PROVISIONAL

STANDARDS AND GUIDELINES
FOR THE USE OF GNSS ON CADASTRAL SURVEYS
WITHIN THE NORTHERN TERRITORY

Version 3.5 – 13 March 2017

Document History

Endorsement

Version	Date	Author	Reason	Sections
3.4	23 February 2017	Rob Sarib	Provisional adoption	
3.5	13 March 2017	Rob Sarib	Minor Amendments - grammatical	Various

Amendments:

Section Title	Section Number	Amendment Summary
Various	Various	Grammatical changes

Note - As GNSS technology in measurement and applications are constantly changing, this document will need to be reviewed regularly. As such, proposed modifications should be communicated to either the Surveyor-General or Secretariat of the Surveyors Board of the NT.

STANDARDS AND GUIDELINES FOR THE USE OF GNSS ON CADASTRAL SURVEYS WITHIN THE NORTHERN TERRITORY

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TERMS AND DEFINITIONS

AHD - Australian Height Datum. Commonly used in reference to Australian Height Datum 1971 (AHD71).

AHD71 - The Australian Height Datum 1971 is the NGRS normal–orthometric height datum for mainland Australia.

AusGeoid - The national quasi–geoid model for converting between GDA94 ellipsoidal heights and AHD heights. The current version of AUSGeoid is AUSGeoid09.

Circular confidence region - A circular measure of uncertainty in the horizontal plane calculated from the standard error ellipse.

Constrained adjustment, fully - An adjustment which has a sufficient number of constrained coordinates to optimally propagate datum and uncertainty throughout the survey control mark network.

Constrained adjustment, minimally - An adjustment which has the minimum number of constrained coordinates required to calculate all dimensions of the network datum (one, two or three dimensions).

CRM – means co-ordinated reference mark, being a tertiary level survey control mark or geodetic mark, approved and registered by the Surveyor-General, with geographical co-ordinate values in the approved geodetic datum – GDA94.

Elevation mask - A GNSS receiver setting that determines whether GNSS signals are recorded below a certain angle above the horizon.

EDM - Electronic Distance Measurement instrument that uses light or sound waves to measure distance.

GDA94 - Geocentric Datum of Australia 1994. Realised by the derived coordinates of the Australian Fiducial Network (AFN) geodetic stations, referenced to the GRS80 ellipsoid and determined with respect to ITRF92 at epoch 1994.0.

Geoid - The equipotential surface of the Earth's gravity field which best fits global mean sea level.

GNSS - A Global Navigation Satellite System(s) – a generic term for satellite based positioning systems.

GRS80 - Geodetic Reference System 1980 reference ellipsoid, where a = 6378137 m, f = 1 / 298.257222101

ITRF - International Terrestrial Reference Frame - a realisation of the International Terrestrial Reference System (ITRS) produced by the International Earth Rotation and Reference Systems Service (IERS).

Measurement - A measurement is an observed value, the outcome of a repeated set of observations, or the result of processing such observations.

Multipath - Errors in GNSS observations caused by reflected GNSS signals interfering with the direct GNSS signal due to their common time origin but different path lengths.

NGRS - National Geospatial Reference System – is Australia's authoritative, reliable, high accuracy spatial referencing system for Australia. It includes the GDA94, and AHD71 datums.

Redundancy - A least squares solution is said to contain redundancy if the total number of measurements exceeds the minimum number required to compute the unknown parameters.

RINEX - Receiver INdependent EXchange – An internationally accepted format for the exchange of GNSS data between software applications and for GNSS data archiving.

SPDs - Survey Practice Directions 2014 Surveys Outside Coordinated Survey Areas or Survey Practice Directions 2003 Surveys Within Coordinated Survey Areas or

Survey control mark - A monument that provides a physical realisation of one or more datums.

Uncertainty - Means the doubt about the validity of a measurement or result of a measurement (e.g. a coordinate). It is an indication of how wrong a value may be and is used to quantify the level of survey quality. Uncertainty is expressed as a standard deviation in the International System of Units (SI) expanded to the 95% confidence level.

Uncertainty, Positional (PU) - The uncertainty of the horizontal and/or vertical coordinates of a survey control mark with respect to datum.

Uncertainty, Survey (SU) - The uncertainty of the horizontal and/or vertical coordinates of a survey control mark independent of datum. That is, the uncertainty of a coordinate relative to the survey in which it was observed, without the contribution of the uncertainty in the underlying datum realisation.

STANDARDS AND GUIDELINES FOR THE USE OF GNSS ON CADASTRAL SURVEYS WITHIN THE NORTHERN TERRITORY

INTRODUCTION

The following Standards and Guidelines for the use Global Navigation Satellite Systems (GNSS) on cadastral surveys has been developed at the request of the Surveyors Board of the Northern Territory (NT), who have responded to a need identified by the survey community.

Surveyors who use this document shall also comply with the Survey Practice Directions issued by the Surveyors Board, and other requirements as issued by the Surveyor-General from time to time.

STANDARDS and GUIDELINES

Geodetic Datum

The official horizontal geodetic datum for cadastral surveys in the NT is the Geocentric Datum of Australia 1994 (GDA94). GDA94 is a static coordinate datum based on ITRF 1992, held fixed at the reference epoch of 1 January 1994.

Note - the official vertical geodetic datum for cadastral surveys in the NT is the Australian Height Datum (AHD) and to compute derived AHD heights from GDA94 ellipsoidal heights, the latest AusGeoid model shall be used. The current model is AusGoeid09.

Quantifying and Expressing Survey Quality for Cadastral Surveys that use GNSS Measurements

When a Surveyor uses GNSS measurements in a cadastral survey the Surveyor will be required to quantify the quality of measurement and prove that the position of the GNSS measured point or boundary corner relative to datum and / or surrounding survey marks is within the specified tolerances or allowable limits as per the relevant SPDs. Presently to quantify this, GNSS measurements can be expressed in two ways.

In a coordinated survey area, the quality of GNSS measurements will be quantified by Survey Uncertainty (SU). SU shall be expressed in terms of a circular confidence region or more specifically an error circle radius, at the 95% confidence region for horizontal co-ordinates only. Please note, this standard enables the quality of survey control to be expressed in a way that is compatible with other geospatial datasets. Refer to Annexure 1 for “Reference Formula for expressing ‘Survey Uncertainty’ ” for technical information regarding the formulae.

In a non-co-ordinated survey area the quality of GNSS measurements will need to be quantified by initially translating absolute or relative positions derived from GNSS observations, to horizontal ground distances (calculated at mid-height) and bearings relative to the datum survey plan (or True Mid in rural regions); and then evaluate if these measurements and survey satisfy the limiting error of closure. That is, the “limiting error of closure being the square root of the sum of the squares of the errors in latitude and departure, which are, together, to be not more than the total perimeter divided by x, plus 0.01 metre, where in surveys of urban and rural land "x" = 10 000.”

Planning a GNSS Survey

When planning a cadastral survey that is going to use GNSS measurements the Surveyor should consider the following –

- The selection of equipment, field technique and reduction method will be assessed and selected by the Surveyor so as to comply with the accuracy requirements for the survey.
- The layout or location and distribution of points to be surveyed by GNSS should ensure sufficient redundancy for carrying out the intent of the survey.
- If the subject cadastral survey requires new CRMs or connection to geodetic survey control then the use of GNSS measurements is permitted.
- The GNSS technique and / or observation method chosen should be selected and planned so as to minimise associated errors. For example GNSS survey points should be placed at locations that have a “clear sky view” and minimal obstructions to avoid interference and multi-path; avoid periods of high solar activity; longer observation times should reduce atmospheric effects due to the ionosphere and troposphere.
- Ensure the GNSS cadastral survey forms a closed figure or closes onto known points that facilitate a comparison with previously surveyed information.
- Applying and receiving approval from the Surveyor-General for the use of a GNSS measurement technique that is NOT in accordance with this document. This type of dispensation or variation needs to be obtained before the cadastral survey plan is lodged for approval.
- The Surveyor-General’s office is available to assist with planning a GNSS cadastral survey.

GNSS Cadastral Survey – Measurement Accuracy

For a GNSS cadastral survey outside co-ordinated survey areas, the limiting error of closure is used to verify accuracy requirements. As a consequence, Surveyors in most circumstances must demonstrate compliance with the survey accuracy Clauses 36 and 37 as stated in the Survey Practice Directions 2014 Surveys Outside Coordinated Survey Areas.

In contrast, the accuracy required for GNSS cadastral surveys within co-ordinated survey areas must comply with the survey accuracy in terms of SU. Surveyors, therefore must demonstrate compliance in accordance with Clause 26 as stated in the Survey Practice Directions 2003 Surveys Within Coordinated Survey Areas.

Marking

Generally, there will be no relaxation of marking standards for cadastral surveys. In other words, marking will be in accordance SPDs or as directed otherwise by the Surveyor-

General.

Please note, in some circumstances Crown land, pastoral lease, long line and mining tenure surveys **may** be eligible for a relaxation of marking standards but such approval will be on a case by case basis and must be sought from the Surveyor-General prior to survey commencement or lodgement of the survey.

The following are examples whereby the Surveyor-General has granted a variation after receiving a proposal or request prior to field survey:

- the frequency of intermediate marking of long line surveys could be amended to intervisible marking or every “x” kms or at salient geographic sites.
- the survey of long irregular boundaries such as roads or fence-able lines following a geographic feature could be marked at each angle point or bend (no intermediates) or only at angle points or bends spaced at “x” kms apart.
- in isolated cases where only the corners are to be marked / observed by GNSS measurement the subsequent scenarios of marking, configuration of marks, and how azimuth for reference marks shall be observed could apply.
- See Annexure 2 for examples.

GNSS Equipment, Measurements and Observations

It is expected that Surveyors will follow fundamental GNSS surveying principles such as working from the whole to the part, observe sufficient redundancy, survey closed figures, avoid radiations, and minimise GNSS site measurement related errors, such as multi-path, electrical interference, and obstructions (clear view to the sky). Surveyors also need to be familiar and generally abide with the procedures, guidelines, and recommendations contained in the GNSS equipment manuals, and also other reputable survey best practice or guideline documents pertaining to techniques. It is also recommended that the following points be considered -

- All ancillary equipment must be in good adjustment and repair and operated by trained and competent personnel.
- Satellite geometry during the field observation of any GNSS survey must be sufficient to ensure accurate results. The maximum geometric dilution of precision (GDOP) should be no greater than 8.
- The minimum number of common healthy satellites simultaneously observed by all receivers required to determine 3 dimensional positioning is four, however 5 is the preferred minimum.
- The elevation mask should generally be not less than 15^{O}, except for specialised applications where a lower elevation mask is allowable.
- Where orthometric heights are to be calculated from the GNSS observations, the selected vertical control stations should have known AHD values. Also, antenna heights should be confirmed by independent measurements.
- Predominantly, GNSS receivers capable of making carrier phase observations are preferred.
- Metrological observations are not necessary as these earth surface observations are not representative of the air mass and result in inferior modelling of tropospheric delay

when processing GNSS observations. Consequently it is recommended to use the GNSS reduction software defaults for tropospheric modelling.

- Most errors associated with GNSS measurement can be overcome with redundancies in observations and / or independent observations.
- The Surveyor-General will not accept multiple consecutive observations to the same GNSS set up over a mark. Redundancy is only achieved by independent occupations OR preferably observations from a different mark.

For cadastral surveys the following GNSS field techniques and observations are permitted –

- Static or rapid static – that is GNSS raw data is collected in the field post processed to compute baselines between stations.

  Static Observations

  - Dual frequency receivers should be used for baselines greater than 15km; single frequency survey quality receivers may be used for shorter lines.
  - Are used primarily for control surveys and therefore high quality tripods and tribrachs with optical plummets must be used.
  - The observation period and collection of GNSS data should be sufficient to resolve ambiguities (fix solution) and fulfil accuracy requirements or project specifications
  - For some situations, ambiguity “float” solutions (that is unresolved ambiguity) will be accepted on baselines greater than 80km.
  - A 15 second epoch recording rate is recommended.
  - The satellite geometry should change significantly during the observation period.

  Rapid Static Observations

  - Dual frequency receivers are preferred, as they allow various data combinations in estimating the solution.
  - Baseline lengths should be limited to a maximum of 10km.
  - Operators should refer to the manufacturer's specifications concerning the length of observation. Ideally, enough data must be collected to resolve ambiguities with at least 5 minutes of "clean" data, and more as determined by the baseline length and number of satellites available.
  - Preferably 5 or more satellites should be common to all survey sites simultaneously occupied.
  - The epoch recording rate normally may vary between 5 and 10 seconds, but can be up to 15 seconds.

- Single based and Networked RTK

  - Dual frequency receivers are preferred, as they allow various data combinations in estimating the solution
  - Must NOT be used for establishing cadastral control or performing CRM surveys

- RTK produces radiations so the Surveyor must give careful consideration to GNSS survey design, redundancy, multiple occupations, and achievement of survey accuracy standards.
- As a minimum, observations to a mark are from at least two independent occupations, and for single based RTK these observations must be from two separate reference stations.
- Sufficient GNSS data needs to be gathered so that ambiguities can be resolved for all occupations
- Observations on marks should be made for a minimum of one minute (using the averaging technique) with at least 30 mins between re-occupations so as to remove biases and allow satellite configuration to change.
- Short observation or occupation periods used in RTK techniques are very susceptible to multipath and can cause significant errors.
- Initialisation and re-initialisation of the rover should comply with manufacturer's instructions.
- If possible, quality indicators / attributes and other metadata about the observation should be recorded or logged with the derived co-ordinates. For example - the rover quality co-ordinate indicator or standard deviations of derived co-ordinates, base station name, date, time, datum, and number of satellites observed should be stored.
- This method should not be used for a short line boundary or baseline GNSS measurement (i.e. less than 100 metres). If approval to use this technique is granted by the Surveyor General then the Surveyor shall check measure such RTK short lines with an alternative calibrated or standardise measuring instrument (i.e. EDM) for both azimuth and distance.

- Absolute positioning or similar – static observations from a single geodetic receiver that are processed by a web based on-line service that computes a position from several permanent GNSS reference stations. An example of such positioning service is AusPos by Geoscience Australia. Refer to web site – http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos

  The accuracy of this technique is dependent on observation length, number and distribution of GNSS reference stations used in the solution, the antenna model, the satellite orbit data adopted for processing, and the transformation parameters used. Consequently, the following is recommended for 'survey' accurate positioning –
  - The use of geodetic, dual frequency, carrier phase and code receivers and antennae in static mode;
  - the duration of the static observations to consist of multiple 6 to 12 hour sessions at a GNSS collection rate of 30 seconds;
  - Positioning solutions based on the IGS final orbit products;
  - At least 3 GNSS reference stations are used in the positioning solution.
  - The positioning solution should be repeatable, with results and / or derived coordinates between 0.025 m and 0.05 m
  - The GDA94 coordinates derived from the positioning service have been transformed from the current ITRF using the ITRF to GDA94 Transformation Parameters.

Processing, Adjustment and Evaluation of a GNSS Cadastral Survey

It is recommended that Surveyors use recognised GNSS software in order to reduce, evaluate, and adjust GNSS observations. In most circumstances this will be the proprietary software provided by the manufacture of the GNSS equipment.

For GNSS cadastral surveys that require an adjustment, it is generally acceptable for the Surveyor to use the Bowditch Rule or a constrained least squares adjustment.

As previously mentioned on other sections, the results must be evaluated and adhere to survey accuracy requirements in the relevant SPDs.

Survey Plan

The Survey Plan Drafting Standards as issued by the Surveyors Board or plan requirements as specified by the Surveyor- General of the NT are to be adhered to with the following additional requirements:

- As GNSS measurements produce three-dimensional positions or vectors these results must be converted to a metes and bounds for boundary definition on the survey plan. Therefore, the distance must be a horizontal ground distance (calculated at mid height) and the bearing as per the datum survey plan or True Mid in rural regions. Note - these will be deemed as a “measured” dimension if derived from a single GNSS vector which was observed simultaneously at each end of the line. Alternatively, they will be deemed as a “calculated” rather than measured dimension, if derived from non-simultaneous GNSS observations at each end of the line.

- A note on the plan stating that GNSS measurements were used on this survey to derive survey datum and / or azimuth.

- A note on the plan stating that GNSS measurements were used on this survey to determine boundaries “a,b,c …” or CRMs “x,y,z…”

- Provisional GDA94 coordinates will **only** be shown on the plan if prior approval from the Surveyor-General has been provided.

- If provisional GDA94 coordinates are required, a schedule is to be shown on the face of the plan. The schedule should alphabetically tabulate in bold font the survey control stations used, showing the primary name, latitude and longitude to 0.0001 arc seconds (0.003m) and an AHD value to 0.01m. The remainder of the schedule should alphabetically tabulate in normal font, only major boundary corners occupied by GNSS and show point ID, latitude and longitude to 0.001 arc seconds (0.03m) and an AHD value to 0.01m. *Refer to Appendix “X” as an example.*

- It is not desirable to clutter the plan with the coordinates of every boundary corner surveyed. On long irregular boundaries for example, only salient, well-spaced angle points need to be shown in the schedule. All remaining intermediate values can be calculated from the boundary dimensions.

- GNSS measured cadastral point identifiers are to be unique, **capitalised** alpha/numeric identifiers, of a maximum of ten characters, prefixed by the Plan number and followed by the point number. Note – non alphanumeric symbols such as forward slash, decimals, colons, hyphens etc. should not be used. If a plan shows, for example, several marks tagged as No.1 and there is likely to be confusion, then the point can be renumbered as say 501 to identify this point as mark No.1 on the 5th traverse leg. Table 1 provides some examples.

Table 1: Point Identifiers

SURVEY No.	POINT	Identifier	Comments
LTO 93/246A	1	L93246001	
S 96/48B	1	S96048001	
S 97/177	1	S97177001	
A 1050	1	A1050001	
B 800	1	B800001	
C 2	1	C002001	
OP 1620	1	OP1620501	if plan shows several marks “1's” then show 501 as point 1 on 5th trav. leg
RP 506	1	RP506001	
DIA 512	1	DIA512001	

Legal Traceability and Equipment Validation

Presently the legal traceability of GNSS measurements cannot be readily achieved in the NT as there are insufficient survey control marks that are *recognised value standards for position.* The Surveyor-General will however allow the use of GNSS measurements and “quasi” traceability to a reference standard if the Surveyor -

- adheres to industry best practice guidelines on the use of GNSS measuring equipment
- validates the GNSS measuring device by a method as prescribed by the Surveyor-General (see below), and
- ensures that an appropriate number of lines in the GNSS survey are measured by or compared with a legally traceable instrument or measurement technique, such as a calibrated EDM. Note the common lines should be selected to provide a long enough distance to identify any possible errors, and should be located at appropriate geometry through the survey. Alternatively, the subject survey should have a ***direct*** connection to at least 2 survey control points that have known GDA94 coordinates, the subsequent least squares adjustment of the survey is constrained to the known GDA94 points, and the length and orientation between the 2 known points satisfy accuracy standards specified for the survey.

To validate and check the GNSS measuring device as per the SPDs, Surveyors are required to undertake GNSS observations at the EDM baseline arrays at either Howard Springs or Morrie Hocking.

For Howard Springs, the Surveyor is required to observe between stations - NTS 903, NTS 675, Pillar 2 and 6; process the baselines, adjust (using NTS 675 as the constraining station) and provide the Surveyor-General with GDA94 coordinates and survey uncertainties of occupied points. In addition, the Surveyor must supply spheroidal distances, and true mid bearings from NTS 675 to the other stations.

At Alice Springs, the surveyor is required to observe between pillars at the Morrie Hocking Baseline – Pillars 6, 4, 1 and 0; process the baselines, adjust (using Pillar 6 as the constraining station) and provide the Surveyor-General with GDA94 coordinates and survey uncertainties of occupied points. In addition, supply spheroidal distances, and true mid bearings from Pillar 6 to the other stations.

For further information, field and reduction instructions, please contact the Surveyor-General's office.

Data Lodgement and Field Information

For GNSS cadastral surveys, the Surveyor shall lodge the required survey data or information in accordance with the relevant clauses of the SPDs or survey requirements as specified by the Surveyor-General. The requirements include-

- a sketch showing all station identification and measured positions and / or baselines;
- GNSS log sheet and notes of the field recorded GNSS data and equipment used (including instrument type / model and serial numbers, antenna details, antenna height measurement and its derivation relative to the antenna reference plane, receiver firmware); refer to attached example – Annexure 3
- raw GNSS data of all static / rapid static observations in RINEX format
- evidence of meeting the survey accuracy requirements as specified in this document and / or the SPDs (*Note*: this may include a least squares adjustment summary of the survey or a short line comparison table of RTK vs EDM measurements);
- a complete listing of all adopted GNSS surveyed GDA94 provisional coordinates.
- a GNSS survey report detailing GNSS equipment validation, observation technique, errors / issues, checks, working datum, processing and calculations, comparisons, compliance with survey accuracy specifications, etc.

ANNEXURE 1

Reference Formula for expressing 'Survey Uncertainty'

The following will be the 'reference' formula to determine the survey uncertainty (horizontal component) or the error circle radius, at the 95% confidence region –

$$r = a \times K$$

where:

a	=	the semi-major axis of the standard (1 sigma) error ellipse (m)
K	=	$q_0 + q_1H + q_2 H^2 + q_3H^3$
H	=	b/a
b	=	the semi-minor axis of the standard (1 sigma) error ellipse (m)
q_0	=	1.9608
q_1	=	0.0041
q_2	=	0.1143
q_3	=	0.3716

Note "a" and "b" are derived from the least squares adjustment.

If required, the survey uncertainty for the vertical component, also at the 95% confidence region, can be obtained by:

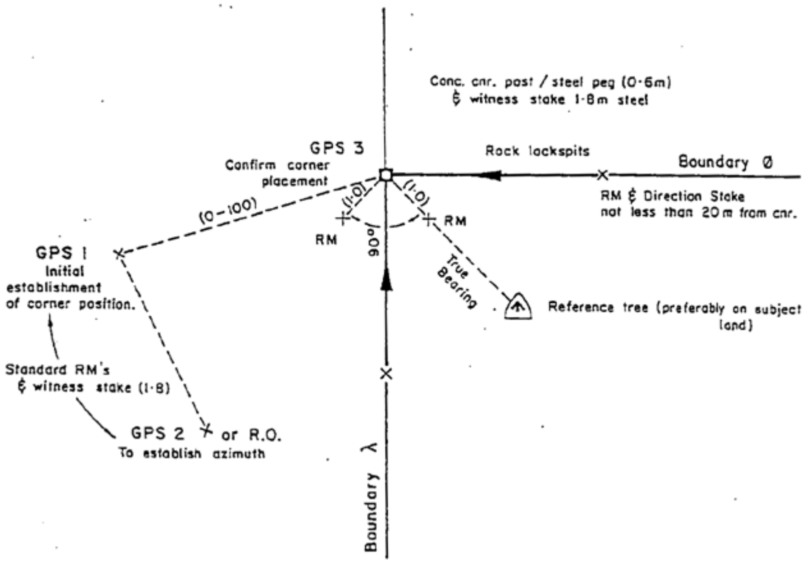
Vertical uncertainty = sd x 1.96

where sd = standard deviation of the adjusted height (m).

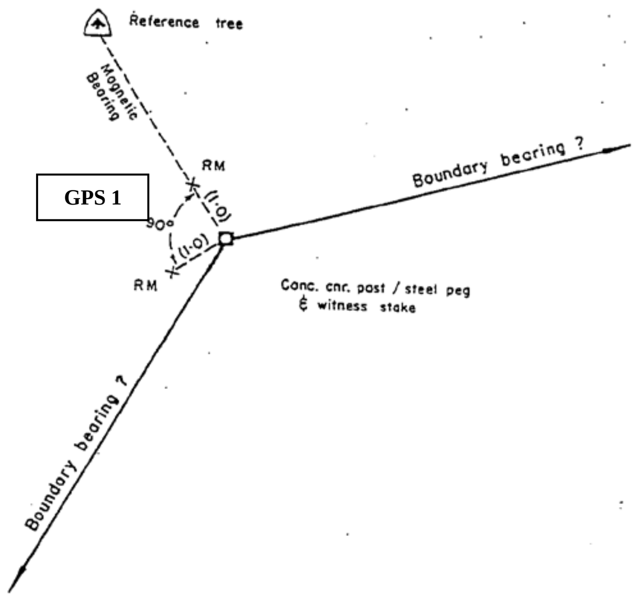
ANNEXURE 2

Examples of Marking

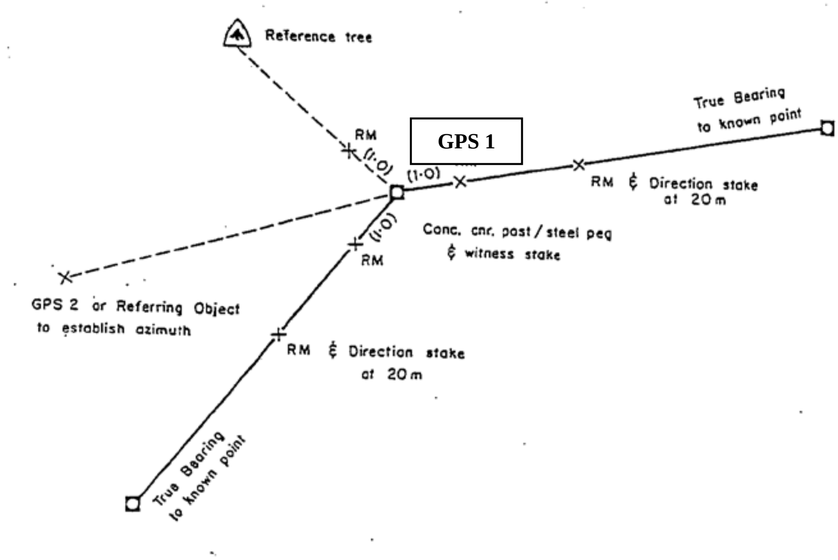
1. where the corner latitude and longitude are to be laid in (constrained)



2. new boundary line (unconstrained) whereby the next point position is unknown until placed and the last position unknown until calculated



3. new boundary line (constrained) when the known terminals or field calculations to next and last points are known.



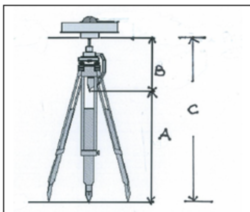
ANNEXURE 3

Example GNSS log field sheets and notes

GNSS LOGSHEET

PROJECT		JOB NAME		LOCATION			
MASK		COLLECTION RATE		DATE		GPS DOY		OPERATOR	

POINT Name	Receiver PT ID	Receiver / Antenna model	Receiver Serial No.	START TIME	END TIME	DURATION	HEIGHT A	OFFSET B	HEIGHT C	Check HT	CHECK HT - End of session	COMMENTS



NOTES:-
A = Height Hook if used
B = Vertical offset
C = Antenna Height ground mark to Antenna Reference Point (ARP) or Phase Centre (PC) depending on the make of GNSS measuring device
Check Height is independent measurement ground mark to ARP/PC.
Please check instrument manual for measuring points and any applicable offsets.
Start/finish time should be CST
This log sheet is for CLASSIC STATIC survey control and the use of geodetic grade (phase measurement) survey receiver and antenna, with high quality tripod, tribrach and optical plummet ancillary equipment.