GUIDELINE No. 9 (21/06/2011)

GNSS EQUIPMENT VERIFICATION

1.0 INTRODUCTION

These guidelines have been prepared to assist surveyors who use Global Navigation Satellite System (GNSS) equipment and require verification of its performance. They describe suggested procedures for testing GNSS equipment for surveying applications using the ACT GNSS Verification Network. The aim of the guidelines is to encourage all surveyors to employ a consistent approach when testing their GNSS equipment so the results obtained provide a reliable verification.

Approved methodologies for establishing legal traceability of position determined by GNSS rovers currently do not exist under the *National Measurement Act 1960 (Cth)*, therefore GNSS derived positions and distances should not be used as the sole method of measurement during a survey. For surveys where GNSS equipment is used, surveyors are strongly encouraged to adopt best practice. For each and every survey this includes, but is not limited to:

- Following the procedures described in ICSM Publication No.1 *Standards and Practices for Control Surveys* (SP1; ICSM, 2007);
- Occupying and verifying the position of at least three established survey control marks;
- Multiple independent GNSS occupations of all survey marks;
- Observing independent distance measurements using a calibrated EDM;
- Including independent angular observations; and
- Performing an annual system test on the ACT GNSS Verification Network, or over established survey control marks with a horizontal Class/Order of B/2 or better.

It is emphasised that these guidelines do not represent legal traceability of GNSS measurement, however by following the verification procedures described herein, surveyors will comply with Direction 17(3) of the *Surveyors (Surveyor-General) Practice Directions 2010 (No.2)*.

The ACT GNSS Verification Network comprises a well-controlled geodetic network of survey pillars, whose ACT Standard Grid coordinates (SGC), Geocentric Datum of Australia 1994 (GDA94) values, GRS80 ellipsoid and orthometric heights, and uncertainties are known. This network consists of Majura(P), Goodwin(P), Ainslie(P) and Lake Base 2 survey pillars, and the pillars of the Watson EDM Base, with baseline lengths ranging from 55m to 15km. Pillar elevations range from 558m to 891m, which allows for testing of the tropospheric modelling component of the software (Boey & Hill, 1995, p. 108).

In conjunction with these guidelines, the ACT GNSS Verification Network provides a number of testing opportunities:

- Using static or RTK techniques, the differences between the instrument/adjustment output against corresponding known coordinate values can be evaluated.

- The manufacturer's stated performance criteria can be verified.

- GNSS baselines to Dickson CORS(P) (NSW TS12097) are included in the Verification Network, allowing for testing of RTK positions derived using CORSnet-NSW.

- Software settings in the users' GNSS instruments and office software can be checked.

- The verification process allows the surveyor to train and evaluate the competency of staff engaged on GNSS surveys.

- Accuracies obtained from different observational procedures may be assessed.

The Verification Network is available for use by all GNSS users, however access to Majura(P) and the EDM base is through locked gates. Additionally, all pillars are covered by locked pillar caps. Keys required to gain access to the GNSS Verification Network and to unlock the pillar caps can be borrowed from the Surveying and Spatial Data workgroup, Environment and Sustainable Development, ACT Government, Ground Floor North, Dame Pattie Menzies House, 16 Challis Street, Dickson ACT 2602 (phone: 6207 1639).

Pillar coordinates are listed in Appendix A and a diagram of the network is shown in Appendix B.

A shifting spanner may be required to loosen the brass nut which protect the 5/8" Whitworth threaded bolts at Majura(P), Goodwin(P), Ainslie(P) and Lake Base 2 survey pillars.

2.0 FREQUENCY OF VERIFICATION

Pursuant to the Direction 17(3) of the *Surveyors (Surveyor-General) Practice Directions 2010 (No.2)*, surveyors are required to test their GNSS equipment on an approved geodetic network:

- at least once every 12 months; and
- immediately after any repairs.

Furthermore, it is strongly recommended that surveyors test their GNSS equipment:

- after a system upgrade (hardware and/or firmware); and
- after any upgrade of the post-processing software. Surveyors using multiple post-processing software packages for their GNSS surveys should compute the GNSS baseline observational data with all programs used.

A separate annual verification must be done for each GNSS technique used by the surveyor, as each observation technique requires a different testing procedure. These GNSS techniques are:

- Static / rapid static techniques which require testing over a network of survey pillars consisting of baselines of varying lengths.
- Real time kinematic (RTK) techniques which require testing over survey pillars that are generally located within 10km of the base station.
- RTK using a continuously operating GNSS reference station (CORS), which can be tested over the EDM base pillars, and other pillars as required.

It is recommended that users who perform surveys that do not fall under the *Surveyors Act 2007* also test their GNSS equipment annually in accordance with the following procedures, in order to provide confidence in the results of those surveys.

3.0 A NOTE ON COORDINATES

The horizontal coordinates of all marks of the ACT GNSS Verification Network, as listed in Appendix A, have been calculated using weighted constrained adjustments in order to minimise any distortions in the control network. Ellipsoid heights have been calculated by a minimally constrained height adjustment, with the current Regulation 13 Certificate height of Dickson CORS(P) (Hu & Dawson, 2010) held fixed. The coordinates listed in Appendix A are to be used for GNSS verification only. The values differ from those published on ACTMAPi and survey control plans.

Geoid – ellipsoid separations (N values) have been determined using AUSGeoid09 and refer to the GRS80 ellipsoid. Orthometric heights, which approximate AHD71 reduced levels, are derived using the listed N values.

4.0 RECOMMENDED PROCEDURES FOR VERIFYING GNSS EQUIPMENT

The following procedures detail the minimum recommended survey methods to be followed during the verification of GNSS equipment. For each test procedure:

- All equipment used in the tests is to be in good working order and adjustment.
- GNSS antennas are to be correctly oriented (north) throughout the tests.
- Field observation recording sheets should be completed for each GNSS verification. The receiver type, serial number and firmware used must be recorded on these sheets.
- Meteorological readings are not required. The reduction software defaults for tropospheric modelling are to be used.

4.1 Zero Baseline Test

A zero baseline test can be used to determine the precision of the receiver measurements, cabling and the data processing software, and hence the correct operation of the surveyor's GNSS system. The test should be performed for all pairs of receivers when the GNSS equipment is first acquired, immediately after any repairs, and before commencing high precision surveys.

SP1 section 2.6.4 *Equipment Validation* (ICSM, 2007) suggests that a useful GNSS equipment validation method is to "measure a 'zero baseline', which is achieved by connecting a single GPS antenna to two GPS receivers using a special antenna cable splitter", as shown in Figures 1 and 2 below.

Figure 1: **Zero baseline test**

Figure 2: GNSS receivers with antenna cable splitter

As two receivers share the same antenna, biases such as those which are satellite dependent (clock and ephemeris) and atmospheric path dependent (troposphere and ionosphere), as well as errors such as multipath, cancel during data processing. The quality of the resulting baseline is therefore a function of random observation error (or noise), and the propagation of any individual receiver biases (Boey & Hill, 1995, p. 108).

The computed baseline should theoretically be equal to zero and any variation will represent a vector of receiver errors. It is suggested that the derived slope distance between the two positions should be better than 3mm at the 95% confidence interval.

4.2 EDM Baseline Comparison Test

The Watson EDM base is calibrated annually and is certified by the Surveyor-General as a reference standard of length under Regulation 13 of the *National Measurement Regulations 1999* (Cth). An annual EDM baseline test allows surveyors to make a comparison of their GNSS derived distances against the certified distances. The recommended procedures are:

4.2.1 Certified distances on the Watson EDM base are reduced to a reference height of 610m, and are equivalent to spheroidal chord distances of the modified Australian National Spheroid used for the ACT Standard Grid (Klinge, 2007, p.6; Wellspring, 1973). Distance comparisons must be performed using observed SGC values.

4.2.2 Setup GNSS unit 1 on pillar EDM1. GNSS unit 2 is to occupy pillars EDM5 (171m) to EDM11 (1117m) in turn. Pillars EDM2 to EDM4 should not be occupied as the inter-pillar distances are less than minimum station spacing recommended by SP1 (ICSM, 2007) using a 5mm noise level.

4.2.3 Swap GNSS units, so that GNSS unit 2 is setup at pillar EDM1. GNSS unit 1 is to occupy pillars EDM5 (171m) to EDM11 (1117m) in turn, in order to provide independent occupations of all pillars. Additional occupations may be included to increase redundancy.

4.2.4 The observation procedures are to follow those described in Section 4.3 or 4.4 below for the chosen GNSS technique (static, rapid static, or RTK).

4.2.5 Pairs of observed SGC values are to be reduced to spheroidal chord distances (NMC, 1986, p. 12-13) and compared against the certified distances. Acceptance criteria for the distances are 5 millimetres or better at the 95% confidence interval.

4.2.6 A spreadsheet for performing the above-mentioned geodetic calculations, and the latest EDM base certified distances are available from the Surveyor-General upon request.

4.3 Static / Rapid Static Verification

Although the EDM Baseline Comparison Test is useful for comparing GNSS derived distances against the certified distances, the single direction and limited length (1117m) of the Watson EDM Base is considered to be inadequate for testing the entire GNSS measurement process. A network consisting of baselines of varying lengths is considered to be a more appropriate verification method (Boey & Hill, 1995, p.102) and allows testing to be carried out under realistic field conditions.

4.3.1 Either SGC, GDA94 or MGA94 values, as shown in Appendix A, may be used during the verification process.

4.3.2 Either orthometric heights or GRS80 ellipsoidal heights, as shown in Appendix A, may be used during the verification process.

4.3.3 Receivers should be set to record at a 5 second data collection rate.

4.3.4 The minimum constellation specification to be simultaneously observed by all receivers is:

- 5 common healthy satellites;
- an elevation angle of 15° or more above the horizon; and
- a GDOP of 5 or less.

4.3.5 Enough data must be observed to produce an Ambiguity Fixed baseline solution and/or a Standard Deviation of less than 3mm. For static GNSS, the suggested minimum session length is 10 minutes + 2 min/km (with a minimum session of 20 minutes). Depending on the satellite geometry, a minimum session length of 5 – 10 minutes is suggested when using rapid static techniques.

4.3.6 A minimum 20 minute gap between observations must be included for back-to-back sessions at any pillar, to allow for a sufficient change in satellite geometry.

4.3.7 As a minimum, a braced figure shall be observed, formed by four (4) of the following pillars (ie: a minimum of six baselines):

- AINSLIE (P);
- MAJURA(P);
- GOODWIN(P);
- LAKE BASE 2;
- EDM1; and
- EDM11.

The baselines are to be observed and processed as independent vectors (ie: no trivial baselines). The choice of pillars to be occupied should be governed by the length of baselines observed during the user's typical GNSS surveys.

Extension of this network is possible by including additional pillars. All additional pillars shall be connected by a minimum of 3 independent baselines, with the recommended minimum pillar spacing being 160m.

4.3.8 All adjustments of GNSS data must be 3 dimensional.

4.3.9 The detection of blunders should be carried out prior to adjustment.

4.3.10 A minimally constrained least squares adjustment of the observed network must be carried out holding one pillar fixed with the values shown in Appendix A, to confirm that no significant observational errors exist in the data and to verify that the survey meets the required standards. Horizontal coordinates resulting from the minimally constrained adjustment should agree within 10mm + 15ppm at the 95% confidence interval, where ppm is calculated from the distance from the fixed pillar.

4.3.11 A constrained least squares adjustment of the observed network must then be carried out holding two pillars fixed with the values shown in Appendix A. It is suggested that the pillars furthest apart be the two marks held fixed. The derived coordinates for the other pillars should then be compared with the promulgated values shown in Appendix A. Acceptance criteria are 15mm or better at the 95% confidence interval for the horizontal vector and 30mm or better at the 95% confidence interval for height.

4.3.12 A statistical analysis of the residuals of the least squares adjustments must be performed. The analysis of observed GNSS baselines and the overall model test should indicate the survey to be within acceptable limits.

4.4 RTK Verification

4.4.1 Depending on the quality of the user's UHF radios, Majura (P), Ainslie (P), Lake Base 2 and EDM base pillars can be used to verify the surveyors RTK GNSS system.

4.4.2 Receivers should be set to record at a 1 second data collection rate.

4.4.3 The suggested minimum session length is 3 minutes if 0.01m – 0.02m horizontal accuracy is required (see 4.4.7.1 below). If 0.02m – 0.04m horizontal accuracy is required, then the minimum session length shall be 1 minute (see 4.4.7.2 below).

4.4.4 The minimum recommended satellite elevation mask is 10° above the horizon.

4.4.5 Each "free" pillar must be occupied at least twice to provide for redundancy, with the re-occupations made from a different base station.

4.4.6 A minimum 20 minute gap between re-occupations at any pillar must be included to allow for a sufficient change in satellite geometry.

4.4.7 The acceptance criteria depends upon the PDOP and number of satellites available at the time of testing:

4.4.7.1 If PDOP ≤ 2.0 and satellites ≥ 7, then the difference between the averaged positions and those listed in Appendix A should be less than 0.02m horizontal and 0.04m vertical (at the 95% confidence interval).

4.4.7.2 If PDOP ≤ 3.0 and satellites ≥ 6, then the difference between the averaged positions and those listed in Appendix A should be less than 0.04m horizontal and 0.05m vertical (at the 95% confidence interval).

4.5 CORS RTK Verification

The GNSS Verification Network can be used to test user's RTK positions derived using CORSnet-NSW. The recommended procedures are:

4.5.1 CORSnet-NSW uses IGS absolute antenna models in its products. Users must ensure that their GNSS rovers and office software also utilise the IGS absolute antenna models (Janssen & Haasdyk, 2011).

4.5.2 Receivers should be set to record at a 1 second data collection rate.

4.5.3 The minimum satellite elevation mask is 10° above the horizon.

4.5.4 As a minimum, occupy all the EDM base pillars twice. Other pillars may be included to extend the range of the testing.

4.5.5 The suggested minimum session length is 3 minutes if 0.01m – 0.02m horizontal accuracy is required (see 4.5.8.1 below). If 0.02m – 0.04m horizontal accuracy is required, then the minimum session length shall be 1 minute (see 4.5.8.2 below).

4.5.6 A minimum 20 minute gap between re-occupations at any pillar must be included to allow for a sufficient change in satellite geometry.

4.5.7 Users must be aware that CORSnet-NSW provides coordinates in GDA94(2010), which is a newer, more homogenous realisation of the Geocentric Datum of Australia 1994 (Janssen & McElroy, 2010). In the ACT, the differences between GDA94(1997) and GDA94(2010) are in the order of 20 – 30mm horizontal and 160 – 210mm vertical.

To account for these differences, users must either perform a "site localisation" on a number of the pillars, or perform a block shift using the differences calculated at Dickson CORS(P).

4.5.8 The acceptance criteria depends upon the PDOP and number of satellites available at the time of testing:

4.5.8.1 If PDOP ≤ 2.0 and satellites ≥ 7, then the difference between the averaged positions and those listed in Appendix A should be less than 0.02m horizontal and 0.04m vertical (at the 95% confidence interval).

4.5.8.2 If PDOP ≤ 3.0 and satellites ≥ 6, then the difference between the averaged positions and those listed in Appendix A should be less than 0.04m horizontal and 0.05m vertical (at the 95% confidence interval).

5.0 FIRMWARE AND SOFTWARE UPDATES

If any significant upgrades are made to the receiver firmware or post-processing software, then the verification must be repeated. To avoid additional fieldwork with every upgrade, it is suggested that the original raw data be reprocessed and the output examined for any changes.

6.0 DATA RETENTION

Surveyors should suitably archive field booking sheets, raw observational data, adjustment results and post-adjustment base line vector comparisons. Surveyors are reminded that pursuant to Direction 17(4) of the *Surveyors (Surveyor-General) Practice Directions 2010 (No.2)*, results of an annual verification of GNSS equipment are to be supplied to the Surveyor-General on request.

7.0 OH&S REQUIREMENTS

Persons using the ACT GNSS Verification Network must comply with the requirements of the ACT *Work Safety Act 2008*, *Work Safety Regulations 2009* and all relevant WorkSafe ACT guidelines.

8.0 ADVICE ON GNSS VERIFICATION

Questions relating to the testing of GNSS equipment can be directed to the Surveyor-General. If differences between observed and published pillar coordinates are greater than the acceptance criteria, surveyors are advised to contact the Surveyor-General (ph: 6207-1639). Additionally, it is suggested that surveyors refer to the reference publications, as they provide a significant amount of best practice advice that is beyond the scope of this guideline.

Bill Hirst
Surveyor-General of the ACT
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APPENDIX A: ACT GNSS Verification Network Coordinates

Station Information

Station: AINSLIE (P)

GDA94
Latitude: S 35° 16’ 10.97193”
Longitude: E 149° 09’ 31.68159”

Ellipsoidal Height: 866.905
N: 19.579
Orthometric Height: 847.326

MGA94 (zone 55)
Easting: 696,361.137
Northing: 6,094,909.318

ACT Standard Grid Coordinates
Easting: 213,494.555
Northing: 605,145.339

Station: DICKSON CORS (P)

GDA94
Latitude: S 35° 15’ 02.71059”
Longitude: E 149° 08’ 08.62219”

Ellipsoidal Height: 613.843
N: 19.557
Orthometric Height: 594.286

MGA94 (zone 55)
Easting: 694,307.493
Northing: 6,097,058.098

ACT Standard Grid Coordinates
Easting: 211,397.769
Northing: 607,252.135

Station: GOODWIN (P)

GDA94
Latitude: S 35° 12’ 31.18746”
Longitude: E 149° 01’ 13.58914”

Ellipsoidal Height: 633.333
N: 19.332
Orthometric Height: 614.001

MGA94 (zone 55)
Easting: 683,912.249
Northing: 6,101,946.539

ACT Standard Grid Coordinates
Easting: 200,905.235
Northing: 611,929.478

Station: LAKE BASE 2

GDA94
Latitude: S 35° 17’ 39.88761”
Longitude: E 149° 07’ 15.67070”

Ellipsoidal Height: 577.574
N: 19.415
Orthometric Height: 558.159

MGA94 (zone 55)
Easting: 692,865.513
Northing: 6,092,243.714

ACT Standard Grid Coordinates
Easting: 210,053.560
Northing: 602,409.386

Station: MAJURA (P)

GDA94
Latitude: S 35° 14' 16.69296"
Longitude: E 149° 10' 52.65003"

Ellipsoidal Height: 911.196
N: 19.722
Orthometric Height: 891.474

MGA94 (zone 55)
Easting: 698,484.651
Northing: 6,098,385.861

ACT Standard Grid Coordinates
Easting: 215,547.274
Northing: 608,664.208

Station: EDM1

GDA94
Latitude: S 35° 14' 20.20220"
Longitude: E 149° 09' 53.13452"

Ellipsoidal Height: 637.491
N: 19.672
Orthometric Height: 617.819

MGA94 (zone 55)
Easting: 696,977.729
Northing: 6,098,310.670

ACT Standard Grid Coordinates
Easting: 214,042.159
Northing: 608,558.524

Station: EDM4

GDA94
Latitude: S 35° 14' 19.06462"
Longitude: E 149° 09' 51.47016"

Ellipsoidal Height: 634.270
N: 19.672
Orthometric Height: 614.598

MGA94 (zone 55)
Easting: 696,936.418
Northing: 6,098,346.640

ACT Standard Grid Coordinates
Easting: 214,000.128
Northing: 608,593.651

Station: EDM5

GDA94
Latitude: S 35° 14' 16.64653"
Longitude: E 149° 09' 47.93235"

Ellipsoidal Height: 630.884
N: 19.670
Orthometric Height: 611.214

MGA94 (zone 55)
Easting: 696,848.607
Northing: 6,098,423.098

ACT Standard Grid Coordinates
Easting: 213,910.785
Northing: 608,668.318

Station: EDM6

GDA94
Latitude: S 35° 14' 13.20354"
Longitude: E 149° 09' 42.89445"

Ellipsoidal Height: 626.103
N: 19.668
Orthometric Height: 606.435

MGA94 (zone 55)
Easting: 696,723.559
Northing: 6,098,531.963

ACT Standard Grid Coordinates
Easting: 213,783.558
Northing: 608,774.631

Station: EDM7

GDA94
Latitude: S 35° 14' 09.75599"
Longitude: E 149° 09' 37.85091"

Ellipsoidal Height: 621.669
N: 19.666
Orthometric Height: 602.003

MGA94 (zone 55)
Easting: 696,598.368
Northing: 6,098,640.969

ACT Standard Grid Coordinates
Easting: 213,656.185
Northing: 608,881.082

Station: EDM8

GDA94
Latitude: S 35° 14' 06.30951"
Longitude: E 149° 09' 32.80801"

Ellipsoidal Height: 618.408
N: 19.663
Orthometric Height: 598.745

MGA94 (zone 55)
Easting: 696,473.190
Northing: 6,098,749.939

ACT Standard Grid Coordinates
Easting: 213,528.825
Northing: 608,987.499

Station: EDM9

GDA94
Latitude: S 35° 14' 02.86160"
Longitude: E 149° 09' 27.76274"

Ellipsoidal Height: 615.146
N: 19.660
Orthometric Height: 595.486

MGA94 (zone 55)
Easting: 696,347.949
Northing: 6,098,858.953

ACT Standard Grid Coordinates
Easting: 213,401.402
Northing: 609,093.958

Station: EDM10

GDA94
Latitude: S 35° 13' 59.41392"
Longitude: E 149° 09' 22.71886"

Ellipsoidal Height: 612.275
N: 19.658
Orthometric Height: 592.617

MGA94 (zone 55)
Easting: 696,222.741
Northing: 6,098,967.958

ACT Standard Grid Coordinates
Easting: 213,274.012
Northing: 609,200.408

Station: EDM11

GDA94
Latitude: S 35° 13' 56.99525"
Longitude: E 149° 09' 19.17965"

Ellipsoidal Height: 611.080
N: 19.657
Orthometric Height: 591.423

MGA94 (zone 55)
Easting: 696,134.882
Northing: 6,099,044.427

ACT Standard Grid Coordinates
Easting: 213,184.622
Northing: 609,275.085

Notes:

1. These coordinates given above are to be used for GNSS verification only. The values differ from those published on ACTMAPi and survey control plans.

2. Heights are to the brass pillar plate.

3. Ellipsoid heights refer to the GRS80 ellipsoid.

4. Orthometric heights are an approximation of Australian Height Datum 1971 (AHD71) and have been derived using AUSGeoid09.

5. Projected coordinates are Map Grid of Australia 1994 (MGA94) Zone 55 and ACT Standard Grid.

6. The sky view at AINSLIE(P) and EDM5 is partly obstructed by tree cover and should only be occupied during periods of low GDOP. Consideration should also be given to extending observation sessions at these pillars.

Appendix B: Diagram of GNSS Verification Network