New South Wales Government

Surveyor General's Directions

No. 9

GPS Surveys

GPS for Cadastral Surveys

Contents

1. Introduction

This Surveyor General's Direction outlines the recommended procedures for use of the Global Positioning System (GPS) to undertake **cadastral surveys**, in accordance with the Surveying Regulation under the Surveying Act 2002.

The use of GPS for control surveys is dealt with by the Intergovernmental Committee on Surveying and Mapping (ICSM) through the following publication:

"Standards and Practices
for
Control Surveys"
(SP1)

These directions were developed following release of the ICSM publication:

"Best Practice Guidelines
Use of the Global Positioning System (GPS)
For Surveying Applications"

These publications can be accessed on Internet at: www.icsm.gov.au/icsm/publications/sp1/sp1.htm

2. Limitations

These directions do not represent legal traceability of measurement. It is the responsibility of the surveyor to ensure that all equipment used in a measurement will achieve a result in terms of the accuracy required.

The most appropriate way to maintain accuracy is by connection to the State Survey Control network which in itself has legal traceability. The use of GPS allows these connections to be made effectively and efficiently.

These directions are specific to the use of GPS as a means of measurement. **All existing regulations, specifications, procedures and practices still apply.**

3. GPS Measurement Validation

In order for a particular set of GPS equipment and its associated post-processing software to be considered appropriate, the equipment must be validated against an approved State GPS test network. The Surveyor General has established a number of test networks, which include existing EDM calibration baselines.

Where travel to an approved State GPS test network is excessive, then GPS equipment may be validated over a local network of State survey control marks. These marks must have published coordinates with a minimum SCIMS accuracy Class B for horizontal and Class LC for vertical.

The validation will test measurement techniques together with processing, transformation and heighting methodologies. Field and processing techniques used for the validation must conform with those set out in section five of these directions.

Three dimensional local coordinates will be provided for all marks in each established test network. By holding the values of at least one of these sites fixed, coordinates for all other sites are derived using the GPS observations.

The difference between derived coordinates and those provided is used to determine whether or not the validation is acceptable. The comparison is made relative to the fixed site(s).

Surveyors should be concerned if this difference is more than 15 mm + 3 ppm for horizontal coordinates and 35 mm + 8 ppm for height.

Validation is acceptable if the difference is less than 25 mm + 5 ppm for horizontal coordinates and 60 mm + 12 ppm for height.

The ppm (part per million) component is computed using the distance from the nearest site with fixed values. (1 ppm is 1 mm per kilometre.)

If any significant modifications or upgrades are made to the GPS receiver or the post-processing software, then the validation must be repeated. To avoid additional fieldwork for every software upgrade, re-process the original validation raw data with the new version and check for any changes in the results.

Detailed instructions for each approved State GPS test network and advice for setting up a local network must be obtained from Survey Services, Land and Property Information NSW, Department of Lands. See Appendix ‘A’

The results of the validation must be forwarded to the Surveyor General when required.

4. Choice of GPS Observation Technique

Only GPS receivers capable of recording carrier phase observations are to be used.

If GPS observations are used in the preparation of a survey plan, then the observations must be retained. Where “real time” GPS is used, it is required that the observations taken to determine final measurements are recorded. These measurements must be checked as part of a closed figure.

Acceptable observation techniques are static and rapid or fast static. The various types of kinematic techniques are not to be used unless the computed baselines are included in a closed figure. This restriction does not apply where natural feature boundaries are being surveyed.

Raw observation files and field notes should be archived.

Under clause 29 of the Surveying Regulation**,** various GPS techniques may be used for surveys not requiring strict accuracy.

5. Guidelines for GPS Surveys

5.1 Observational Requirements

GPS is a three-dimensional (3D) measurement technique. Exact measurements from the ground mark to the electrical phase centre of the antenna are required. This is referred to as the “antenna height”.

The geometric dilution of precision (GDOP) is a measure of satellite geometry. The GDOP value during the observation must be as low as possible to ensure accurate results. A GDOP value less than eight is acceptable.

The number of satellites observed at any one time must be at least four.
(Note that rapid/fast static and kinematic methods generally require five or more satellites.)

The elevation mask must not be less than 15 degrees above the horizon.

Do not take meteorological readings, use the post-processing software defaults.

For baselines less than 15 kilometres, the observation period must be sufficient to enable ambiguity resolution. To achieve this, follow the recommendations as set out in the manufacturer’s handbooks.

The typical short observation periods used for rapid/fast static methods must not be used for measurement of baselines over 10 kilometres.

Single frequency receivers are not to be used to measure baselines over 10 km.

GPS observations, and in particular rapid/ fast static and kinematic methods, may contain small biases that cannot be accounted for by even the most rigorous surveying practice. The result is an error in the computed baselines in the order of a centimetre. For this reason, GPS should not be used to derive distances less than 120 metres. If it is necessary to do so, then the surveyor must ensure that the accuracy of the measurement can be checked within a closed figure or by EDM.

The most effective way to minimise undetected errors in data collection is to have sufficient redundancy in the observations. To build in redundancy, each mark must be occupied more than once in an independent manner. The second occupation does not have to be a GPS observation.

Observations taken using two or more base/reference sites simultaneously does not constitute redundancy. All computations using this field technique are made with one set of rover data which may be corrupted in some way.

Further redundancy can be achieved by:

- closing onto existing control where available.

- observing for longer if there is likely to be interference nearby. (ie, multipath or signal loss from tree cover)
- making an independent measurement of the antenna height.

5.2 Field Notes

Concise field notes must be kept for each GPS occupation, and should contain the following information:

- Observers name.
- Receiver and antenna identification.
- Date of observation.
- Start and stop time of observation.
- Mark type and name / number.
- Antenna height and confirmation.
- GDOP/PDOP and number of observed satellites.
- Diagram or description of obstructions.

5.3 Processing Requirements

In order to minimise post-processing errors and biases, calculation of baselines must start from a mark which has a WGS84 coordinate and ellipsoid height. The accuracy of these values must be better than 10 metres both horizontally and vertically.

Connection to the State survey control network is the most appropriate way to ensure that an accurate starting coordinate is used. AGD66 coordinates require transformation to the satellite datum WGS84. For this purpose, GDA94 coordinates are equivalent to WGS84. Ellipsoid height is obtained from AHD with the appropriate WGS84 geoid separation value applied.

Processed baselines must form part of a closed figure. In this way, the misclose can be checked, and adjustments made if necessary. It is recommended that a least squares adjustment of the network is carried out. Determination of the CLASS of the survey will verify that the survey meets the required standards of accuracy.

6. Information Shown on Deposited Plans

The use of GPS leads to a variety of outcomes not achievable by traditional cadastral survey methods. Therefore until GPS becomes a common measurement tool for cadastral applications, it is desirable that the next user of a deposited plan is made aware that GPS observations were used to derive some of the measurements shown.

As an interim solution, it is required that all deposited plans where GPS measurements are involved must be annotated as follows:

“GPS observations were used to derive part of this survey.”

In addition and only if it is practical to do so, each measurement derived by GPS should be identified.

7. Analysis of Least Squares Adjustments (Class)

This section refers to the Intergovernmental Committee on Surveying and Mapping (ICSM) Publication SP1 - Standards and Practices for Control Surveys. This ICSM publication maintains national standards by which surveys are assigned uniform levels of accuracy. Surveys of similar accuracy are grouped together and allocated a "CLASS".

Cadastral surveys using GPS must conform to CLASS C standards of accuracy.

The Class of a survey is determined from two sources:

(a) The field and post-processing methods. Adoption of the procedures set out in section 5 will ensure that this requirement is met.

(b) Analysis of relative error ellipses in a minimally constrained least squares adjustment.

A relative error ellipse is an indication of the precision of the adjusted coordinates between two marks. If the ellipses are too large, then the survey may be poorly designed. Unsatisfactory measurement errors or biases are indicated by outliers in the adjustment residuals.

The rejection criteria set out below are based on standard 2-D relative error ellipses at the 95% confidence level.

To conform to class C then each error ellipse must be smaller than 'r'. Where 'r' expressed in millimetres is the maximum allowable length of the semi major axis, calculated from the following formula:

$$r = 2.45 \times c (d + 0.2)$$

Where:
- r is the maximum allowable length in millimetres.
- d is the distance between the marks in kilometres.
- c is 30 for class C surveys. This factor varies for each class.

For example, if two marks are 900 metres apart, then the relative error ellipse must be smaller than 80 millimetres.

Keep in mind that this is a 95% confidence level, which represents about 2½ times the standard deviation of the measurement.

Glossary of Terms

AGD66

Australian Geodetic Datum 1966, the New South Wales horizontal coordinate datum, using the Australian National Spheroid (ANS).

AHD71
Australian Height Datum 1971. This is the height datum used for the survey control network in New South Wales.

Ambiguity resolution
Occurs where the exact number of complete wavelengths (cycles) to each satellite is successfully computed. This condition is necessary to achieve the required accuracy.

Base station
A GPS site where the three-dimensional coordinates of the mark are known quantities.

Bias
One of many small errors and noise in the GPS system which will contribute to the total error in a systematic way.

Baseline
The three dimensional vector computed from GPS observations at two sites. It is normally expressed as dX, dY and dZ components in a cartesian coordinate system. The vector is computed from mark to mark.

Carrier phase
Special GPS observations where the receiver compares the incoming satellite carrier waves with those generated internally by the receiver and computes the remaining phase. Correct terminology is "carrier beat phase".

CLASS
Terminology adopted by the Intergovernmental Committee on Surveying and Mapping (ICSM) to define the precision of the coordinates of a survey mark. CLASS is assigned on the basis of field survey methods, reduction techniques and the results of a minimally constrained adjustment. Refer to the ICSM publication dealing with standards and practices for control surveys - SP1.

Closed figure
A set of survey observations when linked together form a figure that makes it possible to check miscloses in an independent manner.

Confidence region
A region within which the true value is expected to fall. It is expressed as a percentage which indicates the level of confidence derived from a statistical model.
For example with a measurement of length; there is a 68% chance that the observation will fall within ± one standard deviation of the true value; or there is a 95% chance that the observation will fall within ± 2½ half standard deviations of the true value.

Electrical phase centre
The location within a GPS antenna where phase observations are measured. All antenna heights must be observed to this point.

Elevation mask
The angle above the horizon, below which GPS observations are not used. This is done to avoid noisy data.

Ellipsoid
The mathematical representation for the shape of the earth. Defined by its dimensions and the position of its origin which is the intersection of the three axis. Examples are GRS80 (Geodetic Reference System 1980, WGS84 (World Geodetic System 1984) and the ANS (Australian National Spheroid). The terms spheroid and ellipsoid are identical.

Ellipsoid height
The height of a mark above an ellipsoid or spheroid.

Fast static GPS
A static GPS technique with short occupation times. This is achieved by special processing techniques using dual frequency data and receiver specific observables.

GDA94
The Geocentric Datum of Australia 1994, the new Australian horizontal datum, using the GRS80 ellipsoid.

GDOP
Geometric Dilution of Position. A numerical value that represents the geometric position of the satellites in view at any one time.

Geoid
Represents the physical shape of the earth as opposed to a mathematical approximation such as an ellipsoid or spheroid. The geoid can be considered equal to Mean Sea Level (MSL) and the projection of MSL through the continent. The shape of the Geoid is irregular and is affected by such things as gravity anomalies and topography.

Geoid separation
The vertical distance between an ellipsoid and the Geoid. This value varies from point to point and each point will have a different value depending on which ellipsoid is used. The geoid sample files supplied with processing software will normally be referenced to WGS84.

GPS
NAVSTAR Global Positioning System.

Kinematic GPS
GPS technique where one receiver remains stationary over a base station and baselines are computed to one or more receivers that rove from mark to mark, or take observations in a continuous mode.

Minimally constrained least squares adjustment
A least squares adjustment of all observations in a network where the only constraints are those necessary to achieve a solution. Usually this is done by holding the latitude, longitude and height of one station fixed.

Multipath
Multipath is an error in GPS observations caused by the antenna picking up multiple signals from reflective surfaces around the site. Its effect is reduced by observing longer than normally required, and/or observing with different satellite configurations.

Navigation solution
The position of a single point computed by a single receiver. Also called "point position".

Obstructions
Objects such as trees, buildings and topography which interfere with the satellite signal reaching the antenna.

ORDER
Terminology adopted by the Intergovernmental Committee on Surveying and Mapping (ICSM) to define the precision of the coordinates of a survey mark. ORDER is a function of the class of the survey, how the survey conforms to constrained coordinates and any transformation process used. Refer to the ICSM publication dealing with standards and practices for control surveys - SP1. www.icsm.gov.au/icsm/publications/sp1/sp1.htm

PDOP
Position Dilution of Precision. A numerical value that indicates the quality of a position with regard to the geometry of the satellites being observed.

Post processing
Is the method of computing GPS results by transferring the collected field data to a computer and using the appropriate reduction software.

Rapid static GPS
See "fast static".

Raw data
Computer files of the GPS carrier phase data collected in the field before any processing takes place.

Real time GPS
A roving GPS receiver computes its position in the field using the data from a reference or base GPS receiver relayed via some form of communication system.

Redundancy
Redundancy occurs where more than the required number of observations are made to compute a result. In other words a check is possible. With GPS, care must be taken that the additional observations are truly independent. Ideally, redundancy is achieved by combining satellite and terrestrial observations.

Reference station
See "base station".

Relative error ellipse
A relative error ellipse indicates the precision of any station in a network relative to another station in that network.

Rover
The GPS receiver which "roves" around taking observations, as opposed to the normally fixed position of a base station. Observers should be aware that a rover/base configuration yields nothing more than a series of radiations, which will require some form of independent check.

SCIMS
Survey Control Information Management System.

Semi major axis
Largest radius of an ellipse.

Single frequency
Term used to describe receivers that store observations from one frequency only. Usually L1 (1575.42 MHZ).

Spheroid
See "ellipsoid".

Static GPS
GPS field technique where the baselines are computed using data from receivers that are stationary for the entire observation.

Transformation
The technique used to derive the coordinates of a set of marks in an alternative datum. For example AGD66 to WGS84
(This differs from a conversion which computes coordinates in another projection within the same datum, for example Latitude & Longitude to MGA.)

WGS84
The GPS datum, using the World Geodetic System 1984 ellipsoid.

Appendix 'A'

Department of Lands
Office Locations

Survey Services :	Land and Property Information NSW Panorama Avenue (PO Box 143) Bathurst NSW 2795 Phone: (02) 6332 8224 Fax: (02) 6332 8230 E-mail: cmu@lands.nsw.gov.au
Survey Services - Sydney:	2nd Floor, Queens Square Building Land and Property Information NSW (GPO Box 15, Sydney, 2001) Sydney NSW 2000 Phone: (02) 8258 7500 Fax: (02) 8258 7555 E-mail: scims@lands.nsw.gov.au

End of Direction