SURVEYOR-GENERAL
OF THE AUSTRALIAN CAPITAL TERRITORY

GUIDELINE No. 10 (29/10/2012)

GNSS and CADASTRAL SURVEYS

1.0 INTRODUCTION

This guideline has been prepared to assist surveyors who are using Global Navigation Satellite System (GNSS) equipment when performing cadastral surveys. **It is emphasised that this guideline does not represent legal traceability of GNSS measurement**, however by following the survey procedures described herein, surveyors will comply with Direction 18(3) of the *Surveyors (Surveyor-General) Practice Directions 2010 (No.2)*:

> *SPD 18(3): The procedures used when operating GNSS must be in a manner approved by the Surveyor-General, and the details and results of the observation reductions are to be supplied to the Surveyor-General on request.*

It is recommended that users who perform GNSS surveys that do not fall under the *Surveyors Act 2007* also follow the practices described herein, in order to provide confidence in the results of those surveys.

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 vectors must 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 to minimise the likelihood of errors.

This guideline must be read in conjunction with the current version of the *Surveyors (Surveyor-General) Practice Directions* (SPDs), the *Standards and Practices for Control Surveys (SP1)* and *Standards and Specifications for Deposited Plans.* Additionally, this guideline is generally compatible with the NSW *Surveyor General's Directions No.9: GNSS for Cadastral and Mining Surveys* (LPI, 2012a).

2.0 GNSS EQUIPMENT VERIFICATION

SPD 17(3) requires GNSS equipment used during cadastral surveys be verified at least once every 12 months, and immediately after repairs, on a geodetic network approved by the Surveyor-General. To enable surveyors to comply with this Direction, the Office of the Surveyor-General has established a GNSS verification network, which incorporates the Watson EDM base. It is recommended that surveyors follow the procedures described *Surveyor-General Guideline No.9: GNSS Equipment Verification* (ESDD, 2011) to test their GNSS system.

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3.0 GNSS OBSERVATION TECHNIQUES

GNSS observation techniques currently acceptable for use in cadastral surveying in the ACT include:

- Static, rapid static, kinematic, and pseudo kinematic post processing techniques that produce single baseline solutions;
- Post processed AusPOS solutions;
- Real Time Kinematic (RTK) techniques using single baseline solutions between the surveyor's base station and rover; and
- Single base RTK and Network Real Time Kinematic (NRTK) solutions from a Continuously Operating Reference Station (CORS) provider (eg: CORSnet-NSW).

When performing cadastral surveys, it is the responsibility of the surveyor to ensure their GNSS measurements achieve the accuracy required by the SPDs. It is recommended that only dual frequency GNSS equipment be used for cadastral surveys. However if older, single frequency receivers are used, observed baselines must be less than 10km.

All observation techniques benefit from additional satellites, therefore multiple constellation (eg: GPS + GLONASS) receivers should be used where available.

The use of GNSS observations for cadastral surveys, in particular RTK techniques, does not preclude the use of well-established, good cadastral survey practice such as:

- Working from the whole to the part;
- Establishing a control framework for the project that is fit for purpose; and
- "Running the boundary" where appropriate.

4.0 RECOMMENDED PRACTICES

4.1 Best Practice

Notwithstanding the GNSS observation technique employed, for each and every survey the recommended best practice includes, but is not limited to the following:

4.1.1 It is important to know the accuracy required by the survey before performing the GNSS fieldwork, and to know the level of accuracy that can be achieved by a particular survey technique;

4.1.2 Following the procedures recommended in ICSM Publication No.1 *Standards and Practices for Control Surveys* (SP1; ICSM, 2007);

4.1.3 Connecting to at least three established survey control marks, in accordance with SPD 45(3);

(Note: Established Survey Control Mark means a survey mark that has a horizontal positional accuracy equal to or better than Class C, as described in SPD 5.)

4.1.4 Performing multiple independent occupations of all marks surveyed using GNSS;

4.1.5 Connecting to GNSS CORS that have Regulation 13 certified coordinates (under the *National Measurement Regulations 1999*), thereby assisting users in establishing some legal traceability of their GNSS derived positions;

4.1.6 Observing and incorporating independent distance measurements using a calibrated EDM;

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4.1.7 Observing and incorporating independent angular observations;

4.1.8 Using appropriate antenna models within the office and rover software. CORSnet-NSW and AusPOS products use IGS absolute antenna models. Surveyors must ensure that their GNSS system also utilises the latest IGS absolute antenna models (Janssen & Haasdyk, 2011). Furthermore, GNSS base and rover antennas should be pointed north;

4.1.9 Observing independent antenna height checks, such as taking a second height measurement using imperial units (inches);

4.1.10 For best vertical results it is recommended that surveyors apply the latest AUSGeoid model, in addition to any site transformation to the vertical control (see section 5.0 below);

4.1.11 Nowadays with multiple constellations available there are generally a sufficient number of GNSS satellites above the horizon. However it is still recommended that surveyors perform GDOP/PDOP predictions prior to any field work, particularly if site conditions are less than ideal;

4.1.12 Periods of increased solar activity may cause longer initialisation times, loss of satellite communication, interruptions to wireless internet or radio blackouts, resulting in degraded GNSS positional accuracy. Surveyors are advised to subscribe to a space weather forecast service (eg: www.swpc.noaa.gov) to stay abreast of solar activity levels;

4.1.13 Retaining all practically available observations when GNSS observations are used in a cadastral surveys, in accordance with SPD 53(2); and

4.1.14 Performing an annual GNSS system test in accordance with *Surveyor-General Guideline No.9: GNSS Equipment Verification* (see section 2.0 above).

4.2 Real Time Kinematic GNSS Surveys

In certain situations, RTK GNSS can be a powerful, cost-effective surveying application for producing and collecting three-dimensional positions relative to a fixed or virtual base station. Expected baseline accuracies are in the order of 20mm + 2ppm (at a 95% confidence interval) using minimal epochs of data collection. However, the reliability of RTK positions are much harder to verify than those of static or rapid static GNSS techniques and the numerous variables involved require good knowledge and attention to detail from surveyors.

Recommended best practice for each and every RTK GNSS survey includes, but is not limited to:

4.2.1 The minimum satellite elevation mask shall be set at 10° - 15° above the horizon.

4.2.2 Receivers should be set to record at a 1-second data collection rate (epoch) using the averaging technique.

4.2.3 With traditional base/rover RTK surveying, it is much better to establish a new, completely open sky view site for the base station than to try to occupy an existing survey control mark with a partly obscured sky view.

4.2.4 The minimum acceptable GNSS rover antenna mount to achieve Class C positions (ie: cadastral surveying) is a rover pole with survey bipod. Higher Class surveys must use a tripod for stability (LPI, 2012a). It is further recommended that a tripod is used when connecting to established survey control marks, especially when the observations are to be used for a site transformation (see section 5.0 below).

4.2.5 Bubbles are to be in adjustment. It is recommended to check bubbles before every survey.

4.2.6 When a RTK rover pole and bipod is used during the survey, rotate the rover pole bubble 180° between each occupation of a survey mark, in order to minimise any residual error in bubble adjustment. However, this may result an inconsistency with keeping the antenna pointing north as described in section 4.1.8 above, therefore surveyors should use professional judgement in managing these two sources of error.

4.2.7 All surveys should connect to established survey control marks before, during and after each RTK session. Furthermore, when collecting important positional data, established survey control marks should be checked with the same initialisation as subsequent points to be collected.

4.2.8 The surveyor must be aware of the GNSS solution state (float or fixed ambiguities). All points shall be observed with ambiguity fixed solutions only. The solution should become fixed in a “normal” amount of time and should remain fixed for the duration of the point occupation.

4.2.9 Positional data should not be collected when the PDOP exceeds 6.

4.2.10 Communication (either wireless internet or radio) between the base station and RTK rover should be continuous while locating a point.

4.2.11 Never perform RTK surveys when weather conditions obviously differ between base and rover.

4.2.12 RTK positioning of survey marks cannot be done reliably without redundancy. The position of all survey marks (control marks, cadastral reference marks, monuments, etc) must be determined by two or more independent occupations.

4.2.13 To be considered an independent occupation, a different base station must be used for the second occupation. It is recommended that the two base stations generally be located on either side of the survey site, but within the polygon formed by the control marks used for the site transformation.

4.2.14 All RTK measurements must form part of a closed figure. This may not be possible when locating a natural feature boundary, however this does not preclude other methods of checking the location of a natural feature boundary.

4.2.15 The RTK rover must be re-initialised between each occupation of a survey mark.

4.2.16 A minimum 30 minute gap must be left between re-occupations at any mark to allow for a sufficient change in satellite geometry. If the subsequent occupation(s) are on separate days, surveyors must be aware of orbital precession due to the difference between sidereal and solar days, resulting in the satellites appearing in the same geometric configuration approximately 4 minutes earlier each day.

4.2.17 The recommended minimum occupation durations (at 1-second epochs using the averaging technique) depend on the nature of the point being observed and are listed in Table 1 below:

Table 1: Minimum recommended RTK Occupation Durations

Type of Point	Occupation Duration
o Survey control mark (connection to datum, site transformations, etc)	3 minutes
o Survey control mark (RTK session checks) o Cadastral reference mark o Cadastral monument	1 minute
o Occupations (eg: fencing) o Natural boundary	15 seconds → 1 minute
o Height critical point	3 minutes

4.2.18 The occupation durations listed in Table 1 are for "good" RTK site conditions. In conditions less than ideal, surveyors should give serious consideration to extending these durations and/or observing survey marks using more than 2 independent occupations.

4.2.19 Multipath:

a) The base station must not be located where multipath may occur.

b) Sites with high multipath should be avoided by RTK rovers. Total stations should be used in preference to RTK rovers in high multipath environments.

c) To minimize errors at locations where some multipath may exist, observation sessions need to be extended and additional sessions, over and above those required to provide redundancy, need to be observed at different times of the day. These sites include locations near tree canopy (eg: wet gum trees), reflective structures within 30m that are taller than the height of the antenna, nearby vehicles and nearby metal objects including signs, and large bodies of water.

5.0 SITE TRANSFORMATIONS

A site transformation (sometimes referred to as a "calibration" or "localization") allows the surveyor to transform the GNSS observed WGS84 coordinates of the survey control to the local datum (eg: SGC or MGA94). This is performed by observing several established survey control marks immediately surrounding (and, if present, within) the project site. The observed control network should not ignore or span existing local control. Furthermore, extrapolation should be avoided (Haasdyk & Janssen, 2012).

To have confidence in a site transformation, it is recommended that the project site be surrounded by at least 4 marks with established horizontal coordinates and 4 marks with established RLs of Class LC or B, or better (Henning, 2011). The survey control marks can be established in both position and height, in position only or in height only. Analysis of the site transformation results are discussed in section 6.4 below.

6.0 ANALYSIS OF THE MEASUREMENTS

6.1 Accuracy versus Precision

Many of the reference publications listed below have investigated the achievable accuracies and precisions of different GNSS observational techniques. Accuracy is the level of the alignment to a datum, as realised by the physical survey control mark infrastructure, while for RTK, precision is the spread of the results (at a certain confidence level) relative to the base station. Table 2 below summarises the typical accuracy and precision that can be expected to be achieved.

Table 2: Typical achievable accuracies and precisions of various GNSS techniques

GNSS Observation Technique	**Accuracy** (at 95% CI)	**Precision** (at 95% CI)	**Recommended Minimum Length** (to achieve Class B)	**Recommended Minimum Length** (to achieve Class C)
Static	10mm + 2ppm (observed baseline)		150m	100m
Single Base RTK	20mm + 2ppm (observed baseline)	20mm (position)	780m	280m
NRTK	40mm (position)	24mm (position)	930m	365m

If the base station is correctly set up over a monument whose coordinates are adopted as the truth, and correct procedures are used, then the achieved RTK precision would indicate project accuracy (Henning, 2011).

6.2 Measures of Precision

The reported coordinate quality (CQ) is an estimation of the precision of the derived GNSS position and is a measure of the scatter of all epochs that went into the final derivation of the position or vector. The surveyor must be aware of the confidence interval of the CQ reported by the GNSS equipment, as it may be at 68% = 1σ, or at 95% = 2σ.

Surveyors should be aware that CQ indicators provided by GNSS rover equipment are often over optimistic. Furthermore, the CQ indicators may report acceptable GNSS positions, even when an incorrect initialisation has occurred.

6.3 Precision Analysis

The precision analysis is a comparison of the multiple independent occupations at each survey mark relative to their difference from the mean. It is recommended that a GNSS positional tolerance of 20mm horizontally and 30mm vertically (at the 95% confidence interval) be adopted for cadastral surveys. Where an occupation exceeds these tolerances, repeat independent occupations must be made in order to determine which observation(s) to discard.

6.4 Accuracy Analysis

An accuracy analysis is a comparison of the difference between the field-derived GNSS values and the published coordinates of the survey control mark. It shall be conducted on the results of the site transformation and on all check observations conducted throughout the survey (see sections 4.2.7 and 5.0 above).

For a site transformation to be considered suitable for cadastral survey purposes, the transformation residual on each adopted survey control mark shall be smaller than the maximum allowable error ellipse commensurate with the Order of the published coordinates relative to the station density, as shown in Tables 3 and 4 below. Check observations on other survey control marks shall also be within these tolerances.

Table 3: Class derived from station density and point error ellipse size (at 95% confidence interval). The relative error ellipse size used in the determination of Class is stated in parentheses (Source: LPI, 2012b).

		Point and (Relative) Error Ellipse						
		0.010m (0.014m)	0.020m (0.028m)	0.030m (0.042m)	0.040m (0.056m)	0.050m (0.070m)	0.060m (0.082m)	0.075m (0.096m)
Station Density (km)	0.1	C	D	E	E	–	–	–
	0.2	C	D	E	E	E	–	–
	0.4	B	C	D	D	E	E	E
	0.6	B	C	C	D	D	E	E
	0.8	A	B	C	C	D	D	D
	1	A	B	B	C	C	D	D
	2	A	A	B	B	C	C	C
	5	2A	2A	A	A	A	B	B
	10	3A	2A	2A	2A	A	A	A

Table 4: CLASS - Highest ORDER Relationship
(Source: ICSM, 2007)

CLASS	ORDER
3A	00
2A	0
A	1
B	2
C	3
D	4
E	5

The values shown in Table 3 are a summary of formula [1] (ICSM, 2007) below and are a guide only. For a detailed investigation of the maximum allowable relative error ellipse between any two survey control marks use:

$$r = c\,(d + 0.2) \qquad [1]$$

where: r = length of maximum allowable semi-major axis of the relative error ellipse in mm;
c = an empirically derived factor represented by historically accepted precision for a particular standard of survey, as listed in Table 5 below; and
d = distance to any station in km.

Table 5: Classification of horizontal control (Source: ICSM, 2007)

Class	c (at 95% CI)	Typical Applications
3A	2	Special high precision surveys
2A	6	High precision national geodetic surveys
A	15	National and state geodetic surveys
B	30	Densification of geodetic surveys
C	60	Survey coordination projects
D	100	Lower Class projects
E	200	Lower Class projects

6.5 Cadastral Accuracy Requirements

Bearings and distances measured for a cadastral survey must satisfy all angular, length and misclose requirements stated in the SPDs. In accordance with SPD 31(2) all lengths must attain an accuracy of 6mm + 30ppm (ie: Class B) or better at a confidence interval of 95%. Surveyors must be aware that short lengths derived between two GNSS positions are unlikely to satisfy this level of required accuracy.

Furthermore, the design accuracy of the ACT cadastre in urban areas potentially limits GNSS applicability in these areas.

7.0 SURVEY PRACTICE DIRECTIONS AND GNSS

In a number of instances the *Surveyors (Surveyor-General) Practice Directions 2010 (No.2)* specifically refer to the use of GNSS equipment, and are summarised below. In the event of an inconsistency between the SPDs and this guideline, the former takes precedence.

- SPD 15(2): The bearing used for the orientation of the survey may be obtained from GNSS observations.
- SPD 17(3): GNSS equipment must be verified at least once every 12 months, and immediately after repairs, on a geodetic network approved by the Surveyor-General.
- SPD 18(1): When making a survey of other than an irregular natural boundary (ie: right-line boundaries) using GNSS equipment, a surveyor must use an approved GNSS surveying technique that will achieve an accuracy of Class B or better, as specified in SP1.
- SPD 18(2): When making a survey of an irregular natural boundary using GNSS equipment, a surveyor must use an approved GNSS surveying technique that will achieve an accuracy of Class C or better, as specified in SP1.
- SPD 18(3): The procedures used when operating GNSS must be in a manner approved by the Surveyor-General, and the details and results of the observation reductions are to be supplied to the Surveyor-General on request.

- SPD 29: A surveyor who makes a survey which exceeds a length of 10km can check their angular work by GNSS observations.

- SPD 30: Wherever practical a complete angular close of a surveyor's traverse shall be obtained. The observed angular misclose may be verified by GNSS observations.

- SPD 45(3): If GNSS equipment is used in the making of a survey then the surveyor shall connect to at least three established survey control marks, the co-ordinates of which are known in the appropriate geocentric datum.

- SPD 53(2): If a survey has been recorded in whole or in part by GNSS methods an electronic copy of all recorded data, and a copy of the reduced baseline or positional results, must be retained.

- SPD 61(2): If GNSS observations are used to determine or confirm the orientation of the survey, the results of the observations are to be shown in a table on the survey plan, together with the derived bearing between the occupied and observed stations.

- SPD 64: A survey plan that includes lines derived from GNSS observations must indicate which of those lines have been so derived.

8.0 ADVICE ON GNSS FOR CADASTRAL SURVEYS

Questions relating to the use of GNSS equipment for cadastral surveys can be directed to the Office of the Surveyor-General (ph: 6207-1639). Furthermore, it is suggested that surveyors refer to the reference publications listed below, as they provide a significant amount of best practice advice that is beyond the scope of this guideline.

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29 October 2012

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Record of Document Issues

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0.1	20/07/2012	Initial version for approval and internal distribution
0.2	3/08/2012	Revised version for approval and internal distribution
0.3	9/08/2012	Amended version for review by Survey Practice Advisory Committee
0.4	20/08/2012	Draft Public Release
1.0	29/10/2012	Approved Initial Public Release