Pacific Sea Level and Geodetic Monitoring Project: Levelling & GNSS Monitoring Survey Report

Honiara, Solomon Islands, August 2019

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A.Lal[1], V.Rattan[1], M.Kalouniviti[1], N.J. Brown[2], B.R.Thomas[2]

Australian Government
Geoscience Australia

1. Pacific Community (SPC), Suva, Fiji
2. Geoscience Australia, Canberra, Australia

Department of Industry, Science and Resources
Minister for Resources and Northern Australia: The Hon Madeleine King MP
Secretary: Ms Meghan Quinn PSM

Geoscience Australia
Chief Executive Officer: Dr James Johnson
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1 Motivation

The Australian Bureau of Meteorology (Bureau), Geoscience Australia (GA) and the Pacific Community (SPC) work together on the Australian Aid funded Pacific Sea Level and Geodetic Monitoring Project (PSLGMP). The project is focused on determining the long-term variation in sea level through observation and analysis of changes in the height of the land (using Global Navigation Satellite System (GNSS) data) and changes in the sea level using tide gauges managed and operated by the Bureau. It is the role of GA and SPC to provide information about ‘absolute’ movement of the tide gauge (managed by Bureau) using GNSS to continuously monitor land motion and using levelling (SPC) to measure the height difference between the tide gauge and GNSS pillar every 18 months.

Land movement caused by earthquakes, subsidence and surface uplift have an important effect on sea level observations at tide gauges. For example, a tide gauge connected to a pier which is subsiding at a rate of 5 mm per year would be observed as a rate of 5 mm per year of sea level rise at the tide gauge. Because of this, it is important to measure, and account for, the movement of land when measuring ‘absolute’ sea level variation - the change in the sea level relative to the centre of the Earth. Relative sea level variation on the other hand is measured relative to local buildings and landmass around the coastline.

Geoscience Australia’s work enables more accurate 'absolute' sea level estimates by providing observations of land motion which can be accounted for by Bureau when analysing the tide gauge data.

2 Introduction

This report provides the results of the GNSS monitoring survey & high precision level survey completed between the Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) tide gauge and the GNSS Continuously Operation Reference Station (CORS) in Honiara, Solomon Islands from 4th to 11th August 2019. It also provides an updated height of the tide gauge derived from GNSS time series analysis and precise levelling observations.

GNSS Monitoring Survey

A high precision geodetic terrestrial survey is undertaken to monitor the stability of the GNSS CORS monument. This survey is used to complement GNSS analysis by determining whether movement detected by GNSS analysis is caused by localised movement of the pillar, or movement of the land across a larger area. Local movement is monitored by examining and comparing the results of repeat surveys to the monument and permanent reference marks at the GNSS CORS site.

Levelling Survey

The Total Station differential levelling technique is used to observe differences in height along the deep driven benchmark array in Honiara, which runs a distance of approximately 2.2 km from the tide gauge to the GNSS CORS. Previous levelling surveys have been conducted along this route using this technique in 2007, 2010, 2012, 2013, 2015, 2016 and 2018. This report contains an analysis of the 2019 Total Station differential levelling and GNSS monitoring results as well as a combined comparison of the previous levelling surveys.

Personal

Personnel involved in the GNSS monitoring and levelling surveys were Andrick Lal and Veenil Rattan, from the Geodetic Survey at SPC. The GNSS time series analysis and derivation of the tide gauge ellipsoidal height was undertaken by the GNSS analysis team at Geoscience Australia.

This survey was carried out in conjunction with the Bureau/SPC Tide Gauge Maintenance Team; the tide gauge station was calibrated and maintained.

2.1 Site Description and Contacts

The levelling benchmark array, GNSS CORS, and SEAFRAME are located within the Honiara town area; from the Tide Gauge at the Police dock, up to and across Mendana Avenue, through the museum grounds and streets, up through the parliament compound to the Meteorology Office on top of the hill, where the GNSS CORS is located.

Local Project Contact:	Mr. David Hiba, Director
	Solomon Islands Meteorological Service, Honiara
Email	david.hiba@met.gov.sb
Phone	+677 27658

Local Project Contact:	Mr. Jimmy Ikina, Surveyor General
	Ministry of Lands, Housing and Survey, Honiara
Email	jikina@lands.gov.sb and ikinajimmy@yahoo.com.au
Phone	+677 7725087

GNSS Contact:	Bart Thomas – GNSS Networks Team, Geoscience Australia
Email:	Bart.Thomas@ga.gov.au
Phone:	+61 2 6249 9590

SEAFRAME Contact:	Jeff Aquilina – Bureau of Meteorology, Australia
Email:	Jeff.Aquilina@bom.gov.au
Phone:	+61 8 8366 2621

2.2 Survey Support

The survey team very much appreciated the assistance from the Solomon Islands Meteorological Service, especially Mr Barnabas Tahunipue, Chief Technical Officer, for his ongoing support with the project.

The PSLGMP Survey team would also like to acknowledge the continued support of the Solomon Island Lands and Survey Department, were able to make a staff member available to assist the survey team during the survey work. Mr Alex Mosese provided the valuable assistance and support in the field.

3 Measurement Network

3.1 Terrestrial Network

The Total Station differential levelling survey was carried out between the SEAFRAME tide gauge sensors, the GNSS CORS along the existing deep driven benchmark array. This consists of Primary deep driven benchmarks, and temporary holding marks:

Table 3.1 The primary survey control network. Locality diagrams of these marks are provided in Appendix A.

Name	Description
SOL103	SEAFRAME Project Plaque Benchmark
SOL18	SEAFRAME Sensor Reference Benchmark
FBM8	Deep driven benchmark located at the entrance to the police dock compound.
FBM4	Deep driven benchmark within the museum compound, at the base of a new wall.
FBM9	Deep driven benchmark located at the intersection of streets below the parliament compound.
RM1	GNSS CORS reference mark 1
RM2	GNSS CORS reference mark 2
RM3	GNSS CORS reference mark 3
SOLOBM	Level reference benchmark for the GNSS pillar

Upon inspection, all the deep benchmarks were located, found in good order, and undisturbed. Included in the survey were the temporary holding marks; SOL110, SOL106, SOL107, SOL112, SOL114.

3.1.1 PSLGMP Vertical Reference Frame Wiring Diagram

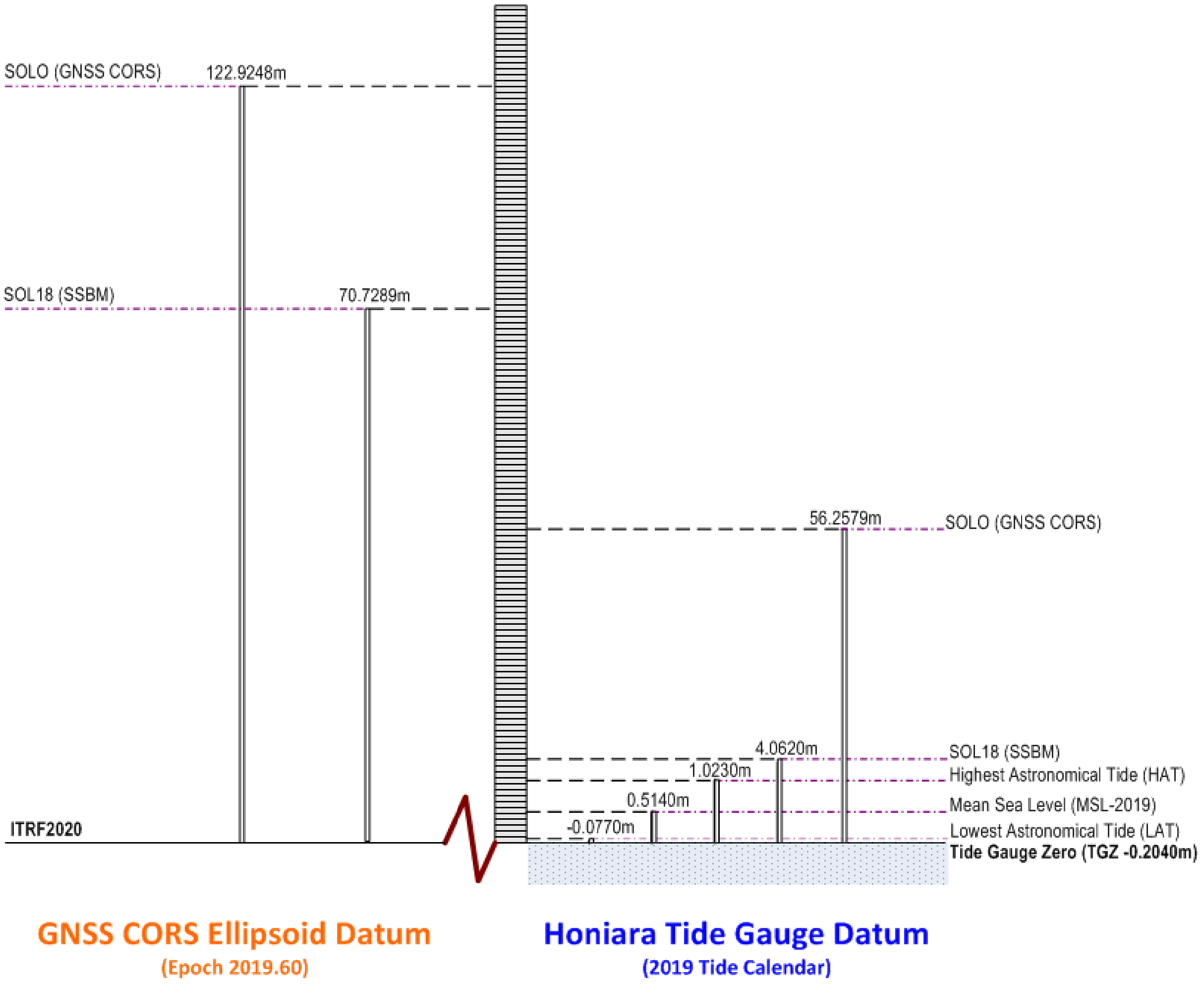


Figure 3.1 Wiring diagram depicting the offsets between surveyed marks. The left-hand side shows the height of the GNSS CORS pillar (SOLO), SEAFRAME sensor reference benchmark (SOL18) with respect to the International Terrestrial Reference Frame 2020 at epoch 2019.60. The right-hand side shows the height of SOLO, SOL18, and tidal datums with respect to tide gauge zero. For more information on tidal datums, please refer to [Pacific Sea Level and Geodetic Monitoring Project File information and Instructions (bom.gov.au)]

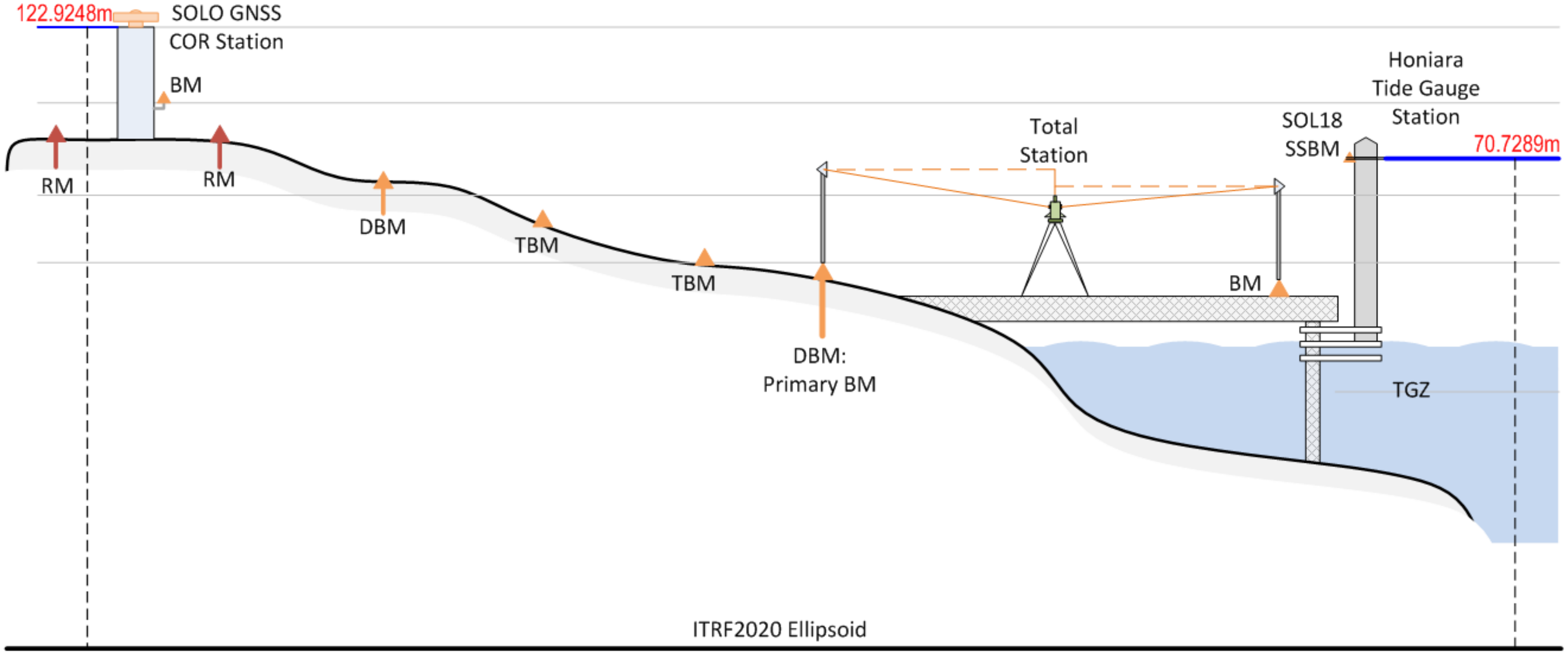


Figure 3.2 Simplified representation of the Total Station differential levelling survey carried out between the GNSS CORS and the SEAFRAME Tide Gauge.

Figure 3.3 Tide Gauge Station at the Police Patrol Jetty

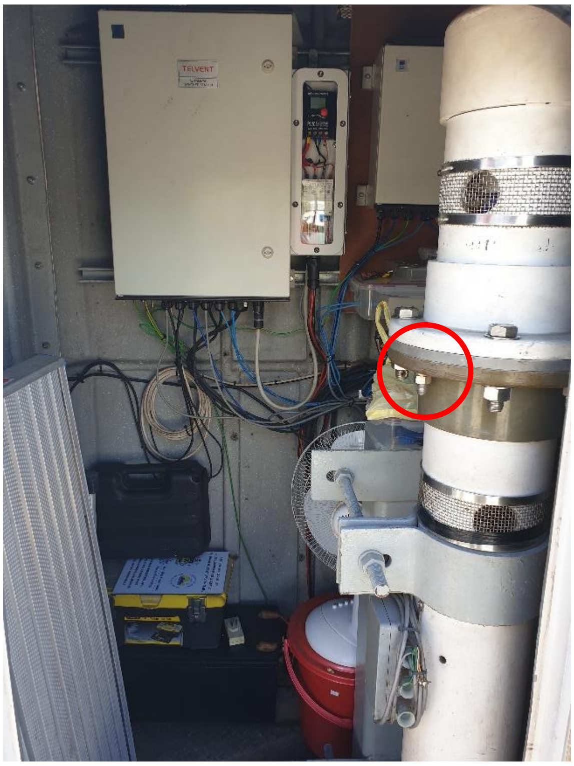


Figure 3.4 Tide Gauge Station. The red circle denotes the location of the SEAFRAME sensor reference benchmark (SOL18) at the Police Patrol Jetty.

Figure 3.5 GNSS COR Station at the Honiara Weather Station Compounds.

Figure 3.6 Levelling benchmark array. Source: Google Maps.

3.1.2 GNSS CORS and Reference Marks

The GNSS CORS site is located within the Solomon Islands Meteorological Service compound, on Vavaea Road, about 0.5 km past Parliament House, in Honiara, Solomon Islands. The site consists of a GNSS building to house the technical equipment and a 1.9 m high antenna pillar. The pillar is 30 metres from the GNSS building, access is via arrangement with the office, but should otherwise be open once they have been told of the survey intentions.

Three primary deep driven benchmarks were placed at the time of installation at a distance of 20m to 30m from the GNSS monument at approximately 120 degree radial spacing from true north (Fig 3.7), where possible. The exception in this survey is RM2, which was placed only a few meters away due to the site falling away steeply on the southern side of the monument. The RM's consist of capped 20mm stainless steel rods driven to refusal and are protected by 150mm PVC pipe within circular poly carbonate boxes.

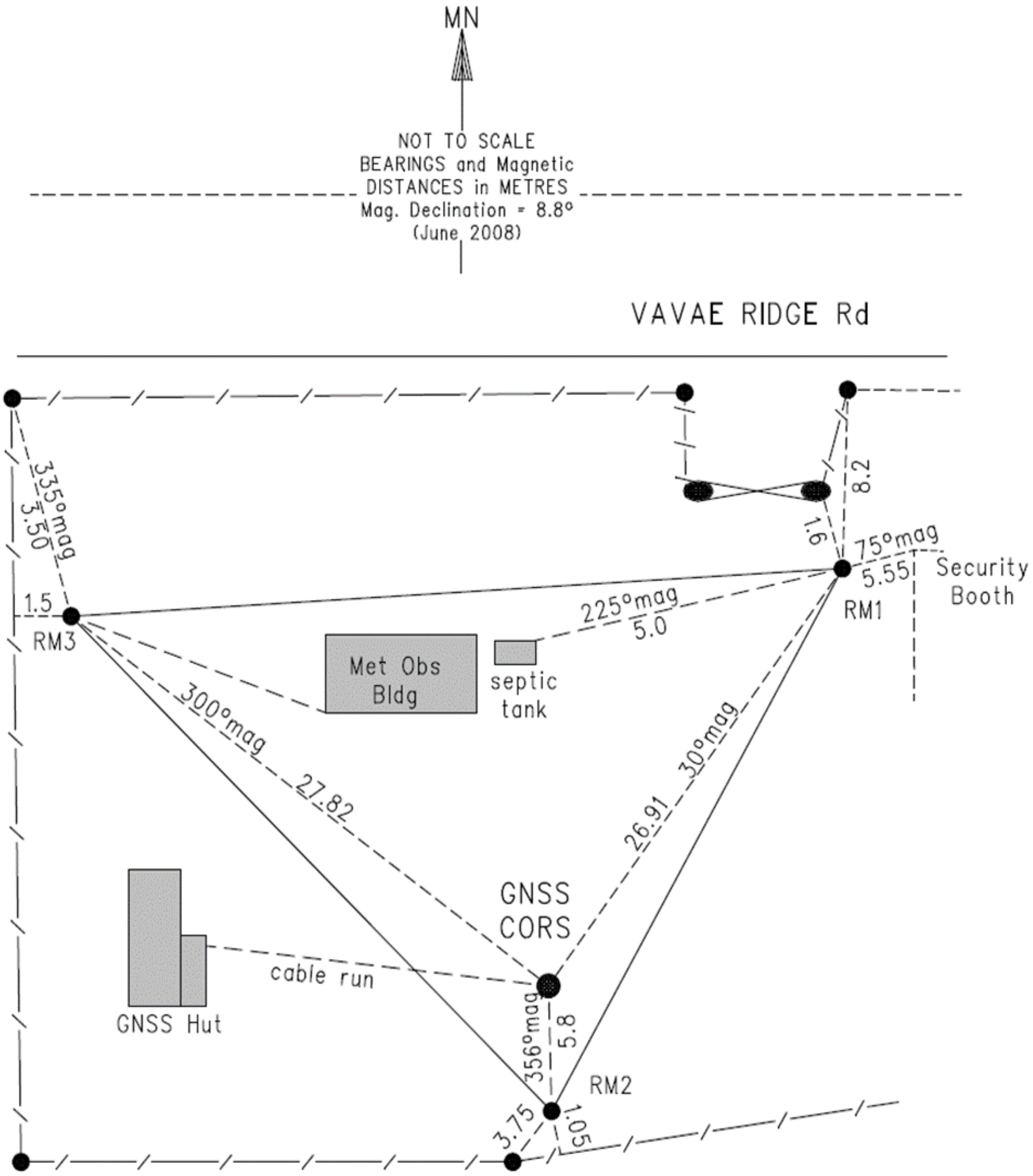


Figure 3.7 GNSS CORS site monitoring survey reference marks.

3.2 Datum

3.2.1 Survey Datum

The adopted reference point for the levelling survey is the levelling benchmark connected to the side of the GNSS CORS pillar (SOLOBM).

3.2.2 Historical Survey Datum

In the past, the adopted reference point for the levelling survey was FBM4 fixed at a RL of 3.61966m Mean Sea level (MSL). This value was determined by the National Tidal Centre Australia (NTCA) in 1994.

4 Monitoring Survey

4.1 Background

A local monitoring survey is undertaken routinely to monitor for any local horizontal or vertical movement of the GNSS pillar, relative to the RM's. The RMs are all located within 30 m of the GNSS pillar. We acknowledge that this monitoring does not account for any movement over the wider area – i.e., movements that might be consistent across all RM's.

4.1.1 Methodology

The Total Station is used to observe and record all horizontal and vertical angles and slope distances in the network by setup and observation from each RM.

Two monitoring techniques can be used to determine movement of the GNSS monument.

The conventional 'Direct Method', involves removing the GNSS antenna and setting up the Total Station on the pillar to directly observe to a prism setup on a tripod over each RM. The Total Station is then moved to each RM in turn and observations are made directly to the pillar and other RMs from each setup. This method can also provide a direct observation to the height of the antenna mount, but obviously requires an interruption to the GNSS data when the antenna is removed, which is not ideal.

The 'Indirect Method' was developed to leave the antenna undisturbed. The symmetrical properties of the antenna are used to indirectly measure the centre of the antenna by triangulation from each RM. To measure the horizontal position of the Antenna Reference Point (ARP), angular direction observations are made to symmetrically coupled points on the external profile of the antenna (Figure 4.1) from each RM. The angular observations from all setups can be averaged and intersected to give a position of the central axis of the antenna by way of triangulation from the three RMs.

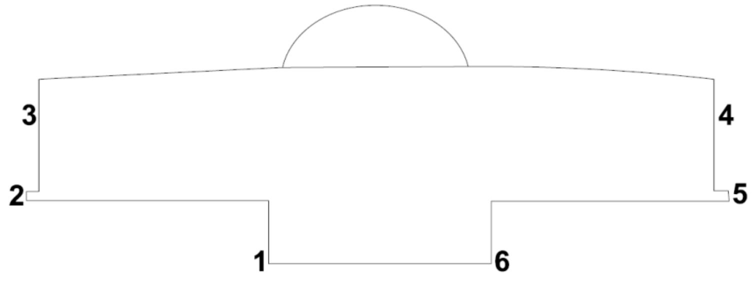


Figure 4.1 Symmetrical points on the antenna profile (TRM59800.00) observed from each RM.

The Indirect Method does not allow for a measurement of the vertical position of the monument. Instead, the result of the RM levelling survey (from each RM to the GNSS BM) is used, and then the known offset from the BM to the antenna mounting plate is applied.

Both techniques used will allow comparison to previous years, to monitor any movement of the pillar over time. The reduced observations are put into a least squares adjustment program, DynAdjust (Fraser et al., 2018), to determine the final coordinates by holding the point at the centre of the GNSS pillar plate fixed, and calculating the relative movement of each RM in ΔE, ΔN & ΔU, and an estimate of the error.

To avoid introducing any discontinuities into the GNSS time-series it is preferred, where possible, that the in-direct method of observation be used.

4.2 Horizontal Observations

The heights of the RMs are observed using the Total Station levelling (EDM height traversing) technique, with a Leica Total Station and two fixed height rods with precision reflectors (see Appendix C).

A horizontal control survey was conducted following the ICSM SP1 Guideline for Conventional Traverse Surveys (ICSM, 2021). Five sets of observations were completed at each standpoint; a set consists of a round of face left observations, followed by a round of face right observations to each of the visible survey marks. For each observation a horizontal direction, zenith angle and slope distance was recorded. At each instrument set-up atmospheric conditions (temperature, pressure and relative humidity) were recorded. Atmospheric conditions were applied during the post-processing stage and not directly into the Total Station. Instrument and target heights were measured using an offset tape.

4.3 Data Analysis and Results

4.3.1 Levelling Survey

Reduction of the digital data was computed using the Geoscience Australia levelling program “leveling1.exe” and LevellingFIELD_3.pl. This program computes the height difference between the two reflectors by taking the mean average of the measured height differences and also providing standard deviations and a misclose for the levelling loop. Refer to Section 5 for a detailed description of the levelling process.

Table 4.3.1 The Reduced Level (RL) shown is the height relative to SOLOBM.

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
SOLOBM				0.0000		0.0000
RM1	**RM1**	0.0000	-0.0680	-0.0680	0.0270	0.0270
RM2	**RM2**	0.0000	-1.2273	-1.2953	0.0327	0.0597
RM3	**RM3**	0.7382	0.0000	-0.5570	0.0330	0.0920
RM2	**RM2**	0.0000	-0.7382	-1.2953	0.0320	
RM1	**RM1**	1.2273	0.0000	-0.0680	0.0327	
	SOLOBM	0.0679	0.0000	-0.0001	0.0270	
	Sum:	2.0334	-2.0335			
	Misclose:		-0.0001	-0.0001	0.1840	(Total Dist.)
			ALLOWABLE (m):	**0.0006**	**2 x Sqrt (km) test:**	**PASS**

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
SOLOBM				0.000		0.0000
RM2	**RM2**	0.0000	-1.2955	-1.2955	0.0090	0.0090
	SOLOBM	1.2954	0.0000	0.0000	0.0090	
	Sum:	1.2954	-1.2955			
	Misclose:		0.0000	0.0000	0.0180	(Total Dist.)
			ALLOWABLE (m):	**0.0002**	**2 x Sqrt (km) test:**	**PASS**

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
SOLOBM				0.0000		0.0000
RM3	**RM3**	0.0000	-0.5575	-0.5575	0.0290	0.0290
	SOLOBM	0.5574	0.0000	-0.0001	0.0280	
	Sum:	0.5574	-0.5575			
	Misclose:		-0.0001	-0.0001	0.057	(Total Dist.)
			ALLOWABLE (m):	**0.0003**	**2 x Sqrt (km) test:**	**PASS**

4.3.2 Geodetic Adjustment

All observations were combined into a geodetic adjustment using DynAdjust (Fraser et al., 2018). In the adjustment, the point on the GNSS pillar plate (SOLO) was tightly constrained to its ITRF2014 coordinates and aligned to SOLO-RM3 with an azimuth of 314° 26' 51.4376", which had been determined in the 2008 survey by GNSS observation to RM3. The angular observations were given a precision of 1.0 mm and the slope distances a precision of 1.0 mm. The estimated coordinates and associated variance-covariance matrix were outputted in a SINEX file format and have been provided to Geoscience Australia.

The ITRF2014@2010.0 latitude and longitude coordinates adopted at SOLO as GNSS constraint are taken from the Geoscience Australia GNSS portal[1]. The ellipsoidal height is the ITRF2020 height from the week of the survey. For more information on how this ellipsoidal height was computed, see Brown et al. (2020).

[1] GNSS Network Portal (ga.gov.au)

Table 4.3.2 Latitude, Longitude and Ellipsoidal Height (metres) for the GNSS & RM stations. ITRF2014@2010.00 Latitude, Longitude coordinates, and ITRF2020@2019.60 ellipsoidal height were adopted at SOLO. CCC means all 3 dimensions (in XYZ) are constrained and FFF means they were all free,

Station	Constraint	Latitude	Longitude	Ellipsoidal height (m)
SOLO	**CCC**	-9° 26’ 05.69373”	159° 57’ 15.6532”	122.9248
RM1	**FFF**	-9° 26’ 05.04764”	159° 57’ 16.2489”	121.3920
RM2	**FFF**	-9° 26’ 05.88579“	159° 57’ 15.6411”	120.1651
RM3	**FFF**	-9° 26’ 05.05966”	159° 57’ 15.0022”	120.9031

Table 4.3.3 Earth Centred Cartesian coordinates and associated standard deviations (metres) for the GNSS & RM stations. ITRF2014@2010.00 Latitude, Longitude coordinates (as per https://gnss.ga.gov.au/network ITRF2020@2019.60 ellipsoidal height were adopted at SOLO

Description	X	Y	Z	SD(e)	SD(n)	SD(up)
SOLO	-5911340.2051	2156887.3968	-1038663.9606	0.0000	0.0000	0.0000
RM1	-5911348.0710	2156870.9208	-1038644.1273	0.0003	0.0004	0.0001
RM2	-5911336.6129	2156886.4777	-1038669.3292	0.0001	0.0002	0.0001
RM3	-5911334.5241	2156906.4651	-1038644.4116	0.0003	0.0003	0.0001

Table 4.3.4 Difference in XYZ coordinates between the GNSS pillar and RMs (metres)

FROM	To	ΔE	ΔN	ΔU
SOLO	**RM1**	18.1740	19.8505	-1.5328
SOLO	**RM2**	-0.3679	-5.9008	-2.7597
SOLO	**RM3**	-19.8604	19.4811	-2.0217

4.4 Assessment of Results

Table 4.4.1 and Figures 4.4.1 – 4.4.3 show the movement of the reference marks with respect to the GNSS pillar in ΔE, ΔN and ΔU. No obvious errors or movement are apparent in the time series.

Table 4.4.1 Topocentric vectors showing delta east, delta north and delta up between the GNSS pillar and each Reference Mark (metres).

YEAR	FROM	To	ΔE	ΔN	ΔU
2008	**SOLO**	**RM1**	18.1741	19.8511	-1.5331
2009	**SOLO**	**RM1**	18.1751	19.8517	-1.5355
2010	**SOLO**	**RM1**	18.1746	19.852	-1.5332
2015	**SOLO**	**RM1**	18.1731	19.8503	-1.5330
2016	**SOLO**	**RM1**	18.1732	19.8502	-1.5329

2018	**SOLO**	**RM1**	18.1740	19.8517	-1.5330
2019	**SOLO**	**RM1**	18.1740	19.8505	-1.5328
Ref RL	**(as at 2010)**		**18.1746**	**19.8516**	**-1.5339**

YEAR	FROM	To	ΔE	ΔN	ΔU
2008	**SOLO**	**RM2**	-0.3666	-5.896	-2.7599
2009	**SOLO**	**RM2**	-0.3661	-5.8972	-2.762
2010	**SOLO**	**RM2**	-0.3665	-5.8965	-2.7597
2015	**SOLO**	**RM2**	-0.3672	-5.8997	-2.7600
2016	**SOLO**	**RM2**	-0.3676	-5.8996	-2.7598
2018	**SOLO**	**RM2**	-0.3679	-5.9009	-2.7600
2019	**SOLO**	**RM2**	-0.3679	-5.9008	-2.7597
Ref RL	**(as at 2010)**		**-0.3664**	**-5.8966**	**-2.7605**

YEAR	FROM	To	ΔE	ΔN	ΔU
2008	**SOLO**	**RM3**	-19.8589	19.4796	-2.0221
2009	**SOLO**	**RM3**	-19.8587	19.4795	-2.0242
2010	**SOLO**	**RM3**	-19.8597	19.4805	-2.0220
2015	**SOLO**	**RM3**	-19.8591	19.4798	-2.0220
2016	**SOLO**	**RM3**	-19.8594	19.4801	-2.0220
2018	**SOLO**	**RM3**	-19.8604	19.4811	-2.0219
2019	**SOLO**	**RM3**	-19.8604	19.4811	-2.0217
Ref RL	**(as at 2010)**		**-19.8591**	**19.4799**	**-2.0228**

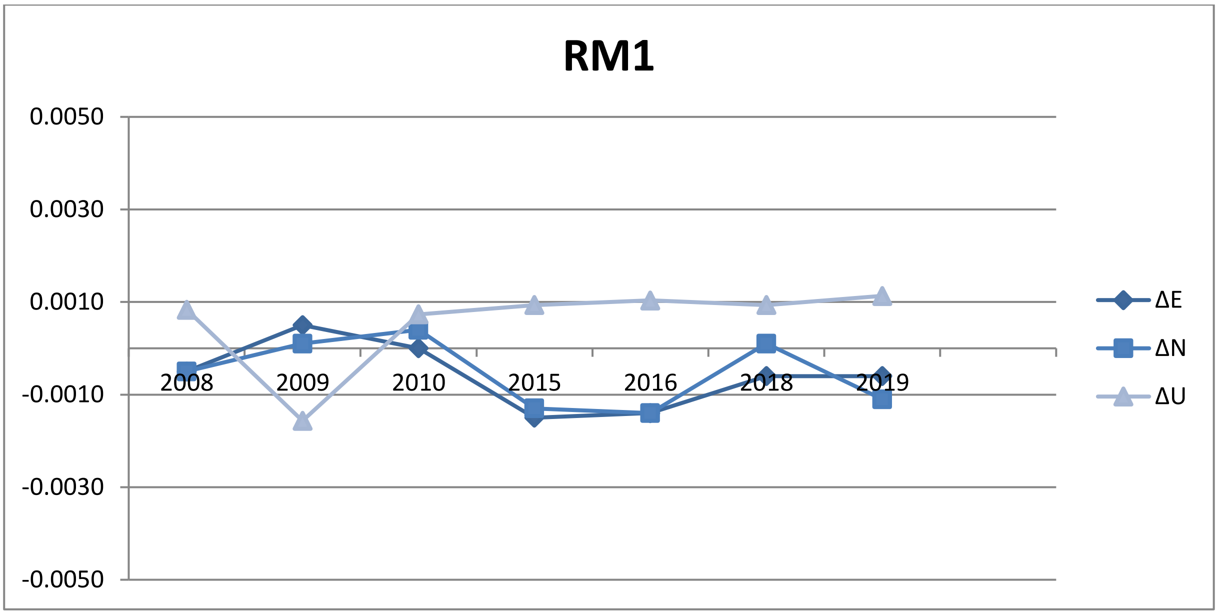


Figure 4.4.1 Time series of RM1 movement relative to GNSS pillar (0 = REF pre 2010 mean).

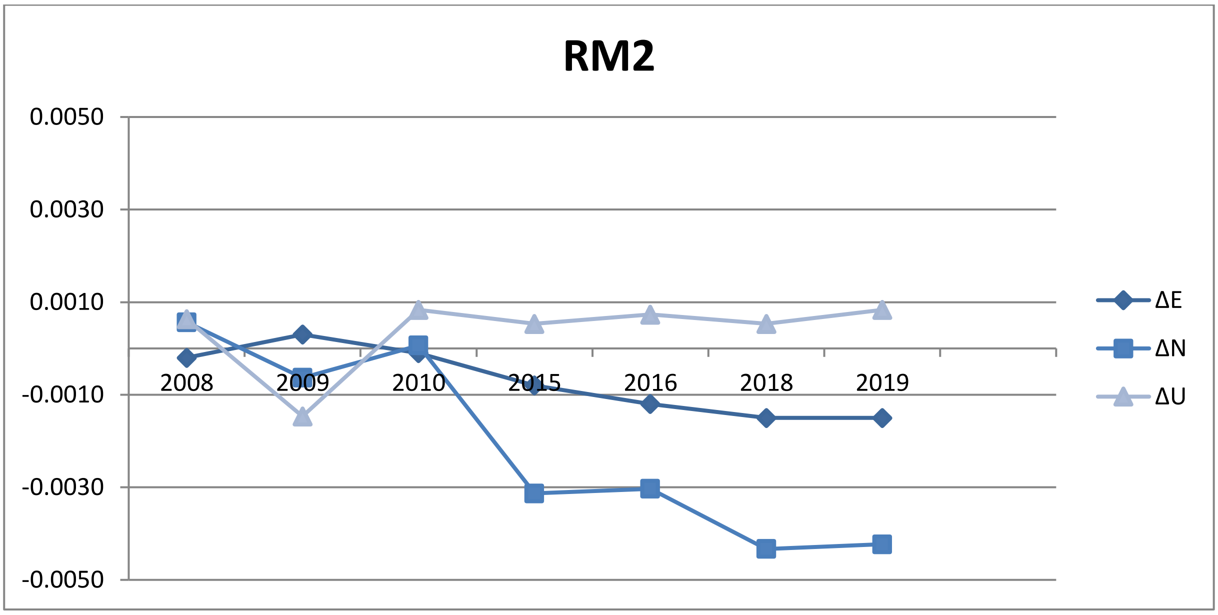


Figure 4.4.2 Time series of RM2 movement relative to GNSS pillar (0 = REF pre 2010 mean).

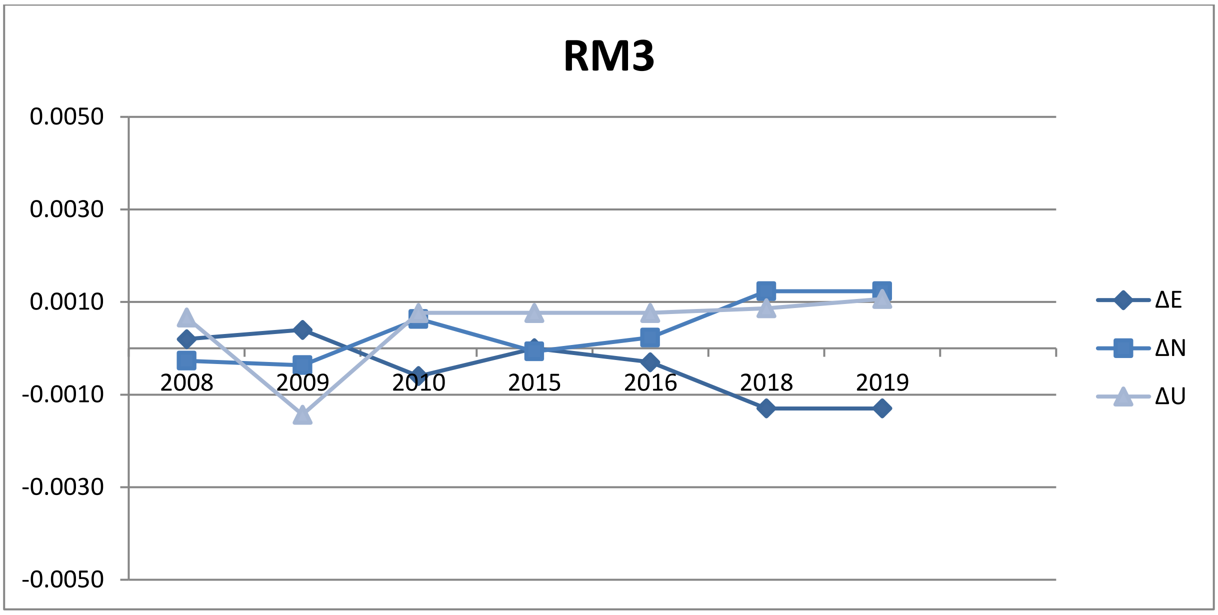


Figure 4.4.3 Time series of RM3 movement relative to GNSS pillar (0 = REF pre 2010 mean).

5 Tide Gauge Level Connection

5.1 Background

The Total Station differential levelling technique was performed in accordance with the SP1 levelling guidelines (ICSM, 2021). After reduction an internal precision of 1mm√K or better was achieved within each survey bay, where K is distance in kilometres.

5.2 Survey Methodology

The Total Station differential levelling technique was used for the Honiara tide gauge levelling survey. This technique uses a 'leap-frog' method which involves setting up a Total Station midway between two target/reflectors (on a reflector rod with bi-pod). The targets remain at a particular change point for the backsight and foresight observations and all levelling runs start and finish with the same reflector and reflector rod to eliminate any reflector rod 'zero error'.

This technique can also be performed using a single set-up / single rod configuration which was the case when levelling between benchmarks which are close together e.g., between the GNSS CORS RMs.

The levelling run was divided into bays between each holding benchmark. Observations were completed in both directions within the bay to close each loop along the way. This method provides a closure between bench marks and allows a hold point in the survey in case of severe weather, physical interference, or time restrictions while completing the survey across the week.

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). Five rounds of observations are taken to the backsight and foresight targets from each instrument setup. The instrument measures slope distances (±1mm) and vertical angle (1") to derive height differences.

Table 5.2.2 contains the values of the constants or calibrated heights used throughout the analysis.

Table 5.2.2 Calibrations and constants.

Name	Value (m)	Description
SOLO (ellipsoidal ht)	122.9248	Observed RL at the ARP of SOLO (Ellipsoidal) @ 2019.60
SOLO - SOLOBM	-1.4646	Offset constant between GNSS BM at GNSS pillar plate
Primary Pole & 1/2m Pole	1.00117	Height difference between poles used (Calibrated August 2019)
Primary Pole & TG Pole	1.43288	Height difference between poles used (Calibrated August 2019)

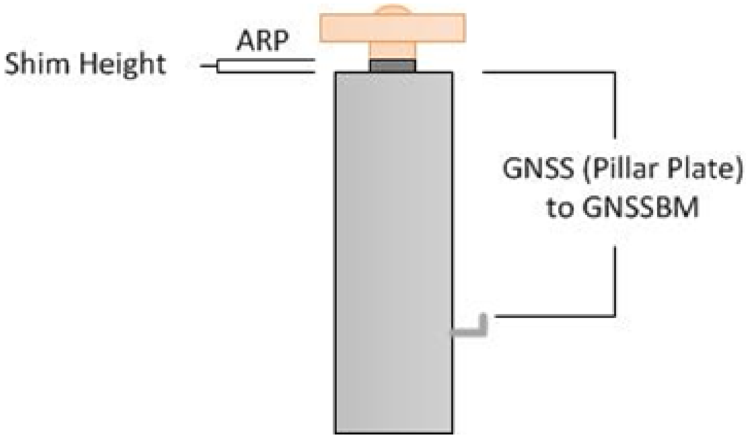


Figure 5.2.1 GNSS Pillar Offsets

5.3 Data Analysis and Results

Reduction of the digital data was computed using the Geoscience Australia levelling program “levelingFIELD_3.pl” and “leveling1.exe”. This program computes the height difference between the two reflectors by taking the mean average of the measured height differences and also providing standard deviations and a misclose for the input levelling loop.

The Reduced Level (RL) shown in Table 5.3.1 below is the height relative to SOLOBM (GNSS BM)

Table 5.3.1 Reduced level data – SOLO (GNSS CORS) to FBM8 (Primary Benchmark)

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
SOLO				1.4646		
SOLOBM	**SOLOBM**	0.0000	-1.4646	0.0000	0.000	0.000
s110	**s110**	0.0000	-0.2249	-0.2249	0.037	0.037
s114	**s114**	0.0000	-8.3889	-8.6138	0.163	0.201
s112	**s112**	0.0000	-39.4765	-48.0903	0.190	0.390
FBM9	**FBM9**	0.0000	-1.4651	-49.5554	0.048	0.439
s107	**s107**	0.2465	0.0000	-49.3089	0.148	0.586
FBM4	**FBM4**	0.0000	-1.3751	-50.6839	0.112	0.698
s106	**s106**	0.0000	-0.4137	-51.0976	0.133	0.831
FBM8	**FBM8**	0.0000	-1.2419	-52.3395	0.140	0.971
s106	**s106**	1.2420	0.0000	-51.0976	0.140	
FBM4	**FBM4**	0.4140	0.0000	-50.6836	0.133	
s107	**s107**	1.3749	0.0000	-49.3087	0.112	
FBM9	**FBM9**	0.0000	-0.2467	-49.5554	0.148	
s112	**s112**	1.4651	0.0000	-48.0904	0.049	
s114	**s114**	39.4763	0.0000	-8.6141	0.190	
s110	**s110**	8.3887	0.0000	-0.2254	0.163	
SOLOBM	**SOLOBM**	0.2251	0.0000	-0.0003	0.038	
	SOLO	1.4646	0.0000	1.4643	0.000	
	Sum:	54.2970	-54.2973			
	Misclose:		-0.0003	-0.0003	1.943	(Total Dist.)
			ALLOWABLE (m):	**0.0020**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.2 Reduced level data – FBM8 (Primary BM) to SOL18 (Tide Gauge Sensor Benchmark)

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
FBM8				-52.3395	0.000	0.971
SOL103	**SOL103**	0.3446	0.0000	-51.9950	0.125	1.095
SOL18	**SOL18**	1.2636	0.0000	-50.7313	0.008	1.103
SOL103	**SOL103**	0.0000	-1.2637	-51.9950	0.008	
	FBM8	0.0000	-0.3445	-52.3395	0.125	
	Sum:	1.6082	-1.6082			
	Misclose:		0.0000	0.0000	0.264	(Total Dist.)
			ALLOWABLE (m):	**0.0007**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.3 Measured height differences (in metres) between all BMs (ΔH_{2019})

	SOLOBM	s110	s114	s112	FBM9	FBM4	FBM8	SOL103	SOL18	RM1	RM2	RM3	SOLO
SOLOBM	-	-0.2251	-8.6139	-48.0903	-49.5554	-50.6838	-52.3395	-51.9950	-50.7313	-0.0680	-1.2953	-0.5570	1.4646
s110	0.2251	-	-8.3888	-47.8652	-49.3303	-50.4586	-52.1144	-51.7698	-50.5062	0.1571	-1.0701	-0.3319	1.6897
s114	8.6139	8.3888	-	-39.4764	-40.9415	-42.0699	-43.7256	-43.3811	-42.1174	8.5459	7.3187	8.0569	10.0785
s112	48.0903	47.8652	39.4764	-	-1.4651	-2.5935	-4.2492	-3.9047	-2.6410	48.0223	46.7950	47.5333	49.5549
FBM9	49.5554	49.3303	40.9415	1.4651	-	-1.1284	-2.7841	-2.4396	-1.1759	49.4874	48.2601	48.9984	51.0200
FBM4	50.6838	50.4586	42.0699	2.5935	1.1284	-	-1.6557	-1.3112	-0.0475	50.6158	49.3885	50.1268	52.1484
FBM8	52.3395	52.1144	43.7256	4.2492	2.7841	1.6557	-	0.3445	1.6082	52.2715	51.0443	51.7825	53.8041
SOL103	51.9950	51.7698	43.3811	3.9047	2.4396	1.3112	-0.3445	-	1.2637	51.9270	50.6997	51.4380	53.4596
SOL18	50.7313	50.5062	42.1174	2.6410	1.1759	0.0475	-1.6082	-1.2637	-	50.6633	49.4361	50.1743	52.1959
RM1	0.0680	-0.1571	-8.5459	-48.0223	-49.4874	-50.6158	-52.2715	-51.9270	-50.6633	-	-1.2273	-0.4890	1.5326
RM2	1.2953	1.0701	-7.3187	-46.7950	-48.2601	-49.3885	-51.0443	-50.6997	-49.4361	1.2273	-	0.7382	2.7599
RM3	0.5570	0.3319	-8.0569	-47.5333	-48.9984	-50.1268	-51.7825	-51.4380	-50.1743	0.4890	-0.7382	-	2.0216
SOLO	-1.4646	-1.6897	-10.0785	-49.5549	-51.0200	-52.1484	-53.8041	-53.4596	-52.1959	-1.5326	-2.7599	-2.0216	-

Table 5.3.4 Time-series of Reduced Levels (with respect to SOLOBM).

YEAR	SOLOBM	s110	s114	s112	FBM9	FBM4	FBM8	SOL103	SOL18	RM1	RM2	RM3	SOLO
2007.7	0.000				-49.5611	-50.6914	-52.3485	-52.0018	-50.7391				
2009.4	0.000	-0.2233			-49.5631	-50.6937	-52.3508	-52.0049	-50.7417				
2010.9	0.000	-0.2239	-8.6146	-48.0813	-49.5532	-50.6835	-52.3412	-51.9955	-50.7327	-0.0686			1.4646
2012.0	0.000	-0.2237	-8.6053	-48.0926	-49.5617	-50.6916	-52.3495	-52.0051	-50.7421				1.4646
2013.0	0.000	-0.2257	-8.6183	-48.0954	-49.5627	-50.6937	-52.3518	-52.0069	-50.7437	-0.0685			
2015.3	0.000	-0.2239	-8.6141	-48.0892	-49.5551	-50.6834	-52.3401	-51.9952	-50.7323	-0.0681	-1.2952	-0.5573	1.4646
2016.6	0.000	-0.2237	-8.6157	-48.0924	-49.5607	-50.6895	-52.3484	-52.0028	-50.7399	-0.0680	-1.2953	-0.5574	1.4646
2018.1	0.000		-8.6106	-48.0892	-49.5545	-50.6823	-52.3393	-51.9949	-50.7316	-0.0681	-1.2954	-0.5575	1.4646
2019.6	0.000	-0.2251	-8.6139	-48.0903	-49.5554	-50.6838	-52.3395	-51.9950	-50.7313	-0.0680	-1.2953	-0.5570	1.4646

5.4 Comparison with previous surveys

All historic data has been readjusted relative to the benchmark attached to the base of the GNSS pillar (SOLOBM) (Table 5.3.4). To investigate whether BMs have moved over time, the RLs from the 2019 survey (RL_{2019}) have been compared to a reference height (RH) defined as the average of all previously calculated RLs. In cases where a site has undergone known movement (e.g., BM removed and reinstalled), the RH is the latest measured RL.

5.4.1 Difference in Reference Height Values

Table 5.4.1.1. ΔRL_{REF} - ΔRL_{2019} values (in metres). Shows the difference in height between two marks from the current survey compared to the reference height difference.

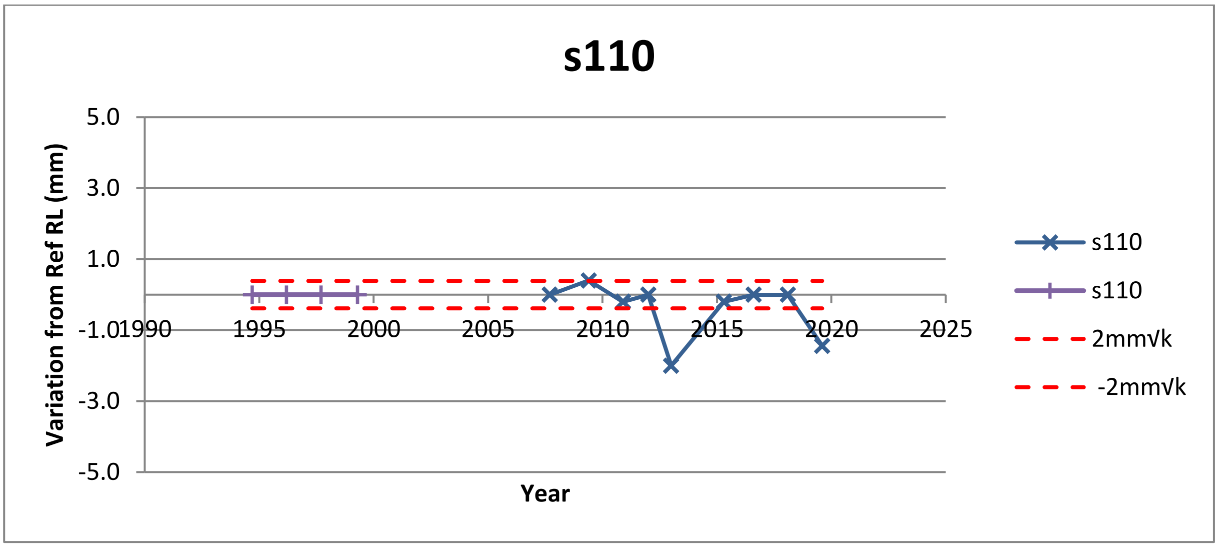
REF - 2019	SOLOBM	s110	s114	s112	FBM9	FBM4	FBM8	SOL103	SOL18	RM1	RM2	RM3	SOLO
SOLOBM	-	0.0014	-0.0007	-0.0015	**-0.0053**	**-0.0058**	**-0.0088**	**-0.0059**	**-0.0075**	-0.0002	-0.0001	-0.0004	0.0000
s110	-0.0014	-	-0.0022	-0.0029	**-0.0068**	**-0.0072**	**-0.0103**	**-0.0073**	**-0.0089**	-0.0016	-0.0015	-0.0018	-0.0014
s114	0.0007	0.0022	-	-0.0007	**-0.0046**	**-0.0050**	**-0.0081**	**-0.0052**	**-0.0067**	0.0005	0.0007	0.0004	0.0007
s112	0.0015	0.0029	0.0007	-	-0.0039	-0.0043	**-0.0074**	-0.0044	**-0.0060**	0.0013	0.0014	0.0011	0.0015
FBM9	**0.0053**	**0.0068**	**0.0046**	0.0039	-	-0.0004	-0.0035	-0.0006	-0.0021	**0.0052**	**0.0053**	**0.0050**	**0.0053**
FBM4	**0.0058**	**0.0072**	**0.0050**	0.0043	0.0004	-	-0.0031	-0.0001	-0.0017	**0.0056**	**0.0057**	**0.0054**	**0.0058**
FBM8	**0.0088**	**0.0103**	**0.0081**	**0.0074**	0.0035	0.0031	-	0.0029	0.0014	**0.0087**	**0.0088**	**0.0085**	**0.0088**
SOL103	**0.0059**	**0.0073**	**0.0052**	0.0044	0.0006	0.0001	-0.0029	-	-0.0016	**0.0057**	**0.0058**	**0.0055**	**0.0059**
SOL18	**0.0075**	**0.0089**	**0.0067**	**0.0060**	0.0021	0.0017	-0.0014	0.0016	-	**0.0073**	**0.0074**	**0.0071**	**0.0075**
RM1	0.0002	0.0016	-0.0005	-0.0013	**-0.0052**	**-0.0056**	**-0.0087**	**-0.0057**	**-0.0073**	-	0.0001	-0.0002	0.0002
RM2	0.0001	0.0015	-0.0007	-0.0014	**-0.0053**	**-0.0057**	**-0.0088**	**-0.0058**	**-0.0074**	-0.0001	-	-0.0003	0.0001
RM3	0.0004	0.0018	-0.0004	-0.0011	**-0.0050**	**-0.0054**	**-0.0085**	**-0.0055**	**-0.0071**	0.0002	0.0003	-	0.0004
SOLO	0.0000	0.0014	-0.0007	-0.0015	**-0.0053**	**-0.0058**	**-0.0088**	**-0.0059**	**-0.0075**	-0.0002	-0.0001	-0.0004	-

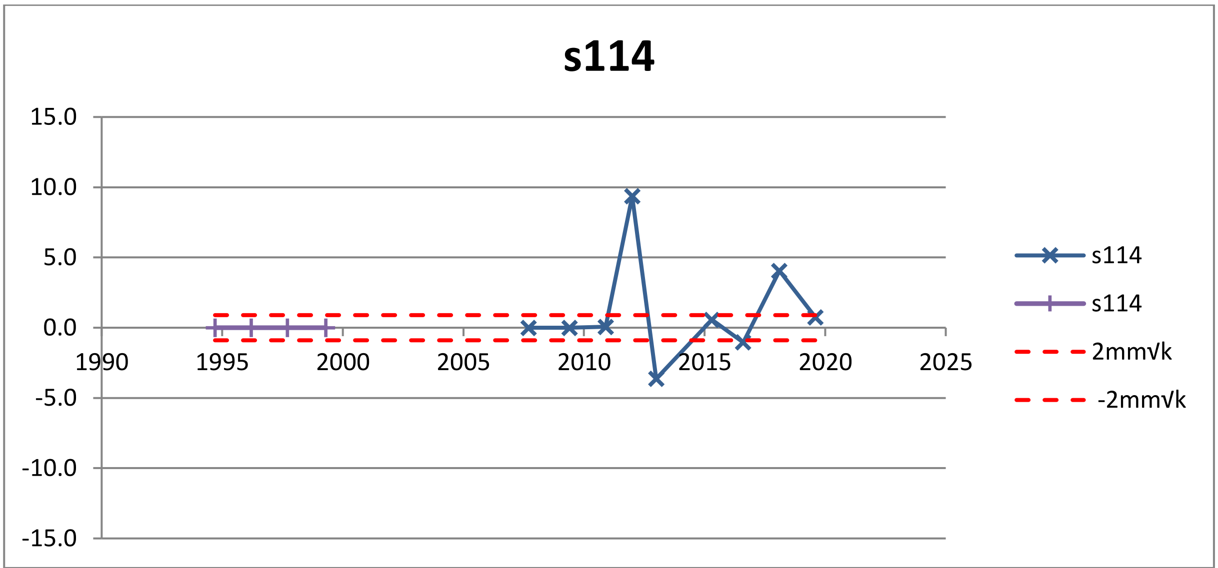
Table 5.4.1.1 values are calculated by subtracting the difference in height between RL_{2019} values (Table 5.3.3) from the difference in height between RL_{REF} values.

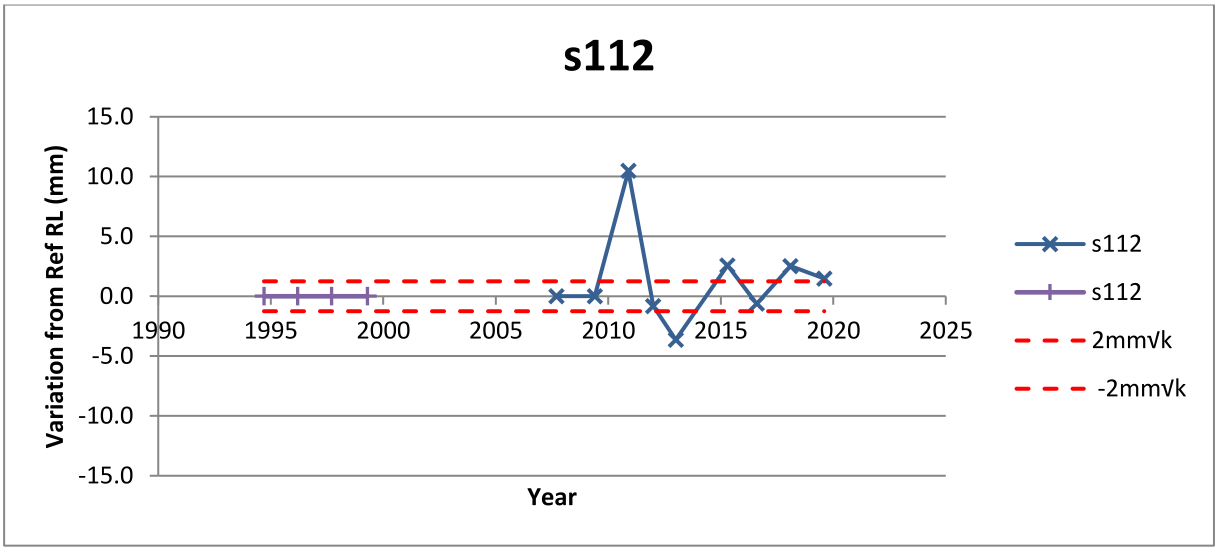
Comparing the change in relative heights between all benchmarks, will help identify movement of a particular BM, inconsistency in survey, or even deformation between the GNSS pillar and levelling run BMs.

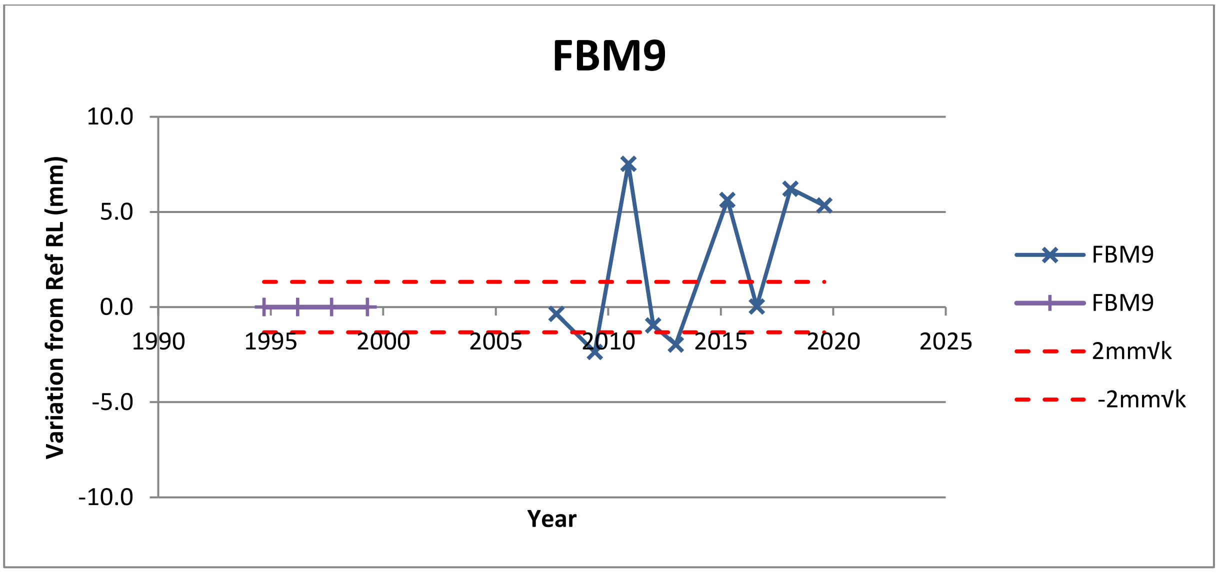
5.4.2 Time Series Charts for each BM

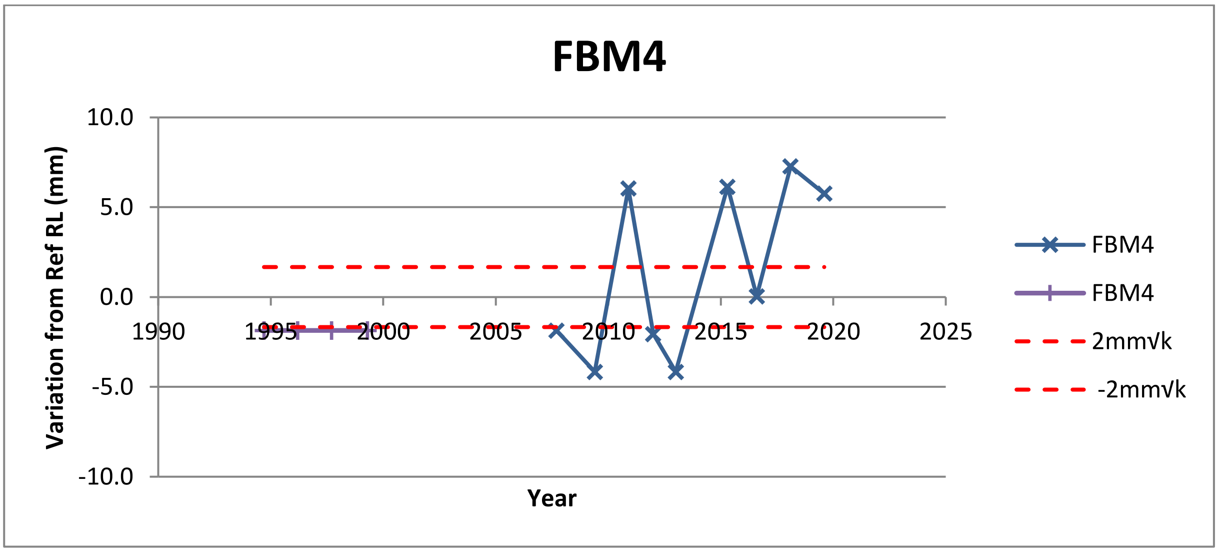
The change in the measured RL for each BM over time can be used to highlight trends of movement or survey errors. In the series of figures below, the red dashed lines represent the allowable error in height based on the levelling technique used and distance of the benchmark from the GNSS pillar ($2mm\sqrt{k}$). The purple line (with crosses) shows the results achieved using precise differential levelling [with a levelling instrument and survey staff] and the blue line with crosses show the levelling results based on the Total Station differential levelling technique.

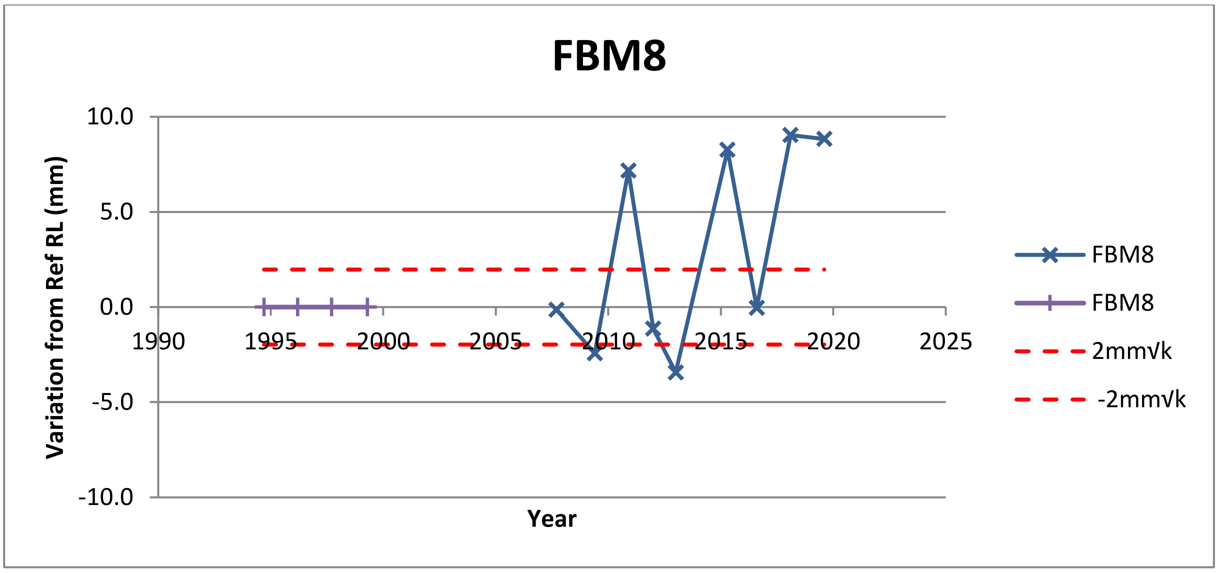


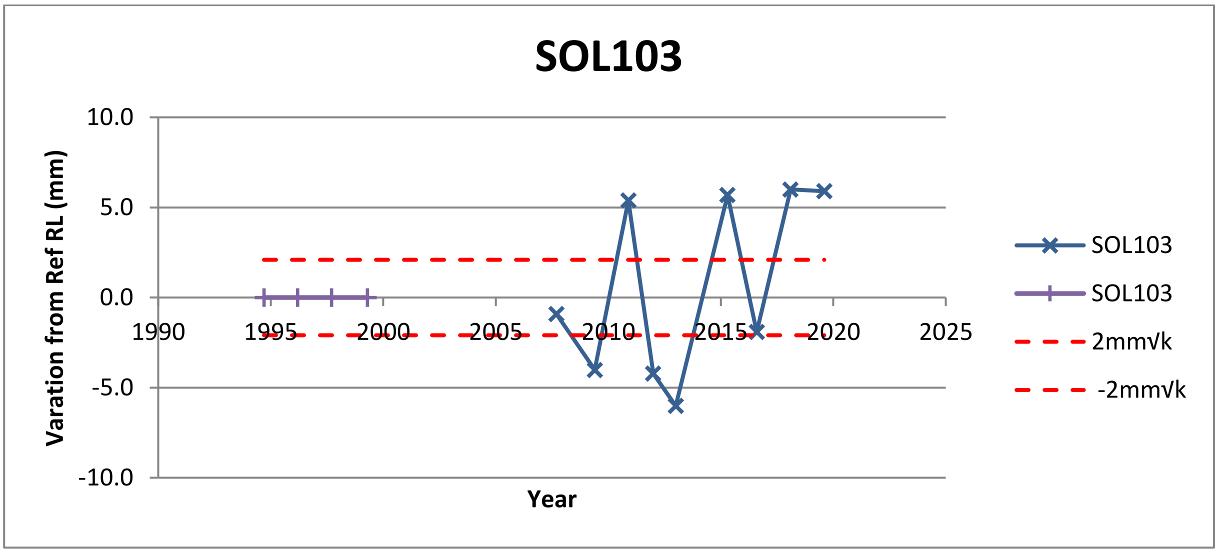


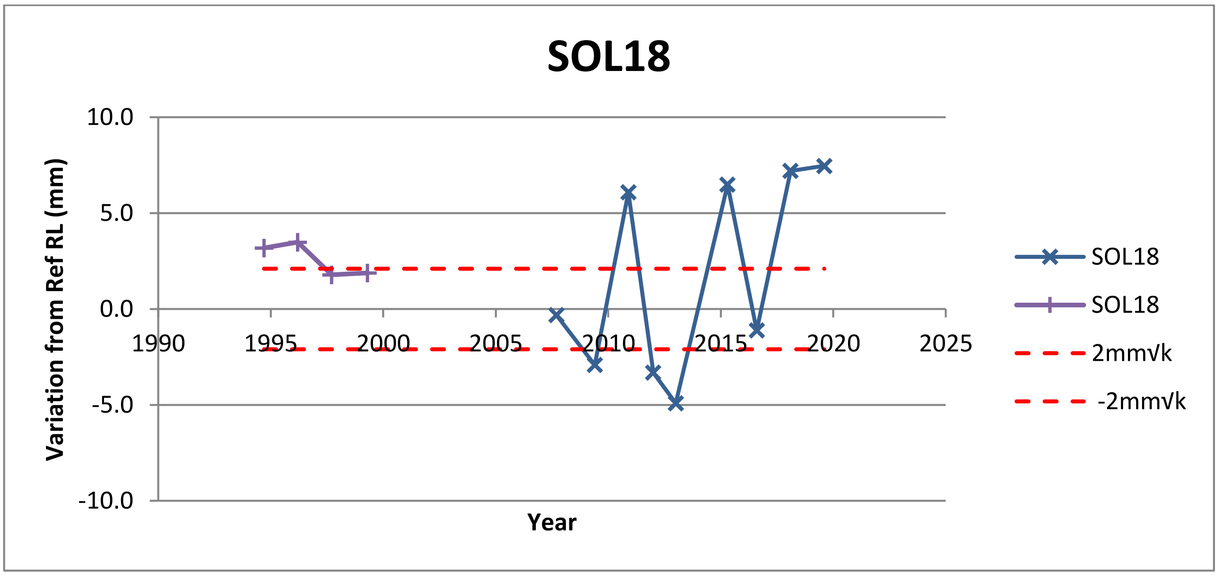

s112
Variation from Ref RL (mm)
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
1990
1995
2000
2005
2010
2015
2020
2025
Year
s112
s112
2mm√k
-2mm√k


FBM9
Variation from Ref RL (mm)
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
2025
Year
FBM9
FBM9
2mm√k
-2mm√k


FBM4
Variation from Ref RL (mm)
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
2025
Year
FBM4
FBM4
2mm√k
-2mm√k


FBM8
10.0
5.0
0.0
-5.0
-10.0
Variation from Ref RL (mm)
1990
1995
2000
2005
2010
2015
2020
2025
Year
FBM8
FBM8
2mm√k
-2mm√k


SOL103
10.0
5.0
0.0
-5.0
-10.0
Variation from Ref RL (mm)
1990
1995
2000
2005
2010
2015
2020
2025
Year
SOL103
SOL103
2mm√k
-2mm√k


SOL18
10.0
5.0
0.0
-5.0
-10.0
Variation from Ref RL (mm)
1990
1995
2000
2005
2010
2015
2020
2025
Year
SOL18
SOL18
2mm√k
-2mm√k

6 Assessment of Results

After a full analysis of the monitoring and levelling survey results, the following conclusions can be drawn. There are several differences above 0.003 m:

- The benchmark survey array from SOLOBM, s110, s114 on the hill to the bottom of the hill to survey benchmarks; s112, FBM9, FBM4, FBM8, SOL103, SOL18 shows the survey profile section (SOLO – SOL18) and a trend of localised movement in reference to the previous years of survey data of the benchmarks at the bottom of the hill to s122, FBM9, FBM4, FBM8 and SOL103 has been identified (Table 5.4.1.1), this could be due to fault line or small tectonic activities along the hill, and as such further investigation is required in consultation with the Solomon Islands Geology Office.

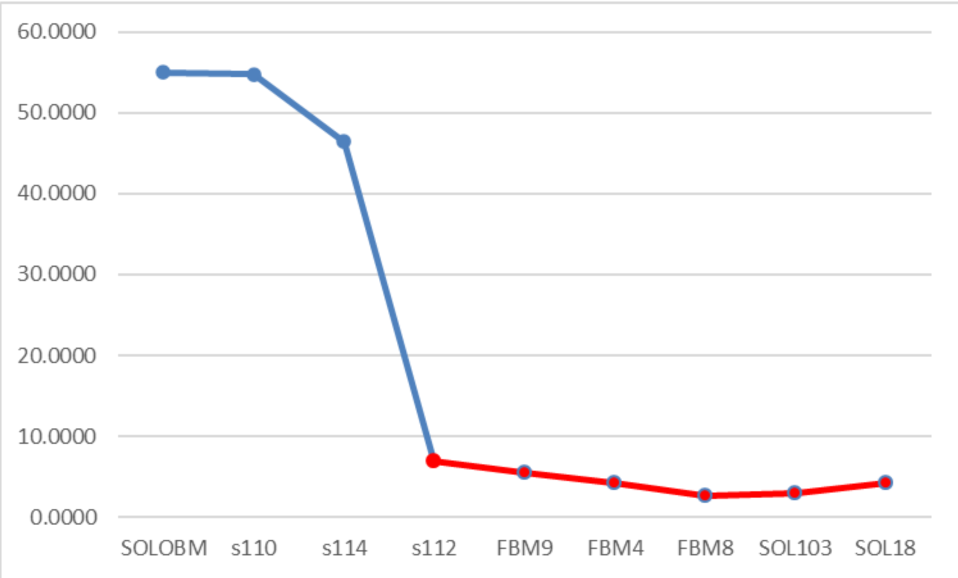


Figure 5.4.1 Profile section (vertical exaggeration) of survey benchmarks irrelevant to location

- The survey from the primary GNSS BM (SOLOBM) to the TG Plaque (SOL103) shows significant change. There is a high chance of deformation on the wharf structure when looking at the two past result of this particular benchmark (SOL103).
- The survey from the GNSS CORS pillar, SOLOBM to the primary BM (FBM8) and to the Tide Gauge station benchmarks (SOL103 and SOL18), shows the height difference between both marks as referenced to 2019.6 value, uplifted by 8-9mm. This survey was aligned to the previous survey carried out in 2018.1. The next few surveys would further validate the trend.

Table 6.1 Comparison of results with Reference ^H (m).

PT ID	Reference ^H (m)	2019.60 Value (m)	Difference
SOLOBM - Primary BM (FBM8)	-52.3484	-52.3395	-0.0088
FBM8 - TG Plaque BM (SOL103)	0.3475	0.3445	-0.0029
FBM8 - TG ref pin (SOL18)	1.6096	1.6082	-0.0014

SOLOBM - FBM4	-50.6895	-50.6838	-0.0058
FBM4 - SOL103	-1.3113	-1.3112	-0.0001
SOL103 - SOL18	1.2621	1.2637	0.0016
SOLO - TG Plaque	-53.4655	-53.4596	-0.0059
SOLO - TG BM	-52.2034	-52.1959	-0.0075
SOLO - TGZ	-56.4694	-56.4619	-0.0075

Table 6.2 List of height differences from SOLOBM to primary benchmarks, and conversion to ITRF2020 & TGZ

PT ID	Reference RL (m)	2019.6 Value (m)	Difference	ITRF2020	TGZ
SOLOBM	0.0000	0.0000	0.0000	121.4602	54.7933
s110	-0.2237	-0.2251	-0.0014	121.2351	54.5682
s114	-8.6147	-8.6139	0.0007	112.8463	46.1794
s112	-48.0918	-48.0903	0.0015	73.3699	6.7030
FBM9	-49.5607	-49.5554	0.0053	71.9048	5.2379
FBM4	-50.6895	-50.6838	0.0058	70.7764	4.1095
FBM8	-52.3484	-52.3395	0.0088	69.1207	2.4538
SOL103	-52.0009	-51.9950	0.0059	69.4652	2.7983
SOL18	-50.7388	-50.7313	0.0075	70.7289	4.0620
RM1	-0.0682	-0.0680	0.0002	121.3922	54.7253
RM2	-1.2953	-1.2953	0.0001	120.1649	53.4981
RM3	-0.5574	-0.5570	0.0004	120.9032	54.2363
SOLO	1.4646	1.4646	0.0000	122.9248	56.2579
TGZ	-55.0048	-54.9973	0.0075	66.4629	-0.2040

7 Absolute height of the tide gauge

When combined, the GNSS and levelling data provide information about the absolute movement of the tide gauge. This information can be used by Bureau to translate relative sea level into absolute sea level.

7.1 GNSS time series analysis

The ellipsoidal height of the GNSS pillar is computed using Geoscience Australia's weekly cumulative GNSS solution and modelled using Chebyshev polynomials[2] (Figure 7.1). Uncertainty regions (95% confidence) were determined using the residuals with respect to the polynomial model. Large outliers (>50cm) were removed manually as they have a significant impact on the estimated uncertainties. The ellipsoidal heights are with respect to the International Terrestrial Reference Frame 2020 (ITRF2020).

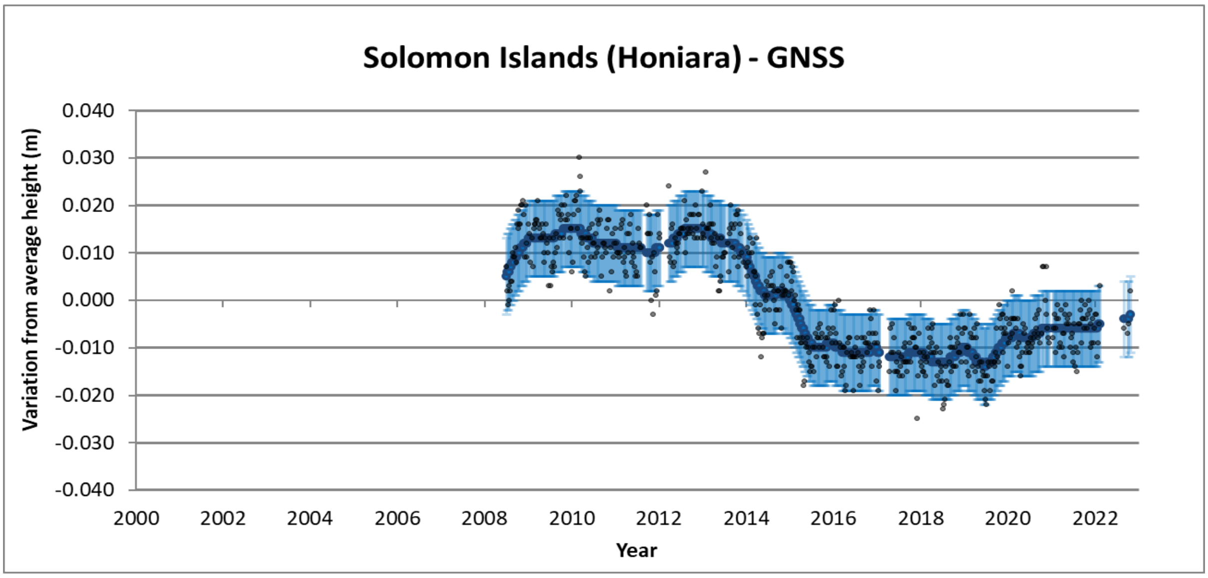


Figure 7.1 Time series of GNSS analysis (dark blue line) with 95%CI uncertainty (light blue lines).

[2] The order of the polynomial was determined iteratively by evaluating the significance of the improvement in model misfit Chi-Squared by an F test. The number of terms used in the preferred models ranged from 2 (i.e. linear) to 10 across the analysed time series and depends on the complexity of the observed signal.

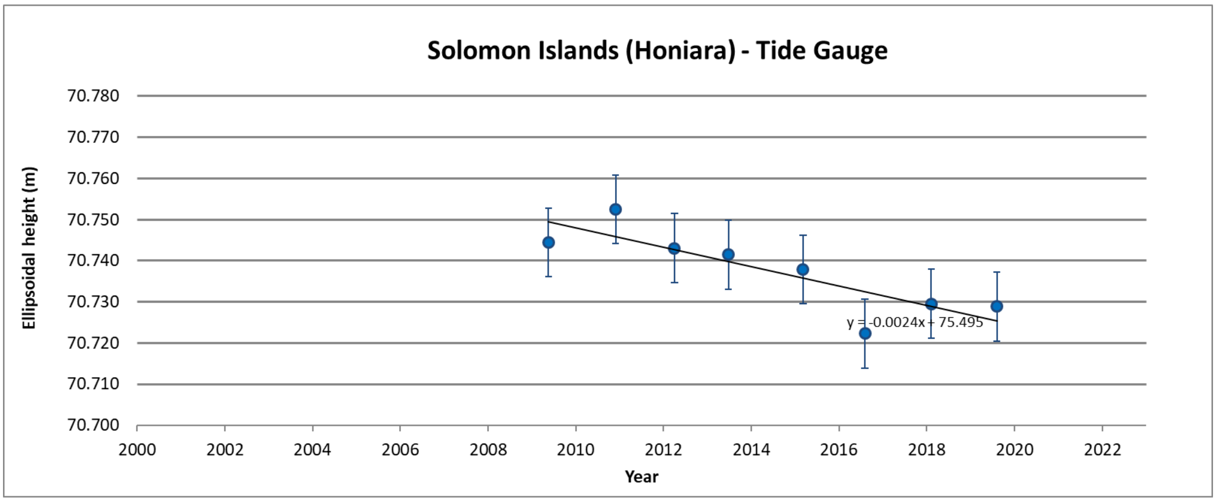


Figure 7.2 The height of the SEAFRAME sensor reference benchmark (with respect to ITRF2020).

The height of the SEAFRAME sensor reference benchmark is the sum of the ellipsoidal height of the GNSS pillar plate and the levelled height difference between the GNSS pillar plate and SEAFRAME sensor reference benchmark (Figure 7.2; Table 7.1))[3]. The height uncertainty is the combined uncertainty from the GNSS analysis and the levelling.

Table 7.1 Ellipsoidal height of the tide gauge along with the 95%CI uncertainty derived from GNSS time series analysis and levelling. Ellipsoidal height is with respect to the International Terrestrial Reference Frame 2020.

Date	Height (m)	Uncertainty (95%CI) (m)
2009.38	70.7445	0.008
2010.91	70.7525	0.008
2012.25	70.7431	0.008
2013.48	70.7415	0.008
2015.18	70.7379	0.008
2016.59	70.7223	0.008
2018.10	70.7296	0.008
2019.60	70.7289	0.008

[3] It is recognised that the height of the SEAFRAME sensor reference benchmark is the sum of the geometric GNSS ellipsoidal height and the physical orthometric levelling height. No geoid corrections were applied to the levelling data because of the short distance of the levelling run and the lack of high resolution gravity data in this region.

8 References

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Rüeger, J.M. & Brunner, F.K. 1982, '*EDM Height Traversing versus Geodetic Levelling'*, The Canadian Surveyor, vol. 36, no. 1, pp. 69-87.

Rueger, J. M., Brunner, F. K., 1981. *Practical Results from EDM-Height Traversing*. The Australian Surveyor. June 1981, Vol. 30, No 6.

Appendix A Locality Diagrams

Source: Adapted from Google Maps.

A 1 Deep Benchmarks

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Aid

Australian Government
Geoscience Australia

SPC
Secretariat of the Pacific Community

SURVEY BENCH MARK RECORD

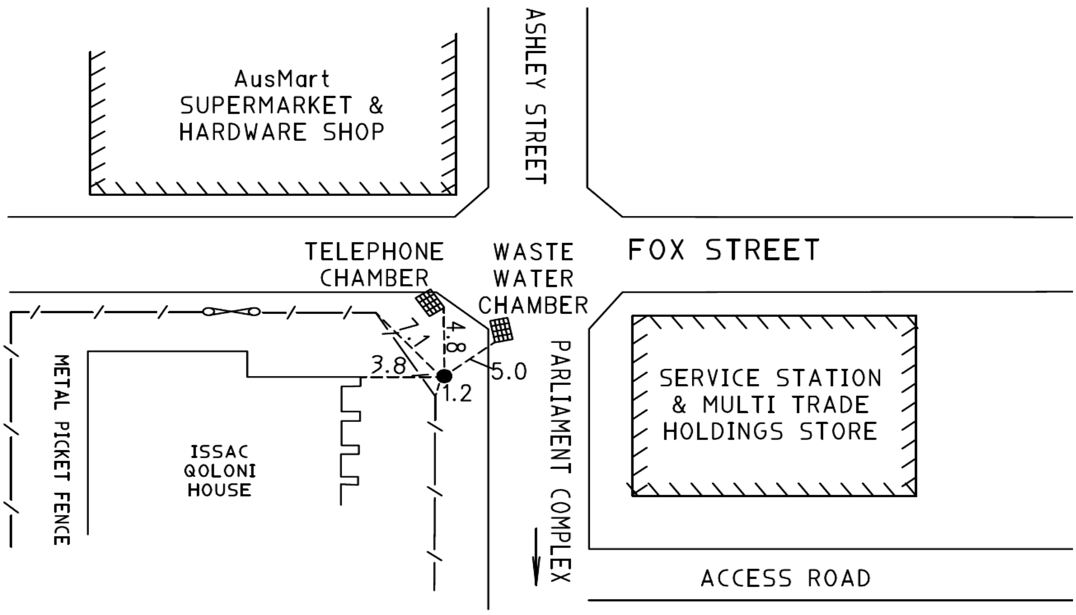
Bench Mark Number: FBM9

Original Bench Mark Established by: National Geospatial Reference Systems, Geospatial & Earth Monitoring Division (GEMD), Geoscience Australia	*Date: 20/08/2007*
Existing Bench Mark Established by:	*Date:*
Notes / References: Deep Benchmark This survey mark is not in a good locality for GPS occupation.	
Country: Solomon Islands *Island: Gaudalcanal*	*City: Honiara*

MARKING AND LOCALITY SKETCH

Bench Mark: 2.0m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube for top 0.3m. Top of mark 0.2m below ground level.

Locality sketch: Mark approximately 125m from the tide gauge station



NOT TO SCALE — Distances in Metres — Magnetic Bearings

Approved by: Geoscience Australia / SPC — *Date: Dec 2007*

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Aid

Australian Government
Geoscience Australia

SPC
Secretariat of the Pacific Community

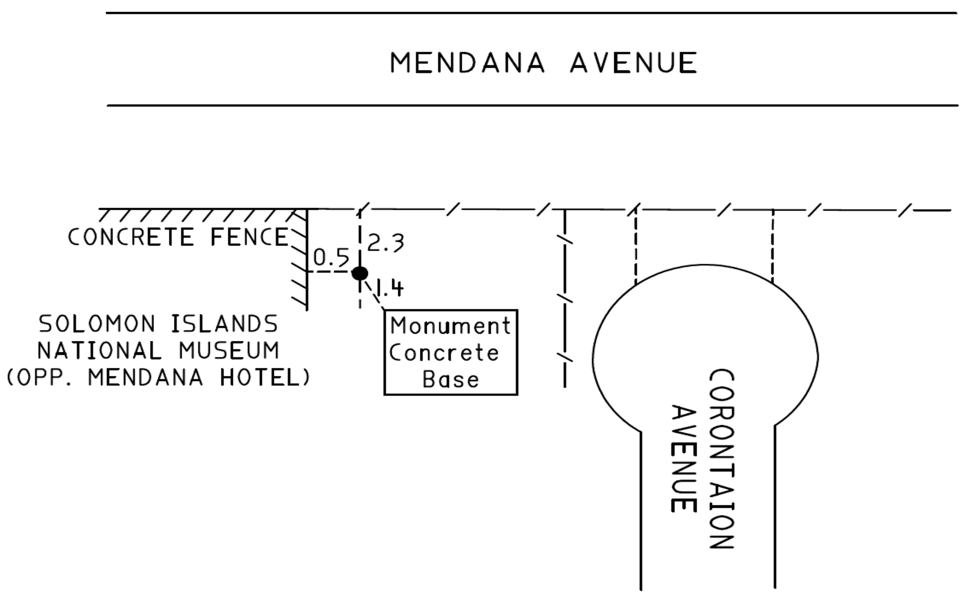
SURVEY BENCH MARK RECORD

Bench Mark Number: FBM4

Original Bench Mark Established by: National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 College Rd, Kent Town, SA.	*Date: 30/07/1994*
Existing Bench Mark Established by:	*Date:*
Notes / References: Deep Benchmark This survey mark is not in a good locality for GPS occupation.	
Country: Solomon Island *Island: Guadalcanal*	*City: Honiara*

MARKING AND LOCALITY SKETCH

Bench Mark: 1.8m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube for top 0.3m. Top of mark 0.5m below ground level.



NOT TO SCALE Distances in Metres Magnetic Bearings

Approved by: Geoscience Australia / SPC *Date: Dec 2007*

Australian Aid

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Government
Geoscience Australia

SPC Secretariat of the Pacific Community

SURVEY BENCH MARK RECORD

Bench Mark Number: **FBM8**

Original Bench Mark Established by: *Date: 20/08/2007*
National Geospatial Reference Systems, Geospatial & Earth Monitoring Division (GEMD), Geoscience Australia

Existing Bench Mark Established by: *Date:*

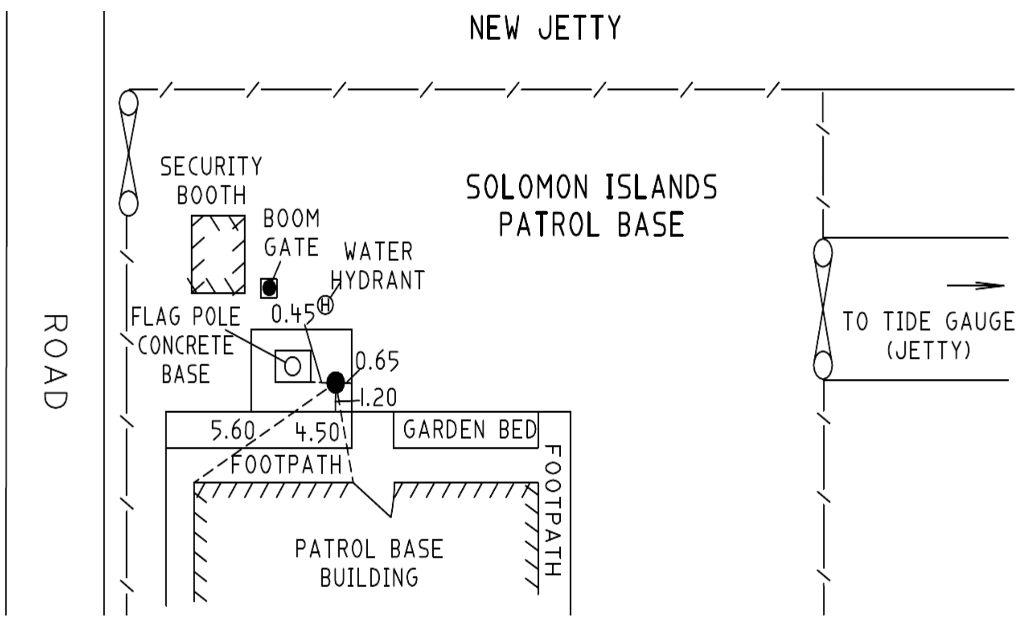
Notes / References: Deep Benchmark
This survey mark is not in a good locality for GPS occupation.

Country: Solomon Islands
Island: Gaudalcanal *City: Honiara*

MARKING AND LOCALITY SKETCH

Bench Mark: 3.0m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube for top 0.3m. Top of mark 0.2m below ground level.

Locality sketch: Mark approximately 125m from the tide gauge station

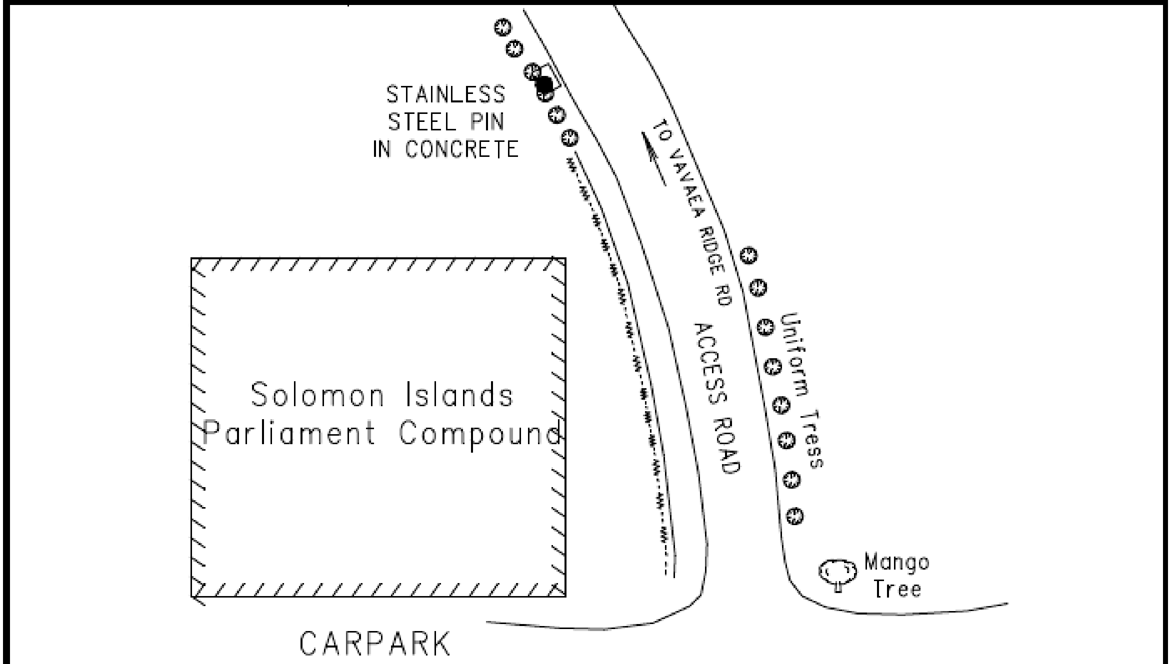


NOT TO SCALE Distances in Metres Magnetic Bearings

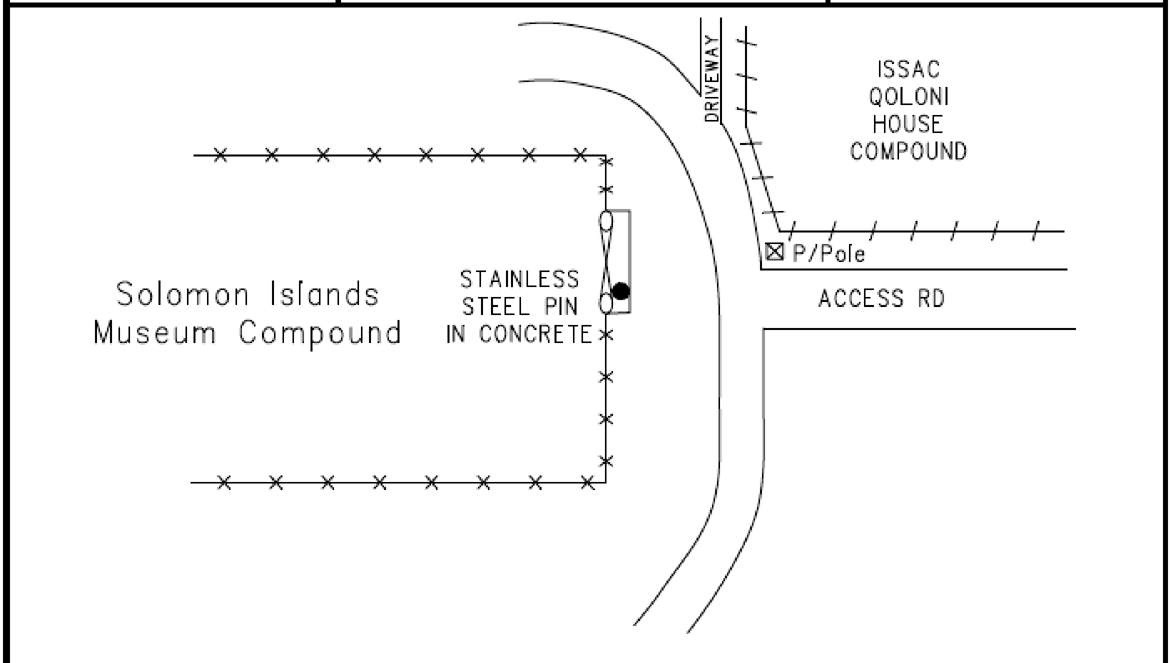
Approved by: Geoscience Australia / SPC *Date: Dec 2007*

A 2 Temporary Holdings Marks

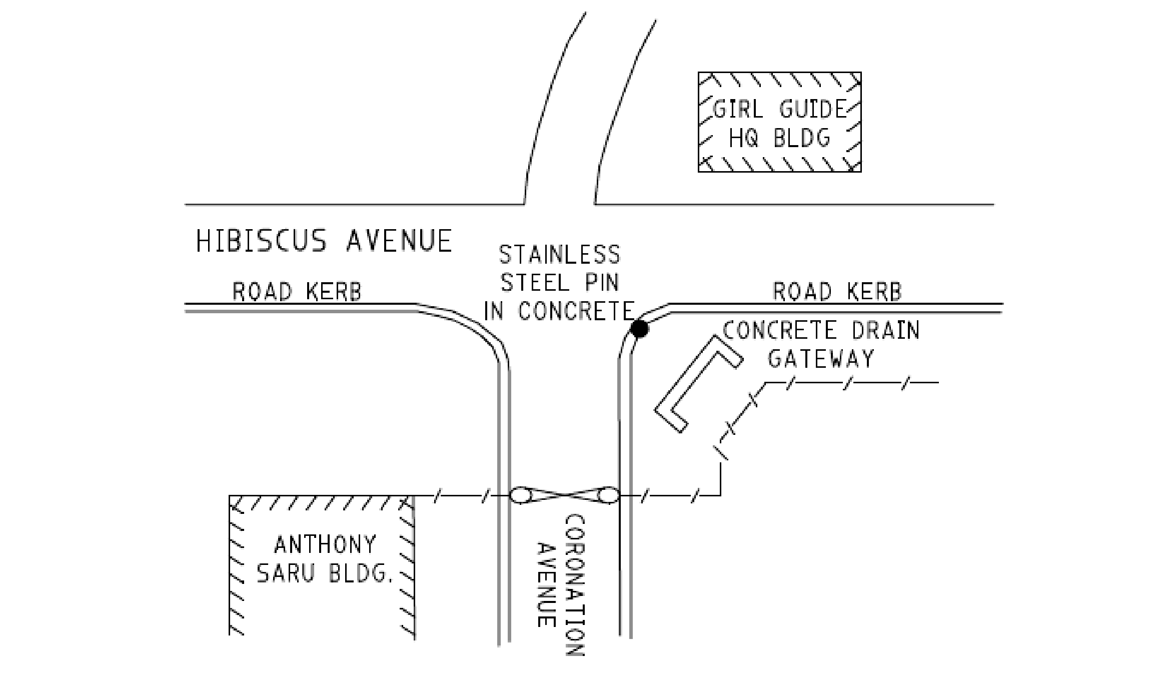
COUNTRY: Solomon Is	ISLAND: Guadalcanal CITY: Honiara	L. D. P. 892 POINT NO. SOL114
PROJECT: SPSLCMP	SURVEYOR: A. Lal & G. Hu	DATE: 25-11-10



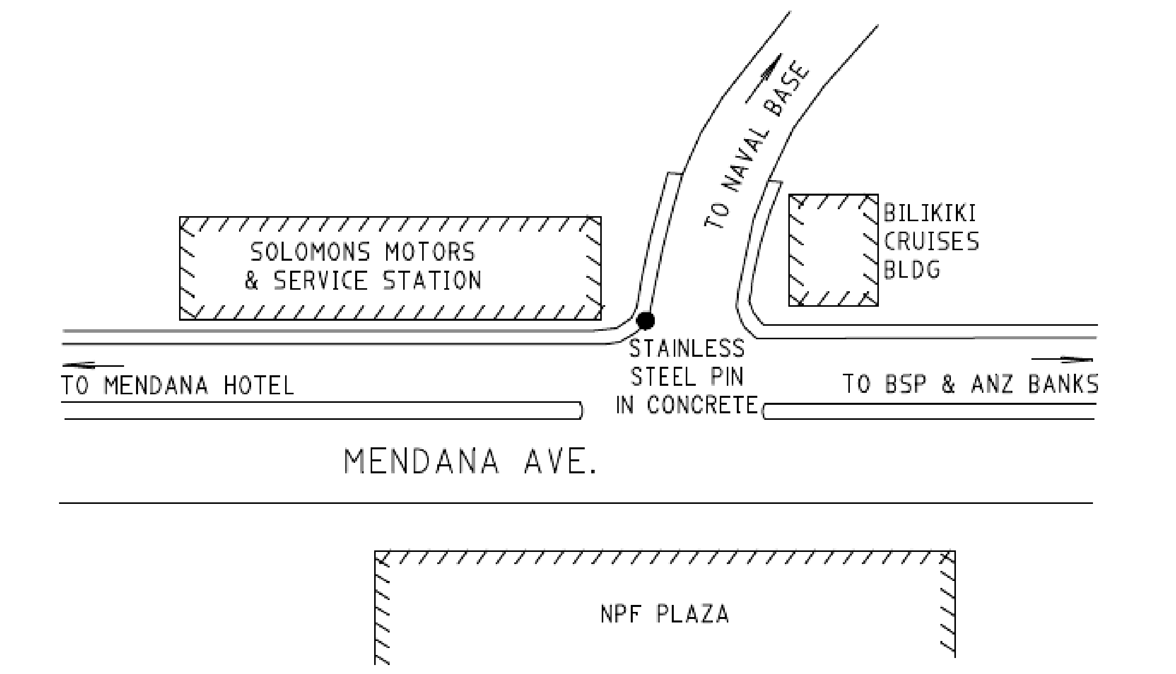
COUNTRY: Solomon Is	ISLAND: Guadalcanal CITY: Honiara	L. D. P. 892 POINT NO. S112
PROJECT: SPSLCMP	SURVEYOR: A.Lal & G. Hu	DATE: 25-11-10



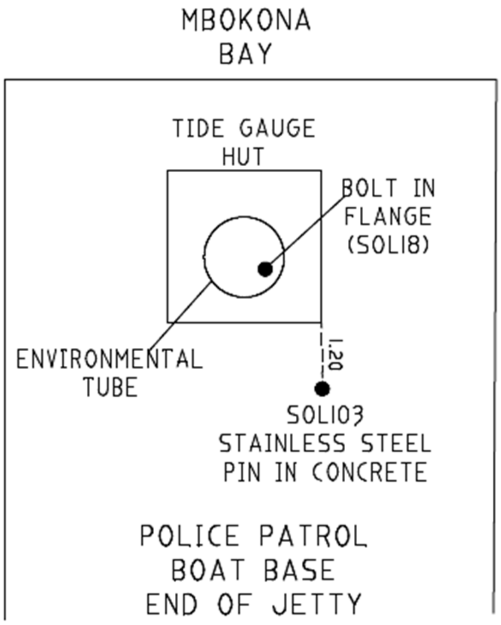
COUNTRY: Solomon Is	ISLAND: Guadalcanal CITY: Honiara	L. D. P. 886 POINT NO. SOLI07
PROJECT: SPSLCMP	SURVEYOR: A. Lal & M. Deo	DATE: 19-05-09



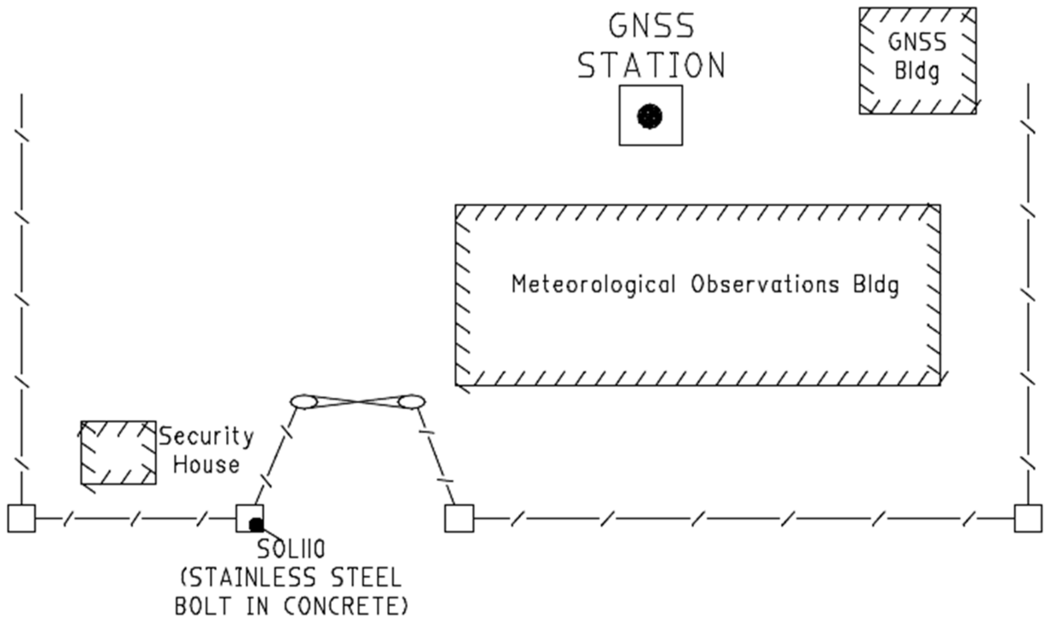
COUNTRY: Solomon Is	ISLAND: Guadalcanal CITY: Honiara	L. D. P. 820 POINT NO. SOLI06
PROJECT: SPSLCMP	SURVEYOR: A.Lal & M. Deo	DATE: 19-05-09



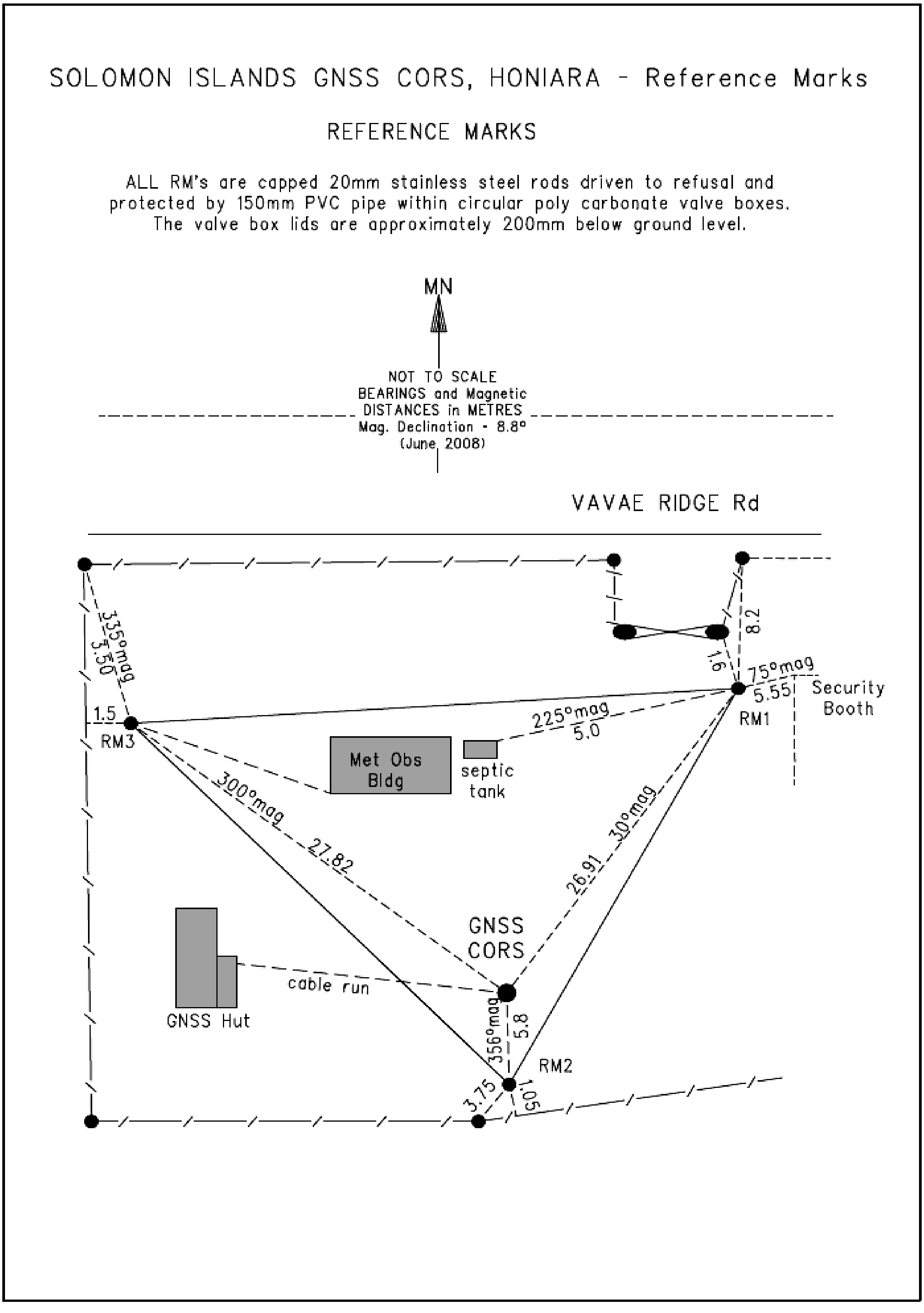
COUNTRY: Solomon Is	ISLAND: Guadalcanal CITY: Honiara	L. D. P. 821 POINT NO. SOLI03
PROJECT: SPSLCMP	SURVEYOR: A. Lal & M. Deo	DATE: 25-08-07



COUNTRY: Solomon Is	ISLAND: Guadalcanal CITY: Honiara	L. D. P. 890 POINT NO. SOLII0
PROJECT: SPSLCMP	SURVEYOR: A.Lal & M. Deo	DATE: 19-05-09



A 3 GNSS Site Reference Marks



Appendix B Planning Aspects and Notes

Upon arranging travel to Solomon Islands, make contact with the project focal point of contact at the Survey Office and the Weather Office in country at least one month in advance.

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.

The local SPC office has been very helpful in receiving and storing the equipment until the survey team arrives.

Prior approvals need to be taken to access the following deep benchmarks; -

- Tide Gauge Station and Deep Driven Benchmark, FBM8 – Police Patrol Base
- FBM4 is now within a locked compound at the museum. Contact the museum director and inform them of the survey work to be completed and arrange access through the side gate.
- Levelling traverse connection through the parliament compound will require pre-approval to access. The weather office staff can help with this, also check what is required with the security station on the main entrance. Photo ID and photo of working staff might be required. Approval could take 24hrs.
- GNSS COR Station – Meteorological Department, meet with local contacts before beginning work.

Due to the heavy traffic, the levelling connection from FBM4 to SOL106 across the road is best attempted early on a Sunday morning before foot & vehicle traffic gets heavy. Sight lines have become partially blocked, and the ½ m pole might need to be used.

FBM4 is buried almost 600mm below the surface, due to the construction of a nearby wall. The mark was found undisturbed and recovered during the 2015 survey.

The GNSS COR Station and the GNSS Pillar was also cleaned.

Daily allowance for food and water was provided to Local Surveyor

The following list of survey equipment is now in the country for future field surveys:-

Quantity	Item & description	Locations
1	**Tool Box**	Tide Gauge Station Hut.
2	*Prism Pole Clamps*	*Tools used by C&M Teams (Bureau & SPC)*
1	*50m Measuring Tape*	
1	*Engineers Hammer*	
1	*Carpenters Hammer*	
1	*Set of Allen Keys*	
1	*Torx Drivers*	
2	*Multigrips pliers*	
1	*Set of Screw Drivers*	

1	**PVC Pipe (1.2m)**	GNSS COR Station Hut
1	*Aluminium GST6 tripod with Feet*	
1	**PVC Pipe (1.7m)**	GNSS COR Station Hut
1	*Ground Base Plate*	
4	*Telescopic-Bi-pods*	
2	*Stainless-steel levelling prism poles*	
1	*Half Stainless-steel levelling prism pole*	
3	**Black Bags - Leica GST20 Telescopic Tripods**	GNSS COR Station Hut
1	**Green Bag - Leica GST40 Rigid Tripod**	GNSS COR Station Hut
1	**Spade**	GNSS COR Station Hut
1	**Crow Bar**	GNSS COR Station Hut

Appendix C Equipment Specifications

Tachymeters, EDM and Theodolites

A Leica TM30 (S/N 361441) Total Station was used to record all angles and distance measurements.

Specification

- EDM (infrared) distance standard deviation of a single measurement (DIN 18723, part 6): 0.6 mm ± 1 ppm.
- Angular standard deviation of a mean direction measured in both faces (DIN 18723, part 3): 0.3 mgon (≈ 1°).

Calibration

The Leica TM30 electronic distance measuring instrument (Serial No. 361441) was calibrated by the Australian National Measurement Institute (NMI) in July 2013. It was found to have an average error of 0.44×10^{-6} mm, which has been added to the Total Station.

Meteorological Sensor

Description

A NK Kestrel 4000 Pocket Weather Tracker (S/N 625479) was used to record meteorological observations (temperature, pressure and relative humidity).

Specification

- Temperature is accurate to 1.0°C between -29.0°C and 70.0°C.
- Pressure is accurate to 1.5 mb at 25°C between 750 mb and 1100 mb.
- Relative humidity is accurate to 3.0%.

Forced Centring

Description

An FG0L30 (S/N 609030) zenith and nadir optical plummet was used to centre and level all instrument and target setups.

Specification

- Accuracy is 1:30 000 (1 mm at 30 m).

Targets and Reflectors

Description

The standard target kit includes:

- 4 x Leica GDF21 tribraches.
- 4 x Leica GZR3 prism carriers with optical plummet.
- 4 x Leica GPH1P precision prisms.

Calibration

The additive constant for the Leica GPH1P precision prism is -34.4 mm which was applied directly into the Leica TM30 Total Station. All prisms were calibrated on a tripod baseline at Geoscience Australia in July 2009. Approximate prism corrections of 0.0 mm were applied to observations during data processing.

Precision Levelling

Levelling Instruments

Refer to section 2.1 for a description of the Leica TM30 Total Station

Levelling Rods

A fixed height stainless steel rod (SP Primary Pole) approximately 1.6 m in height with Leica style bayonet mount on top for mounting a precision prism was used with a Leica bi-pod for stability.

A fixed height short stainless-steel rod (SP 1/2m TG Pole) approximately 0.5 m in height with Leica style bayonet mount on top for mounting a precision prism was used.

A height offset between the pole (SP Primary Pole) and the short pole (SP 1/2m TG Pole) was determined by observing both on a low mark. Multi-set, dual face observations were used to eliminate collimation effects. The resulting height offset was 1.00054m.

Tripods

Description

Leica GST20 heavy-duty timber tripods with adjustable legs was used on all marks, with the exception of the pillars, during the monitoring survey.

A Leica rigid timber tripod was used to mount the TM30 on for the purpose of this levelling survey.

Note: Three Leica adjustable leg tripods was left on site in the current GNSS hut for carrying out the associated RM horizontal survey.

GNSS Equipment

Description

At the time of the survey, the GNSS equipment in use at the GNSS CORS site was:

- Trimble NETR9 GNSS receiver (S/N 5041K71018) (firmware: 5.37)
- Javad Choke Ring antenna (S/N 954)