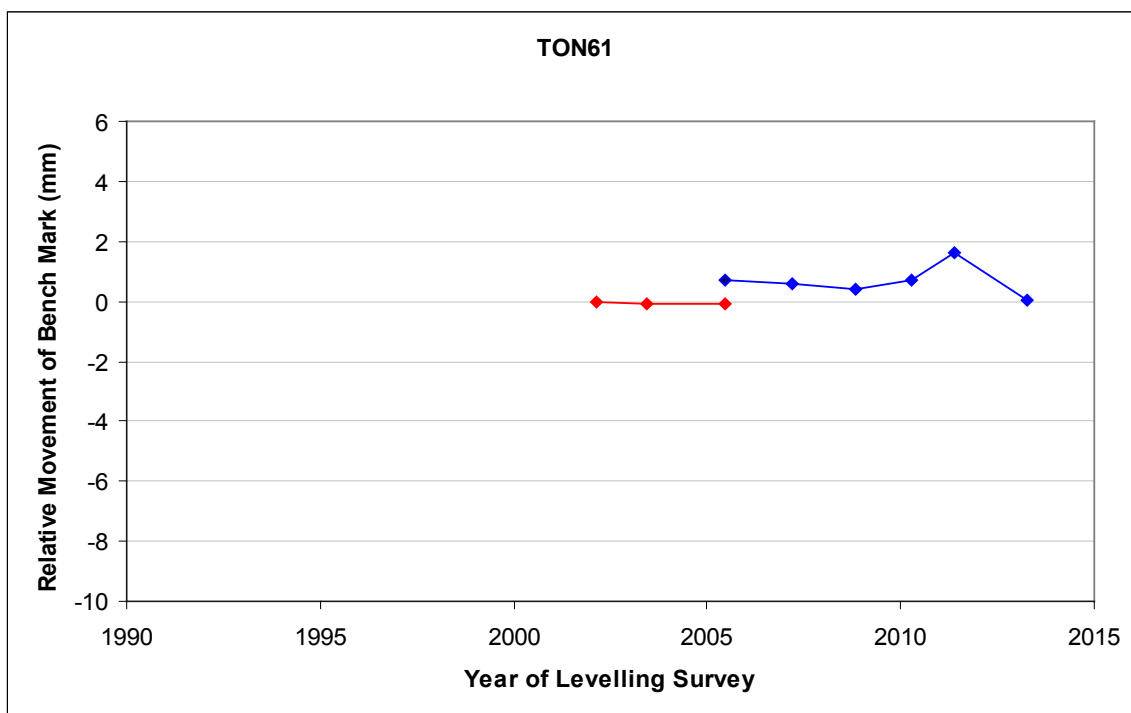
The other point which has undergone significant motion is TON60 which dropped by ~8 mm between mid 2005 and early 2007. Since that time two surveys have shown little motion at this site, however, there is an overall downward trend.

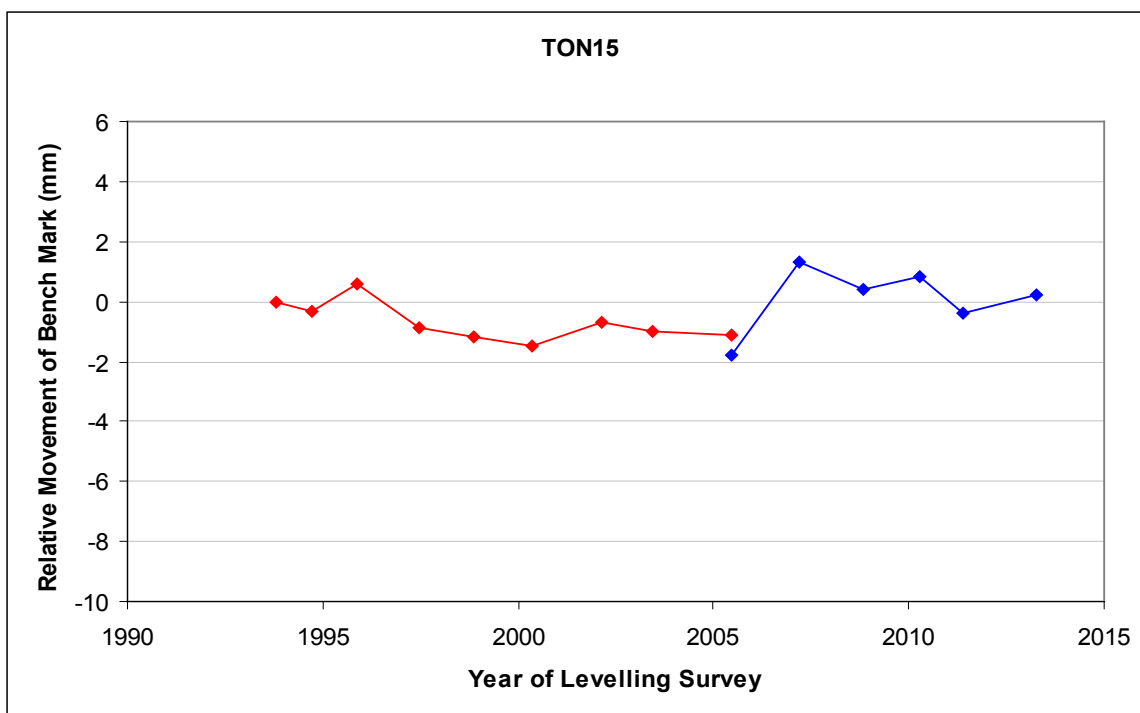
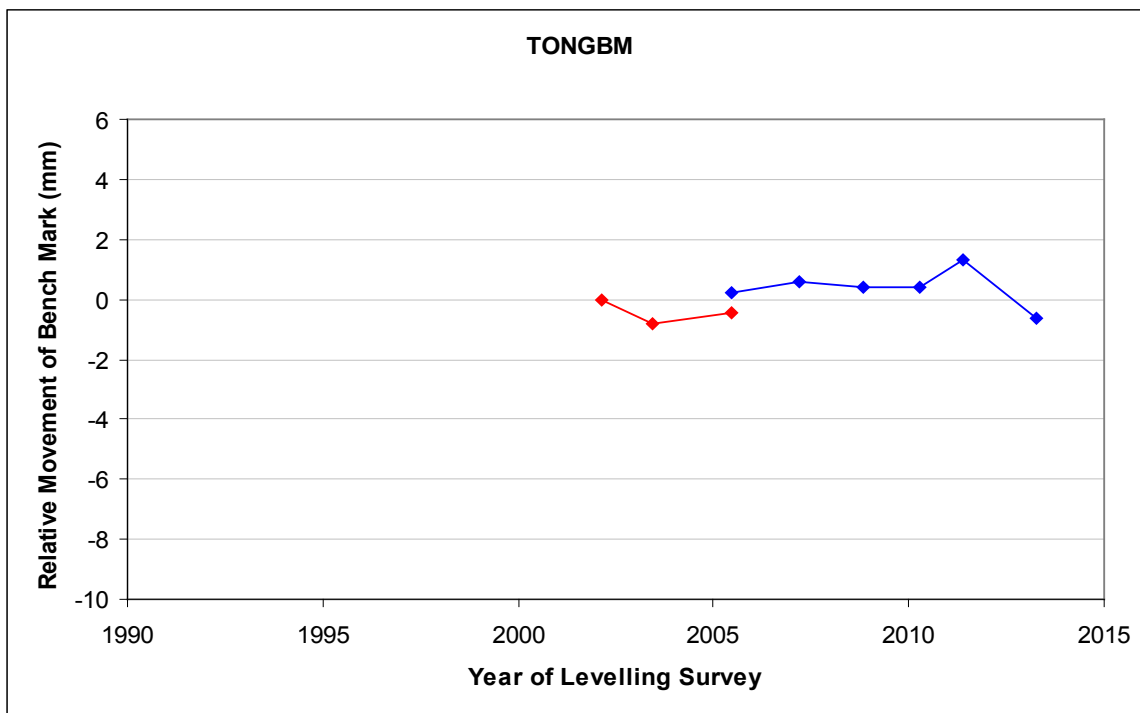
During this survey, temporary benchmark TON107 showed a significant drop by ~17 mm, this is due to its nature of establishment; it is a stainless pin in bitumen and have a tendency to move due to its location.

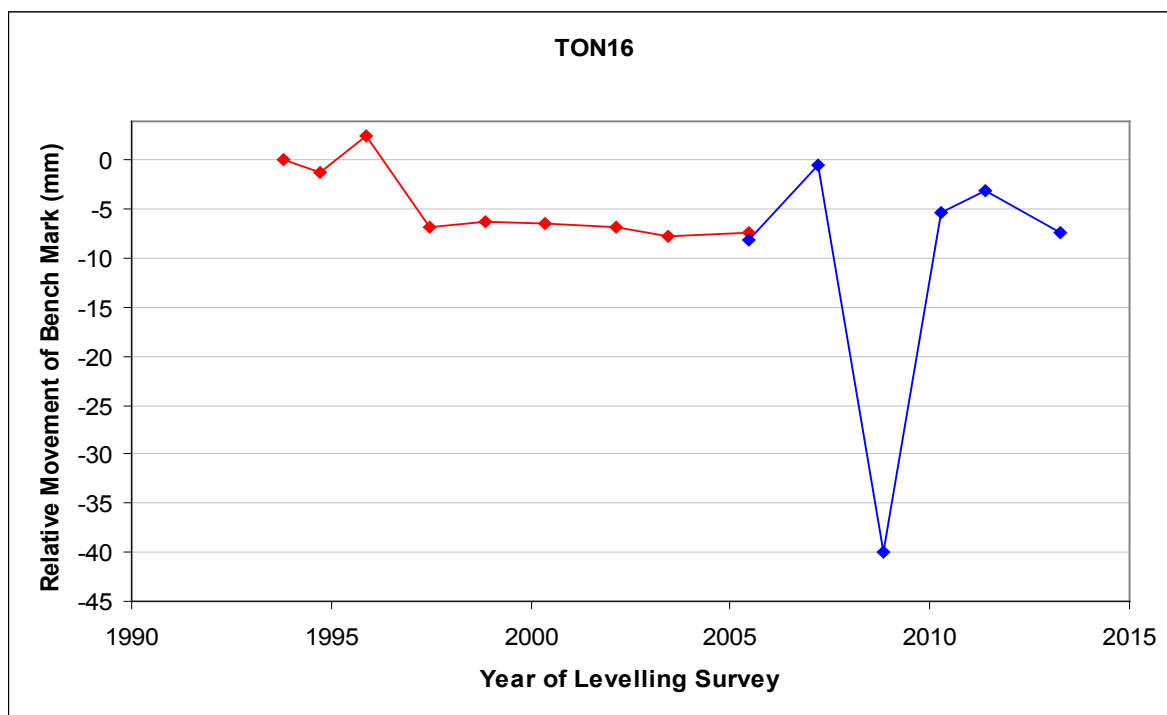
Precise Differential Levelling: 1993 - 2005 ◆ —◆
EDM Height Traversing: 2005 onwards ◆ —◆











4 Deep Bench Mark Locality Diagrams



SOUTH PACIFIC SEA LEVEL & CLIMATE MONITORING PROJECT



Survey Bench Mark Record

Bench Mark Number: TON1

Original Bench Mark Established by: National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 College Rd, Kent Town, SA.	Date: 26-11-91
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Existing Bench Mark Established by:	Date:
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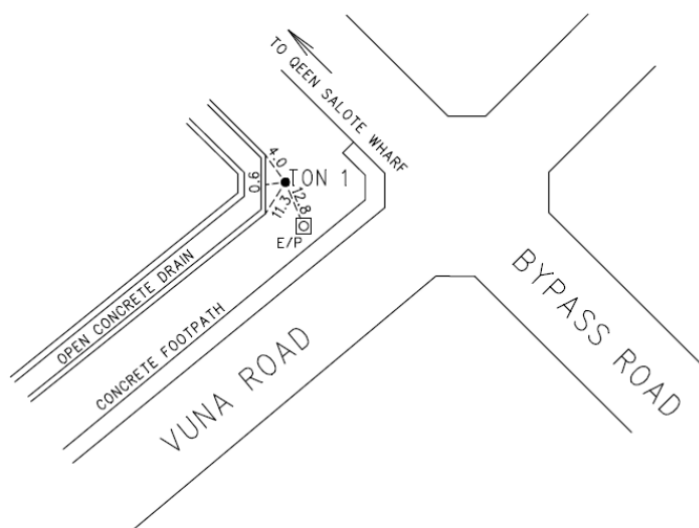
Notes / References: Deep Survey Benchmark
This survey mark is in a good locality for GPS occupation.

Country: Tonga Island: Tongatapu	City: Nuku'alofa
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Marking and locality sketch

Bench Mark: 10.6m 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 350m from the tide gauge station.



Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC	Date: April 2007
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c:\users\landrick\spslcmp\localitydiagrams\tonga



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



Survey Bench Mark Record

Bench Mark Number: TON2

<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> 25-11-91
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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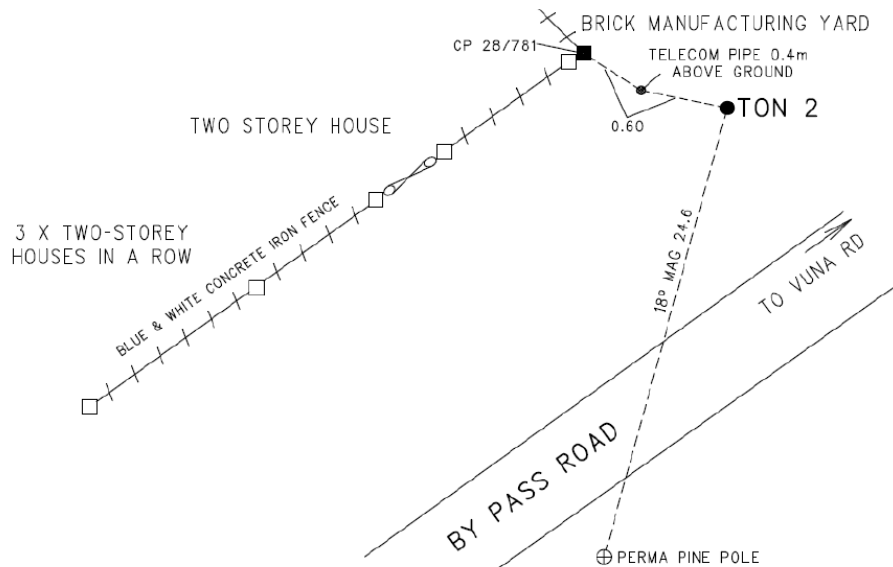
<i>Notes / References:</i> Deep Survey Benchmark This survey mark is not in a good locality for GPS occupation.
--

<i>Country:</i> Tonga <i>Island:</i> Tongatapu	<i>City:</i> Nuku'alofa
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Marking and locality sketch

Bench Mark: 3.0m 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 1000m from the tide gauge station.



Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC	Date: April 2007 c:\users\andrick\spslcmp\localitydiagrams\tonga
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**SOUTH PACIFIC SEA LEVEL
&
CLIMATE MONITORING PROJECT**



Survey Bench Mark Record

Bench Mark Number: TON3

<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> 25-11-91
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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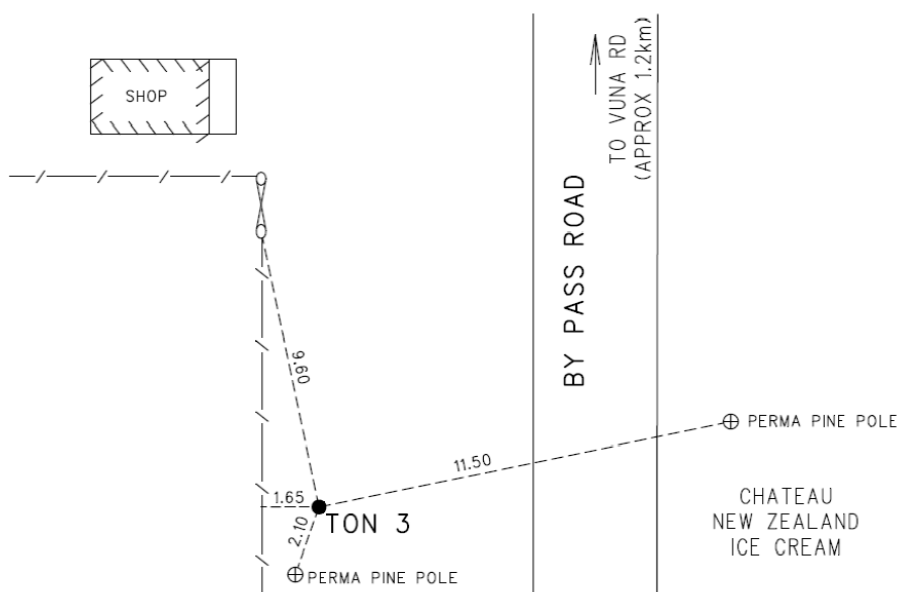
Notes / References: Deep Survey Benchmark
 This survey mark is in a good locality for GPS occupation.

<i>Country:</i> Tonga <i>Island:</i> Tongatapu	<i>City:</i> Nuku'alofa
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Marking and locality sketch

Bench Mark: 3.3m of 19mm diameter stainless steel capped rod driven to refusal.
 Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 1.5m. 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: April 2007

c:\users\andrick\spslcmp\localitydiagrams\tonga



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



Survey Bench Mark Record

Bench Mark Number: TON60

<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> 21-02-02
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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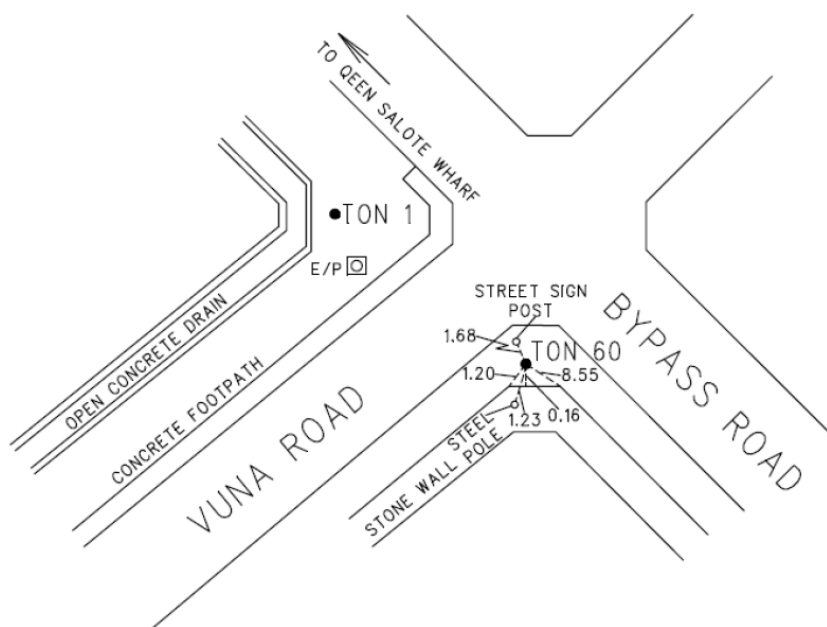
<i>Notes / References:</i> Deep Survey Benchmark This survey mark is not in a good locality for GPS occupation.
--

<i>Country:</i> Tonga <i>Island:</i> Tongatapu	<i>City:</i> Nuku'alofa
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Marking and locality sketch

Bench Mark: 1.7m 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 0.1m below ground level.

Locality sketch: Mark approximately 475m from the tide gauge station.



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

Date: April 2007

c:\users\andrick\splscmp\localitydiagrams\tonga



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



Survey Bench Mark Record

Bench Mark Number: TON61

<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> 21-02-02
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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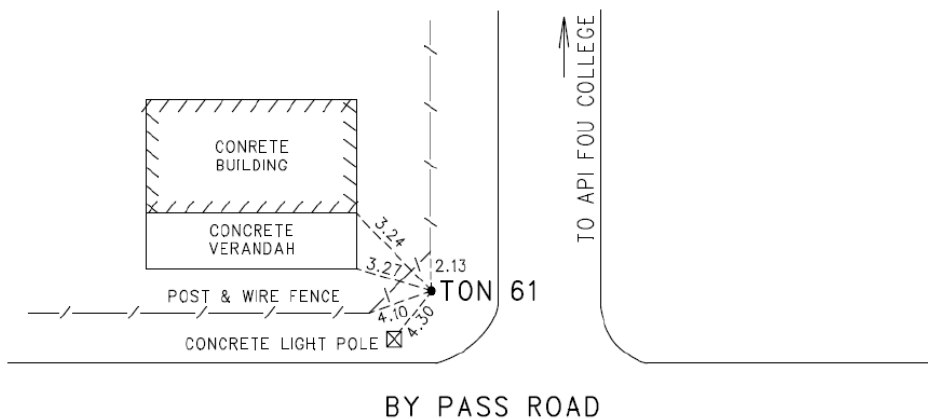
<i>Notes / References:</i> Deep Survey Benchmark This survey mark is in a good locality for GPS occupation.
--

<i>Country:</i> Tonga <i>Island:</i> Tongatapu	<i>City:</i> Nuku'alofa
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Marking and locality sketch

Bench Mark: 7.6m 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 0.1m below ground level.

Locality sketch: Mark approximately 800m from the tide gauge station.



Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC	Date: April 2007 c:\users\andrick\spslcmp\localitydiagrams\tonga
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**SOUTH PACIFIC SEA LEVEL
&
CLIMATE MONITORING PROJECT**



Survey Bench Mark Record

Bench Mark Number: TON62

<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> 21-02-02
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<i>Existing Bench Mark Established by:</i>	<i>Date:</i>
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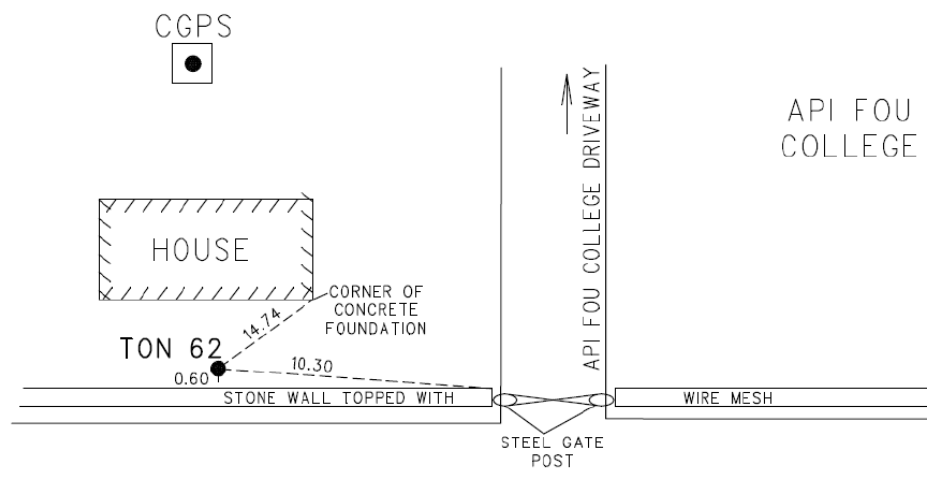
<i>Notes / References:</i> Deep Survey Benchmark This survey mark is in a good locality for GPS occupation.
--

<i>Country:</i> Tonga <i>Island:</i> Tongatapu	<i>City:</i> Nuku'alofa
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Marking and locality sketch

Bench Mark: 5.8m 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 0.1m below ground level.

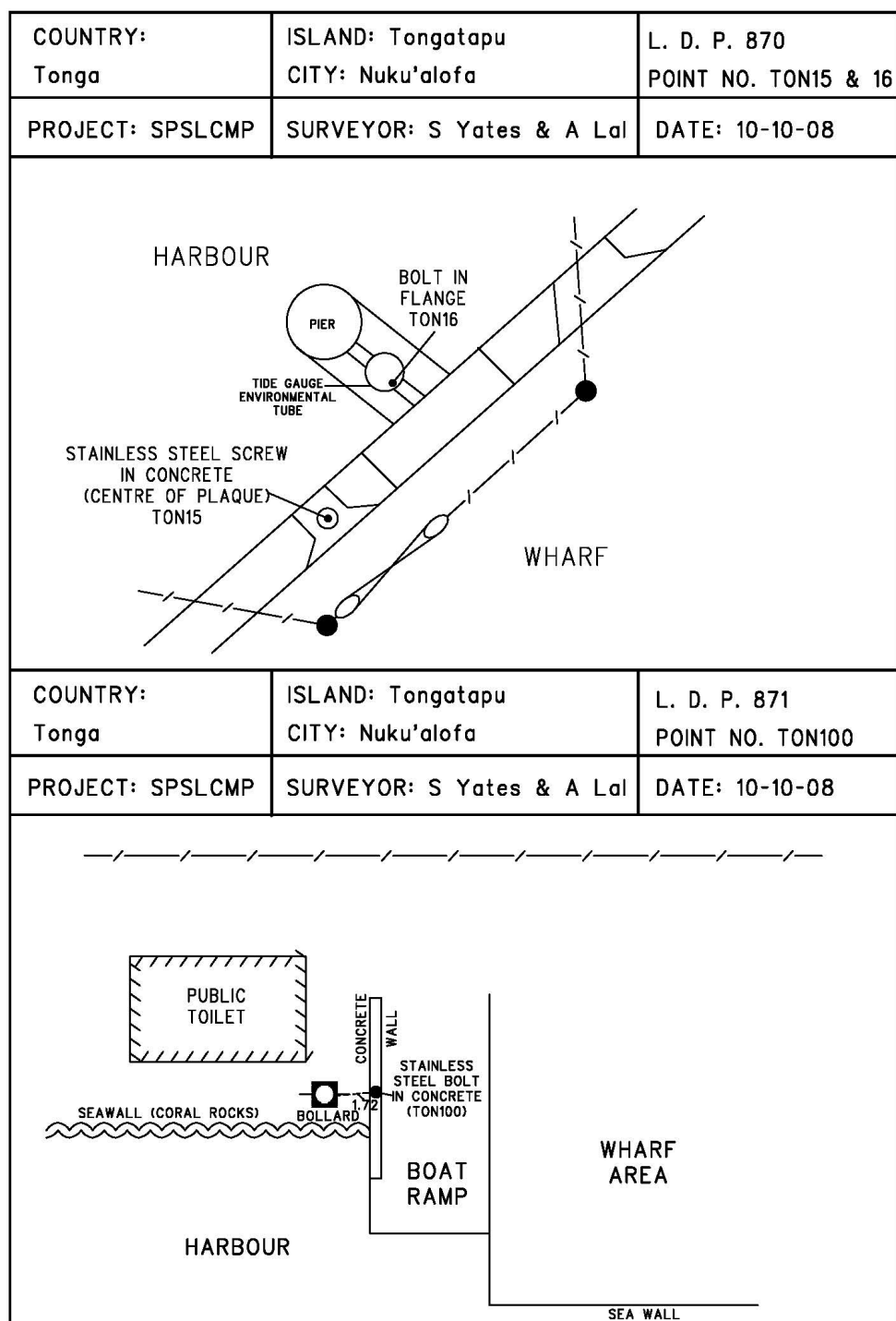
Locality sketch: Mark approximately 1100m from the tide gauge station.



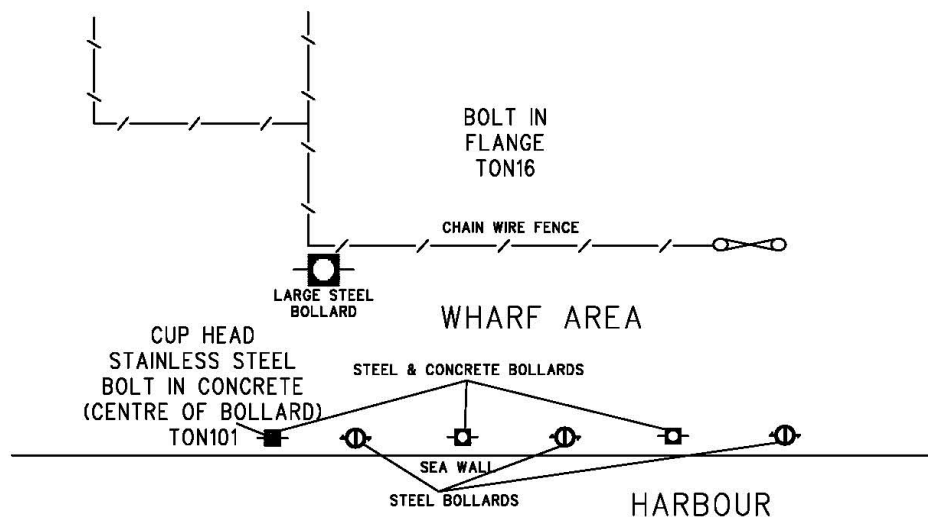
Not to scale	Distances in Metres	Magnetic bearings
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Approved by: Geoscience Australia / SOPAC	Date: April 2007 c:\users\andrick\spslcmp\localitydiagrams\tonga
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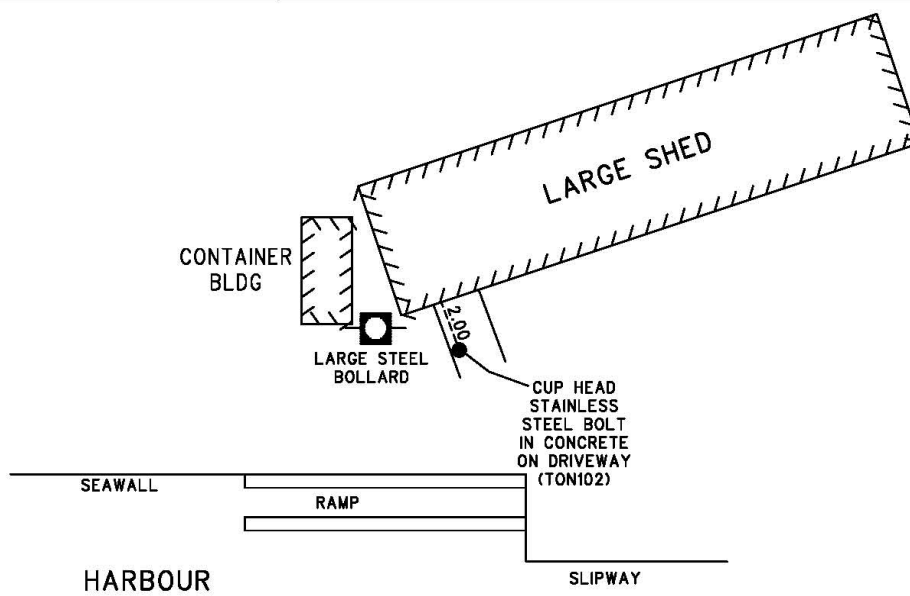
5 Temporary Holding Mark Locality Diagrams

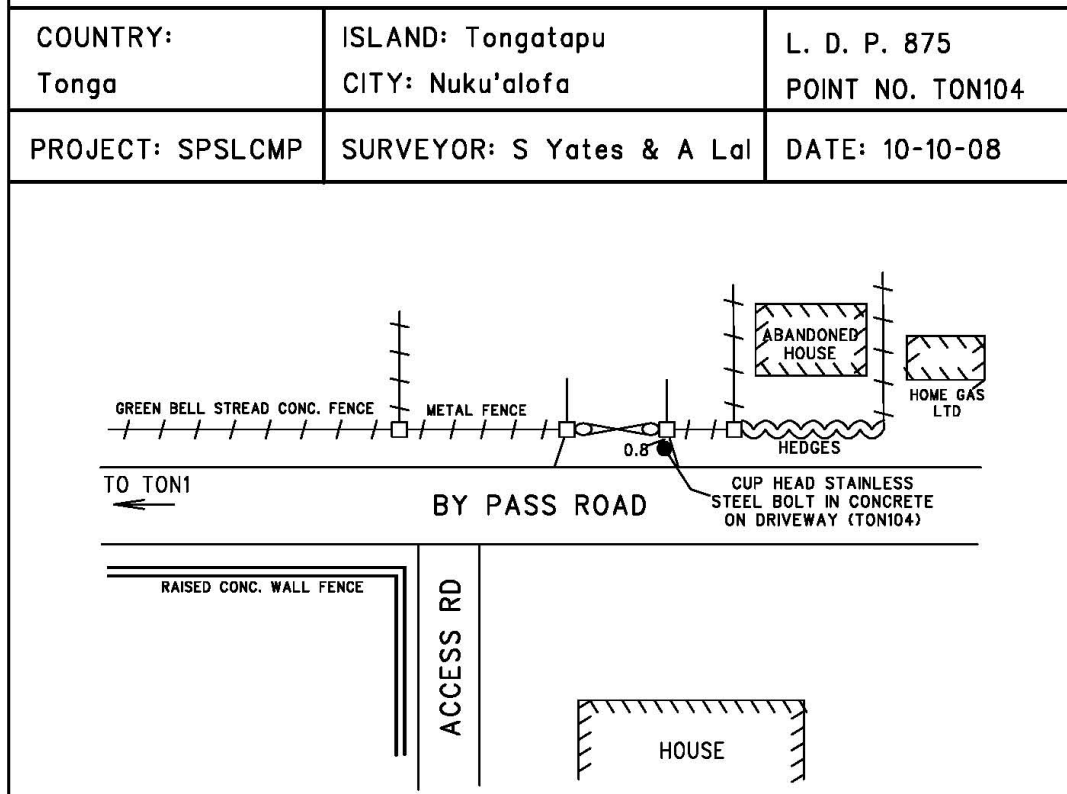
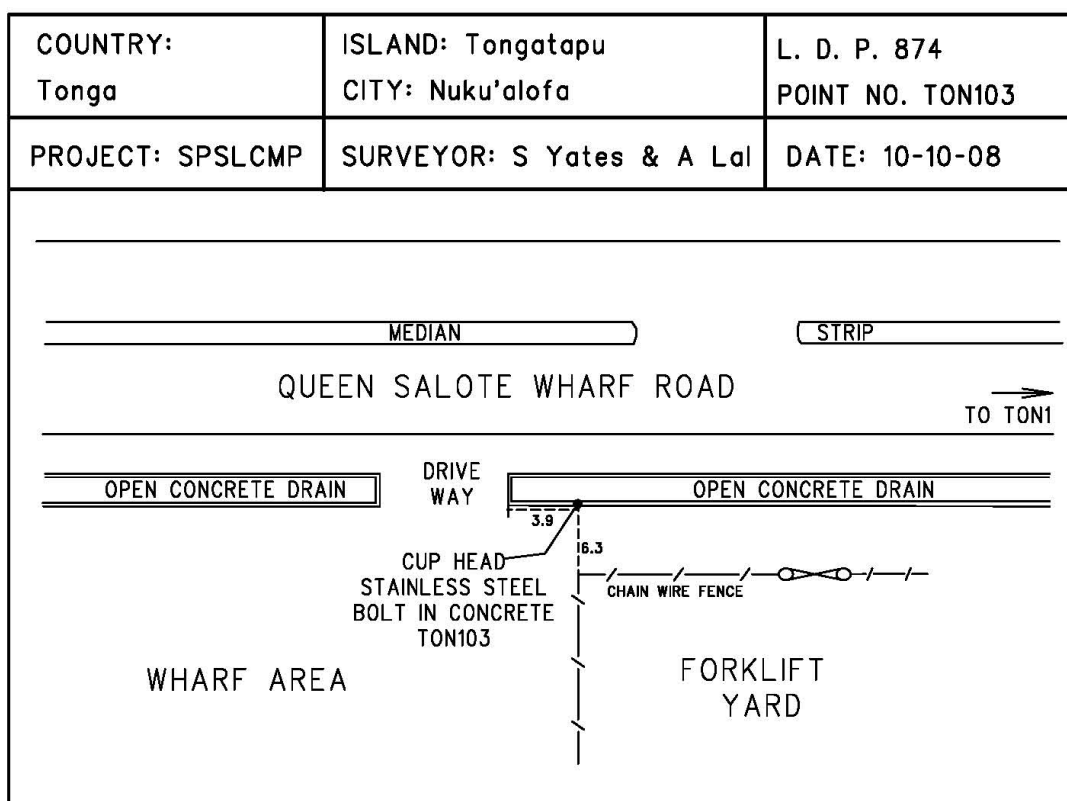


COUNTRY: Tonga	ISLAND: Tongatapu CITY: Nuku'alofa	L. D. P. 872 POINT NO. TON101
PROJECT: SPSLCMP	SURVEYOR: S Yates & A Lal	DATE: 10-10-08

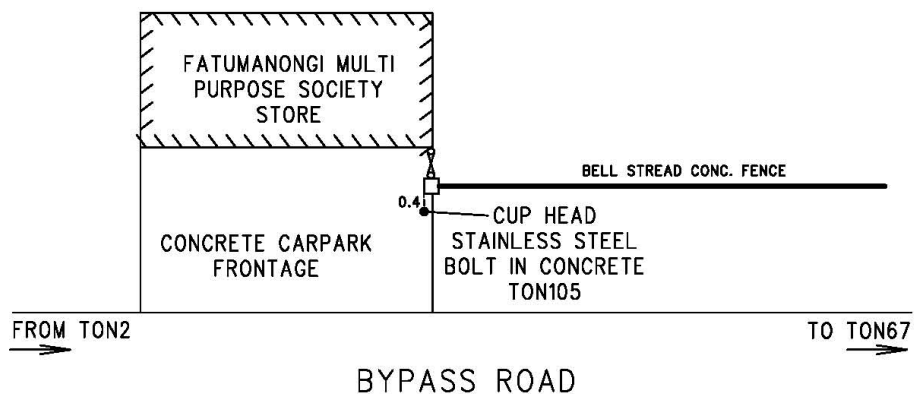


COUNTRY: Tonga	ISLAND: Tongatapu CITY: Nuku'alofa	L. D. P. 873 POINT NO. TON102
PROJECT: SPSLCMP	SURVEYOR: S Yates & A Lal	DATE: 10-10-08

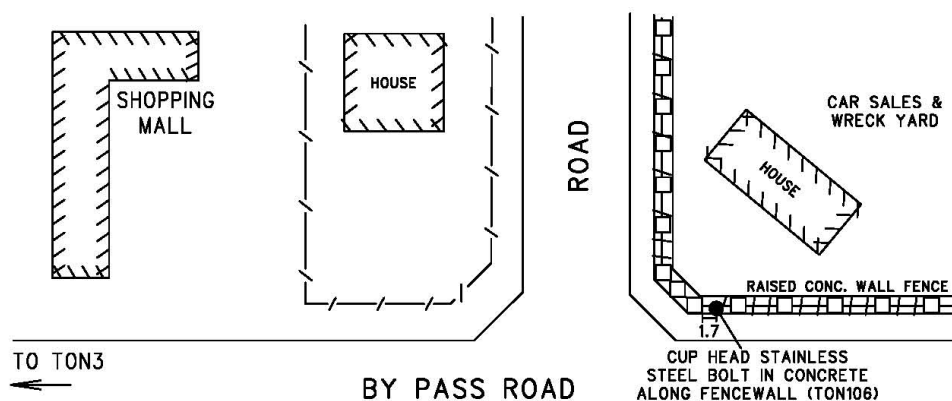




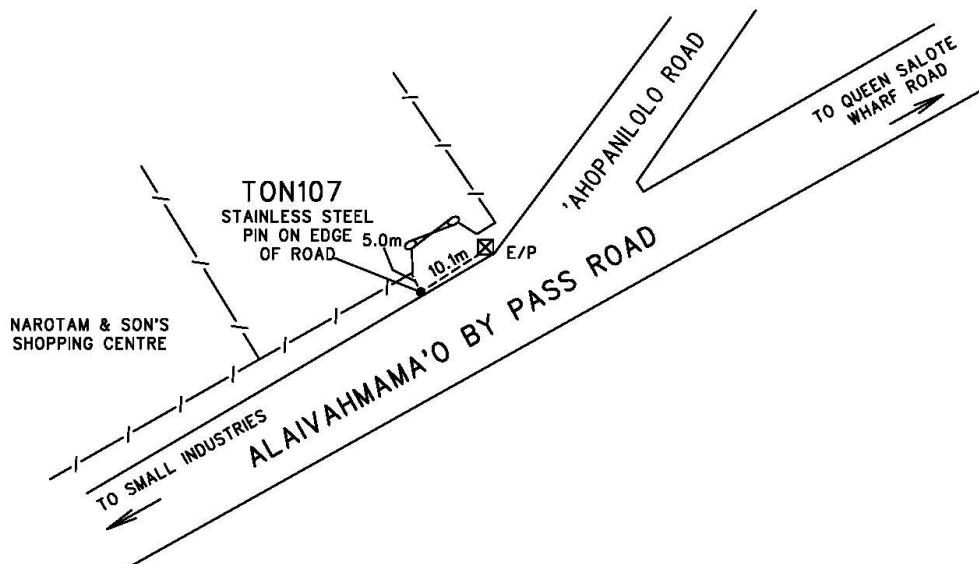
COUNTRY: Tonga	ISLAND: Tongatapu CITY: Nuku'alofa	L. D. P. 876 POINT NO. TON105
PROJECT: SPSLCMP	SURVEYOR: S Yates & A Lal	DATE: 10-10-08



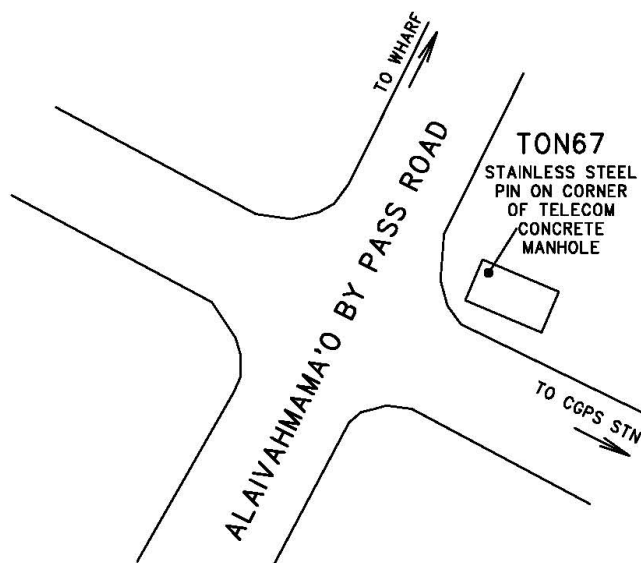
COUNTRY: Fiji Islands	ISLAND: Tongatapu CITY: Nuku'alofa	L. D. P. 877 POINT NO. TON106
PROJECT: SPSLCMP	SURVEYOR: S Yates & A Lal	DATE: 10-10-08



COUNTRY: Tonga	ISLAND: Tongatapu CITY: Nuku'alofa	L. D. P. 884 POINT NO. TON 107
PROJECT: SPSLCMP	SURVEYOR: N Brown & A Lal	DATE: 22-04-10



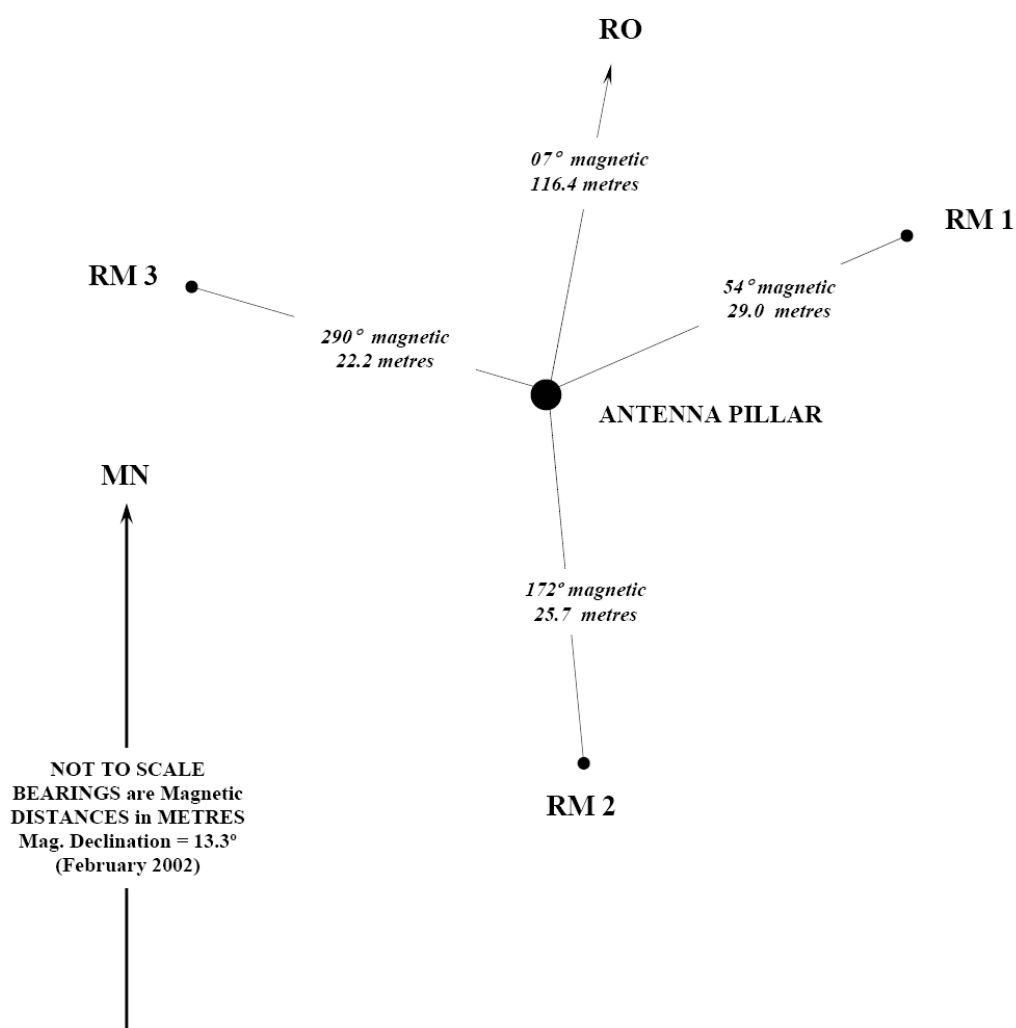
COUNTRY: Tonga	ISLAND: Tongatapu CITY: Nuku'alofa	L. D. P. 529 POINT NO. TON 67
PROJECT: SPSLCMP	SURVEYOR: S Turner & A Lal	DATE: 21-02-02



6 Reference Mark Locality Diagram

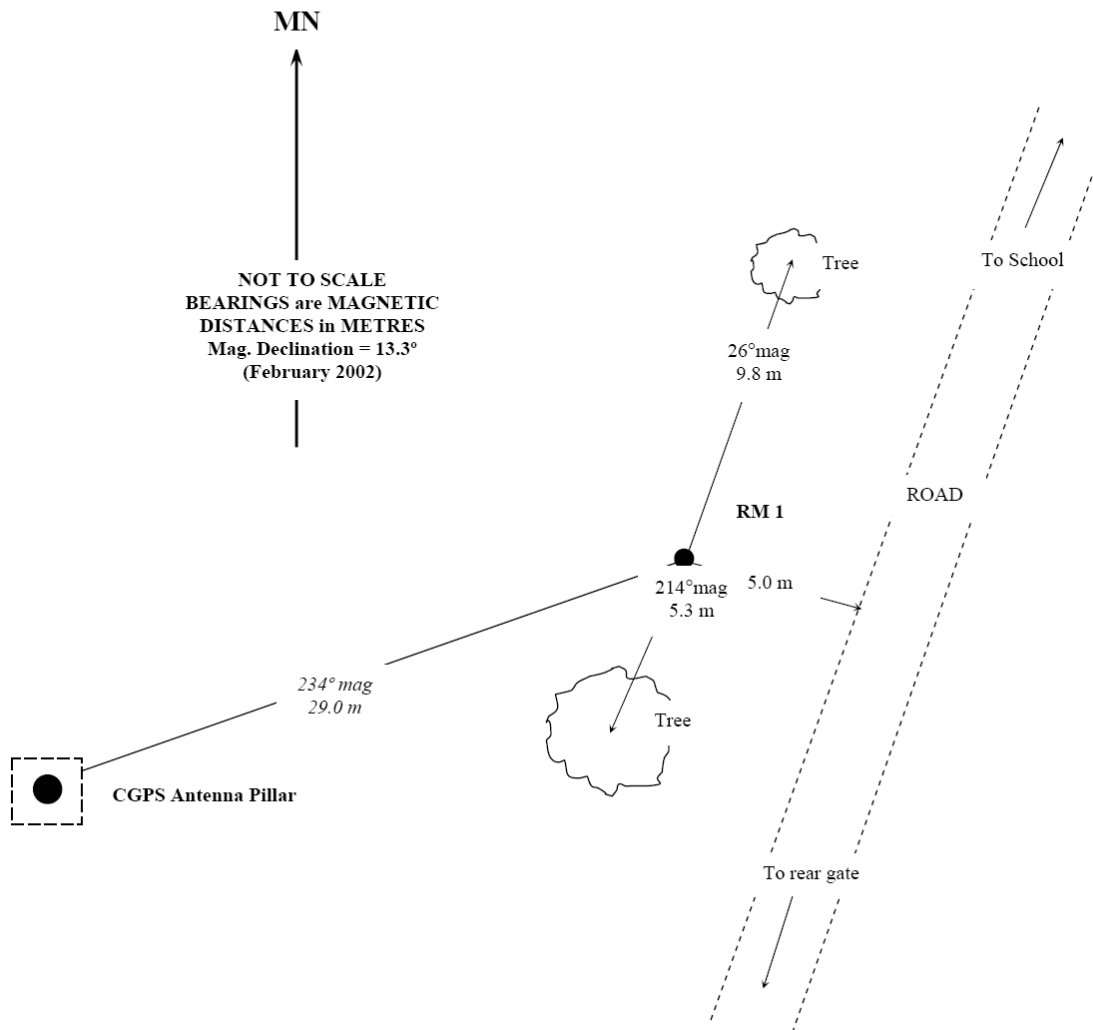
REFERENCE MARKS

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 150mm below ground level.



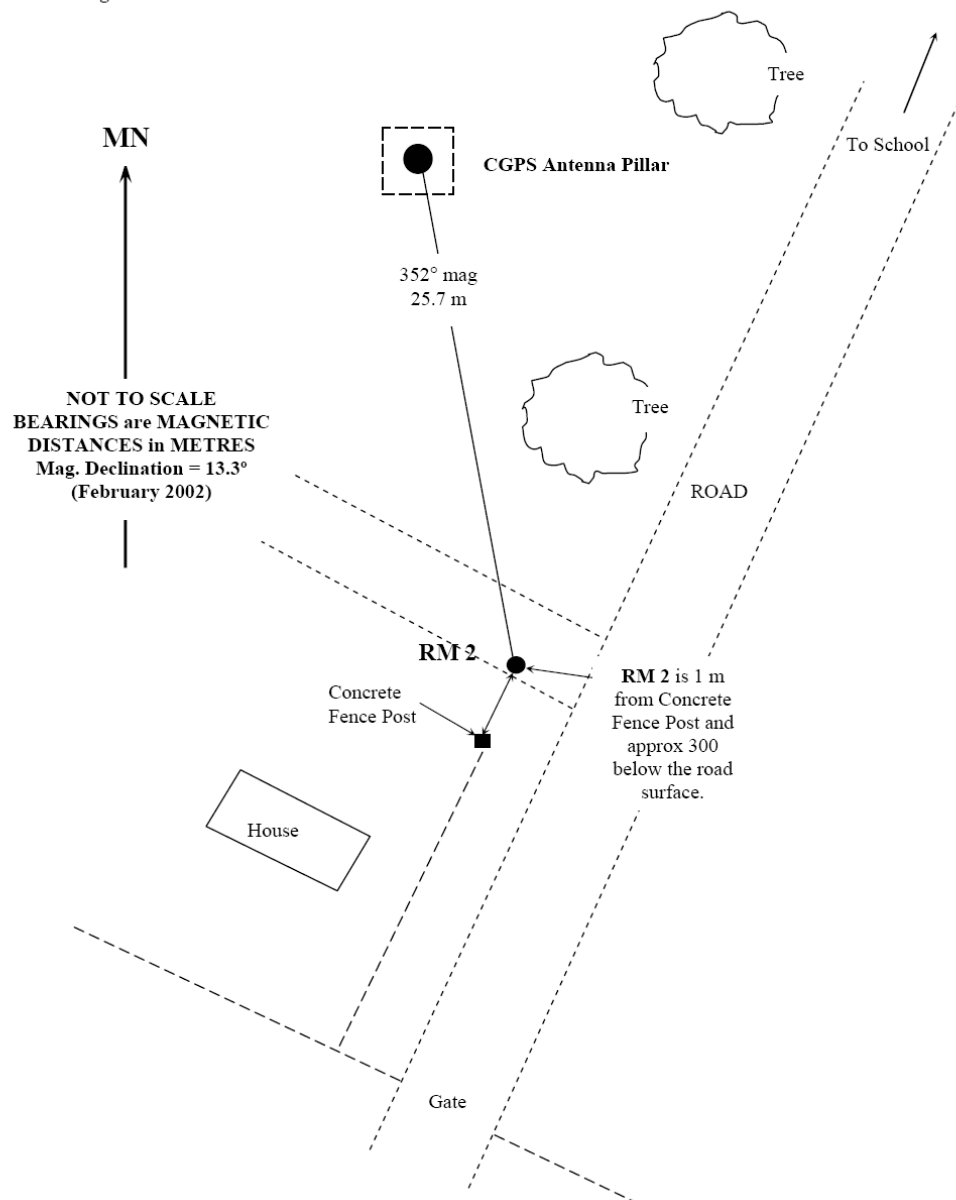
TONGA CGPS Station, Nukualofa – RM 1 Location Diagram

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 150 mm below ground level.



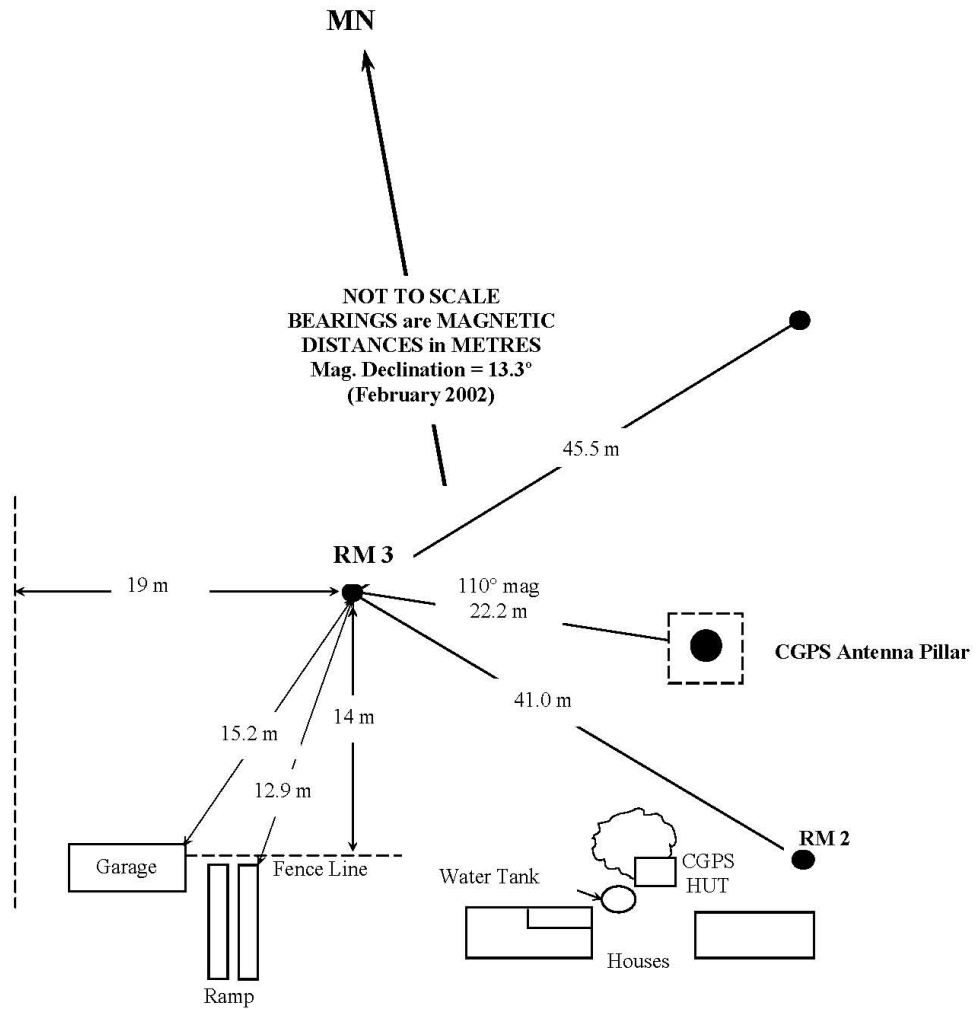
TONGA CGPS Station, Nukualofa – RM 2 Location Diagram

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 150 mm below ground level.



TONGA CGPS Station, Nukualofa – RM 3 Location Diagram

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 150 mm 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.