[EA]Geodetic and Vertical Datums Used in Papua New Guinea – An Overview*

Richard Stanaway[1]

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[1]Quickclose Pty Ltd, Melbourne, Australia (richard.stanaway@quickclose.com.au)

Abstract

The resource sector in Papua New Guinea uses a diverse selection of geodetic datums, coordinate reference systems, map projections, and vertical (height) systems at all levels of company operations. The aim of this presentation is to provide a practical overview of these systems and is focused at GIS professionals, database managers, civil works managers, and subsurface engineers.

Discussion

The *PNG Oil and Gas Act 1998* still proscribes the geodetic datum used for petroleum operations in PNG. Currently, the Australian Geodetic Datum 1966 (AGD66) defined by the Bevan Rapids origin AA070 (NW of Kerema) is mandated by the Act. Consequently, spatial definition and reporting of leases, well locations, and other data are required by the Department of Petroleum and Energy (DPE) to be submitted in AGD66.

The current PNG national geodetic datum gazetted by the PNG Lands Department is PNG94 and is somewhat different from AGD66 being a geocentric frame offset from AGD66 by approximately 200 m. The coordinates of PNG94 are fixed at the 1st January 1994 (reference epoch) and ignore any tectonic motion after that time. Global reference frames used by GNSS/GPS positioning use a kinematic global frame currently the International Terrestrial Reference Frame (ITRF) and closely related WGS84. Coordinates of ground features in these frames move continuously by several centimetres a year due to plate tectonics. In some instances, coordinates and elevations can change by metres after large earthquakes.

Transformations between these geodetic datums and reference frames can be a complex exercise if the software used is not configured or customised properly or if metadata is absent. Some common pitfalls and resolutions are discussed.

The diverse nature of height datums in PNG are also summarised. The main height datum used is Mean Sea Level (MSL), however the geoid models used to determine heights using GPS techniques in remote locations vary considerably in resolution and precision. This can lead to large inconsistencies in civil projects and resource modelling.

The International Terrestrial Reference Frame (ITRF) and World Geodetic System 1984 (WGS 84)

These reference frames or datums are used globally, especially by GNSS/GPS systems and are closely aligned at the cm level. The current realisation of ITRF is ITRF2014 and the coordinates of the defining stations now have uncertainties of only a few mm. An important characteristic of ITRF and WGS 84 is that the coordinates of apparently fixed features (e.g. well heads and survey control points) are in fact moving by up to several cm a year due to secular tectonic motion of the underlying plate. This means that an epoch or time stamp is required to be provided with ITRF or WGS 84 coordinate data. This is especially important if ITRF/WGS 84 data on an oil and gas project acquired over a long period is combined or transformed to another datum. If the epoch of ITRF or WGS 84 is not provided or is unknown then the uncertainty of the data degrades to the metre level making it unsuitable and even unsafe for most engineering, monitoring, and sub-surface precision requirements. A precise time-dependent transformation is required to combine precise ITRF and WGS 84 spatial data at a common epoch for analysis and visualisation. In Papua New Guinea a tectonic site velocity model is required to do this due to the tectonic complexity that exists within PNG.

Papua New Guinea Geodetic Datum 1994 (PNG94)

PNG94 is the geodetic datum currently mandated by the PNG Department of Lands and Physical Planning through the Office of the Surveyor-General (OSG) for all cadastral land surveys in PNG. PNG94 is defined by ITRF92 at epoch 1994.0 with coordinates fixed at 1st January 1994 (static datum). Secular tectonic movement between 1994 and 2020 is ignored, however earthquakes such as the 2018 Highlands earthquake frequently result in updates to PNG94 in affected areas as the need arises. Because secular tectonic effects (stable interseismic plate movement) are ignored in a static datum such as PNG94 the difference between PNG94 and ITRF/WGS 84 increases with time. In the PNG Oil and Gas fields the difference is now approaching 1.6 metres for most sites with the difference increasing by several cm a year. For surveys and spatial data where a precision of better that 2 metres is required, PNG94 and ITRF/WGS 84 now cannot be considered the same. The OSG is currently proposing an updated geodetic datum in PNG, PNG2020 to bring coordinates closer to current ITRF and WGS 84 in order to avoid any issues arising from assumption of datums and epochs of acquistion.

Australian Geodetic Datum 1966 (AGD66)

AGD66 was the geodetic datum gazetted for use in Australia and Papua New Guinea until c. 1998. In PNG, AGD66 was superseded by PNG94, however PNG Oil and Gas Legislation is still bound by AGD66, specifically defined by station AA 070 at Bevan Rapids on the Purari River in Gulf Province. AGD66 is not a geocentric datum and it is really important to note that difference between AGD66 and PNG94/ITRF/WGS 84 can be up to 200 metres (Figure 1). In other words, well coordinates and petroleum leases will have AGD66 and PNG94/WGS 84 coordinates that are up to 200 metres different for the same point. Another important characteristic of AGD66 is that the internal accuracy of the datum is only at 1- 2 metre level due to inherent inaccuracies of terrestrial surveying techniques that were used to define AGD66 in PNG in the 1970s.

Vertical Datums and Mean Sea Level

Most height datums used for land surveys are related to mean sea level (MSL). Traditional geometric levelling techniques were used to propagate elevations over a network of bench marks and then on to well heads and engineering projects. The mountainous terrain and lack of road infrastructure in PNG has meant that levelling networks are often not connected and can be imprecise due to propagation of error (up to 5 metres in the PNG Highlands). The use of GNSS/GPS has enabled much more accurate and rapid height datum transfer into remote areas of PNG however there are a couple of important differences to note with existing levelling datums. Firstly, GNSS/GPS natively use an ellipsoidal height system which is referred to a regular ellipsoid which most closely fits MSL globally. The Earth, however, is not a perfect ellipsoid due to gravity variations. The geoid is a surface that closely approximates MSL and the difference between the geoid and the ellipsoid can be up to 90 metres which PNG having some of the highest differences globally. A geoid model is required by GPS/GNSS to convert ellipsoidal heights to heights above the geoid (approximating MSL). The second point is that there are numerous geoids in use that are used to estimate MSL from input ellipsoidal heights and this can result in differences of up to 18 metres between derived MSL elevations (Figure 2). Additionally, global geoid models only approximate MSL and in tropical regions such as PNG there is an additional offset applied (between 0.8 and 1.4 meters in PNG) due to thermal expansion of the ocean above a global equipotential gravity surface that best fits MSL. The current MSL definition used by the main section of the PNG Oil and Gas fields is based on station 34 bench mark on the Kumul offshore terminal and propagated using the EGM96 derived geoid model with a -0.87 m offset applied to align ellipsoid heights with station 34. The datum is often called MSL(Kumul 34). Other projects in PNG use different geoid models and offsets.

Transformations Between Datums

Great care is required if spatial data are transformed from one datum to another, particularly with the choice and configuration of transformation model. ITRF/WGS 84 to PNG94 and ITRF/WGS 84 to AGD66 transformations are complex as they are two step and also time dependent. An NTv2 grid transformation model is currently being developed to enable full automation of this transformation within GIS packages. PNG94 to AGD66 transformations are more straightforward with the adoption of the EPSG standard transformations by PNG agencies in 2014 (Figure 3). There are also two different widely used conventions for describing rotations in a conformal transformation. The Coordinate Frame (CF) method has the opposite sign from the Position Vector (PV) notation method. It is therefore critically important to test any transformation with authoritative known data before implementation in a GIS, especially if the parameters are manually entered.

There are many different WGS 84 to AGD66 and PNG94 to AGD66 transformations which can result in differences of several metres in the transformed coordinates. For example, the default NIMA transformation is commonly used to transform WGS 84 to AGD66 and this transformation is up to several metres different from AGD66 realised in PNG (Figure 4). The EPSG transformation code should be clearly identified with any transformed datasets in order to prevent large errors if the transformation model is assumed. For most of the PNG Mainland, EPSG: 6937 should be used to transform between PNG94 and AGD66 as this is the most precise transformation between the realisation of the two datums and is also fixed to the Bevan Rapids Origin to comply with *PNG Oil and Gas Act*. In the Purari region, EPSG: 6939 is widely used. This PNG94 to AGD66 transformation is also fixed to the Bevan Rapids Origin and is slightly different from EPSG: 6937. In the North Fly District of Western Province, EPSG: 6941 is used due to an error in the original AGD66 realisation widely used in that district. The difference with EPSG: 6937 is up to several metres. The use of other transformations is not recommended if a precision of better than 7 metres is required for transformed data. The use of the EPSG transformations may still result in differences with historical coordinates (e.g. in earlier databases). This difference is due to propagation of errors in the original survey or seismic displacement.

Further Information

The Association of Surveyors of Papua New Guinea (ASPNG) website http://www.aspng.org can provide guidance for users. Richard Stanaway of Quickclose Pty Ltd can also be contacted for technical assistance and enquiries at richard.stanaway@quickclose.com.au .

Website Cited

The Association of Surveyors of Papua New Guinea (ASPNG) website http://www.aspng.org. Website accessed August 2020.

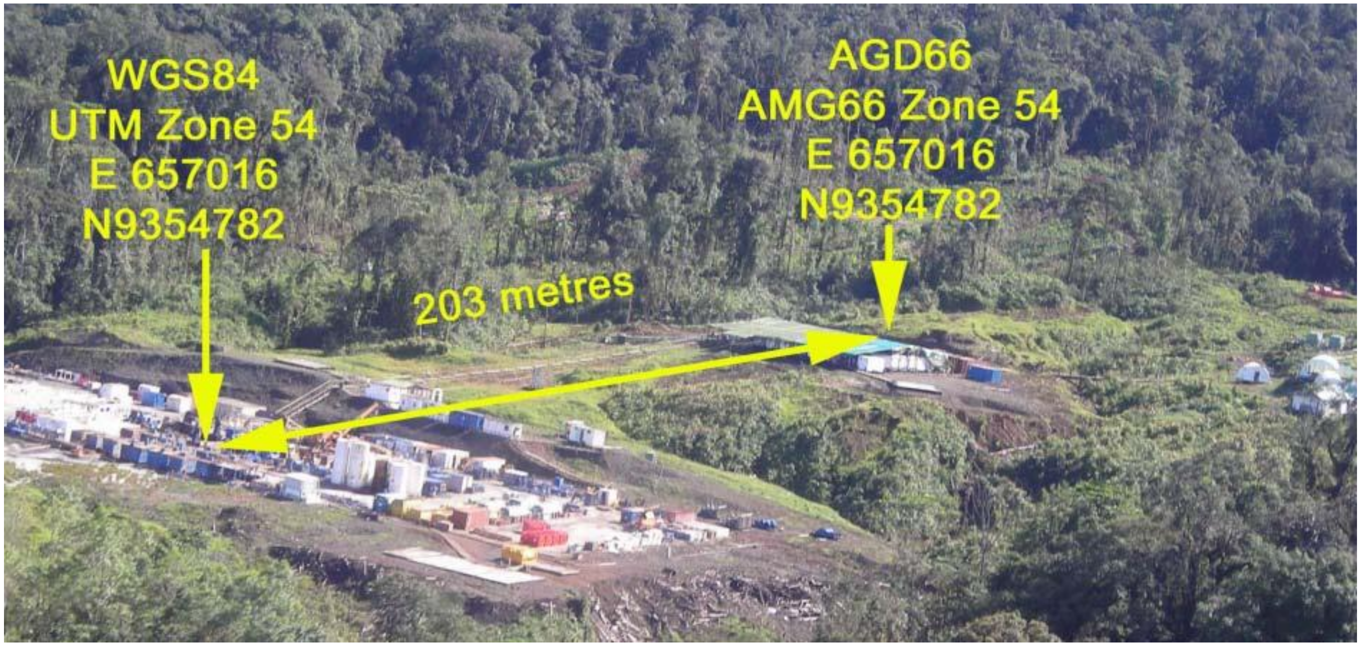

Figure 1. 200+ m difference between WGS84 and AGD66 in PNG.

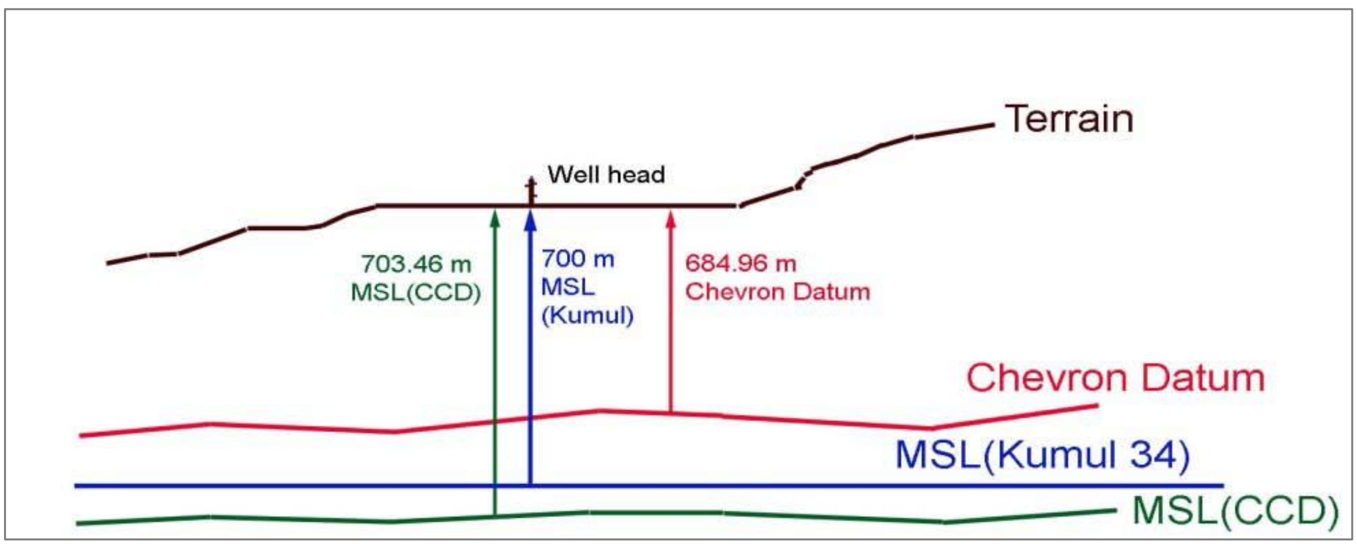

Figure 2. Example of different height systems used in the PNG Oilfields.

AGD66 to PNG94 transformation parameters

Area of Use	EPSG Code	Accuracy (m)	Tx (m)	Ty (m)	Tz (m)	Rx (sec)	Ry (sec)	Rz (sec)	Sc (ppm)
Medium accuracy - 7 parameter Position Vector convention									
PNG Mainland	6937	1.0	-0.41	-2.37	2.00	3.592	3.698	3.989	8.843
PFTB	6939	1.0	-131.876	-54.554	453.346	-5.2155	-8.2042	0.0900	5.02
North Fly	6941	0.5	45.928	-177.212	336.867	-4.6039	-3.0921	0.5729	36.796
Medium accuracy - 7 parameter Coordinate Frame rotation convention									
PNG Mainland	6937	1.0	-0.41	-2.37	2.00	-3.592	-3.698	-3.989	8.843
PFTB	6939	1.0	-131.876	-54.554	453.346	5.2155	8.2042	-0.0900	5.02
North Fly	6941	0.5	45.928	-177.212	336.867	4.6039	3.0921	-0.5729	36.796
Lower accuracy - 3 parameter									
PNG Mainland	6938	4.0	-129	-58	152				
PFTB	6940	2.0	-131.3	-55.3	151.8				
North Fly	6942	2.5	-137.4	-58.9	150.4				

AGD66 to WGS84 transformation parameters (3 parameter) in PNG

Area of Use	EPSG Code	Accuracy (m)	Tx (m)	Ty (m)	Tz (m)
PNG Mainland	6943	5.0	-129	-58	152
PFTB	6944	4.0	-131.3	-55.3	151.8
North Fly	6945	4.0	-137.4	-58.9	150.4

Figure 3. Summary of AGD66 / PNG94 transformations used in PNG.

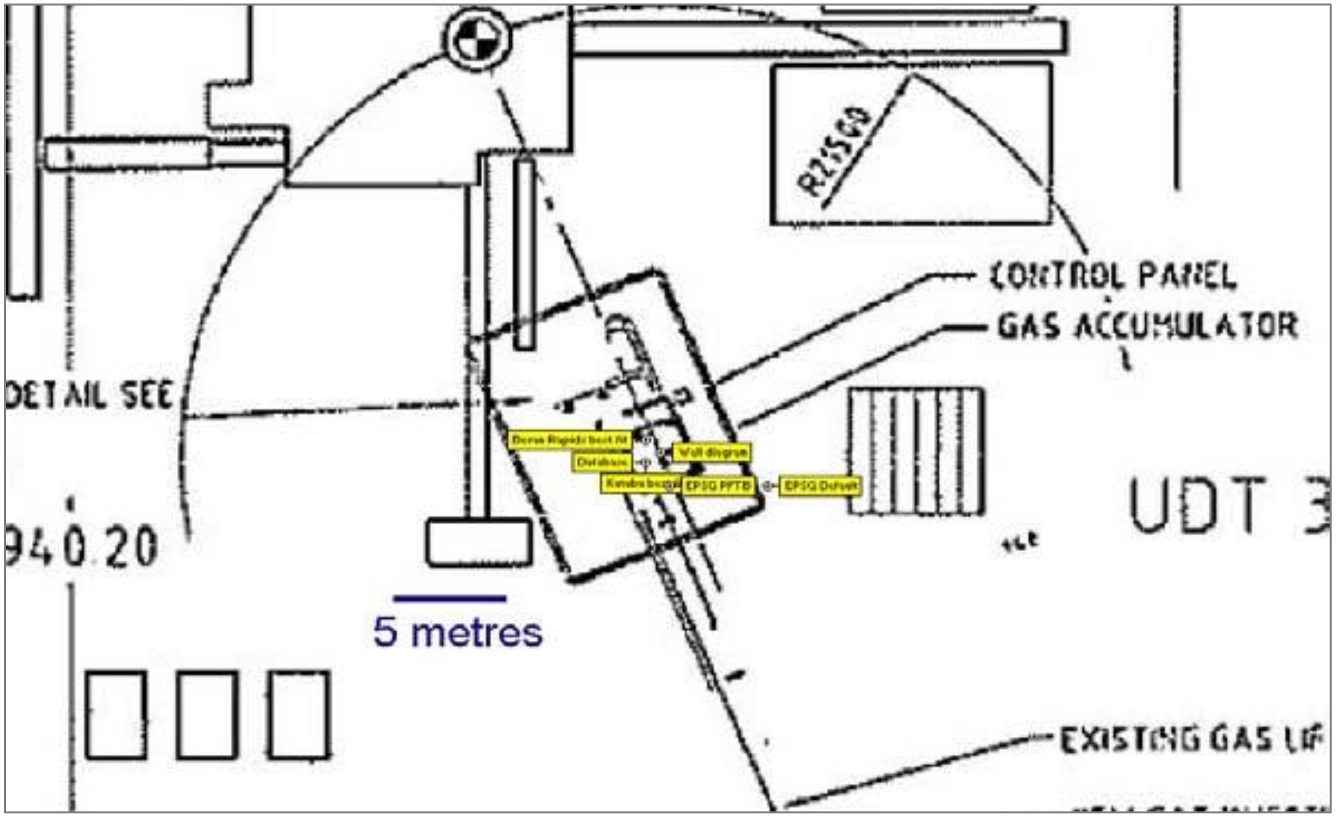

Figure 4. Differences between different AGD66 transformations on a well pad.