A DYNAMIC DATUM FOR PNG - IMPROVING PNG94

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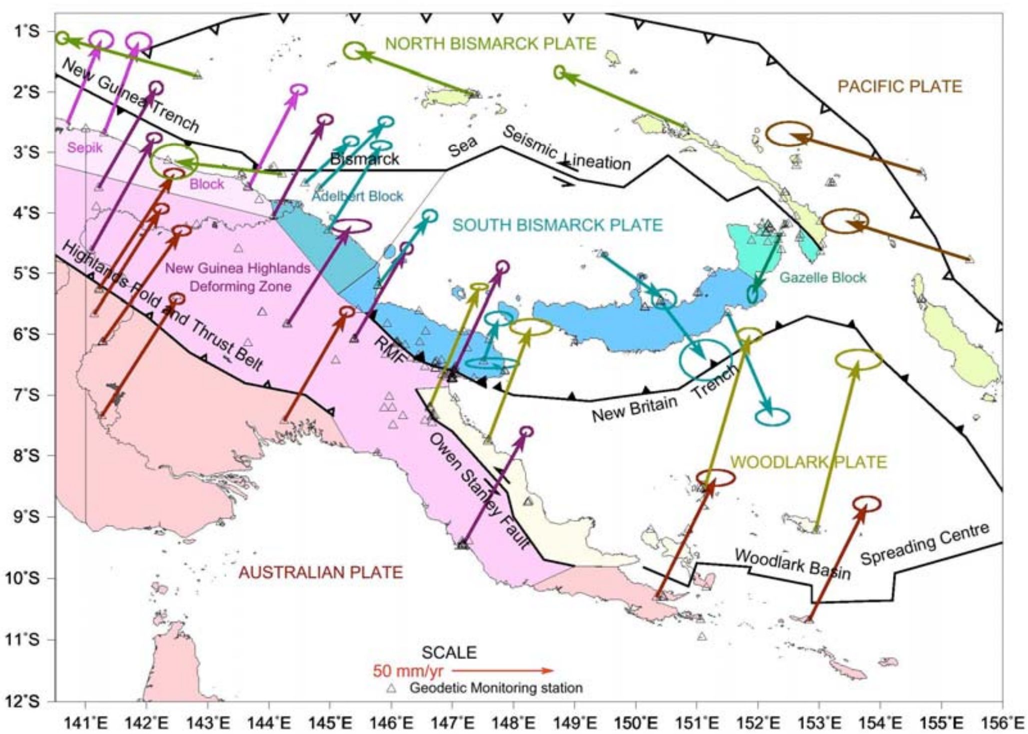
Abstract

Surveyors often assume that a geodetic datum is stable and "accurate" to the extent that coordinates do not change. PNG, like it's Pacific neighbours Indonesia and New Zealand, lies in one of the most tectonically active regions on the planet. Since 1990, high precision GPS measurements have shown that parts of PNG lying on different tectonic plates are moving at up to two metres every decade with respect to each other. This has major implications for geodetic surveys where the base station and roving stations are located on different tectonic plates. Which baseline measurement and reference coordinate should a surveyor use? This paper presents an outline of the different tectonic regions in PNG and discusses how surveyors can deal with tectonic motion across the network using reference epochs and site velocities. Practical examples are presented. The paper also introduces significant improvements to the densification and accuracy of PNG94 that have been made since it was introduced.

Introduction

Papua New Guinea's geodetic datum, PNG94, was realised at the same time as GDA94 in Australia. The coordinates of GDA94 and PNG94 are essentially "snapshots" of the dynamic International Terrestrial Reference Frame 1992 (ITRF92) on the 1st January 1994 (Epoch 1994.0). ITRF (and WGS84) coordinates of fixed stations anywhere on the planet change at up to 100mm/yr due to the motion of the Earth's tectonic plates. Unlike Australia, however, PNG is very active tectonically, due to its location on the edge of the colliding Australian and Pacific plates. Within this collision zone in PNG there are also several smaller microplates and zones of diffuse deformation, which add to the complexity of the tectonic setting (Figure 1).

Figure 1. The tectonic setting in PNG, showing plate boundaries & ITRF/WGS84 site velocities

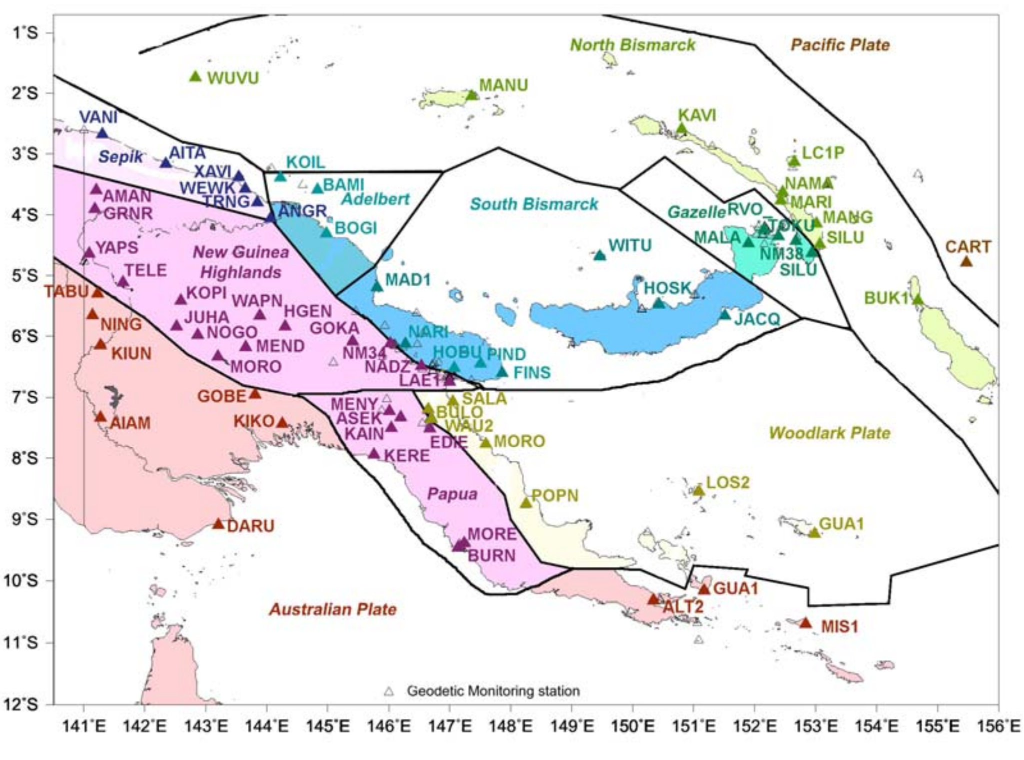


Interseismic deformation (between earthquakes) across plate boundaries within PNG is rapid (up to 120 mm/yr) and the cosesimic and postseismic deformation resulting from large shallow earthquakes can be up to several metres in magnitude. Since the beginning of 1994, there have been almost 1,500 earthquakes above Magnitude 5 in PNG, including 20 above magnitude 7 (NEIC database). 14 years of tectonic deformation and seismic deformation have resulted in baseline changes of up to six metres between many PNG94 geodetic stations.

Such significant internal deformation of the geodetic network makes it practically impossible for users of GNSS precise point positioning (PPP) and static systems to obtain any meaningful precision in PNG, unless this deformation is modelled and a fixed reference epoch is formalised. In many other tectonically active areas e.g. New Zealand (Blick *et al.*, 2003) and California, site velocity and deformation models have been implemented in geodetic datums to ensure that geodetic infrastructure is not degraded by unmodelled deformation. Use of a velocity model enables site motion between the date (epoch) of measurement and a reference epoch to be computed. In this way, computed coordinates can be related to the reference epoch to ensure that coordinates of spatial datasets remain "static" within a dynamic environment. Continually changing coordinates related to arbitrary epochs have no real value in spatial systems and in fact degrade them. A datum where dynamic coordinates are regressed to a specific fixed epoch is referred to as a semi-dynamic datum. Currently there is no strategy in place within PNG to deal with tectonic deformation in such a way.

In order to gain a better understanding of the tectonic setting in PNG, researchers have established a widespread network of stable geodynamic monitoring sites in PNG, principally, the Australian National University's Research School of Earth Sciences (ANU RSES). Important collaborators have included: The PNG National Mapping Bureau (NMB), The Department of Surveying and Land Studies at UniTech, The Rabaul Volcanological Observatory (RVO), and the University of California Santa Cruz (UCSC). Several campaigns of repeat measurements of these stations have enabled sub-centimetre accurate ITRF coordinates and site velocities, euler poles of microplates, and fault locking parameters to be estimated. The extensive network of stations and results from these studies can form the basis of very significant improvements to PNG's geodetic datum (Figure 2, and Table 1 at end of paper).

Figure 2. PNG geodetic monitoring network (primary stations) and plate zones



How accurate is PNG94?

The 14 primary PNG94 stations (Allman, 1996) surveyed in the regional GPS campaigns between 1992 and 1994 mostly have positional uncertainties less than 5 cm. All other stations have PNG94 coordinates derived by GPS where tectonic deformation has not been modelled, or by transformation from AGD66 or WGS72 using standard transformation parameters (e.g. NGA parameters widely used in GIS and data logging software). PNG94 coordinates of these stations can be in error by up to 9 metres, though 1-2 metre uncertainties are more typical.

Why should PNG have a semi-dynamic datum and what accuracy is required?

Uses of spatial data in PNG are increasingly diverse: Cadastral surveys (including customary land and DCDB surveys), exploration and mining, engineering (bridges, dams, power, roads, pipelines), mapping, navigation (air, land and sea), hazard monitoring (volcanoes, earthquakes, landslides, sea-level change), and all require a homogenous spatial reference system or datum. PNG94 has errors of several metres accommodated within it. For some users of spatial data, an absolute accuracy or positional uncertainty of this magnitude maybe acceptable, although smaller relative uncertainties are usually required, e.g. for deformation monitoring, engineering surveys and cadastral surveys. Integration of separate and adjoining surveys, however, usually require an absolute accuracy of 10 cm or better. PNG94 in its current form is not sufficiently accurate for this purpose. A centimetre accurate geodetic datum is increasingly underpinning any successful modern economy. In the case of PNG, an accurate datum is especially important for large-scale engineering projects such as the LNG project, which is now entering its front-end engineering and design (FEED) stage. The success of this project, which will bring an estimated US $8bn into the PNG economy, is contingent on construction within a centimetre accurate survey datum.

Why shouldn't WGS84 and ITRF be used in PNG?

It is often assumed that PNG94 is identical to WGS84 and ITRF. This assumption was true in 1994, but since then coordinates in the different systems have diverged because of ongoing tectonic deformation, and the differences are now a metre or more in PNG. Although the reference ellipsoids used by these three datums are similar at the sub-millimetre level, actual differences in station coordinates are now significant and the difference is increasing by several centimetres a year. By fixing a reference epoch (1st January 1994), coordinates of PNG's datum can become traceable to a physical network by means of a site velocity model. WGS84 and ITRF2000 coordinates are meaningless unless an epoch and physical datum are assigned to spatial data. For this reason WGS84 and ITRF should not be used for most surveys. ITRF will continue to form the basis for geodynamic monitoring (e.g. geological hazards such as volcanic activity, island subsidence and sea-level change) in PNG, due to the stability and millimetric accuracy of the external reference frame. Using ITRF or WGS84 for infrastructure surveys without making corrections for tectonic deformation represents very poor surveying practice.

What problems can surveyors experience with PNG94 at present?

Surveyors using GNSS methods to establish control in remote locations will find coordinates changing significantly over periods of a few years if their base stations are located on different plates from their survey area. For example, where the NMB (MORE) and UniTech (LAE1) GPS base stations are used to coordinate stations in East New Britain or New Ireland.

PPP systems such as AUSPOS and OmniStar produce coordinates in ITRF2000/WGS84 or ITRF2005. "Accurate" coordinates derived by these will change by several centimetres a year in PNG to reflect the magnitude of tectonic motion of the site. Users of these systems will notice repeat measurements of stations changing even over an interval of several months. For example, if AUSPOS or OmniStar were used to establish geodetic control for a new mining operation in the PNG Highlands in 2002, a surveyor reobserving these stations in 2008 would notice that the ITRF2000/WGS84 coordinates would be 30cm different! A local correction has to be applied to convert new measurements back to epoch used in the 2002 survey. If the surveyor in 2002 had known what the site velocity was, they would have converted the 2002 coordinates back to epoch 1994 to be coincident with PNG94, so that the survey could be related to other surveys in the area (Figure 3).

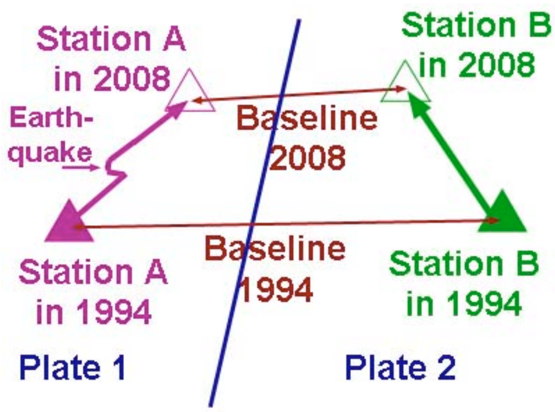


Figure 3. Effect of tectonic deformation on coordinates & baselines

Within rigid plate zones (Figure 1), away from plate boundaries (mostly south of the Highlands and Owen Stanley Range), baseline changes are likely to be small in magnitude and it is usually safe to use base stations up to 100km from a survey area within the same zone without significant degradation of relative accuracy. In broadly deforming zones that are relatively aseismic, such as the PNG Highlands, West New Britain and Milne Bay Province, baseline changes may be evident for baselines longer than 100km so that the closest geodetic station should be used. Rapidly deforming plate boundary zones: e.g. North of Nadzab and Lae, the entire Gazelle Peninsula and Southern New Ireland are very seismically active and also have rapid aseismic (slow creep) deformation with baseline changes of a few centimetres each year even over a few kilometres. The baseline from Unitech Lae to Hobu a few kilometres north is shortening at 5 cm/yr. Volcanic activity and large earthquakes also result in significant surface deformation. Geodetic surveyors at RVO use a real-time GPS monitoring system to provide early warnings of uplift associated with imminent eruptions. The November 2000 earthquake swarm (up to Magnitude 8.0) near southern New Ireland resulted in lateral displacements of 5-6 metres, with Tokua some 80 km from the epicentre of the lateral strike-slip event being displaced by 1m.

What strategies can surveyors use to connect to PNG94?

Static GPS and PPP (OmniStar-HP, AUSPOS etc..) are two of the principal methods (other than classical terrestrial methods) that surveyors in PNG can use to connect their surveys to PNG94. Dual-frequency GPS receivers can typically measure baselines of up to 50 km with a precision of less than 20 mm using a broadcast ephemeris. Baselines measured by single-frequency receivers and RTK methods are typically limited to 10 km or less. GPS surveys in PNG should consider the following points:

The base station and rover station should be on the same plate (i.e. the baseline between them should not cross a plate boundary as shown in Figures 1 and 2). In areas of rapid relative deformation such as East New Britain, Southern New Ireland and the Huon Peninsula, surveyors must use the closest geodetic station available to them as use of stations even 10 km from the project area will have undergone significant relative deformation between 1994 and the epoch of measurement.

If a baseline measurement has to be made across a plate boundary or deforming zone, the ITRF coordinates at the epoch of measurement of the base station should be computed first using the site velocity. The coordinates of the rover station are then converted back to PNG94 using the site velocity computed from the plate motion model.

ITRF coordinates derived by AUSPOS or OmniStar need to be converted to PNG94 using the site velocity computed from a PNG plate motion model, or by comparing PPP coordinates with the closest primary PNG94 station in order to estimate any corrections in the local area

The following expressions can be used to compute PNG94/PNGMG coordinates from ITRF UTM at different epochs:

Easting(PNG94) = Easting(*t*) + Velocity(E) * (1994 - *t*) + Σqe
Northing(PNG94) = Northing(*t*) + Velocity(N) * (1994 - *t*) + Σqn

Where;
t = Epoch of measurement in decimal years
(e.g. 31st July (day of year 213) 2008 is 2008 + 213/366 = 2008.582)
Easting(*t*) is the ITRF2000/WGS84 Easting at the epoch of measurement (at time ***t***)
Northing(*t*) is the ITRF2000/WGS84 Northing at the epoch of measurement (at time ***t***)
Σqe and **Σqn** are the total coseismic and postseismic displacements (East and North components) between epoch ***t*** and 1994
Velocity(E) and **Velocity(N)** are the site velocity components in Easting & Northing, in metres per year

Practical Examples

Using AUSPOS

10 hours of dual-frequency carrier phase measurements are made at a new station (PSM 1768) between Hides and Moran in the PNG Oilfields on the 2nd July 2008. The raw GPS data are converted to Receiver Independent Exchange (RINEX) Format and submitted to Geoscience Australia's (GA) AUSPOS service at http://www.ga.gov.au/bin/gps.pl . The resulting report shows ITRF2000 Ellipsoidal Coordinates as follows:

1768 -6°14'12.1512" 143°02'03.1876"

To convert these coordinates to PNG94;

1. Convert the coordinates to UTM using a Geographical calculator (WGS84/GRS80 ellipsoid):
= Zone 54 E 725073.31 N 9310194.84

2. Compute the epoch of measurement
2nd July 2008 = day of year 184, 2008 = epoch 2008 + 184/366 = 2008.503

3. Compute the site velocity of 1768
(In the absence of an online plate motion calculator, adopt the velocity of the nearest tabulated PNG94 station on the same plate, or interpolate between adjoining stations on the same plate)
The nearest tabulated station is MORA which has a velocity of
0.032 m/yr in Easting and -0.054 m/yr in Northing

4. Compute the displacement between the epoch of measurement (2008.503) and the reference epoch 1994.0 (PNG94)
*Difference in Eastings = (1994.0-2008.503)*0.032 = -0.464*
*Difference in Northings = (1994.0-2008.503)*0.054 = -0.783*

5. Compute the equivalent PNG94 coordinates
PNGMG94 Zone 54 Easting = 725073.31 -0.464 = 725072.85
PNGMG94 Zone 54 Northing = 9310194.84 -0.783 = 9310194.06

Using OmniSTAR HP

Repeat OmniSTAR-HP measurements are made at a new station (1768) between Hides and Moran in the PNG Oilfields between the 2nd and 5th of July 2008. The mean logged ITRF2000 UTM Zone 54 Grid Coordinates over the three days are as follows:

1768 Zone 54 E 725073.24 N 9310194.75

To convert these coordinates to PNG94;

1. Determine the epoch of measurement
   OmniSTAR-HP uses epoch 2008.75 between 1st July 2008 and 31st December 2008

2. Compute the site velocity of 1768
   (In the absence of an online plate motion calculator, adopt the velocity of the nearest tabulated PNG94 station on the same plate, or interpolate between adjoining stations on the same plate)
   The nearest tabulated station is MORA (Table 1) which has a velocity of
   0.032 m/yr in Easting and 0.054 m/yr in Northing

3. Compute the displacement between the OmniSTAR-HP epoch (2008.75) and the reference epoch 1994.0 (PNG94)
   *Difference in Eastings = (1994.0-2008.75)*0.032 = -0.472*
   *Difference in Northings = (1994.0-2008.75)*0.054 = -0.797*

4. Compute the equivalent PNG94 coordinates
   PNGMG94 Zone 54 Easting = 725073.24 -0.472 = 725072.8
   PNGMG94 Zone 54 Northing = 9310194.75 -0.797 = 9310194.0

An example of baseline processing across plate boundaries in PNG
(not recommended due to the large uncertainties involved)

GPS dual-frequency carrier-phase measurements are made on a baseline between MORE (NMB GPS Base station in Port Moresby) and a new station (PSM 35676) near Tokua in East New Britain Province on the 1st February 2008. PNG94 coordinates are required for the new station. The two stations are on different tectonic plates and in addition, the new station has been subject to several displacements as a result of large earthquakes in the local area.

1. Compute the epoch of measurement
   1st February 2008 = day of year 32, 2008 = epoch 2008 + 32/366 = 2008.087

2. Extract the ITRF site velocity of MORE (Table 1)
   0.028 m/yr in Easting and 0.053 m/yr in Northing

3. Compute the displacement of MORE between the reference epoch 1994.0 (PNG94) and the epoch of measurement (2008.087)
   *Difference in Eastings = (2008.087-1994.0)*0.028 = 0.394*
   *Difference in Northings = (2008.087-1994.0)*0.053 = 0.747*

4. Compute the ITRF2000 coordinates of MORE at the epoch of measurement
   ITRF2000 UTM Zone 55 Easting = 520498.42 + 0.394 = 520498.81
   ITRF2000 UTM Zone 55 Northing = 8957148.59 + 0.747 = 8957149.34

5. Use the coordinates above as the reference station in the baseline processing to compute ITRF2000 coordinates of the new station PSM 35676. The ITRF2000 coordinates at epoch 2008.087 of PSM 35676 are Zone 56 E 428137.64 N 9518146.01

6. Compute the site velocity of PSM 35676
   (In the absence of an online plate motion calculator, adopt the velocity of the nearest tabulated PNG94 station on the same plate, or interpolate between adjoining stations on the same plate)
   The nearest tabulated station is TOKU which has a velocity of
   -0.010 m/yr in Easting and -0.036 m/yr in Northing

7. Compute the inter-seismic displacement of 35678 between the epoch of measurement (2008.087) and the reference epoch 1994.0 (PNG94)

   Difference in Eastings = (1994.0-2008.087)-0.010 = 0.141*
   Difference in Northings = (1994.0-2008.087)-0.036 = 0.507*

8. Compute the summed coseismic and postseismic displacements of the site between 1994 and 2008.

   (In the absence of an online displacement database, adopt known displacements of the nearest station) The nearest tabulated station is TOKU which has been subject to the following earthquake related displacements between 1994 and 2008
   -0.45 m in Easting and +1.45 m in Northing

9. Compute the equivalent PNG94 coordinates of PSM 35676

   PNGMG94 Zone 56 Easting = 428137.64 + 0.141 + 0.45 = 428138.23
   PNGMG94 Zone 56 Northing = 9518146.01 +0.507 - 1.45 = 9518145.07

Conclusions - How can be PNG94 be improved?

PNG94 is in urgent need of improvement. The risk to multi-billion Kina resource projects and the PNG economy by having errors of several metres in the geodetic datum is not well appreciated either within or outside the spatial science professions. Many projects in PNG have already suffered costly losses and delays resulting from uncertainties in the datum. Accurate survey information now more than ever before underpins the viability of the PNG economy by providing the homogeneous spatial framework, necessary for the definition of cadastral surveys and integrated engineering projects. PNG94 needs to account for the significant tectonic deformation occurring in PNG and it needs to be made more accessible to surveyors. Up-to-date coordinate listings and station data should be made freely available over the internet, in order to encourage compliance.

The existing network of geodetic monitoring sites (Figure 2) can be used to densify the existing datum. In order to make PNG94 more accessible to surveyors, geodetic stations should be located in more secure areas with good sky visibility such as airports, helipads and the grounds and roofs of government or commercial offices. Stations located on remote mountain tops, gardens and public areas are generally unsuitable because of the high risk of destruction, lack of security, difficulty of access and lack of maintenance. Fortunately most airstrips in PNG already have at least one geodetic station within their perimeters, though many do not yet have sufficiently accurate PNG94 coordinates. To facilitate RTK surveying, base stations and antenna masts can be established within offices with power supply, referenced to the local geodetic network of ground stations. Only several hours of GPS observations are required on these stations in order to update coordinates to centimetre level accuracy. PNG94 is inadequately tied to MSL with uncertainties of MSL elevations in the order of a few metres for most stations. Many resource companies would benefit from a collaborative effort between their survey consultants and the National Mapping Bureau Geodetic section to establish PNG94 in their operational areas. Direction and funding are required to coordinate a collaborative effort to update PNG94.

An online calculator and software package should be developed to enable spatial professionals to extract a site velocity using PNG specific plate models and a database of historical earthquake displacements, by entering site coordinates (either ellipsoidal or UTM) or to compute coordinates at a specific epoch. Ultimately, an online service such as PNGPOS could be developed to enable users to submit GPS data to a central processing facility in order to produce PNG94 coordinates in much the same way as AUSPOS currently does in Australia.

In order to make these datum improvements a reality PNG surveyors need greater exposure to well targeted CPD workshops and seminars in order to update their professional skills, especially with the use of GPS. Ultimately, it will be these surveyors who will take PNG forward.

References

Allman, J., *Geodetic Datum & Geodetic Adjustment for Papua New Guinea (PNG94)*, ACLMP report, 1996.

Blick G., Crook, C., Grant D., Beavan, J., Implementation of a Semi-Dynamic Datum for New Zealand, *International Association of Geodesy Symposia, Volume 128*, Springer, 2005.

Stanaway, R., *Implementation of a Dynamic Geodetic Datum in Papua New Guinea: A case study*, MPhil thesis, The Australian National University, 2004

Table 1 PNG94 1st order control listing - Provisional update 7th June 2008 (verification required)

Station location			PNG94 Ellipsoidal Coordinates			PNGMG94 Grid Coordinates			MSL	Site Velocity	
Location	GPS ID	NMB Reg. No.	Latitude	Longitude	Ellipsoid Height	Zone	Easting	Northing	RL	E m/yr	N m/yr
Aiambak	AIAM	PSM 9550	-7°20'51.8206"	141°16'01.4470"	95.52	54	529475.73	9187801.94	21.7	0.037	0.058
Alotau - Gurney Airport	ALT2	PSM 9538	-10°18'37.5094"	150°20'18.0912"	94.87	56	208478.37	8859053.57	16.3	0.031	0.058
Buka Airport	BUK1	PSM 4871	-5°25'34.3712"	154°40'08.4373"	73.25	56	684918.22	9399967.57	4.3	-0.059	0.031
Daru	DARU	AA 440/A	-9°05'15.5229"	143°12'27.1952"	80.28	54	742639.83	8994719.42	4.9	0.035	0.055
Finschhafen	FINS	PSM 19471	-6°36'55.4209"	147°51'17.6868"	74.24	55	594504.66	9268686.35	9.5	-0.006	0.004
Goroka - Airport	GOKA	PSM 9833	-6°04'53.0717"	145°23'30.4470"	1664.47	55	322023.98	9327531.64	1585.4	0.023	0.046
Hoskins - Airport	HOSK	PSM 9795	-5°28'00.4073"	150°24'31.6614"	101.35	56	212869.72	9395119.32	18.0	0.022	-0.027
Kavieng - Airport	KAVI	PSM 9513	-2°34'53.0660"	150°48'22.5361"	78.81	56	256077.96	9714464.61	2.7	-0.067	0.027
Kenabot - Lands Base	KENB	PSM 23342	-4°20'45.1168"	152°16'07.9951"	136.69	56	418875.65	9519602.79	63.2	-0.002	-0.041
Kerema - Catholic Mission	KERE	PSM 31703	-7°57'28.0191"	145°46'19.0726"	97.57	55	364647.58	9120168.45	21.5	0.030	0.052
Kikori - Airport	KIKO	PSM 5583	-7°25'24.6531"	144°14'55.7677"	88.93	55	196298.45	9178490.00	12.01	0.035	0.054
Kiunga - Airport	KIUN	PSM 9465	-6°07'37.9805"	141°16'41.2696"	103.27	54	530773.45	9322724.61	27.7	0.038	0.056
Lae - Unitech DSLS Base	LAE1	PSM 31107	-6°40'25.3661"	146°59'35.4668"	140.37	55	499246.79	9262320.80	67.12	0.026	0.052
Lae - Unitech Sports	9799	PSM 9799	-6°40'16.9707"	146°59'52.3754"	130.31	55	499765.91	9262578.60	57.06	0.026	0.052
Lake Kopiago - Airport	KOPI	PSM 17001	-5°23'09.0852"	142°29'42.1907"	1412.79	54	665650.98	9404480.51	1327.7	0.031	0.055
Losuia	LOSU	AA 583	-8°32'07.2596"	151°07'30.8181"	85.16	56	293644.60	9056016.40	6.1	0.021	0.071
Madang - Airport	MAD1	GS 15495	-5°12'41.2891"	145°46'56.1940"	73.27	55	365044.17	9423829.87	5.0	0.023	0.039
Manus - Lombrum Secor	MANU	PSM 9522	-2°03'02.2944"	147°21'37.6363"	129.77	55	540084.32	9773337.48	50.8	-0.065	0.027
Mendi	MEND	PSM 3507	-6°08'36.7344"	143°39'22.1658"	1815.08	54	793981.21	9320198.80	1732.6	0.029	0.047
Misima - Airport	MIS1	PSM 9195	-10°41'19.9049"	152°49'58.9388"	87.46	56	481741.61	8818417.91	13.1	0.030	0.055
Moro - Airport	MORA	PSM 17442	-6°21'44.9072"	143°13'46.0940"	917.86	54	746627.49	9296194.53	837.4	0.033	0.054
Mount Hagen - Airport	HGEN	PSM 3419	-5°49'55.7591"	144°18'23.7948"	1710.15	55	201725.79	9354636.51	1626.5	0.030	0.048
Nadzab - Airport	NADZ	ST 31024	-6°33'47.9879"	146°43'39.6541"	148.83	55	469894.96	9274514.88	77.4	0.024	0.056
Namatanai - Airport	NAMA	GS 19461	-3°39'58.5422"	152°26'06.1582"	114.96	56	437261.32	9594742.59	43.9	-0.061	0.001
Nogoli Hides - Helipad	NOGO	PSM 30041	-5°56'02.4348"	142°47'16.7455"	1340.20	54	697930.59	9343770.78	1257.5	0.032	0.054
Pomio	JACQ	PSM 9515	-5°38'42.9782"	151°30'19.6067"	151.55	56	334476.29	9375795.22	77.3	0.020	-0.053
Popondetta	POPN	PSM 9371	-8°46'09.6499"	148°14'00.3966"	187.53	55	635667.54	9030425.34	106.8	0.024	0.054
Port Moresby - NMB Base	MORE	PSM 15832	-9°26'02.7696"	147°11'12.2016"	116.74	55	520498.42	8957148.59	41.3	0.028	0.053
Rabaul - RVO Base	RVO_	RVO	-4°11'27.1915"	152°09'49.5108"	266.24	56	407190.52	9536723.33	191.9	0.007	-0.052
Tokua - Airport	TOKU	GS 9822	-4°20'27.7832"	152°22'45.8215"	82.05	56	431137.64	9520146.01	9.5	-0.010	-0.036
Vanimo - Doppler	VANI	PM 63/1	-2°41'05.2819"	141°18'15.6562"	80.59	54	533829.65	9703242.49	3.4	0.013	0.045
Wankkun - Pillar	NM34	NM/J/34	-6°08'52.0739"	146°04'52.4422"	509.98	55	398344.12	9320370.15	436.7	0.026	0.047
Wau - MCG Base New	WAU1	WAU1	-7°20'57.0996"	146°42'55.7613"	1224.79	55	468599.31	9187638.65	1144.5	0.025	0.056
Wewak - Airport	WEWK	PSM 15497	-3°35'02.5848"	143°40'00.1481"	83.91	54	796268.18	9603418.22	5.8	0.017	0.053
Wuvulu	WUVU	PSM 15456	-1°44'07.5951"	142°50'10.0781"	79.03	54	704257.66	9808081.66	2.4	-0.068	0.019

Horizontal Coordinates - Positional Uncertainty < 0.05m, Ellipsoidal Heights - Uncertainty < 0.10m, MSL RLs - Uncertainty < 0.5m (except Lae & Kikori < 0.10m)

*** Coordinates require verification by resurvey**