New South Wales Government

Surveyor General's Directions

No. 12

Control Surveys and SCIMS

DOCUMENT CONTROL SHEET

Contact for Enquires and Proposed Changes

If you have any questions regarding this document, contact:

Designation: Document Sponsor
Name: Doug Kinlyside
Phone: 02 6332 8372
Fax: 02 6332 8366
Email: Doug.Kinlyside@lpi.nsw.gov.au

Designation: Author
Name: Greg Dickson
Phone: 02 6332 8412
Fax: 02 6332 8479
Email: Greg.Dickson@lpi.nsw.gov.au

Record of Document Issues

Version No	Issue Date	Nature of Amendment
0.1	22/11/2007	Initial draft of “Control Surveys and SCIMS: What’s acceptable?”
1.0	21/12/2007	Final for approval and distribution
1.1	21/10/2011	Draft of major update as Surveyor General’s Direction No. 12
1.2	22/12/2011	Internal agreement of draft for industry feedback
2.0	15/08/2012	Final for approval and distribution

Document Distribution

Name	Organisation	Distribution Channel
General Public	–	LPI website

Document Approval:

Approved By:

……………………………..
Des Mooney
Surveyor General of NSW
Date of Approval: 30th August 2012

Contents

1 Scope

This Surveyor General's Direction provides a guide as to what Land and Property Information (LPI), a division of the NSW Department of Finance and Services, requires before it will place coordinates, heights and quality of survey monuments on **public record** in the Survey Control Information Management System (SCIMS). This Direction supersedes the document "Control Surveys and SCIMS: What is acceptable?" which was published in 2007. Issues covered include marking, positioning technologies, survey practice, data processing, least squares adjustment and reporting.

This Direction provides a **guide** to typical requirements for LPI to place coordinate values of survey marks on public record in SCIMS at an "**established**" level, i.e. horizontal Class C and vertical Class B or LD or better. It outlines the process that LPI follows to assess Class (and, to an extent, Order) of submitted control surveys. This Direction is not exhaustive, and other techniques may exist to achieve a particular Class of survey. The classification of Order is only discussed briefly because its assessment, which is a function of overall fit with surrounding control, remains solely with LPI.

Other documents such as the Surveying and Spatial Information Regulation 2006, other Surveyor General's Directions and ICSM's publication "Standards and Practices for Control Surveys (SP1), Version 1.7" are referred to by this Direction where appropriate. This Direction may not agree with SP1 or other external documents. As of the date of this document, SP1 is under review. The new version may abolish Class and alter the definition of Order. In such cases, this Direction will take precedence when the control survey is to be placed on public record in the State of New South Wales. The ultimate responsibility for the assignment of **Class** and **Order** to the marks of a submitted survey control network remains within the subjective judgement of LPI as the relevant authority.

Control surveys are performed by making suitably accurate measurements and referring them to identifiable adjacent control marks in the existing control network. The survey control requirements outlined in this Direction are by no means exhaustive, and are certainly not regarded as the mandatory process necessary to achieving required accuracy outcomes. This is particularly relevant in regard to the preparation and assessment of contracts.

Details of LPI's full requirements and the interpretation of this Direction **must be discussed and agreed with an LPI Senior Surveyor prior to commencement of control surveys to be placed on public record**.

2 Introduction to SCIMS

The Survey Control Information Management System (SCIMS) was introduced in 2000 and is managed by LPI. It is the central registry of spatial data related to survey monuments throughout New South Wales. SCIMS contains coordinates and related information for survey marks established under the direction of the Surveyor General and is maintained for the purposes of cadastral and engineering surveys, mapping, and a variety of other spatial applications. It provides a whole-of-government service for survey infrastructure in NSW. The more common survey monuments contained in SCIMS can be identified as State Survey Marks (SSM), Permanent Marks (PM), Trigonometrical Stations (TS) and Cadastral Reference Marks (CR).

The purpose of SCIMS is the maintenance and the realisation on the ground, through monumentation, of the horizontal geodetic datum (GDA94) and the vertical height datum (AHD71). **Control surveys** provide the method to extend this network. Control surveys are applicable to all scales of projects. For LPI, this extends from the cadastral fabric up to the Geodetic Survey of NSW. All marks within SCIMS, both horizontally and vertically, are subject to the rigour of accuracy and precision evaluation. This is represented by a number of terms, e.g. Class, Order, and Uncertainty.

Why include data in SCIMS that was sourced externally to LPI? SCIMS is a public repository of survey information; it is also an **authoritative** dataset. It not only serves the surveying community but provides the spatial reference for other disciplines such as aerial imagery, hydrology and asset capture. It is appropriate to include externally sourced data if it meets the specifications that LPI requires and provides a benefit to the State.

The Surveying and Spatial Information Regulation 2006 (Clauses 42, 43 and 44) defines the requirement of survey marks becoming part of SCIMS. Generally, external data is submitted to LPI as the result of requirements between a contractor and an agency. LPI will accept such data, **but it is not the role of LPI to be the arbitrator over whether the contractor has fulfilled their obligation under their contract**.

This Direction outlines typical requirements for Control Surveys to meet LPI's specifications for inclusion in SCIMS at an established level. Common reasons why submissions are not included in SCIMS at the desired Class are:

- No consultation of LPI and/or agreement before commencement of the control survey.
- Inappropriate station density.
- Poor network design.
- Lack of redundancy.
- Poor marking.
- Inappropriate observation and processing techniques.
- Inappropriate use or disregard of existing control.
- Techniques and equipment used fail to meet specifications of the desired Class.
- Lack of information in the survey report.
- Lack of appropriate data.
- Insufficient metadata.

3 Overview of SCIMS - Class

The term **Class** is used to assess the quality of a control survey. Class is dependent on a number of conditions, e.g. mark type, observation techniques, measurement standards, the results of rigorous minimally constrained least square adjustments and analysis of error ellipses. SP1 defines Class as:

> "Class is a function of the planned and achieved precision of a survey network and is dependent upon the following components:
>
> - the network design,
> - the survey practices adopted,
> - the equipment and instruments used, and

- the reduction techniques employed,

all of which are usually proven by the results of a successful, minimally constrained least squares network adjustment computed on the ellipsoid associated with the datum on which the observations were acquired."

To manage the emergence of new positioning technologies, LPI also includes the following criteria to assign Class (this list is not exhaustive):

- What is the intent of the survey?
- Is the marking appropriate?
- Is the station density appropriate?
- Is there sufficient redundancy?
- Is there any duplication of infrastructure (e.g. marks placed in close proximity to existing marks)?
- Are the observation and processing techniques appropriate?
- Can the results be easily interpreted and analysed?
- Can the correctness of the results be demonstrated?

3.1 SCIMS, Class and GDA94 Coordinates

LPI uses the following business rules in regards to the assessment of horizontal Class:

Class U is assigned for coordinates with unknown or approximate accuracy, derived from locality sketches, scaled from a map or captured with hand-held GNSS. (SCIMS publishes these coordinates rounded to the nearest metre.)

Class E is assigned where a "survey" was undertaken and the results are intended for applications requiring sub-metre accuracies such as mapping/imagery control and asset capture. These surveys require differential GNSS and or Precise Point Positioning (PPP), either in real-time or post-processing mode. (SCIMS publishes these coordinates rounded to 0.1 metre.)

Class D is assigned where the survey methodology has delivered accurate coordinates (a few centimetres or better) but may involve unchecked radiations, only single occupations with GNSS or a similar survey with insufficient redundancy. Coordinates are suitable for asset management, high-resolution imagery rectification and other lower order surveys. (SCIMS delivers these coordinates rounded to 0.01 metre.)

Class C is assigned where the coordinates are "**established**", allowing use under the Surveying and Spatial Information Regulation 2006 for cadastral surveys. The surveys in this case must have sufficient redundancy and checks to guarantee the accuracy of the coordinates. Therefore, closed figures when traversing, multiple occupations (i.e. at least double occupations for all stations irrespective of method used) and well-configured connections to existing established control are required. In locations where there is no established control, GNSS techniques such as AUSPOS (see section 11) may be used. (SCIMS publishes these coordinates rounded to 0.001 metre.)

Class B is assigned to rigorous control and geodetic surveys where high accuracy is required for engineering/construction and local infrastructure applications. (SCIMS publishes these coordinates rounded to 0.001 metre.)

Class A, **2A** & **3A** is assigned to rigorous control and geodetic surveys where high accuracy is required for engineering/construction, state-wide or national infrastructure applications. (SCIMS publishes these coordinates rounded to 0.001 metre.)

3.2 SCIMS, Class and AHD71 Heights

LPI uses the following business rules in regards to the assessment of vertical Class:

Class U is assigned for heights with unknown or approximate accuracy, usually derived from the nearest map contour. (SCIMS publishes these coordinates rounded to the nearest metre.)

Class E is assigned where the results are intended for mapping/imagery control and similar sub-metre applications. (SCIMS publishes these coordinates rounded to 0.1 metre.)

Class D is assigned where the survey methodology has delivered heights accurate to several centimetres but may involve unchecked radiations, trigonometric heighting, only single occupations with GNSS or a similar survey with insufficient redundancy. Heights are suitable for imagery rectification and other lower order surveys. (SCIMS delivers these coordinates rounded to 0.01 metre.)

Class C is assigned where the heights are derived from surveys with sufficient redundancy and multiple occupations (i.e. at least double occupations for all stations) but may be some distance from reliable height control and relying solely on a geoid model. Heights are suitable for applications such as high-resolution image rectification but should be used with caution. (SCIMS publishes these coordinates rounded to 0.001 metre.)

Class B is assigned where the heights are "**accurate**", in terms of the Surveying and Spatial Information Regulation 2006. As a guide, the accuracy of the height is considered similar to that of traditional 3rd Order levelling. Surveys in this case must have sufficient redundancy and checks to guarantee the accuracy of the heights. Therefore closed figures, multiple occupations and well-configured connections to existing accurate height control are required. (SCIMS publishes these coordinates rounded to 0.001 metre.)

Class A, **2A** & **3A** is assigned to rigorous control and geodetic surveys where high accuracy is required for engineering/construction, state-wide or national infrastructure applications. (SCIMS publishes these coordinates rounded to 0.001 metre.)

Levelled classes such as **LB** or **LC** are assigned to height values depending on how the survey conforms to differential levelling specifications in SP1 (see Part B, section 2.4). Note that SP1 assigns the L prefix to **spirit** levelling only.

4 Assigning Class

As stated in SP1, the ultimate responsibility for the assignment of **Class** to the marks of a survey network must remain within the subjective judgement of the relevant authority (i.e. LPI). Class is typically assigned as described in the following sections of this Direction, which outline requirements in regards to:

- Mark placement.
- Equipment.
- Network design.
- Observations.
- Computation and adjustment.
- Survey report.

A major aspect in assigning a particular **Class** to a control survey is the investigation of the observation statistics stemming from a least squares adjustment. SP1 states:

> "The allocation of Class to a survey on the basis of the results of a successful minimally constrained least squares adjustment may generally be achieved by assessing whether the semi-major axis of each relative standard error ellipse or ellipsoid (i.e. one sigma) is less than or equal to the length of the maximum allowable semi-major axis (*r*) using the following formula:
>
> $$r = c\,(d + 0.2)$$
>
> where
> *r* = length of maximum allowable semi-major axis in mm,
> *c* = an empirically derived factor represented by historically accepted precision for a particular standard of survey,
> *d* = distance to any station in km."

This simple formula is easy to implement. It can be seen that when *d* is small then *r* will be small for a given value of *c*. Table 1 lists the *c* values (for one sigma) applicable for the allocation of Class for horizontal control surveys and the allocation of Class for vertical control surveys using trigonometric or GNSS heighting. Allocation of Class for differential levelling is based on a different formula – refer to SP1 for the specifications and a similar table.

Table 1: Classification of horizontal control surveys and vertical control surveys (using trigonometric or GNSS heighting) based on the *c* value according to SP1.

Class	C (for one sigma)	Typical Applications
3A	1	Special high precision surveys
2A	3	High precision national geodetic surveys
A	7.5	National and state geodetic surveys
B	15	Densification of geodetic surveys
C	30	Survey coordination projects
D	50	Lower Class projects
E	100	Lower Class projects

LPI applies the simple formula stated above to all survey adjustments (except spirit levelling) **regardless of the survey technology/techniques used**. LPI has derived Table 2 to demonstrate the impact of the size of the error ellipse of a survey mark on the determination of Class for different station densities (here defined as the average distance between adjacent stations in the control network).

Using the highlighted cell in Table 2 as an example, let us say that the error ellipse around a survey mark is 0.015 m. This could be the result of a Network RTK position observation or it could be the result of intersected direction observations. Let us assume that all marks in the survey have this same size error ellipse (this is not always the case!). Now the definition above for the determination of Class is based on the relative error ellipse (REE) between marks. In this case the REE between two marks is $\sqrt{(0.015^2 + 0.015^2)}$ which results in 0.021 m. This REE size is the bracketed value shown in Table 2 below the 0.015 m point error ellipse size.

Now we need to determine which Class we can achieve based on the REE (i.e. 0.021 m in our example) when the station density of our survey is 600 m. This is done by applying the simple formula above and the empirical values for c stated in Table 1. It follows, for example:

- To achieve Class 2A, c = 3 and d = 0.6, the REE must be less than 0.0024 m.
- To achieve Class B, c = 15 and d = 0.6, the REE must be less than 0.012 m.
- To achieve Class C, c = 30 and d = 0.6, the minimum REE is 0.024 m.

The REE in our example (i.e. 0.021 m) is less than this value, so we have met Class C for this station density. To achieve a higher Class, we would need to use a lower mark density or a higher measurement accuracy. This example demonstrates that appropriate instrumentation and techniques must be used to achieve a desired Class for a control survey network of a certain density.

Table 2: Class derived from station density and point error ellipse size (at one sigma). The relative error ellipse size used in the determination of Class is stated in parentheses.

Point and (Relative) Error Ellipse / **Station Density (km)**	0.005m (0.007m)	0.010m (0.014m)	0.015m (0.021m)	0.020m (0.028m)	0.025m (0.035m)	0.030m (0.042m)	0.035m (0.049m)
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

5 Assigning Order

The assessment of **Order** is not discussed here in detail (refer to SP1 for more information). Order is an estimation of the derived coordinate quality and is a function of the overall fit with surrounding control. It does not impact on the Class of the survey. Order cannot be better than the Class of the survey in terms of the empirical value c. The assessment of Order remains with LPI. To this end, some of the requirements outlined in this document are included specifically to allow the assessment of Order.

LPI recommends connection to horizontal Class C of 3rd Order or better and vertical Class B or LD or better as a minimum to enable sufficient management and maintenance of the datum in NSW. The highest available Class and Order control in and adjacent to the survey area should be used.

6 Mark Placement

Survey marks must be **stable**. Refer to Surveyor General's Direction No.1 which details the different types of **approved permanent marks** and their construction.

Marks are to be placed with special consideration for Work Health and Safety (**WHS**) issues, particularly with respect to high-speed roadways. Unsafe marks placed in public areas may be included in SCIMS but with mark status set as "restricted".

Marks should be publically accessible if possible. Marks should not be placed in restricted locations such as railway corridors or private property. Locations selected should preferably be **GNSS friendly**, i.e. exhibit a clear skyview with minimal obstructions and/or multipath reflectors.

As described in Surveyor General's Direction No. 2, it is required that **locality sketch plans** of all marks placed are submitted as soon as possible. The sketch plans **must** contain measurements to physical features.

Note that the quality of marking plays a significant role in the determination of Class.

LPI will not approve a survey and update SCIMS unless:

- *Marks are placed such that WHS risks are minimised.*
- *All marks are placed to the approved standard detailed in Surveyor General's Direction No. 1.*
- *A satisfactory locality sketch plan is received for each mark placed, as described in Surveyor General's Direction No. 2.*

7 Equipment

The Class assigned to a survey depends on the precision of the equipment used. For example:

- A 5" total station is suitable for Class E to Class C surveys.
- A 5 mm + 5 ppm EDM is suitable for Class E to Class B surveys.
- A dual-frequency geodetic GNSS receiver is suitable for Class E to Class 3A surveys.

Appropriate instrument calibration documents, defined by the desired Class, must be available on request for all equipment used.

For more information refer to SP1 and the instrument manufacturer's specifications.

8 Network Design and Geometry

For control surveys to be included in SCIMS at the established level, **connections to existing local control** in and adjacent to the survey must be part of the design. This not only provides propagation, densification and homogeneity of the local datum but also provides LPI with the information it requires to determine the **Order** of the resulting coordinates.

When designing a network, it is advisable that it is optimised and not over-specified or over-observed. Connections between adjacent stations should be observed. Measurements which span the extent of the survey may be redundant and contribute little to the determination of the coordinates but tend to exaggerate the statistics. Strong survey control networks are characterised by connections between **adjacent** marks and good geometry of survey observations. This also applies to GNSS networks.

Where possible, connections to accurate height control should include an **overlap** to additional marks to check that marks have not moved. An extension of the existing height control network may be required, rather than relying solely on the accuracy of a geoid model.

Good survey control practice is to work from the whole to the part by observing a **primary network** to establish the datum, then in-fill other control as necessary. The primary and in-fill networks may be submitted to LPI as separate submissions.

The overall network geometry must be “fit-for-purpose”. This implies sufficient redundancy, closed figures and **avoiding radiations**. LPI policy is that multiple observations to the **same** setup over a mark are radiations and that redundancy is only achieved by a new setup (new occupation) – preferably observed to from a different mark. Good network design avoids duplication of infrastructure and does not extrapolate any coordinates or heights, i.e. the survey is contained within the surrounding control.

Established horizontal coordinates (Class C or better) or accurate height (Class B, LD or better) will **not** be assigned for values derived from radiations.

LPI will not accept a survey and update SCIMS unless:

- *Proper connection is made to existing local control with appropriate Order in and adjacent to the survey.*
- *The network design is appropriate (as determined by LPI) and includes sufficient redundancy.*
- *A network diagram is provided.*

9 Observations

Most of today’s observations fall into two categories: terrestrial observations and GNSS observations. Terrestrial observations use instruments such as total stations and levels. GNSS-based observations include absolute point positioning, static surveys or baseline determination, as well as kinematic and RTK/NRTK observations. Regardless of which technology is used, LPI requires that this Direction be followed for the inclusion of survey submissions into SCIMS. LPI supports the use of all or any combination of the following observation types.

9.1 Terrestrial Observations

Modern terrestrial instruments are capable of highly precise measurements. Most equipment used today has digital capability. Some are robotic, have reflectorless capability, and others can read barcodes.

Regardless of these abilities, established principles still apply to control survey work. Some of these principles are:

- Does the instrument meet the specifications to achieve the desired Class?
- Do the observing procedures follow the methods defined by the desired Class? This also applies to robotic equipment.
- Are the appropriate instrument calibration documents, defined by the desired Class, available for all equipment used?
- Do the observations meet the standards defined by the desired Class?
- Have the correct datum-specific parameters been applied correctly, e.g. reduction to the correct ellipsoid?

LPI requires that this information be part of the survey report submitted with the project (see section 13). LPI also requires that the data be submitted in collated form, i.e. angle/direction data has been abstracted to **reduced means** appropriate for the Class of survey. Similarly, distances are to be **averaged** and **reduced** with full **metadata** to:

- Spatial Distances (mark to mark) with corresponding vertical angles or height differences, **or**
- Ground Distances (horizontal) with an average AHD71 height over each distance observation, **or**
- Mean Sea Level Distances, **or**
- Ellipsoidal Distances.

Other **metadata** such as instrument serial numbers and calibration documents as well as instrument checking details (e.g. EDM, tribrachs, verticality of bipods and staves, collimation checks, thermometers and barometers) should also be included.

The submitted data must also be supplied in the form of an **input file** to a least squares adjustment (see section 12).

9.2 GNSS Observations

Global Navigation Satellite System (GNSS) technology offers very effective methods to establish survey control. However, basic survey principles with regard to network design and connection to the datum (see section 8) still apply. The standards for determining Class are still the same.

The selected marks should preferably be **GNSS friendly**, i.e. exhibit a clear skyview with minimal obstructions and/or multipath reflectors (see section 6), and **GNSS best practice** should be followed. Various techniques are used in conjunction with GNSS observations:

- **Post processing**, where **static** observations are made in the field and baseline vectors between the stations are computed later using processing software.

- **Single-base RTK**, where the roving user receiver computes the baseline vector from the reference (base) station using data transmitted via a communication link in **real time**.
- **Network RTK**, where the roving user receiver computes its position based on connections to multiple reference stations surrounding the user in **real time**.

A **static** observation technique based on the local datum or GDA94 is currently the normal practice for control survey networks.

There are limitations to the achievable Class using GNSS techniques, particularly when the distance between adjacent stations is reduced (refer to Table 2). In this case, terrestrial observations can assist in ensuring the desired Class is achieved. Most EDM or total stations perform well in the micro-survey environment such as the cadastre where mark density tends to be high (< 100 m) and GNSS techniques may be challenged at this density. Adding terrestrial data to a GNSS survey may be able to deliver the desired Class.

Field notes or **log sheets** are an invaluable record of what is actually surveyed and **must** include the following details:

- Observer's name.
- Date and start/stop times, clearly indicating whether local or GPS time is used.
- Mark labels (full mark type & number should be entered in the field).
- Receiver filenames.
- Equipment details, including antenna & receiver type and serial numbers.
- Details of antenna height measurement and method used. It must be obvious whether the antenna reference point (ARP) or phase centre is used for the antenna height – a simple sketch shows this easily and clearly.

A useful **independent check for antenna heights** is to take a second measurement using imperial units (inches) and to convert to metres.

For static surveys, a session-by-session **observation diagram** is useful and allows for easy analysis of network design and, in particular, redundancy. Clear identification of the independent (i.e. non-trivial) baselines observed should easily be possible.

Although final coordinates and reduced observations are included in the least squares adjustment, LPI requires the following data to be submitted:

- Raw GNSS observations in **RINEX** format for all static and reference station occupations.
- Processed GNSS baseline vector data in an **ASCII** data exchange format as exported from proprietary software. Variance/covariance information is to be included.

The submitted data must also be supplied in the form of an **input file** to a least squares adjustment (see section 12).

Generic log sheets and a completed example for GNSS observations can be found at:
http://www.lpi.nsw.gov.au/surveying/surveying_services/survey_information

LPI will not approve a GNSS survey and update SCIMS unless:

- *Appropriate field notes or log sheets are submitted.*
- *Antenna height measurements are unambiguous.*
- *Observation data in RINEX format is submitted.*

9.2.1 Post-Processed Static GNSS

The careful selection of **post-processed** static baselines introduces redundancy into the control network which impacts on the Class of the survey. LPI will evaluate all elements of the survey in the determination of Class. In particular, the survey will be subject to the analysis of a least squares adjustment and the consequences of station density (refer to Table 2). With regard to network design, post-processed baselines derived from one GNSS reference station are **radiations** and treated accordingly.

9.2.2 Single-Base RTK

Although single-base Real Time Kinematic (RTK) is an efficient method to capture position, its use for control surveys is limited. Given the technology employed and the equipment used (e.g. bipods to stabilise the antenna pole), LPI maintains that **RTK accuracy** is at the 2 cm level or better horizontally and 3-5 cm in the vertical within 20 km from the reference station.

RTK produces **radiations**, therefore careful network design and redundancy considerations, including **multiple occupations**, are essential to achieve an acceptable control survey outcome.

Given these limitations, LPI **may** update SCIMS with RTK-derived coordinates at an established accuracy, if observations to the mark have been made from **at least two independent occupations** using **two separate reference stations** (i.e. occupation 1 from reference station A and occupation 2 from reference station B) set on existing established SCIMS marks or on marks surveyed in as part of the primary network. The GNSS reference stations used may be one's own, temporary base stations or continuously operating reference stations (CORS) operated by private or public organisations, including CORSnet-NSW (see section 10). The observations on each mark should be made for a **minimum of two minutes** (using the averaging technique) with **at least 30 minutes** between re-occupations to remove biases.

Such updates will still be subject to the analysis of a least squares adjustment and the consequences of station density (refer to Table 2).

9.2.3 Network RTK

Network RTK (NRTK) works in much the same way as single-base RTK but is based on several CORS surrounding the user rather than only one reference station. NRTK observations are **point position type solutions** and require different analysis techniques. A point observation solution provides little in the way of relativity between adjacent marks because it does not provide a baseline to a single reference station. LPI maintains that **NRTK accuracy** is at least as good as single-base RTK accuracy, i.e. at the 2 cm level or better horizontally and 3-5 cm in the vertical.

Every mark in the NRTK survey must be observed **at least twice**. A single observation determines the coordinates only. Additional observations provide redundancy to assess the quality of the observations. The observations on each mark should be made for a **minimum of two minutes** (using the averaging technique) with **at least 30 minutes** between re-occupations to remove biases.

The estimate of Class is based upon the repeatability of observed coordinates and station density (refer to Table 2). Good repeatability equates to smaller error ellipses and vice versa. Similarly, multiple occupations of marks will provide an indication of the achievable precision of the system/survey and the performance of the employed GNSS technique at individual marks.

Given these limitations, LPI **may** update SCIMS with NRTK-derived coordinates at an established accuracy, if observations to each mark have been made at least twice using CORSnet-NSW (see section 10) or another approved CORS network.

10 Using CORSnet-NSW

CORSnet-NSW is a network of GNSS continuously operating reference stations (CORS) providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use. The CORSnet-NSW network continuously observes and corrects satellite navigation signals in order to provide international standard, high-accuracy positioning across NSW. Real-time data is streamed to users via a wireless internet connection.

The benefits of CORS networks include datum definition, rationalisation of infrastructure, establishment of multi-user systems, positioning services that are similar across and between networks, consistent and reliable connectivity to the national datum, and the ability to provide a degree of traceability to a recognised value standard for satellite-based positioning. RTK and NRTK in particular provide high-precision coordinates and allow ‘real-world digitising’ with the ability to significantly enhance productivity.

However, fundamental surveying principles, accuracy issues and the requirements related to control surveys must still apply. With regard to network design, post-processed baselines derived from one CORS or baselines from single-base RTK are **radiations** and treated accordingly.

Post-processed baselines or single-base RTK using more than one CORSnet-NSW station introduce redundancy which impacts on the Class of the survey. LPI will evaluate all elements of the survey in the determination of Class, including station density (refer to Table 2).

Real-time solutions using CORSnet-NSW are provided in terms of GDA94(2010) and ellipsoidal height. GDA94(2010) is a new, ad-hoc realisation of GDA94 which is essential to make NRTK possible by eliminating the distortions present in the original realisation of the current national datum, now termed GDA94(1997), and allowing compatibility and interoperability between different CORS networks. As a result, a **site transformation** (see section 10.1) is required to derive local GDA94(1997) coordinates (i.e. those stated in SCIMS) from CORSnet-NSW solutions. Similarly, a geoid model (the current model being AUSGeoid09) is needed to realise an estimate of AHD71. This applies to both single-base RTK and Network RTK.

Without the inclusion of existing control data LPI cannot determine GDA94(1997) coordinates or AHD71 heights in either GNSS or terrestrial surveys. LPI requires the existing control information used in the survey to determine the **Order** of the adjusted final coordinates. At least **three** control marks **surrounding** the survey area with at least horizontal Class C coordinates and vertical Class B or LD or better (with the highest available Order) should be observed. Note that the **raw** position or baseline results (i.e. coordinate results **without** applying a site transformation), collected on all marks (including existing control), must be submitted.

LPI will not approve an RTK/NRTK survey and update SCIMS unless:

- *Every mark is observed using a bipod or tripod for stability.*
- *Verticality of RTK/NRTK pole and correct operation of bubble is checked and validated.*
- *At least three control marks surrounding the survey area with at least horizontal Class C coordinates and vertical Class B or LD (with the highest available Order) are observed. The nearest existing control marks are to be used, i.e. the network should not ignore or span existing local control.*
- *Every mark is observed for at least 2 minutes (at a 1-second sampling rate) using the averaging technique. The coordinate result of each occupation must be supplied.*
- *Every mark in the survey (including existing control) is observed at least twice.*
- *Observations at marks are repeated at least 30 minutes later.*
- *Repeat observations where agreement has exceeded the specifications of the desired Class (refer to Table 2 as a guide) are made at least 30 minutes later (back-to-back observations are unacceptable).*
- *Rejected position or baseline observations are included in the observation data submitted to LPI.*
- *The raw coordinate result data (without applying a site transformation), observed on all marks (including existing control), is supplied.*
- *If the survey does not meet the requirements, an LPI Senior Surveyor should be contacted prior to submission.*

10.1 Site Transformation

Users may need to perform a **site transformation** (also known as site calibration or localisation) to derive local GDA94(1997) coordinates (i.e. those stated in SCIMS) from CORSnet-NSW real-time observations. The coordinates derived directly from CORSnet-NSW using RTK/NRTK refer to GDA94(2010) and may not be consistent with local ground control marks. Although CORSnet-NSW reference stations are also assigned local GDA94(1997) and AHD71 values (available through SCIMS), these values are only used for post-processing of observations and do not apply for real-time applications.

A site transformation is **not** required if:

- The control survey uses single-base, post-processing techniques with baseline processing and adjustments performed using GDA94(1997) coordinate values from SCIMS.
- The RTK/NRTK survey is in an isolated location where connections to existing control are not feasible. The definition of an isolated area will be determined by an LPI Senior Surveyor on a case-by-case basis.

If the survey coordinates are required in GDA94(1997) and AHD71, then LPI recommends that a simple block-shift transformation solving for the mean translations in East, North and Height is sufficient (provided that AUSGeoid09 is used), i.e. a **3-parameter** site transformation. At a practical level, there is no need to solve for scale and rotation parameters since by definition GDA94(2010) and GDA94(1997) share the same ellipsoid and coordinate axes. The only difference between the coordinates is the **local** difference.

The latest version of AUSGeoid (currently AUSGeoid09) **must** be used as part of the site transformation. Using a site transformation without the use of a geoid model, i.e. considering the geoid-ellipsoid separation as part of the direct site transformation parameters from GDA94(2010) to local GDA94(1997) and AHD71 coordinates, is **not** recommended.

A minimum of **three** known marks immediately **surrounding** the survey area should be observed to calculate the transformation parameters. The nearest existing control marks should be used, i.e. the network should not ignore or span existing local control. Selection of these control marks will be based on the requirements of the survey, i.e. either 1D, 2D or 3D.

Every mark (including existing control) in the RTK/NRTK survey should be observed **at least twice**. A single observation determines the coordinates only. Additional observations provide redundancy to assess the quality of the observations. The observations on each mark should be made for a **minimum of two minutes** (using the averaging technique) with **at least 30 minutes** between re-occupations to remove biases. This ensures that both the GNSS constellation and other conditions have sufficiently changed.

11 AUSPOS

AUSPOS is Geoscience Australia’s free online GPS processing service, available for static observations of at least one hour duration. AUSPOS delivers coordinates that are independent of the local datum, similar to GDA94(2010) coordinates derived by CORSnet-NSW without a site transformation. AUSPOS coordinates are derived by applying transformation parameters from the current global reference frame (ITRF20xx) to GDA94. Heights are derived from ellipsoidal height values with the geoid-ellipsoid separation applied and are therefore not strictly AHD71 (the current AUSGeoid09 geoid model provides AHD71 heights from GNSS observations with an estimated accuracy of 50 mm across NSW).

The **accuracy of the technique** is dependent on observation length, number and distribution of GNSS reference stations used in the AUSPOS solution, the antenna model and the satellite orbit data adopted for processing, and the transformation parameters used.

LPI uses coordinates from precisely determined AUSPOS sites for quality assurance of the existing survey control network, and the data will be included in future re-adjustments of the national datum.

LPI archives AUSPOS **raw observation data** (RINEX files) and intends to store the results in SCIMS with absolute coordinates and ellipsoidal heights (not published at this point in time). LPI is therefore interested in receiving raw observations (RINEX files) for long occupations (in excess of four hours) of any survey control mark.

The major issue with AUSPOS solutions is their **proximity to existing control** (refer to Table 2). In some areas of the State, the difference between GDA94(2010) and locally derived GDA94(1997) and AHD71 reaches 0.3 metres in horizontal position and 0.5 metres in height.

LPI **may** update SCIMS with established coordinate values derived from AUSPOS, under the following conditions:

- Occupations are at least four hours long.
- Log sheets are complete.
- Antenna model type and antenna height measurements are unambiguous.
- IGS final orbit type ephemerides are used for the online computation.
- Internal AUSPOS quality indicators are satisfactory.
- There is redundancy with multiple occupations or coordinates are verified by ground survey.
- There is no conflict with existing local control.
- The following is submitted to LPI for each mark occupied: RINEX data, scanned log sheet, AUSPOS report, and additional information (e.g. ground survey connections).

Accuracy Class for AUSPOS observations is assigned at the discretion of LPI. Factors to be considered include:

- Station marking.
- Session length.
- Redundancy.
- Data quality.
- AUSPOS processing quality indicators.

Based on AUSPOS solutions, LPI **may** assign a horizontal accuracy of up to and including Class 2A. The assigned AHD71 accuracy will not exceed Class C. AUSPOS observations will be subject to the consequences of station density (refer to Table 2).

12 Computation and Adjustment

Aside from the appropriate computation of coordinate values, the intent is that all data submitted is suitable to be archived for use in later re-calculations or combined adjustments. Therefore, the following requirements must be met.

All observation data must be submitted in an **organised and unambiguous digital format**. To this end, it is required that adjustments use **reduced sets of observations** (i.e. angle/direction data has been abstracted to reduced means and distances are averaged and reduced according to section 9.1) rather than individual pointings which bias the statistics and make analysis difficult. The standard deviations of observations must comply with SP1 requirements.

LPI will perform its own **least squares adjustment** using the submitted data. Therefore, the submitted data must also be supplied in the form of an **input file** to a least squares adjustment.

However, adjustment by a least squares method **prior** to submission is strongly recommended to indicate whether the computation results meet the requirements.

Fundamental to the adjustment are the standard deviations (weighting) applied to observations. These values must be clearly stated and include the reasoning behind choosing the values applied.

Explanation and justification is required where any of the following options are used in the adjustment:

- Re-weighting or rejection of observations.
- Scaling of observations.
- Solving for rotation/orientation or scale parameters.
- Standard deviations applied to constraints.
- Scaling of error ellipses.

LPI will not approve a survey and update SCIMS unless:

- *Observation data is suitably organised in digital format.*
- *All adjustment options employed are acceptable.*
- *The results are easy to interpret and analyse.*
- *The correctness of the results is demonstrated.*
- *Sufficient metadata is supplied.*

13 Survey Report

A survey report containing a description of the following is required in digital format:

- The overall job, including purpose, background and intent.
- Fieldwork equipment, observation techniques, sketches, photographs, etc.
- Data processing, including software used and options applied.
- Network design and geometry.
- Adjustment, including software used, options applied, constraints, analysis and results.
- Recommendations for Class.
- Data archive, presentation and formats.
- Submission statement.

To accompany the report, digital diagrams/plans of individual GNSS sessions and the complete survey are necessary to show the geometry of the network, connections to existing control and other relevant information as required. Ideally, these should be in Arc shapefile, DWG or similar vector graphic formats which include attribute information such as mark labels, coordinates and observation types.

Other useful information includes the status of existing control and digital photographs of trigonometric stations and other marks. A signed **check list** (see Appendix) must also be included.

A template for the survey report, along with a sample survey report, can be found at: http://www.lpi.nsw.gov.au/surveying/surveying_services/survey_information

LPI will not approve a survey and update SCIMS unless a satisfactory survey report and associated information is submitted in a timely manner. The survey report should be submitted in both pdf format (with your signature) ***and*** *Word format (required for follow-on work at LPI).*

Acknowledgements

An earlier version of this document was authored by Glenn Jones in 2007. It was substantially updated by Greg Dickson, Dr Volker Janssen and Simon McElroy as Surveyor General's Direction No. 12. This document is available online from http://www.lpi.nsw.gov.au/about_lpi/publications/guidelines/surveyor_generals_directions.

References

GA (2011) AUSGeoid09, http://www.ga.gov.au/geodesy/ausgeoid/nvalcomp.jsp (accessed Aug 2012).

GA (2011) AUSPOS, http://www.ga.gov.au/earth-monitoring/geodesy/auspos-online-gps-processing-service.html (accessed Aug 2012).

GA (2011) Australian Height Datum, http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/australian-height-datum-ahd.html (accessed Aug 2012).

ICSM (2006). Geocentric Datum of Australia technical manual, version 2.3, http://www.icsm.gov.au/icsm/gda/gdatm/index.html (accessed Aug 2012).

ICSM (2007) Standards and practices for control surveys (SP1), version 1.7, http://www.icsm.gov.au/icsm/publications/sp1/sp1v1-7.pdf (accessed Aug 2012).

Haasdyk J. and Janssen V. (2012) Site transformations: A block shift in thinking, *Proceedings of APAS2012*, 19-21 March, Wollongong, Australia, 29-47, http://www.lpi.nsw.gov.au/__data/assets/pdf_file/0005/169952/2012_Haasdyk_and_Janssen_APAS2012_site_transformations.pdf (accessed Aug 2012).

Janssen V. and McElroy S. (2010) Coordinates and CORSnet-NSW: Dealing with distortions in GDA94, *Position*, 50, 24-27, http://www.lpi.nsw.gov.au/__data/assets/pdf_file/0008/144944/2010_Janssen_and_McElroy_Position50_coords_and_CORSnet-NSW.pdf (accessed Aug 2012).

Lands (2006) Surveying and Spatial Information Regulation 2006, http://www.legislation.nsw.gov.au/maintop/view/inforce/subordleg+530+2006+cd+0+N (accessed Aug 2012).

LPI (2009) Surveyor General's Direction No. 1: Approved permanent marks, http://www.lpi.nsw.gov.au/__data/assets/pdf_file/0007/25936/sgddir1_Ver2009.pdf (accessed Aug 2012).

LPI (2009) Surveyor General's Direction No. 2: Preparation of locality sketch plans, http://www.lpi.nsw.gov.au/__data/assets/pdf_file/0008/25937/sgddir2_Ver2009.pdf (accessed Aug 2012).

LPI (2012) CORSnet-NSW, http://www.corsnet.com.au/ (accessed Aug 2012).

LPI (2012) SCIMS online, http://www.lpi.nsw.gov.au/surveying/scims_online (accessed Aug 2012).

Appendix: Check List

This Appendix provides a check list summarising the requirements and guidelines for externally sourced data of control surveys to be included in SCIMS at an "established" level. This list is not exhaustive and certainly not intended to describe the mandatory process necessary to achieving required accuracy outcomes. It should be emphasised that the ultimate responsibility for the assignment of **Class** and **Order** to the marks of a survey network remains within the subjective judgement of LPI as the relevant authority. This check list is to be **completed**, **signed** and **submitted** as part of the survey report (see section 13).

Issue	Requirements and Guidelines	Yes,No,N/A
Consultation	Details of LPI's full requirements and the interpretation of this Direction must be **discussed** with an LPI Senior Surveyor **prior** to commencement of the survey.	
	Details of LPI's full requirements and the interpretation of this Direction must be **agreed** with an LPI Senior Surveyor **prior** to commencement of the survey.	
	If data processing reveals that the survey does not meet the requirements for the desired Class, an LPI Senior Surveyor should be contacted **prior** to submission.	
Mark Placement	Marks are placed such that WHS risks are minimised.	
	Marks placed in restricted areas can be accessed and occupied as safely as possible.	
	Marks should be GNSS friendly, i.e. exhibit a clear skyview with minimal obstructions.	
	Marks are placed to the approved standard detailed in Surveyor General's Direction No. 1.	
	A satisfactory locality sketch plan is received for each mark placed, with measurements to physical features as described in Surveyor General's Direction No. 2.	
	Mark quality is appropriate to Class of survey.	
Equipment	Equipment used is appropriate to meet the specifications of the desired Class.	
	Appropriate instrument calibration documents, defined by the desired Class are supplied for all equipment used.	
Network Design and Geometry	The network design is appropriate (as determined by LPI), includes sufficient redundancy, closed figures and avoids radiations.	
	The network is optimised and not over observed.	
	Connections between adjacent stations have been observed (were appropriate).	
	Proper connection is made to existing local control with the highest available Order in and adjacent to the survey. LPI recommends connection to horizontal Class C marks of 3^{rd} Order and vertical Class B or LD as a minimum.	
	The survey is contained within the surrounding control, i.e. coordinates or heights are not extrapolated.	
	The station density is appropriate for the desired Class.	
	Duplication of infrastructure is avoided.	
	A network diagram is provided.	

Terrestrial Observations	Observation procedures follow the methods defined by the desired Class.	
	Observations meet the specifications defined by the desired Class.	
	The correct datum-specific parameters have been applied correctly, e.g. the correct geoid model.	
	Angle/direction data has been abstracted to reduced means appropriate for the Class of survey.	
	Distances are averaged and reduced with full metadata to Spatial Distances (mark to mark) with corresponding vertical angles or height differences, or Ground Distances with an average AHD71 height over each distance observation, or Mean Sea Level Distances, or Ellipsoidal Distances.	
	Instrument serial numbers and instrument checking details (e.g. EDM, tribrachs, verticality of bipods and staves, collimation checks, thermometers and barometers) are available.	
	The submitted data is supplied in the form of an input file to a least squares adjustment.	
GNSS Observations	Observation procedures follow the methods defined by the desired Class.	
	The minimum acceptable GNSS antenna mount for Class C is a survey bipod. Higher Class surveys must use a tripod for stability.	
	Verticality of RTK/NRTK bipod setup and correct operation of bubble is checked and verified.	
	Observations meet the specifications defined by the desired Class.	
	The correct datum-specific parameters have been applied correctly, e.g. the correct geoid model.	
	Field notes or log sheets are supplied and include observer, date, start/stop times (clearly indicating the use of local or GPS time), mark labels (full mark type & number should be entered in the field), receiver filenames, equipment details (incl. antenna & receiver type and serial numbers), details of antenna height measurement and method used (a simple sketch clearly states whether it refers to the antenna reference point (ARP) or phase centre).	
	The antenna height measurement is unambiguous and checked. A useful independent check for antenna heights is to take a second measurement using imperial units (inches) and to convert to metres.	
	A session-by-session observation diagram is provided for static surveys, allowing clear identification of the independent (i.e. non-trivial) baselines observed.	
	Raw observations in RINEX format for all static and reference station occupations are submitted.	
	Processed baseline vector data (incl. variance/covariance information) is provided in an ASCII data exchange format as exported from proprietary software.	
	The submitted data is supplied in the form of an input file to a least squares adjustment.	
	Single-base RTK observations are made from at least two independent occupations using two separate reference stations (i.e. occupation 1 to reference station A and occupation 2 to reference station B) set on existing established SCIMS marks or on marks surveyed in as part of the primary network.	

GNSS Observations (*continued*)	Single-base RTK observations on each mark should be made for a minimum of two minutes (using the averaging technique) with at least 30 minutes between re-occupations to remove biases.	
	NRTK observations on each mark must be observed at least twice (better three times) for a minimum of two minutes (using the averaging technique) with at least 30 minutes between re-occupations to remove biases.	
	At least three control marks surrounding the survey area with at least Class C coordinates (with the highest available Order) should be observed. The nearest existing control marks are to be used, i.e. the network should not ignore or span existing local control.	
	The raw RTK/NRTK position or baseline results (i.e. coordinate results **without** applying a site transformation), collected on all marks (incl. existing control), must be submitted.	
	Repeat observations where agreement has exceeded the specifications of the desired Class (refer to Table 2 as a guide) are made at least 30 minutes later (back-to-back observations are unacceptable).	
	Rejected observations are included in the observation data submitted to LPI.	
	The latest AUSGeoid product (currently AUSGeoid09) must be used as part of the site transformation.	
	The submitted data is supplied in the form of an input file to a least squares adjustment.	
AUSPOS Observations	Occupations are at least four hours long.	
	Antenna model type and antenna height measurements are unambiguous and checked.	
	Log sheets are unambiguous and complete.	
	IGS final orbit type ephemerides are used in the online computation.	
	Internal AUSPOS quality indicators are satisfactory.	
	There is redundancy with multiple occupations or coordinates are verified by a ground survey.	
	There is no conflict with existing local control.	
Computation and Adjustment	Adjustment by a least squares method **prior** to submission is strongly recommended to indicate whether the computation results meet the requirements.	
	The submitted data is supplied in an organised and unambiguous digital format, and in the form of an input file to a least squares adjustment.	
	The standard deviations of observations must comply with SP1 requirements.	
	The standard deviations (weighting) applied to observations must be clearly stated and include the reasoning behind choosing the values applied.	
	Explanation and justification is required where any of the following options are used in the adjustment: Re-weighting or rejection of observations, scaling of observations, solving for rotation / orientation or scale parameters, standard deviations applied to constraints, scaling of error ellipses.	
	The correctness of the results is demonstrated.	
	The results must allow easy interpretation and analysis by LPI.	

Survey Report	Required in digital format (pdf and Word) as part of the submission.	
	Description of the overall job, including background and intent.	
	Description of fieldwork equipment, observation techniques, sketches, photographs, etc.	
	Description of the data processing, including software and options used.	
	Description of the network geometry, including a network diagram.	
	Description of the adjustment software used, options applied, analysis and results.	
	Recommendations for Class.	
	Description of the data archive, presentation and formats used.	
	Digital diagrams/plans of the complete survey to show the geometry of the network, connections to existing control and other relevant information as required (in Arc shapefile, DWG or similar vector graphic formats which include attribute information such as mark labels, coordinates and observation types).	
	Other useful information, e.g. the status of existing control and digital photographs of trigonometric stations and other marks.	

Notes:

Signed...

Name...

Organisation...

Dated...

End of Direction