Surveyor-General
of the Australian Capital Territory

Guideline No. 9

GNSS Equipment Verification

Office of the Surveyor-General and Land Information

ACT Government

November 2023

Record of Document Issues

Version	Issue Date	Nature of Amendment
1.0	21 June 2011	Original Issue
2.0	25 October 2023	General revision resulting from GDA2020 introduction

Any queries regarding this Guideline may be directed as above.

In the event of an inconsistency between these guidelines and any Act or Regulation, the Act or Regulation takes precedence.

Approved by

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Surveyor-General of the ACT

Date of Approval: 28 November 2023

Contents

1 Introduction

This guideline has been prepared to assist surveyors who use Global Navigation Satellite System (GNSS) equipment and require verification of its performance. It describes suggested procedures for testing GNSS equipment for surveying applications using the ACT GNSS Verification Network. The aim of this guideline 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 projects where GNSS equipment is used, surveyors are strongly encouraged to adopt best practice. For every survey this includes, but is not limited to:

- Following the procedures described in ICSM publications Standard for the Australian Survey Control Network – Special Publication 1 (SP1; ICSM, 2020a) and Guideline for Control Surveys by GNSS (ICSM, 2020b);
- 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 GNSS Verification Network.

It is emphasised that this guideline does not represent legal traceability of GNSS measurement, however by following these verification procedures, surveyors will comply with Direction 17(c) of the *Surveyors (Surveyor-General) Practice Directions 2023*.

The GNSS Verification Network comprises a well-controlled geodetic network of survey pillars, whose ACT Standard Grid Coordinates (SGC), Geocentric Datum of Australia 2020 (GDA2020) coordinates, 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 Baseline, 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). Pillar coordinates are listed in Appendix A and a diagram of the network is shown in Appendix B.

In conjunction with this guideline, the GNSS Verification Network provides several testing opportunities:

- Using static or real-time kinematic (RTK) techniques, the differences between the instrument/adjustment output against corresponding known coordinate values can be evaluated.
- The equipment manufacturer's stated performance criteria can be verified.
- Testing of single baseline RTK or network RTK (NRTK) positions derived using a CORS network (e.g. CORSnet-NSW).
- Software settings in the users' GNSS instruments and office software can be checked.

- The verification process allows for training and evaluation of 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 Watson EDM Baseline is through locked gates. Additionally, all pillars are covered by locked pillar caps. Keys required for MAJURA(P), GOODWIN(P), AINSLIE(P) and LAKE BASE 2 survey pillars can be borrowed from the Office of the Surveyor-General and Land Information (OSGLI). Combination padlocks have been fitted to the Watson EDM Baseline pillar lids and gate. Access to the EDM baseline must be booked, and the customer will be provided with the combination code at the time of booking.

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   Frequency of Verification

Pursuant to Direction 17(c) of the *Surveyors (Surveyor-General) Practice Directions 2023*, surveyors are required to test their GNSS equipment on an approved geodetic network:
- at least once every 12 months; and
- immediately after any repairs or change of software.

GNSS equipment testing is required:
- after a system upgrade (hardware, firmware and/or software); 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 include:
- Static / rapid-static techniques which require testing over a network of survey pillars consisting of baselines of varying lengths.
- Static GNSS with post-processing using AUSPOS.
- Classic RTK techniques using a base station and rover.
- Single base RTK or NRTK using a GNSS CORS network.

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, to provide confidence in the results of those surveys.

3   A Note on Coordinates

The GNSS Verification Network provides for testing using either ACT SGC or GDA2020.

The SGC values of the GNSS Verification Network pillars (Appendix A) have been calculated using a weighted constrained least squares adjustment to minimise any distortions in the coordinates of the ground control network. Therefore, the SGC values listed in Appendix A are to be used for GNSS verification only. The values differ from those published on ACTmapi and survey control plans.

Geoscience Australia processes the national least squares adjustment (NADJ) to compute GDA2020 coordinates and uncertainties. The adjustment is a national scale, fully rigorous, 3D network adjustment of all available GNSS and terrestrial data from Commonwealth, State and Territories (ICSM, 2022). The GDA2020 coordinates of all marks of the GNSS Verification Network (Appendix A) were calculated from the NADJ version 20221201. However, as the NADJ is processed monthly, the ACT extract from the latest NADJ, which includes the GNSS Verification Network pillars, is available on request.

GDA2020 ellipsoid-to-AHD separations ($N_{AUSGeoid2020}$) have been determined using AUSGeoid2020 and refer to the GRS80 ellipsoid. Orthometric heights, also known as Derived AHD heights, are an approximation of AHD71 reduced levels. For further information on AUSGeoid2020, please refer to the GDA2020 Technical Manual (ICSM, 2021).

Note: Following the modernisation of the Australian Geospatial Reference System (ICSM, 2022), including the release of GDA2020, the previously published GDA94 coordinates of the GNSS Verification Network are no longer supported. Please contact OSGLI if you require legacy GDA94 coordinates.

4   Recommended Procedure for Verifying GNSS Equipment

4.1   Survey procedure

Ultimately, it is up to the surveyor's professional judgement to determine the scope and extent of their GNSS verification. The minimum recommended survey procedure for verifying GNSS equipment is:
- All equipment used in the tests must be in good working order and adjustment.
- GNSS antennas are to be correctly oriented to north throughout the tests.
- Field observation recording sheets should be completed for each GNSS verification. The receiver type, serial numbers and firmware used must be recorded on these sheets.
- Meteorological readings are not required, however rapidly changing weather conditions can affect all GNSS results especially over longer distances. The software defaults for tropospheric modelling are to be used.

4.2   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 GNSS system. The test should be performed for all pairs of receivers when the GNSS equipment is first acquired, immediately after any repairs or change of software, and before commencing high precision surveys.

A zero baseline test is achieved by connecting a single GNSS antenna to two GNSS receivers using a special antenna cable splitter (ICSM, 2007), as shown in Figures 1 and 2 below.

As the 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).

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 2mm at the 95% confidence interval.

Note: a zero baseline test may not be possible using GNSS equipment that solely relies on Bluetooth connectivity between the GNSS antenna and receiver/controller.

FIGURE 1: ZERO BASELINE TEST

FIGURE 2: GNSS RECEIVERS WITH ANTENNA CABLE SPLITTER

4.3   EDM Baseline Comparison Test.

The Watson EDM baseline 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:

4.3.1   Certified distances on the Watson EDM baseline 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; Wellspring, 1973). Distance comparisons must be performed using observed SGC values.

4.3.2   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 the recommended minimum station spacing using a 5mm noise level.

4.3.3   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, to provide independent occupations of all pillars. Additional occupations may be included to increase redundancy.

4.3.4   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.

4.3.5   A spreadsheet for performing the above-mentioned geodetic calculations is available from the OSGLI website. The latest EDM baseline certified distances are available from the Surveyor-General upon request.

4.4   Static / Rapid-Static Verification

4.4.1   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 Baseline is inadequate for testing the entire GNSS measurement process. A network consisting of baselines of varying lengths is a more appropriate verification method and allows testing to be carried out under realistic field conditions.

4.4.2   Either SGC, GDA2020 or MGA2020 values, as shown in Appendix A, may be used during the verification process.

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

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

4.4.5 The minimum constellation specification to be simultaneously observed by all receivers is:
- 5 common healthy satellites;
- a satellite elevation mask of 15° above the horizon; and
- a GDOP of 5 or less.

4.4.6 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 30 minutes + 5 min/km (with a minimum session of 30 minutes). Depending on the satellite geometry, a minimum session length of 5 – 10 minutes is suggested when using rapid-static techniques.

4.4.7 To allow for a sufficient change in satellite geometry, a minimum 30 minute gap between observations must be included for back-to-back sessions at any pillar.

4.4.8 As a minimum, a braced figure shall be observed, formed by four (4) of the following pillars (i.e. a minimum of six baselines):
- AINSLIE(P)
- MAJURA(P)
- GOODWIN(P)
- LAKE BASE 2
- EDM1
- EDM11

4.4.9 The baselines are to be observed and processed as independent vectors (i.e. 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.

4.4.10 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.

4.4.11 All adjustments of GNSS data must be 3 dimensional.

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

4.4.13 A <u>minimally constrained</u> 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.

4.4.14 A <u>constrained</u> 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.

4.4.15 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.

4.5 Classic RTK Verification

4.5.1 Classic RTK techniques use a base station and rover, which require testing over survey pillars that are generally located within 10km of the base station.

4.5.2 Depending on the quality of the user's UHF radios, MAJURA(P), AINSLIE(P), LAKE BASE 2 and the EDM baseline pillars can be used to verify the surveyors RTK GNSS system.

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

4.5.4 The suggested minimum session length is 3 minutes if 0.01m – 0.02m horizontal accuracy is required. If 0.02m – 0.04m horizontal accuracy is required, then the minimum session length shall be 1 minute.

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

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

4.5.7 A minimum 30 minute gap between re-occupations at any pillar must be included to allow for a sufficient change in satellite geometry.

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

- 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).

- 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).

4.6   AUSPOS Verification

4.6.1   Geoscience Australia's free online GPS processing service, AUSPOS, was developed to provide an online positioning service based on Continuously Operating Reference Stations (CORS). AUSPOS accepts dual-frequency, geodetic-quality GNSS data in RINEX format that was observed in static mode (Janssen & McElroy, 2022).

4.6.2   The AUSPOS website contains background information, a submission checklist, a step-by-step submission guide and frequently asked questions to help users submit data, understand the results and aid trouble shooting.

4.6.1   For an AUSPOS verification, the number of GNSS Verification Network pillars to be occupied is at the discretion of the user.

4.6.2   Static dual-frequency GPS carrier phase and code data of at least 1 hour duration (recommended minimum of 2 hours) shall be observed.

4.6.3   It is recommended that each pillar be re-occupied for a second observation. A minimum 30 minute gap between re-occupations at any pillar must be included to allow for a sufficient change in satellite geometry.

4.6.4   For best processing results, it is recommended that RINEX data is submitted to AUSPOS when the IGS final orbits are available (approximately 2 – 3 weeks after the observation). Note: IGS rapid orbits are available 2 days after the observation and are typically very close to the final orbit solution.

4.6.5   The computed AUSPOS coordinates shall be compared against the published pillar coordinates, as shown in Appendix A. The acceptance criteria are that horizontal and vertical coordinate differences are within the Positional Uncertainties shown on the AUSPOS report.

4.7 CORS RTK Verification

4.7.1 Single base RTK or NRTK positions using a GNSS CORS network (e.g. CORSnet-NSW) can be tested over the EDM baseline pillars, and other pillars as required.

4.7.2 CORS networks use IGS absolute antenna models in their products. Users must ensure that their GNSS rovers and office software also utilise the IGS absolute antenna models (Janssen & Haasdyk, 2011).

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

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

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

4.7.4 The suggested minimum session length is 3 minutes if 0.01m – 0.02m horizontal accuracy is required. If 0.02m – 0.04m horizontal accuracy is required, then the minimum session length can be reduced to 1 minute.

4.7.5 A minimum 30 minute gap between re-occupations at any pillar must be included to allow for a sufficient change in satellite geometry.

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

- 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).

- 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   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   Data Retention

Surveyors should suitably archive field booking sheets, raw observational data, adjustment results and post-adjustment baseline vector comparisons. Surveyors are reminded that pursuant to Direction 17(d) of the Surveyors (Surveyor-General) Practice Directions 2023, results of an annual verification of GNSS equipment are to be supplied to the Surveyor-General on request.

7   OH&S Requirements

Persons using the GNSS Verification Network must comply with the requirements of the Work Health and Safety Act 2011 , Work Health and Safety Regulation 2011 and all relevant WorkSafe ACT guidelines.

8   Advice on GNSS Verification

Questions relating to the testing of GNSS equipment can be directed to the Office of the Surveyor-General and Land Information. 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.

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Appendix A: GNSS Verification Network Coordinates

Station: AINSLIE(P)

GDA2020
Latitude: S   35° 16' 10.92596"
Longitude: E 149° 09' 31.70114"

Ellipsoidal Height: 866.784
$N_{AUSGeoid2020}$: 19.473
Orthometric Height: 847.311

MGA2020 (zone 55)
Easting: 696,361.662
Northing: 6,094,910.723

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

See Note 7 below.

Station: GOODWIN(P)

GDA2020
Latitude: S   35° 12' 31.14163"
Longitude: E 149° 01' 13.60962"

Ellipsoidal Height: 633.217
$N_{AUSGeoid2020}$: 19.250
Orthometric Height: 613.967

MGA2020 (zone 55)
Easting: 683,912.796
Northing: 6,101,947.941

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

Station: LAKE BASE 2

GDA2020
Latitude: S   35° 17' 39.84158"
Longitude: E 149° 07' 15.69070"

Ellipsoidal Height: 577.453
$N_{AUSGeoid2020}$: 19.318
Orthometric Height: 558.135

MGA2020 (zone 55)
Easting: 692,866.048
Northing: 6,092,245.122

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

Station: MAJURA(P)

GDA2020
Latitude: S   35° 14' 16.64709"
Longitude: E 149° 10' 52.66953"

Ellipsoidal Height: 911.071
$N_{AUSGeoid2020}$: 19.620
Orthometric Height: 891.451

MGA2020 (zone 55)
Easting: 698,485.175
Northing: 6,098,387.263

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

Station: EDM1

GDA2020
Latitude: S   35° 14' 20.15632"
Longitude: E 149° 09' 53.15439"

Ellipsoidal Height: 637.377
$N_{AUSGeoid2020}$: 19.564
Orthometric Height: 617.813

MGA2020 (zone 55)
Easting: 696,978.262
Northing: 6,098,312.072

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

Station: EDM4

GDA2020
Latitude: S   35° 14' 19.01888"
Longitude: E 149° 09' 51.48999"

Ellipsoidal Height: 634.143
$N_{AUSGeoid2020}$: 19.563
Orthometric Height: 614.580

MGA2020 (zone 55)
Easting: 696,936.950
Northing: 6,098,348.038

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

Station: EDM5

GDA2020
Latitude: S   35° 14' 16.60082"
Longitude: E 149° 09' 47.95226"

Ellipsoidal Height: 630.763
$N_{AUSGeoid2020}$: 19.562
Orthometric Height: 611.201

MGA2020 (zone 55)
Easting: 696,849.141
Northing: 6,098,424.496

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

See Note 7 below.

Station: EDM6

GDA2020
Latitude: S   35° 14' 13.15780"
Longitude: E 149° 09' 42.91430"

Ellipsoidal Height: 625.975
$N_{AUSGeoid2020}$: 19.560
Orthometric Height: 606.415

MGA2020 (zone 55)
Easting: 696,724.091
Northing: 6,098,533.361

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

Station: EDM7

GDA2020
Latitude: S   35° 14' 09.71028"
Longitude: E 149° 09' 37.87076"

Ellipsoidal Height: 621.545
$N_{AUSGeoid2020}$: 19.558
Orthometric Height: 601.987

MGA2020 (zone 55)
Easting: 696,598.900
Northing: 6,098,642.366

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

Station: EDM8

GDA2020
Latitude: S   35° 14' 06.26380"
Longitude: E 149° 09' 32.82791"

Ellipsoidal Height: 618.286
$N_{AUSGeoid2020}$: 19.556
Orthometric Height: 598.730

MGA2020 (zone 55)
Easting: 696,473.723
Northing: 6,098,751.336

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

Station: EDM9

GDA2020
Latitude: S   35° 14' 02.81591"
Longitude: E 149° 09' 27.78263"

Ellipsoidal Height: 615.022
$N_{AUSGeoid2020}$: 19.554
Orthometric Height: 595.469

MGA2020 (zone 55)
Easting: 696,348.483
Northing: 6,098,860.350

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

Station: EDM10

GDA2020
Latitude: S   35° 13' 59.36822"
Longitude: E 149° 09' 22.73878"

Ellipsoidal Height: 612.158
$N_{AUSGeoid2020}$: 19.551
Orthometric Height: 592.607

MGA2020 (zone 55)
Easting: 696,223.275
Northing: 6,098,969.355

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

Station: EDM11

GDA2020
Latitude: S   35° 13' 56.94951"
Longitude: E 149° 09' 19.19955"

Ellipsoidal Height: 610.959
N$_{AUSGeoid2020}$: 19.550
Orthometric Height: 591.409

MGA2020 (zone 55)
Easting: 696,135.416
Northing: 6,099,045.826

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

Notes

1. GDA2020 coordinates are from the national least squares adjustment (NADJ) version 20221201.

2. Projected coordinates are Map Grid of Australia 2020 (MGA2020) Zone 55 and ACT Standard Grid (SGC).

3. ACT Standard Grid Coordinates listed above are to be used for GNSS verification only. The values differ from those published on ACTmapi and survey control plans.

4. Heights are to the brass pillar plate.

5. GDA2020 Ellipsoid heights refer to the GRS80 ellipsoid.

6. Orthometric heights approximate Australian Height Datum 1971 (AHD71) and have been derived using AUSGeoid2020.

7. 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: GNSS Verification Network

NOTE: Observed baselines to pillars EDM4 to EDM10 have been omitted for clarity.