Connecting a Survey to PNG94 and MSL using GNSS

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Workshop overview

Legal requirements to connect surveys to PNG94

Accuracy and Precision - Positional & Local Uncertainty

What GNSS equipment and technique to be used

Network design and observing procedure

Loop closures, fault finding and adjustment

Grid to Plane computations

Worked example
What is PNG94?

14 Stations around PNG surveyed by GPS between 1992 and 1994

5 cm accuracy

UTM Grid Projection is PNGMG94

Offset from WGS84 >1.5m

Gazetted national geodetic datum for PNG
Legal Requirements

Cadastral surveys to be connected to PNG94 (e.g. via connected PSMs)

A closed loop survey or double check is required (for quality assurance)

Coordinates for survey should be legally traceable (by proven connection to PNG94)

WGS84 and uncorrected ITRF not acceptable for Cadastral Surveys in PNG (no datum point)

Handheld GNSS/GPS not acceptable (no quality assurance or traceability)

Distances to be converted to local “ground” distance (Grid distance is not a legal boundary dimension)
Pros. of using GNSS

mm / cm accuracy over hundreds of km
No line of sight required
Fast

Cons. of using GNSS

Needs clear view of sky (requires tree clearing)
Large errors if incorrect technique used
Accuracy can cause problems!
(e.g. unmodelled tectonic deformation)
PNG site velocities and plates. Ellipses show error ell.
4 million years before present
now
4 million years in the future?
Rapid uplift (2 - 7 mm/yr)

Sialum coral terraces - Photo: Sandy Tudhope
Effect of tectonic deformation on survey baselines & PNG94

May need to use a model to get back to 1994 coordinates
Coseismic deformation – Weitin Fault Nov 2000

SOUTH BISMARCK PLATE

5 metre offset

PACIFIC PLATE

Photo: Jim Mori 2001
The guiding principle is that PNG94 coordinates for any point should not change from where they were on 1/1/94.
Positional Uncertainty (PU)
How accurate a coordinate is with respect to PNG94

Local Uncertainty (LU)
How precise a coordinate is in relation to adjoining survey control or cadastral corners
### Suggested PU and LU for PNG Cadstral Surveys

<table>
<thead>
<tr>
<th>Classification</th>
<th>Application</th>
<th>Suggested Positional Uncertainty (PU)</th>
<th>Suggested Local Uncertainty (LU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Class 1</td>
<td>Urban, residential, commercial</td>
<td>100 mm</td>
<td>30 mm</td>
</tr>
<tr>
<td>Rural Class 1</td>
<td>Land used for resource extraction, utilities, pipelines</td>
<td>300 mm</td>
<td>100 mm</td>
</tr>
<tr>
<td>Rural Class 2 (A)</td>
<td>smaller settlement blocks</td>
<td>1 m</td>
<td>300 mm</td>
</tr>
<tr>
<td>Rural Class 2 (B)</td>
<td>larger settlement blocks</td>
<td>2 m</td>
<td>500 mm</td>
</tr>
<tr>
<td>Rural Class 3</td>
<td>Customary Registration of rural land for individuals or families</td>
<td>10 m</td>
<td>3 m</td>
</tr>
<tr>
<td>Rural Class 4</td>
<td>Other Customary Land surveys</td>
<td>30 m</td>
<td>10 m</td>
</tr>
</tbody>
</table>

PNG Cadastral surveying accuracy requirements (derived from *PNG Survey Directions, 1990*)
GNSS Equipment

Handheld (or vehicle based) stand-alone
3 - 50 metre “accuracy” on WGS84 or user datum

DGPS enabled geodetic receivers (e.g. OmniStar VBS)
1 metre precision in ITRF2005 (WGS84)

Precision DGPS enabled receivers (e.g. OmniStar HP)
0.1 metre precision in ITRF2005 (WGS84)

Single-Frequency geodetic receivers (carrier-phase)
(e.g. Sokkia Stratus, 1700CSX; Trimble L1 only; Leica GR20)
7-30mm precision up to 10 km from base station

Dual-Frequency geodetic receivers (carrier-phase)
(e.g. Trimble R8; Sokkia 2700ISX; Leica 1200)
7-30mm precision up to 50 km from base station
(2000 km with precise orbits)
GNSS Techniques & Cadastral Usage

Point Positioning

Uses broadcast orbit - **Not acceptable for Cadastral**

DGPS

1 receiver - Calibration with PNG94 reqd.
and double-checks essential

Real-Time Kinematic

2 receivers - Double checks essential

Post-processed Static

2+ receivers - Loop closure or double checks reqd.

Precise Point Positioning (PPP)

1 d/f receiver - 6 hrs+ observations -
Calibration with PNG94 reqd.
Static GNSS surveying
(preferred method)
Static GNSS - What’s needed

1 single-frequency receiver
   Requires CORS < 10 km range

2 or more single-frequency receivers
   < 10 km from PNG94 control & between receivers

1 dual-frequency receiver
   Requires CORS < 50 km range
   or PPP observations (6 hrs+ observations)

2 or more dual-frequency receivers
   < 50 km from PNG94 control (30 km is better)

Need post-processing and adjustment software
   e.g. Trimble Geomatics Office, Sokkia Spectrum, GPPS
Some continuous GPS (CORS) stations in PNG

Lands Kenabot - KENB

UniTech Base - LAE1

NMB Base - MORE
1. Find nearest validated PNG94 station ON THE SAME PLATE (< 50 km)
A preliminary update for PNG94 showing selected stations

1. Obtain **VALIDATED** PNG94 coordinates
2. Obtain PSM sketches, plans & reports
3. Choose positioning equipment
4. Place new stations for GNSS
5. Clear vegetation
What if no station within 50 km on same tectonic plate?

Use AUSPOS, NRCan, or IGS Precise Orbit
Network design - 2 receivers

First set of radiations from central base station
Network design - 2 receivers

Second set of radiations from second station
Network design - 2 receivers

Minimum network of closed loops
Network design - to support total station surveys

First set of radiations
Network design - to support total station surveys

Baselines between stations
Network design - to support total station surveys

Closed loops
Network design - Corridor surveys

"Traverse" of baselines between PNG94 control
LEAP FROG TECHNIQUE
How long should I observe for?

Table 1. Occupation times for different baseline lengths (good observing conditions)

<table>
<thead>
<tr>
<th>Baseline length</th>
<th>dual - frequency (minutes)</th>
<th>single - frequency (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 km</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>5-10 km</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>10-20 km</td>
<td>30</td>
<td>60+ 50% chance</td>
</tr>
<tr>
<td>20-30 km</td>
<td>40</td>
<td>unlikely</td>
</tr>
<tr>
<td>30-40 km</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>40-50 km</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>&gt; 50 km*</td>
<td>300</td>
<td></td>
</tr>
</tbody>
</table>

* over 50 km requires PPP such as AUSPOS or precise orbit. If using AUSPOS start obs after 10:00 PNG Time if possible.

If **bad conditions** (nearby trees, high grass, buildings, towers, periods of bad DOP or SV availability, or if >400m elevation difference on baseline, then **double or triple the time**

AUSPOS best to get 24 hrs obs for best result
Receiver setup

Check free memory (download, backup and delete old files)

Set all observables recorded

10 second epoch (30 sec for AUSPOS/NRCan) elevation mask 10° (5°-15°)

Clear any trees or branches nearby to improve sky visibility
Station and antenna setup

Check battery levels & eqpt.

Level and centre the antenna

Check centering with plumb-bob

measure antenna height (3 points)

kisim piksa
## Site Log

### GPS Occupation Log

<table>
<thead>
<tr>
<th>Site ID or filename</th>
<th>Antenna sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station Name</td>
<td>show point where measurement</td>
</tr>
<tr>
<td>Antenna type</td>
<td>to antenna is taken</td>
</tr>
<tr>
<td>Antenna serial number</td>
<td></td>
</tr>
<tr>
<td>Height measurement (start)</td>
<td></td>
</tr>
<tr>
<td>Height measurement (end)</td>
<td></td>
</tr>
<tr>
<td>Height to Phase Centre</td>
<td></td>
</tr>
<tr>
<td>Date start</td>
<td></td>
</tr>
<tr>
<td>Time start (PNG Time)</td>
<td></td>
</tr>
<tr>
<td>Time end (PNG Time)</td>
<td>Approximate position</td>
</tr>
<tr>
<td>Date end</td>
<td>Latitude</td>
</tr>
<tr>
<td></td>
<td>Longitude</td>
</tr>
</tbody>
</table>
Antenna heights (take care)

“Instrument height” is L1 antenna phase centre

“Antenna Reference Point (ARP)” is also commonly used

\[ H = \sqrt{S^2 - R^2} - O + P \]
GPS data processing

Static baseline processing using carrier-phase observations

May need software to convert receiver raw data to RINEX (Receiver Independent Exchange Format) if different receivers used and for AUSPOS / NRCan

Can use AUSPOS if no PNG94 reference station used (or > 50 km from PNG94 Control), or for QA

AUSPOS  www.ga.gov.au/bin/gps.pl

NRCan  www.geod.nrcan.gc.ca/online_data_e.php
Baseline Processing

Setup project (can use WGS84 & UTM parameters)

Use EGM2008 or EGM96 Geoid if available

Load raw or RINEX data

Enter known PNG94 coordinates and ellipsoid height for validated PNG94 reference station (set as fixed)

Leave ? for orthometric (MSL) height

Run the baseline processing
Baseline assessment

Should use “fixed” solution as “float” solution often unreliable for cm accuracy surveys

Shouldn’t use code solution for accurate surveys

$L1$ fixed or narrow lane fixed

$L1/L2$ fixed or ionospheric free fixed

If you get a float or code solution, reobserve the baseline for longer or improved conditions

RMS should be between 0.004 and 0.030

Reference variance ideally 1, but up to 10 usually OK

Ratio $1:n$ the higher $n$ is the better ($>10$)

Reobserve if outside tolerances

Observe new station from different station (compare)
Loop Closure & Adjustment

Loop closures should be within PU and LU tolerances.

If loop doesn’t close, 1 or more baselines (usually float or high RMS will need to be reobserved).

Radiations (baselines not in loop) should have two measurements from different stations, and coordinates should agree within tolerances.

Once loop closures have been checked - run the Network Adjustment.

Network Reference Factor ideally 1, but up to 5 usually OK.
If > 1, then reduce weight of high RMS baselines.
If < 1, then baseline precision underestimated (not common).
AUSPOS or NRCan

Dual-frequency RINEX file required
Need 1 hr obs for +/- 20-30 cm
Need 6 hrs obs for +/- 2-3 cm
Need 24 hrs obs for +/- 1 cm

Should wait 2-3 days to get Rapid Orbit
Should wait 2-3 weeks to get Final Orbit

GDA94 and ITRF report sent by email

Ignore GDA94, and ITRF needs to be converted to PNG94 using site velocity or by comparison with PNG94 control
Using a site velocity model?

Need to convert AUSPOS/NrCan ITRF ellipsoid or cartesian coordinates to UTM (using geographical calculator)

The site velocity is the rate of change of coordinates due to overall tectonic movement (refer to Stanaway)

\[
E_{PNGMG} = E_{UTM(ITRF)} + V_E (1994.0 - Y_M)
\]

\[
N_{PNGMG} = N_{UTM(ITRF)} + V_N (1994.0 - Y_M)
\]

\(E_{PNGMG}\) and \(N_{PNGMG}\) are the PNG Map Grid Coords.

\(E_{UTM(ITRF)}\) and \(N_{UTM(ITRF)}\) are the ITRF/WGS84 UTM Coords at the time of measurement

\(V_E\) and \(V_N\) are site velocity components (Easting and Northing)

1994.0 and \(Y_M\) is the reference epoch and measurement epoch
Obtaining MSL values

Baseline processing or AUSPOS will give MSL values using the EGM96 geoid model if selected

If possible observe at a nearby 1st order MSL station (i.e. next to tide gauges) otherwise at any existing high order MSL station used as existing height datum

Compare EGM96 MSL with existing MSL. The difference is correction to be applied to all other EGM96 derived heights

$$MSL_{local} = h - N_{EGM96} + c$$

$$c = MSL_{local,datum} - MSL_{EGM96}$$

EGM96 available on web if not built in to processing software, or use older PNG geoid model
Using RTK for control surveys

Should use post-processing for better reliability

RTK can be used for local < 5 km range control

Check that a geoid model is used in the system

Should not do RTK when DOP high or satellite availability is low

Before racing off, check the performance of the RTK by observing another fixed station first

Must do repeat measurement on different day at a different time of the day

Can use site calibration but geometry must be good (must span survey area)
Using OmniStar

For Rural Class 2A, 2B, 3 or 4 only

Uses ITRF2005 - So conversion to PNG94 required!

Three main service (accuracy levels):

- OmniStar-HP (+/- 100 mm) - Rural 2A +
- OmniStar-XP (+/- 300 mm) - Rural 2B, 3, 4
- OmniStar-VBS (+/- 1000 mm) - Rural 3, 4

Requirements:

1. **Conversion** obtained by observing known PNG94
2. Displayed accuracy x 3 to get realistic tolerance
3. **REPEAT OBSERVATIONS ESSENTIAL**
4. Must “Close” survey by comparing with PNG94
Setting up a cadastral plane grid

Can’t use PNGMG distances for cadastral surveys where ground distances are required

Scale factor of 1 often used with PNGMG/AMG coords
MUST NOT DO THIS OR BIG ERRORS WILL HAPPEN

Scale factor can be very different from 1, especially at high elevations near the central meridian

Choose a local origin at centre of survey area (e.g. mean coordinates and height of rural land parcel)

Use same azimuth and drop “sleeping” figures off PNGMG coordinates so they are more manageable

Can extend Plane grid 10 km away from datum or less if there are large elevation changes
Plane Grid conversions

\[ E_{\text{PLANE}} = E0_{\text{PLANE}} + \frac{1}{k_p} (E_{\text{PNGMG}} - E0_{\text{PNGMG}}) \]  
(Eq. 4.11)

\[ N_{\text{PLANE}} = N0_{\text{PLANE}} + \frac{1}{k_p} (N_{\text{PNGMG}} - N0_{\text{PNGMG}}) \]  
(Eq. 4.12)

\[ E_{\text{PNGMG}} = E0_{\text{PNGMG}} + k_p (E_{\text{PLANE}} - E0_{\text{PLANE}}) \]  
(Eq. 4.13)

\[ N_{\text{PNGMG}} = N0_{\text{PNGMG}} + k_p (N_{\text{PLANE}} - N0_{\text{PLANE}}) \]  
(Eq. 4.14)

where,

- \( E_{\text{PLANE}} \) & \( N_{\text{PLANE}} \) are the local plane coordinates
- \( E_{\text{PNGMG}} \) & \( N_{\text{PNGMG}} \) are the PNGMG coordinates to be converted
- \( E0_{\text{PLANE}} \) & \( N0_{\text{PLANE}} \) are the Plane coordinates of the Plane datum origin
- \( E0_{\text{PNGMG}} \) & \( N0_{\text{PNGMG}} \) are the PNGMG coordinates of the Plane datum Origin
- \( k_p \) is the is the combined PNGMG Grid and Height scale factor at the Plane Origin
1. Obtain **VALIDATED** PNG94 coordinates

2. Obtain PSM sketches, plans & reports

3. Choose positioning equipment

>10 km  dual-frequency GPS (static)

<10 km  single-frequency GPS (static)

<5 km   single-frequency GPS (RTK)

<1 km   line of sight:  total stations
Take away points:

Connect to nearest PNG94!!

Loop Closures / double checks

Control for total station surveys