SURVEYORS BOARD OF QUEENSLAND

RTK GNSS for Cadastral Surveys

Guideline

31 November 2012

RTK GNSS for Cadastral Surveys

General

The Surveyors Board of Queensland has recently become aware of some issues with the use of GNSS/GPS, particularly Real-Time Kinematic (RTK), on cadastral surveys. This document is designed to provide a summary of overarching principles that should govern how surveyors go about this task. It is not exhaustive: rather it is essentially an interim document designed to bring attention to some common errors in practice and will be later supplemented by more detailed guidelines. It is also designed to be read in conjunction with best practice guidelines such as SP#1 (refer to References). In this document RTK refers to the use of good quality geodetic receivers and antennas and not hand held mapping grade receivers, nor DGPS systems. Although this guideline primarily covers cadastral surveys where some aspects of the work will be carried out using RTK GNSS, these principles may be also applicable to engineering, topographic, and other surveys, particularly where local ground-based coordinates and dimensions are required. For completeness and clarity, parts of the document also may refer to GNSS observational techniques other than RTK. Logically, this guideline is not applicable when using conventional measurement techniques only.

The document **does not cover**

- legal traceability of measurement and survey integration – you should refer to requirements of the appropriate verifying authority for details on that aspect.
- the general operational aspects of RTK GNSS – you should refer to manufacturers' specifications and other guidelines.

Responsibilities

It is the responsibility of the Surveyor who carries out the RTK field work to ensure that the work is carried out in accordance with this guideline. Where appropriate it is also the responsibility of the supervising Surveyor to ensure that this guideline is followed.

References

Surveying and Mapping Infrastructure Act 2003
Surveying and Mapping Infrastructure Regulation 2004
Surveying DERM
Standards for Control Surveys – ICSM - SP#1 – V 1.7

The Guideline

A. General Requirements

1. An overarching tenet of this guideline is that all marks found and placed on the cadastral survey must have at least one **independent check** placed on them.

2. **Conventional measurements -** an appropriate number of conventional measurements (normally with a legally traceable total station) should be taken on selected lines as checks on all cadastral surveys where GNSS is used. The lines should be selected to provide a long enough distance to identify any possible errors, and should be located at appropriate geometry throughout the project.

3. Most errors with RTK can be overcome with **redundancies in observations**. This can be achieved by independent RTK measurement from a second base station (and some from a third) after the elapse of sufficient time (at least 30 minutes). An alternative to a second base station is a) the inclusion of the mark in an independent post processed baseline (not including the RTK base station) to appropriate accuracy and precision, b) the addition of conventional terrestrial observations with calibrated total station, or c) if operating within a CORS networks, an independent measurement after the elapse of sufficient time (suggested 30 minutes).

> Note – it is not acceptable to measure a series of rover stations from a single base station without independent checks on those rover stations.
>
> Note **-** If checks are made with conventional terrestrial observations, it is preferable that they be made between rover stations.

B. Equipment Validation

1. Hardware and software used in the measurement system may be validated by comparison with existing high quality geodetic marks (preferably first order fixed by GNSS).

2. Ground distances from the GNSS measurement system must be verified periodically (note that this does not constitute legal traceability of the GNSS). Comparison of ground distances from the measurement system can be made with, for example, distances measured with a legally traceable total station. This general verification should be carried out and documented on a regular basis, similar to total station calibration. This periodic verification is in addition to conventional measurements in A2, which should be taken on all projects.

3. GNSS receivers, antennae and processing/reduction software must be of geodetic quality.

4. All ancillary equipment must be in good adjustment and repair and operated competently by trained personnel.

5. For all observations for control purposes (for example: base stations, total station set-up stations, site calibration stations) **preference** should be given to using properly adjusted and maintained tripods and tribrachs rather than prism and pole set-up.

6. Particular care should be taken with measurement of heights of antennae so that correct antenna phase offsets are applied. Of critical importance are: a) antenna type, b) the physical location on the antenna where the heights were measured to, and c) the measured heights themselves.

C. Observation Techniques

1. Although the general operation of the RTK GNSS system is beyond the scope of this guideline, the following are considered absolute minimum requisite standards:

- A fixed ambiguity solution must be maintained during all GNSS measurements.
- Compliance with manufacturers' recommendations and application of professional judgement with respect to number of satellites, satellite geometry, DOPs (generally not greater than 8), base station requirements, baseline lengths, elevation mask, and expected point accuracy and precision.
- Base stations (when not using continuously operating reference stations (CORS)) shall be set on a recoverable, stable control mark in a well protected position.
- Rovers and base stations must be in low multipath environments since site specific factors are critical to the reliability of GNSS measurements.

2. All base stations should be established with three dimensional geodetic coordinates within 10m of true position on the GDA94 datum or its equivalent on your project datum. The reason for this is that every 10m error in positioning on the datum can potentially lead to a 1ppm error in calculated baselines.

> Note – Usually (though not always) the 'here' function (or similar depending on equipment used) at the base station can achieve this, however, this is not recommended in general. A better option is to log data for a period of time and average the point positions (this can be done in most software packages) rather than relying only on the single epoch observation normally achieved from the 'here' function.

3. All base stations on a project should be accurately connected to each other, and preferably coordinated, at the beginning of the survey.

   a. On small projects where this is not practical, new base stations must still be related to other base stations to sufficient accuracy by appropriate observations with redundancies.
   b. On large projects, and particularly on long line surveys, all base stations will be coordinated using static or fast/quick/rapid static GNSS methods, and coordinates calculated before commencing RTK.

D. Project Control

1. There are many advantages of connecting to control marks for checking aspects of a GNSS survey and RTK performance. It is recommended that where practical, control should be connected to State Coordinated Geodetic control marks of the best quality available in the vicinity (on, or related to, MGA) except where the extra time taken would be disproportionate to the potential benefits.

2. Connection to State Coordinated Geodetic control marks, in good geometry in relation to the survey, is mandatory if reliable MGA coordinates of the survey are a required output.

   Note – it is not acceptable to simply rely on the 'here' function at the base station as a means of outputting reliable coordinates on any datum.

E. Datum and Coordinate System

1. Most issues relating to project datums are beyond the scope of this document. It is worth noting that GNSS will be working on its own datum, which is compatible with GDA but not necessarily compatible with your project datum. Therefore, care needs to be taken in how

MGA and other coordinates are output. Further information on appropriate project datums and coordinate systems may be addressed in a more detailed survey standard when it is available.

F. Grid and Ground Distances

1. Ground dimensions (horizontal distances at mean terrain height) appropriate for a cadastral survey may be achieved by separately interrogating each line on the survey. This method is most reliable.

> Note – the horizontal distances at mean terrain height is not the same as the MGA grid distance, nor the geodetic plane distance, nor the ellipsoidal distance. To illustrate this problem take the 400m line depicted in Figure 1. This line is at a mean terrain height of 719 in MGA zone 56. In this case the MGA grid distance is 400.0, the geodetic plane distance is 400.0, the ellipsoidal distance is 400.16, and none of these is suitable to be shown as a distance on a cadastral survey plan.

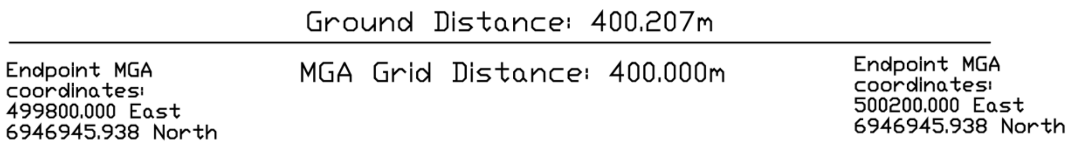

Figure 1 - Ground and MGA grid distance comparison

> Clearly, the horizontal distances at mean terrain height (719m in this example) is different from the distance that would be achieved by simple coordinate geometry (geodetic plane distance). In this example, 400.207 would be the distance that ought to be shown on a cadastral survey plan since it represents a horizontal plane distance at ground level.
>
> Note – in general, the distance achieved by using a simple coordinate routine in a calculator [SQRT ($\Delta E^2+\Delta N^2$)] is not what you would expect to measure on the ground.

2. Alternatively, appropriate ground dimensions may be achieved by establishing a project specific local ground-based coordinate system, at mean terrain height, in accordance with a validated procedure. Several assumptions are made with this process. **Great care must be taken if using this method,** particularly when working a significant distance (generally two kilometres) from the central projection point/meridian of your local ground-based coordinate system, or if the project height changes by more than 20-30 metres (as a guide, 6m change in height will represent about 1ppm error in distance) – these situations will require further consideration.

> Note – the practice of producing a single scale factor for a project by comparing a GNSS derived distance with a single terrestrial measurement is not acceptable.

3. **Short Distances**. Lines calculated from two RTK points are typically at the several centimetre level of accuracy. Therefore, care must be taken to ensure compliance with cadastral surveying Regulations. It is recommended that documentation be developed to justify procedures adopted for measuring short lines (appropriate measurement techniques, reoccupation, observation times, and checks), and to demonstrate compliance with relevant Regulations.

> Cautionary Note – Using the example in SP#1 (refer to References section) version 1.7, page B-27, the standard deviation on a sample line between two RTK points was calculated as 17mm. The 95% confidence interval was 42mm. The surveying standards require 10mm + 50ppm vector accuracy. This leads to a minimum distance of 640 metres below which distances should be measured with a conventional total

station. It is recognised that the precision of observations in the example in SP#1 may be improved, for example, by using longer observation times. Recent research indicates significant benefits in averaging observations over one to two minutes and reoccupying 10 to 30 minutes (refer to Janssen, Volker and Haasdyk, Joel, 2011, 'Assessment of Network RTK Performance using CORSnet-NSW', International Global Navigation Satellite Systems Society IGNSS Symposium 2011, Sydney, Australia). Subject to using these improved observations, some jurisdictions have adopted 120 metres as the distance below which distances should be measured with a conventional total station.

G. Connections and Radiations

1. When using a total station to measure **corner information**, best practice is that checks are made between radiated points, particularly when working over small distances e.g. connecting to iron pins and other corner recoveries. The same philosophy should be adopted when measuring marks with RTK GNSS. When an original corner mark, occupation, or reference mark is found, and its position is measured by RTK, check distances between these should be measured by conventional methods. This can be done by establishing (by RTK or static GNSS) at least one temporary mark close to the corner to be used as total station set up station and using a temporary mark, at a suitable distance, as a backsight to provide orientation for the corner information. In these situations, conventional tape or total station measurements will take precedence over the RTK observations.

2. **Backsight lengths** to be used for conventional total station observations – Professional judgement must be used to determine suitable distances for backsight stations. Consideration must be had for the method used to establish the setup and backsight stations, and also the maximum length of line to be measured from the setup station. It is suggested that in general, when using GNSS to establish total station instrument and backsight stations, backsight lengths should normally be: a) when using RTK, greater than 200m and never less than 100m except in difficult terrain; and b) never less than 60m when using Static GNSS methods.

3. **Reference trees**. Care should be taken to ensure lock (fixed solution) is maintained when measuring under or close to tree canopy. Reference trees can be measured by establishing (by RTK or static GNSS) one temporary mark close to the tree to be used as total station set up station and using a temporary mark, at a suitable distance, as a backsight.

   Note – the practice of using two or three temporary marks established by RTK, combined with distance measurements, to allow the tree's position to be calculated is suitable for establishing an approximate position only (for the purposes of finding other marks, when the original surveyed location of the tree is in some doubt, or on a topographic survey) or as a check observation. Conventional tape or total station measurements are required to accurately position reference trees and these measurements will take precedence over any RTK observations.

H. Site Calibrations

1. At times, for purposes such as locating existing marks, it may be beneficial to establish a coordinate system that is aligned with existing marks (sometimes called a site calibration).

   Note – the practice of producing a single scale factor for a project by comparing a GNSS derived distance with a single terrestrial measurement is not acceptable. A much more rigorous process of deriving ground distance is required in accordance with other sections of this guideline.

2. When an original mark is located, and its position is measured by RTK, suitable measurements must also be taken in accordance with section G.

3. It is important to note that when downloading the electronic job file, if the site calibration coordinate system from the GNSS controller is accepted, then bearings and distances between the originally coordinated points will still reflect the original plan dimensions. In essence, the field observations will have been forced (distorted) to conform to the original plan dimensions, which can mask any excess or shortage present. It is therefore necessary to remove the field generated local coordinate system (site calibration) before dealing with the dimensions so that undistorted measurements are used in the cadastral reinstatement. This is recommended even if a scale factor of one is set in the site calibration so you have full control of the process and are fully aware of the assumptions made in the coordinate system, particularly the project height.

4. **Check distances between measured points with a legally traceable total station** – this is probably the most important step of all. The lines should be selected to provide a long enough distance to identify any possible errors, and should be located at appropriate geometry throughout the project. Although this step refers specifically to site calibrations, in accordance with A2, it should become standard practice whenever GNSS is used for cadastral surveys.

Definitions

RTK – Real-Time Kinematic.
GPS – Global Positioning System.
GNSS – Global Navigation Satellite System.