Surveyor-General's Direction

No. 12

Control Surveys and SCIMS

Title: Surveyor-General's Direction No. 12
Control Surveys and SCIMS

Published by

Spatial Services
A Unit of the Department of Customer Service
346 Panorama Avenue
BATHURST NSW 2795
Tel: (02) 6332 8287

https://www.spatial.nsw.gov.au

Cover photograph shows a GNSS survey at Kulwin Continuously Operating Reference Station (CORS), Western NSW. Included in the photo is TS4833 Wong (cairn) and surrounding survey marks (astro pillar).

Photographer: Russell Commins.

Enquiries

Any enquiries regarding this Direction should be forwarded to
Surveyor-General-Approvals@customerservice.nsw.gov.au

For access to legislation in force in NSW go to the official NSW Government website for online publication of legislation at www.legislation.nsw.gov.au.

Spatial Services (B) P21/10/008

Document Control Sheet

Record of Document Issues

Version No.	Issue Date	Nature of Amendment
0.1	November 2007	Initial draft of "Control Surveys and SCIMS: What's acceptable?"
1.0	December 2007	Final for approval and distribution
1.1	October 2011	Draft of major update as Surveyor-General's Direction No. 12
1.2	December 2011	Internal agreement of draft for industry feedback
2.0	August 2012	Final for approval and distribution
2.1	May 2019	Minor Revision – formatting and *Surveying and Spatial Information Regulation 2017*
2.2	January 2021	Draft of major revision - adoption of GDA2020 and rigorous uncertainty in SCIMS, introduction of *Technical Specifications for NSW Secondary Control Surveys.*
3.0	April 2021	Final for approval and distribution

Document Approval:

Approved By:

Narelle Underwood
Surveyor-General of NSW
Date of Approval: April 2021

1. Contents

Definitions

In this Direction, the following terms have the meaning as indicated below.

the Act	Means the Surveying and Spatial Information Act 2002.
AFN	Means the Australian Fiducial Network, a network of 109 GNSS CORS which provides the legal foundation of GDA2020 and ATRF. The AFN provides the recognized-value standard of measurement of position.
AGD	Means the Australian Geodetic Datum. The accompanying national map projection is called the Australian Map Grid (AMG).
AGRS	Means the Australian Geospatial Reference System, a collection of datums, infrastructure, models and standards managed by ICSM's Permanent Committee on Geodesy.
ANLN	Means the Australian National Levelling Network, a network of primary and secondary levelling adjusted to realise the Australian Height Datum 1971.
AHD	As defined in Clause 3 of the Act. AHD71 is the datum surface approximating mean sea level that was adopted by the National Mapping Council of Australia in May 1971.
AVWS	Means the Australian Vertical Working Surface, a reference surface for physical heights realised by the Australian Gravimetric Quasigeoid (AGQG). AVWS heights are derived by subtracting the AGQG separation from the GDA2020 ellipsoidal height.
Calibration	As defined in *Surveyor-General's Direction No. 5 – Calibration of Electronic Distance Measuring (EDM) Equipment* (SGD5), calibration is the determination of instrument errors by comparing the value indicated by the measuring equipment with the known or true value. Consequently, corrections must be applied to all measurements made with the equipment in order to obtain 'true' measurements.
Constrained adjustment - fully	Means an adjustment which has a sufficient number of constrained survey control marks, identified in the control strategy (see **Section 8.2**), to propagate datum and uncertainty throughout the control survey.
Constrained adjustment - minimally	Means an adjustment which has the minimum number of constrained survey control marks to calculate all dimensions of the adjustment and assess Class.
Control survey	A control survey is performed by making suitably accurate measurements between new or existing survey marks and referring them to identifiable survey control marks in an existing control network. In the context of this Direction, a control survey is taken to mean any survey that is carried out for the purpose of deriving coordinates, heights and related information of survey marks underpinning the State Control Survey Network for update of SCIMS.
CORSnet-NSW	CORSnet-NSW is a network of GNSS continuously operating reference stations (CORS) operated by Spatial Services, providing fundamental positioning infrastructure for New South Wales. CORSnet-NSW continuously observes and corrects satellite navigation signals in order to provide high-accuracy positioning across NSW to an international standard. Real-time data is streamed to users via a wireless internet connection.

GDA	Means the Geocentric Datum of Australia, as defined in Clause 3 of the Act.
GDA94	Means the Geocentric Datum of Australia 1994.
GDA2020	Means the Geocentric Datum of Australia 2020.
GNSS	Means Global Navigation Satellite System.
ICSM	Means the Intergovernmental Committee on Surveying and Mapping, a standing committee of the ANZLIC - the Spatial Information Council.
ISG	Means the Integrated Survey Grid based on AGD.
ITRFxxxx	Means one of the realisations of the International Terrestrial Reference Frame (ITRF). It is usually accompanied with an epoch, e.g. ITRF(realisation)@(epoch in decimal years) such as ITRF2014@2020.0.
LSP	Means Locality Sketch Plan, see *Surveyor-General's Direction No. 2 – Preparation of Locality Sketch Plans* (SGD2).
MGA	Means the Map Grid of Australia, as defined in Clause 5 of the Regulation.
Primary Control Survey	In the context of this Direction, a primary control survey is a survey that: Is considered of State or National significance and serves to establish and propagate datum such as GDA2020 and AHD71. This includes, as an example, survey networks such as the Australian National Levelling Network (ANLN), CORSnet-NSW and the GDA Spine and Subspine network(s), and Is identified as such by the Surveyor-General of NSW and/or Spatial Services.
PSM	Means a Permanent Survey Mark (PSM) as defined in Schedule 4 of the Regulation.
Public Authorities	As defined in Clause 3 of the Act.
the Regulation	Means the Surveying and Spatial Information Regulation 2017.
SCIMS	Means the information management system maintained by the Surveyor-General and known as the "Survey Control Information Management System", as defined in Clause 5 of the Regulation.
SCIMS Online	Is the web mapping tool that makes SCIMS data available to the public via the SIX Spatial Services Portal.
Secondary Control Survey	In the context of this Direction, a secondary control survey is a survey: That is not defined as a Primary Control Survey, That predominately serves to refine/maintain the State Control Survey Network as well as propagate datum, That is common for projects that require survey control to be densified from the Primary Control Survey to the site to establish datum, e.g. infrastructure projects, and That is identified as such by the Surveyor-General of NSW and/or Spatial Services.
Source Identification (SID)	A unique number identifying the adjustment source that created the coordinates and/or height of a survey mark in SCIMS, see *Surveyor-General's Direction No. 4 – Interpreting the Survey Control Information Management System (SCIMS)* (SGD4).

SP1 v1.7	Means the Intergovernmental Committee on Surveying and Mapping (ICSM) publication 'Standards and Practices for Control Surveys (SP1), Version 1.7'.
SP1 v2.2	Means the Intergovernmental Committee on Surveying and Mapping (ICSM) publication 'Standard for the Australian Survey Control Network (SP1), Version 2.2'.
Spine Network	The NSW 'Spine' network (also known as GDA Spine) refers to the original 1997 adjustment of GDA94 that featured a mixture of GPS-only baselines and terrestrial distance and direction (DDS) observations of varying quality. The Spine network is usually identified in SCIMS through its Class 2A0 allocation.
Subspine Network(s)	Subspine networks are high-Class regional control survey networks connecting into the NSW Spine network and providing homogeneous survey control in localised areas. Notable subspine networks in NSW include the Greater Sydney Subspine Network (GSSN), the South Coast A1 Subspine Network, and the Hunter A1 Subspine Network.
the State Adjustment	A subset of the State control survey maintained by Spatial Services containing survey measurements used to determine coordinates, heights and qualities with respect to the national reference frames as prescribed in the Act.
State control survey	As defined in Clause 3 of the Act. Also known as the State Control Survey Network.
State Control Survey Network	Means the State control survey as defined in Clause 3 of the Act. A network of stations and survey measurements maintained by Spatial Services used to determine coordinates, heights and qualities with respect to the national reference frames.
Station Density	Is the term used to express the distance **(d)** between survey marks when calculating Class. Spatial Services uses horizontal distance in kilometres to express station density.
Survey Mark	Means any mark as defined in Clause 27 & Schedules 1, 2, 3 or 4 of the Regulation.
Survey Control Mark	Means a survey mark that forms part of a control strategy (see **Section 8.2**) that will be used to constrain a control survey and establish datum (GDA2020, AHD71, or both).
Spatial Services	Means the Department of Customer Service – Spatial Services.
Surveyor-General	As defined in Clause 3 of the Act.
Verification	As defined in *Surveyor-General's Direction No. 5 – Calibration of Electronic Distance Measuring (EDM) Equipment* (SGD5), verification is a test to confirm that the accuracy attained by a measuring instrument is within allowable accuracy limits as defined in a specification or as required by legislation.
Uncertainty	As defined in SP1 v2.2, uncertainty in this Direction means doubt about the validity of a measurement or result of a measurement (e.g. a position). Uncertainty is an indication of how wrong a value may be and is used in this Direction to quantify the level of survey quality, expressed as a standard deviation in the International System of Units (SI) expanded to the 95% confidence level.

1. Preamble

Under the *Surveying and Spatial Information Act 2002* (the Act), the Surveyor-General of NSW is responsible for the establishment of the State control survey (hereafter the State Control Survey Network) and provisions for the coordination of surveys undertaken by public authorities. The Department of Customer Service - Spatial Services (hereafter Spatial Services), on behalf of the Surveyor-General of NSW, carries out this function through the extension, densification and refinement of the State Control Survey Network and the administration and management of this information through the Survey Control Information Management System (SCIMS). It also sets the standards for control surveys in NSW through the ongoing development of the Surveyor-General's Directions as well as the revision and implementation of national and international surveying standards.

The State Control Survey Network provides, through physical monumentation on the ground (permanent survey marks) as well as high-accuracy real-time positioning services (CORSnet-NSW), direct connection to a reliable, accurate and nationally adopted spatial referencing system that underpins surveying, land information and mapping systems. Along with other States and Territories, the State Control Survey Network forms part of Australia's control survey network. This network is considered a critical infrastructure component of the Australian Geospatial Reference System (AGRS) that realises the Geocentric Datum of Australia 2020 (GDA2020) and the Australian Height Datum (AHD71).

The *Surveying and Spatial Information Regulation 2017* (the Regulation) defines the requirements to propagate and connect to the State Control Survey Network, and to ensure that permanent survey marks are placed at appropriate locations and identified on a Locality Sketch Plan (LSP) so that they are correctly recorded in SCIMS. External data is often submitted to Spatial Services as the result of an agreement between a contractor and a public authority who are required to place survey information on public record. Additionally, the recent update and enforcement of *Surveyor-General's Direction No. 11 – Preservation of Survey Infrastructure* (SGD11) has resulted in many private surveyors undertaking their own control surveys in an effort to preserve the integrity of the State Control Survey Network and State Cadastre.

The Regulation mandates that, subject to Surveyor-General Directions, surveys relating to the State Control Survey Network must be carried out in accordance with the requirements set out in the Intergovernmental Committee on Surveying and Mapping (ICSM) publication *'Standards and Practices for Control Surveys (SP1), Version 1.7'* (SP1 v1.7). Spatial Services has developed the Technical Specifications for NSW Secondary Control Surveys as addendum to this Direction, to provide further specifications for secondary control surveys. Similarly, the SGD12 Resource Pack is made available as an additional resource to provide supplementary documentation, templates and examples of the material covered within this Direction. The Surveyor-General of NSW has also released other Directions to regulate the propagation and preservation of the State Control Survey Network and SCIMS.

2. Introduction

Surveyor-General's Direction No. 12 – Control Surveys and SCIMS (SGD12) has been developed to standardise the undertaking of control surveys that contribute towards the ongoing extension, maintenance and preservation of the NSW State Control Survey Network, and to outline the requirements for survey results and information to be placed on public record in SCIMS. This includes aspects of best survey practice, appropriate survey equipment, network design, reduction techniques and adjustment strategies needed to achieve a required standard for update of coordinates, heights, and statements of accuracy of survey marks.

SCIMS relies on the continuing contribution from private and public surveyors, as well as standards and specifications to maintain its currency and integrity. This Direction provides users with the information and tools necessary to carry out control surveys to a recognised standard, fit for update of SCIMS and placement on public record in NSW.

Ultimately, the assignment of quality statements such as Class and uncertainty is dependent upon the subjective judgement of Spatial Services as the relevant authority administering the State Control Survey Network and SCIMS.

Any clarification or deviation on the requirements of this Direction must be discussed and approved by a Spatial Services' Senior Surveyor or nominated representative prior to the commencement of the survey.

3. The Survey Control Information Management System (SCIMS)

The Survey Control Information Management System (SCIMS) is a database of coordinates, heights, accuracies and related attributes (metadata) of survey marks constituting the State Control Survey Network under the direction of the Surveyor-General of NSW. This information is collected through the operation of the Act and the Regulation. SCIMS is a central registry of survey control data that is considered authoritative and is maintained for the purposes of cadastral and engineering surveys, mapping and a variety of other spatial applications. Spatial Services manages SCIMS and carries out control surveys for the extension, maintenance and preservation of the State Control Survey Network as part of its core functions.

SCIMS supports the surveying and spatial information industry by providing a whole-of-government service for survey infrastructure in NSW, enabling a direct connection to approved datums including the Geocentric Datum of Australia 2020 (GDA2020) and the Australian Height Datum (AHD71). SCIMS currently still supports the now superseded Geocentric Datum of Australia 1994 (GDA94) and provides limited information in the former Australian Geodetic Datum 1966 (AGD66; including ISG66 & AMG66 coordinates).

SCIMS consists of over 250,000 survey marks, the more common mark types identified as State Survey Marks (SS), Permanent Marks (PM), and Trigonmetrical Stations (TS). SCIMS stores supplementary information (metadata) for each survey mark including (but not limited to) monumentation type, mark status, name/alias, source identification number (SID) and date for each coordinate/height record, and any eccentric or witness marks. *Surveyor-General's Direction No. 4 – Interpreting the Survey Control Information Management System (SCIMS)* (SGD4) provides further details on the SCIMS database and how to interpret the information contained within it.

All survey mark position information within SCIMS is evaluated for accuracy and precision, expressed as Class, Positional Uncertainty (PU) and Local Uncertainty (LU). This enables a standardised approach in evaluating and reporting the quality of a survey mark, its coordinates and its connection to datum.

Spatial Services maintains and periodically re-adjusts a subset of the State Control Survey Network, known as the State Adjustment, by least squares to update SCIMS with the best estimates of position, height and uncertainty, based on all available measurements. Spatial Services is actively updating the State Adjustment using both newly submitted surveys and existing/legacy adjustments. As such, for control surveys to be merged into the State Control Survey Network and placed on public record in SCIMS, they must meet all requirements outlined in this Direction.

Spatial Services encourages the submission of control surveys for ingestion into the State Adjustment and update of SCIMS. It will be up to the user to prove that their survey meets the standards and requirements outlined in this Direction. Spatial Services will not act as an arbitrator on whether a user has fulfilled their obligations under an external contract but will exercise discretion in determining what is fit-for-purpose for update of SCIMS.

4. Datums and AUSGeoid Products

SCIMS provides an accurate and authoritative spatial reference frame, allowing users to connect into Australia's national coordinate reference systems for positioning and heighting purposes. SCIMS stores coordinate information in both the Geocentric Datum of Australia 2020 (GDA2020) and the Geocentric Datum of Australia 1994 (GDA94). Height information is stored in relation to the Australian Height Datum (AHD71) and GDA2020 (for ellipsoidal heights as part of the State Adjustment). Limited information is maintained in the former Australian Geodetic Datum 1966 (AGD66).

4.1 Geocentric Datum of Australia 2020 (GDA2020)

GDA2020 is Australia's national datum and is legislated as NSW's prescribed horizontal datum having commenced on 1 January 2020. It is a geocentric 'plate-fixed' coordinate reference system aligned with the International Terrestrial Reference Frame 2014 (ITRF2014) at epoch 1 January 2020. Refer to the GDA2020 Technical Manual for more information.

GDA2020 is propagated in NSW through the State Adjustment using the Australian Fiducial Network (AFN) as the primary constraint. The AFN consists of 109 GNSS CORS across Australia, 15 of which are located in NSW as part of CORSnet-NSW. Survey marks in SCIMS either have *adjusted* or *transformed* GDA2020 coordinates depending on their method of update and connection to datum.

Adjusted GDA2020 coordinates generally have been determined through the State Adjustment or through a smaller least squares adjustment. Adjusted GDA2020 coordinates appear in SCIMS with an associated Positional Uncertainty (PU) and Local Uncertainty (LU), informing the user of how well the survey mark connects into datum and fits within the State Adjustment. As of April 2021, the State Adjustment consists of approximately 42,000 survey marks. Spatial Services is actively updating the State Adjustment as new measurements become available to increase the number of adjusted survey marks with published uncertainty in SCIMS.

Survey marks that are **not** currently in the State Adjustment generally have been transformed from GDA94 to GDA2020 using the 'conformal plus distortion' NTv2 transformation grid or have been updated via a non-rigorous approach – see Gowans (2018) for further information. These survey marks appear in SCIMS with a NULL PU/LU value and can be identified using a survey mark's SID, adjustment type and method provided in SCIMS (e.g. a transformed mark has 'transformation' under adjustment method). Caution should be exercised when mixing *adjusted* and *transformed* GDA2020 survey control marks (particularly when coordinates have been double-transformed, i.e. from AGD66 <> GDA94 and then again from GDA94 <> GDA2020).

GDA2020 is a three-dimensional datum offering horizontal coordinates and ellipsoidal heights. Ellipsoidal heights are an important component of state infrastructure and are particularly valuable for large-scale projects that require robust height control over long distances including geodesy, LiDAR surveys, flood/storm modelling and hydrography. It is anticipated that physical heights (which relate to the quasi/geoid and can correctly predict the flow of fluids) derived from ellipsoidal heights (e.g. observed using GNSS) will be increasingly employed following the recent release of the Australian Vertical Working Surface (AVWS) and associated geoid model(s). Spatial Services supports these applications by providing ellipsoidal heights and their quality through the State Control Survey Network.

All control surveys conducted in GDA2020 must be capable of delivering three-dimensional coordinates (easting, northing, MGA zone and ellipsoidal height) for ingestion into the State Adjustment and update of SCIMS.

GDA2020 ellipsoidal heights are not the same as AHD71 heights and in many cases have been coordinated through different surveys. As such, the Class and uncertainty of an AHD71 height on a survey mark is not coincident with the Class and uncertainty of its corresponding ellipsoidal height.

AHD71 remains the legal height datum in NSW, and only AHD71 heights can be considered 'accurate' under the Regulation and used for such applications.

4.2 Geocentric Datum of Australia 1994 (GDA94)

GDA94 is a geocentric 'plate-fixed' coordinate reference system based on the International Terrestrial Reference Frame 1992 (ITRF92) at epoch 1 January 1994.

Since the adoption of GDA2020 in NSW, GDA94 is now considered a historical datum and, for a few exceptions, is no longer being updated for survey marks in SCIMS. GDA94 coordinates differ from GDA2020 coordinates by approximately 1.5 m across NSW, primarily due to tectonic motion of the Australian plate in the years since GDA94 was realised and the removal of local distortions in GDA94.

Spatial Services never actively assigned uncertainty to survey marks in GDA94, and instead used Class and Order to describe a survey mark's fit within the State Control Survey Network as this was the technical specification regulated at the time.

For more information, refer to the GDA94 Technical Manual.

4.3 Australian Height Datum (AHD71)

The Australian Height Datum (AHD71) is the current national datum for physical heights, i.e. those which describe the flow of fluids, and is legislated as NSW's prescribed vertical datum. It was computed by adjusting 97,230 km of 2-way levelling to mean sea level observed (1966-1968) at 30 tide gauges around mainland Australia (Roelse et al., 1971). AHD71 is comprised of first, second and third Order levelling that ran between junction points in the Australian National Levelling Network (ANLN), and as such certain areas may be subject to limitations in accuracy and homogeneity. Furthermore, AHD71 is 50 years old and survey marks may have been subject to ground deformation, movement and/or disturbance.

As of April 2021, approximately 62,000 survey marks have AHD71 positional and local uncertainties computed through the AHD71 component of the State Adjustment. A further ~8,000 have AHD71 heights and positional uncertainties derived from GNSS and AUSGeoid2020 using absolute geoid techniques.

For more information, refer to Roelse et al. (1971).

4.4 AUSGeoid09 vs. AUSGeoid2020

In NSW, the AUSGeoid model provides correction values (N) between GDA ellipsoidal heights and AHD71. The choice of AUSGeoid model is dependent on the datum selected:

- **AUSGeoid09** must be used with **GDA94**.
- **AUSGeoid2020** must be used with **GDA2020**.

Between GDA94 and GDA2020, ellipsoidal heights have decreased by approximately 0.09 m across NSW because of improvements in the underlying global reference frame from ITRF92 to ITRF2014. It is therefore **extremely important that the correct AUSGeoid model is used** with the corresponding datum as indicated above to avoid the introduction of a gross error into a control survey.

For further information regarding AUSGeoid products and how they interact with SCIMS, see Janssen & Watson (2018).

5. Statements of Accuracy and Precision

SCIMS expresses the accuracy and precision of a survey mark in terms of Class, Positional Uncertainty (PU) and Local Uncertainty (LU) as defined in SP1 v1.7.

Each survey mark in SCIMS has a Class value corresponding to its GDA2020 horizontal coordinates, GDA2020 ellipsoidal height and AHD71 height. Positional Uncertainty is only published where it has been rigorously computed with a well-defined connection to datum, e.g. by least squares adjustment. Local Uncertainty is only published for coordinates/heights computed through the State Adjustment. PU and LU are not published where they have not been rigorously computed, e.g. for transformed survey mark coordinates.

Uncertainty values published in SCIMS Online are rounded according to a set of rules as defined in SGD4. For additional information regarding uncertainty and its relationship to SCIMS, see Janssen et al. (2019).

5.1 Class

The term Class is used to assess the quality of a control survey and is calculated independently of the fit with the local datum. It is a function of the planned and achieved precision of a survey network and is dependent upon the following components:

- the network design (see **Section 8**),
- the survey practices adopted (see **Section 7**),
- the equipment and instruments used (see **Section 7**), and
- the reduction techniques employed (see **Sections 7** and **9**),

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

In addition, there are several other practical factors that must be considered when assigning Class:

- the intent of the survey,
- the station density adjoining the survey,
- the marking/monumentation standard (see **Section 6**), and whether
- the survey is connected to sufficient survey control at the equivalent Class or better.

A control survey should be designed so that all survey marks will achieve the proposed Class, however, Class must be individually assessed between every survey mark. Further detail is provided in **Section 5.1.1** for all approved survey techniques except differential levelling (see **Section 5.1.2**).

Under the Regulation:

- GDA2020 horizontal coordinates of **Class D** or better are "**established**".
- AHD71 heights of **Class B** / **Class LD** or better are "**accurate**".
- GDA2020 ellipsoidal heights are **neither** "accurate" **nor** "established".

GDA2020 coordinates are three-dimensional, so in many cases the same survey will be used to assess Class for horizontal coordinates and ellipsoidal height. Conversely, AHD71 heights are generally determined through a separate survey (or adjustment) and so will differ in Class to GDA2020 ellipsoidal heights. Class cannot be transferred between physical and ellipsoidal heights without considering the uncertainty in the quasi/geoid model employed.

Examples of typical applications for each Class are provided in **Sections 5.1.3**, **5.1.4** and **5.1.5** for GDA2020 horizontal coordinates, GDA2020 ellipsoidal heights and AHD71 heights respectively.

Dickson (2012) provides further useful information regarding Class and its application to control surveys.

5.1.1 Assigning Class

Provided the criteria outlined above in **Section 5.1** are met, Class is assigned to a control survey from the statistical analysis of a successful minimally constrained least squares adjustment.

The output relative uncertainties depend largely on the input standard deviations of the observations. As such, these should be based on the expected precision of the survey technique and instrument, rather than attempting to balance the global variance factor for the sake of a statistically clean least squares adjustment.

Class is allocated separately for the horizontal and vertical components of a survey and is achieved by assessing whether each relative standard error is less than or equal to the maximum allowable relative standard error, using the following formula:

$$\mathbf{r = c\ (\ d + 0.2\ )} \qquad \mathbf{(1)}$$

where

r = the maximum allowable standard error.

c = an empirically derived factor represented by historically accepted precision for a particular standard of survey (applicable values are listed in **Table 1**).

d = distance to any station in km.

The interpretation of the value **r** depends on whether Class is being determined for coordinates (two dimensions) or height (one dimension).

- **Coordinates**: **r** is the maximum allowable length of the semi-major axis of each relative standard error ellipse (in mm).
- **Height**: **r** is the maximum allowable value for each relative standard deviation (in mm).

To assess Class, Spatial Services applies **Equation (1)** between all marks in a survey adjustment (except for differential levelling) – **Appendix A** provides an example of this process.

Table 1: Values of **c** assigned to Class for horizontal and vertical control surveys.

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

The **c** values in **Table 1** only apply to statistics presented at one sigma (68% confidence level (CL)). If the least squares adjustment package outputs the relative errors at the 95% confidence level, they must be converted back to one sigma using the appropriate expansion factor before Class can be determined. These factors are:

- 2.4477 for coordinates (two dimensions)
- 1.9600 for height (one dimension)

The conversion is accomplished as follows:

- **95% CL** ⟶ **one sigma** divide by the expansion factor
- **one sigma** ⟶ **95% CL** multiply by the expansion factor

Investigating **Equation (1)**, **r** will be small when **d** is small for a given value of **c**. Thus, for a given Class, as **d** gets smaller, finer precision is required in the measurement technique. **Table 2** demonstrates the balance between station density and measurement precision, and the impact of this relationship when determining Class.

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)	0.005mm (0.007m)	0.010mm (0.014m)	0.015mm (0.021m)	0.020mm (0.028m)	0.025mm (0.035m)	0.030mm (0.042m)	0.035mm (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

Using the highlighted cell in **Table 2** as an example, a survey mark has a point error ellipse (at one sigma) of 0.015 m which has been determined using GNSS Static. For the purpose of this example, all survey marks in the survey have the same point error ellipse size (this is not always the case, see **Appendix A**) and as such the relative error ellipse (REE) between two survey marks is determined to be $\sqrt{(0.015^2 + 0.015^2)}$ = 0.021 m.

Based on the size of the REE (0.021 m) and given a station density (**d**) of 600 m, the survey is assessed for Class by applying **Equation (1)** and using the empirical values for **c** stated in **Table 1**.

- 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.

Since the size of the surveyed REE (0.021 m) is less than 0.024 m, the survey has met Class C for this station density. To achieve a higher Class, the survey would need to either use a lower survey mark density (i.e. increase **d**) or use a survey technique (or instrument) with a higher measurement precision.

5.1.2 Assigning Class for Differential Levelling

Provided the criteria outlined above in **Section 5.1** are met, the allocation of Class for differential levelling surveys is based on the results of a successful minimally constrained adjustment and is achieved by assessing whether:

- the misclose between the forward and return section of a levelling run between consecutive survey marks, and
- the misclose between the terminals of a level run,

is less than or equal to the maximum allowable relative standard error, using the following formula:

$$\mathbf{r = c \sqrt{d}} \quad \textbf{(2)}$$

where

r = maximum allowable error (in mm).

c = an empirically derived factor for each Class of survey result listed in **Table 3.**

d = distance to any station (in km).

Table 3 lists the **c** values (for one sigma) applicable to the assessment of Class for differential levelling surveys.

Table 3: Values of **c** assigned to Class for differential levelling surveys.

Class	c (for one sigma)
L2A	2
LA	4
LB	8
LC	12
LD	18
LE	36

The adjustment output must be at the same confidence level (one sigma) as **c**, as in **Section 5.1.1**.

As part of the assessment of Class, the local AHD71 datum must be verified according to the specifications outlined in **Section 7**. **Appendix B** provides an example of this process.

5.1.3 SCIMS, Class and GDA2020 Horizontal Coordinates

Spatial Services considers the following business rules in the assessment of Class for GDA2020 horizontal coordinates. These coordinates are published in SCIMS Online to an appropriate precision (i.e. number of decimals), as noted.

Class U is assigned for coordinates with unknown or approximate accuracy that are not supported by a survey adjustment that is held by Spatial Services. These are generally survey marks that have been initialised into SCIMS from survey plans on public record, Locality Sketch Plans (LSPs), scaled from a map or captured with hand-held GNSS, and are allocated Class U to indicate the estimated and/or unverified position. (Rounded to the nearest metre.)

Class E is assigned where a “survey” was undertaken, and the results are sub-metre in accuracy. These surveys may have been performed by differential GNSS and/or Precise Point Positioning (PPP), either in real-time or post-processing mode, e.g. an AUSPOS solution with a poor PU. It is assigned to any coordinate value that is not supported by a survey adjustment held by Spatial Services. (Rounded to nearest 0.1 metre.)

Class D is assigned where the survey methodology has delivered coordinates accurate to a few centimetres or better but may involve unchecked radiations. For example, reduced observations derived from a survey plan on public record, a single 2hr+ AUSPOS occupation with checks or validation, double-occupied RTK surveys with verification to local datum, or a similar survey with limited redundancy. **Any survey mark recorded in SCIMS with a horizontal position equal to or better than Class D is an “established mark” under the Regulation**. (Rounded to nearest 0.001 metre.)

Class C is assigned where a survey has incorporated enough redundancy and checks to guarantee the accuracy of the coordinates to within a few centimetres or better. Therefore, requirements for Class C include 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 survey control. (Rounded to nearest 0.001 metre.)

Class B is assigned to rigorous survey control and geodetic surveys where high accuracy is required, e.g. engineering, construction and local infrastructure applications. (Rounded to nearest 0.001 metre.)

Class A, 2A and 3A is assigned to rigorous survey control and geodetic surveys where very high accuracy is required for the extension of the State Control Survey Network and propagation of datum. Generally, only Spatial Services carries out surveys of these Classes (A, 2A and 3A) for datum modernisation and refinement activities. Users wishing to carry out surveys of Class A or 2A for update of SCIMS must consult and receive agreement on a strategy with Spatial Services beforehand. Class 3A has generally been reserved and restricted for geodetic infrastructure such as the CORS network that realises GDA2020 within NSW. (Rounded to nearest 0.001 metre.)

5.1.4 SCIMS, Class and GDA2020 Ellipsoidal Heights

Spatial Services considers the following business rules in the assessment of Class for GDA2020 ellipsoidal heights. These ellipsoidal heights are published in SCIMS Online to an appropriate precision (i.e. number of decimals), as noted:

Class U is assigned for ellipsoidal heights with unknown or approximate accuracy, derived from hand-held GNSS or other low-accuracy positioning technologies. It is assigned to any ellipsoidal height that is not supported by a survey adjustment held by Spatial Services. (Rounded to the nearest metre.)

Class E is assigned where the heights are intended for sub-metre applications, derived from low-accuracy positioning technologies, e.g. an AUSPOS solution with a poor PU. It is assigned to any ellipsoidal height that is not supported by a survey adjustment held by Spatial Services. (Rounded to nearest 0.1 metre.)

Class D is assigned where the survey methodology has delivered ellipsoidal heights with uncertainties of several centimetres but may involve unchecked radiations, single occupations with GNSS or a similar survey with limited redundancy. Heights are suitable for imagery rectification and survey control, as well as other lower-Class surveys. (Rounded to nearest 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 survey height control. Heights are suitable for applications such as high-resolution imagery rectification but should be used with caution. (Rounded to nearest 0.001 metre.)

Class B is assigned to rigorous survey height control where the survey has achieved sufficient redundancy and checks to guarantee the accuracy of the height. Therefore, closed figures, multiple occupations and well-configured connections to existing survey height control are required. GDA2020 ellipsoidal heights are **not** considered "accurate" **nor** "established" under the Regulation. (Rounded to nearest 0.001 metre.)

Class A, 2A and 3A is assigned to rigorous survey control and geodetic surveys where very high accuracy is required. Generally, only Spatial Services carries out surveys of this Class (A, 2A and 3A) for datum modernisation and refinement activities. Users wishing to carry out surveys of Class A and 2A for update of SCIMS must consult and receive agreement on a strategy with Spatial Services beforehand. Class 3A has generally been reserved and restricted for geodetic infrastructure such as the CORS network that realises GDA2020 within NSW. (Rounded to nearest 0.001 metre.)

Levelled Classes such as LA, LB, LC, LD or LE are **not** assigned to GDA2020 ellipsoidal heights.

5.1.5 SCIMS, Class and AHD71 Heights

Spatial Services considers the following business rules in the assessment of Class for AHD71 heights. These physical heights are published in SCIMS Online to an appropriate precision (i.e. number of decimals), as noted.

Class U is assigned for heights with unknown or approximate accuracy, derived from Deposited Plans, LSPs, LiDAR, contours or surface elevation maps. It is assigned to any height that is not supported by a survey adjustment held by Spatial Services. (Rounded to the nearest metre.)

Class E is assigned where the results are intended for mapping/imagery control and similar sub-metre applications. It is assigned to any height that is not supported by a survey adjustment held by Spatial Services. (Rounded to nearest 0.1 metre.)

Class D is assigned where the survey methodology has delivered heights with uncertainties of several centimetres but may involve unchecked radiations, only single occupations with GNSS or a similar survey with limited redundancy. Spatial Services updates survey marks as AHD71 Class D if they have been derived using an AUSGeoid model via techniques such as AUSPOS or double-occupied RTK (considering station density). Heights are suitable for imagery rectification and other lower-Class surveys. (Rounded to nearest 0.01 metre.)

Class C is assigned where the heights are derived from surveys with sufficient redundancy and multiple occupations but may be some distance from reliable survey height control. Heights derived from total station traversing must be appropriately reduced and ensure correct field methodologies have been followed to limit the effects of refraction. Heights are generally suitable for applications such as high-resolution imagery rectification but should be used with caution as they are not considered rigorous. (Rounded to nearest 0.001 metre.)

Class B is assigned to rigorous survey height control where the survey has achieved sufficient redundancy and checks to guarantee the accuracy of the height. Therefore, closed figures, multiple occupations and well-configured connections to existing accurate survey height control are required. Heights derived from total station traversing must be appropriately reduced, ensure correct field methodologies have been followed to limit the impact of refraction and other atmospheric effects, as well as consider station density. As a guide, the accuracy of the height is considered similar to that of traditional Class LD levelling. **Any survey mark recorded in SCIMS with an AHD71 height equal to or better than Class B / LD has an "accurate AHD71 value" under the Regulation**. (Rounded to nearest 0.001 metre.)

Class A, 2A and 3A is assigned to rigorous survey control and geodetic surveys where very high accuracy is required, e.g. engineering, construction, state-wide or national infrastructure applications. Generally, only Spatial Services carries out surveys of this Class for datum modernisation and refinement activities. Users wishing to carry out surveys of Class A and 2A for update of SCIMS must consult and receive agreement on a strategy with Spatial Services beforehand. Class 3A has generally been reserved and restricted for geodetic infrastructure such as the CORS network that realises GDA2020 within NSW. (Rounded to nearest 0.001 metre.)

Levelled classes such as **LA**, **LB**, **LC** or **LD** are assigned to height values depending on how the survey conforms to the accuracy standards listed in **Section 5.1.2** and meets the differential levelling specifications outlined in **Section 7**. Class **LE** is generally reserved for lower accuracy levelling surveys or for approximate levelled AHD71 heights that are not supported by a survey adjustment held by Spatial Services. Note that SCIMS assigns the L prefix to differential levelling only. **Any survey mark recorded in SCIMS with an AHD71 height equal to or better than Class B / LD has an "accurate AHD71 value" under the Regulation**. Users wishing to carry out surveys of Class LA for update of SCIMS, must consult and agree on a strategy with Spatial Services beforehand. (Rounded to nearest 0.001 metre.)

5.2 Positional Uncertainty

Positional Uncertainty (PU) describes the radius of a 95% (two sigma) circle of uncertainty of the coordinates or height of a survey mark, with respect to the defined reference frame (datum). PU is reported in metres.

In the context of the State Control Survey Network and SCIMS, PU is defined as the uncertainty of a survey mark with respect to GDA2020 or AHD71. For GDA2020, PU is reported as the total uncertainty propagated from the Australian Fiducial Network (AFN) based on the results of a fully constrained least squares adjustment (see **Figure 1**). For AHD71, PU is reported as the total uncertainty propagated from the Australian National Levelling Network (ANLN) Junction Points. PU is generally smaller for survey marks with a direct connection to the defined reference frame.

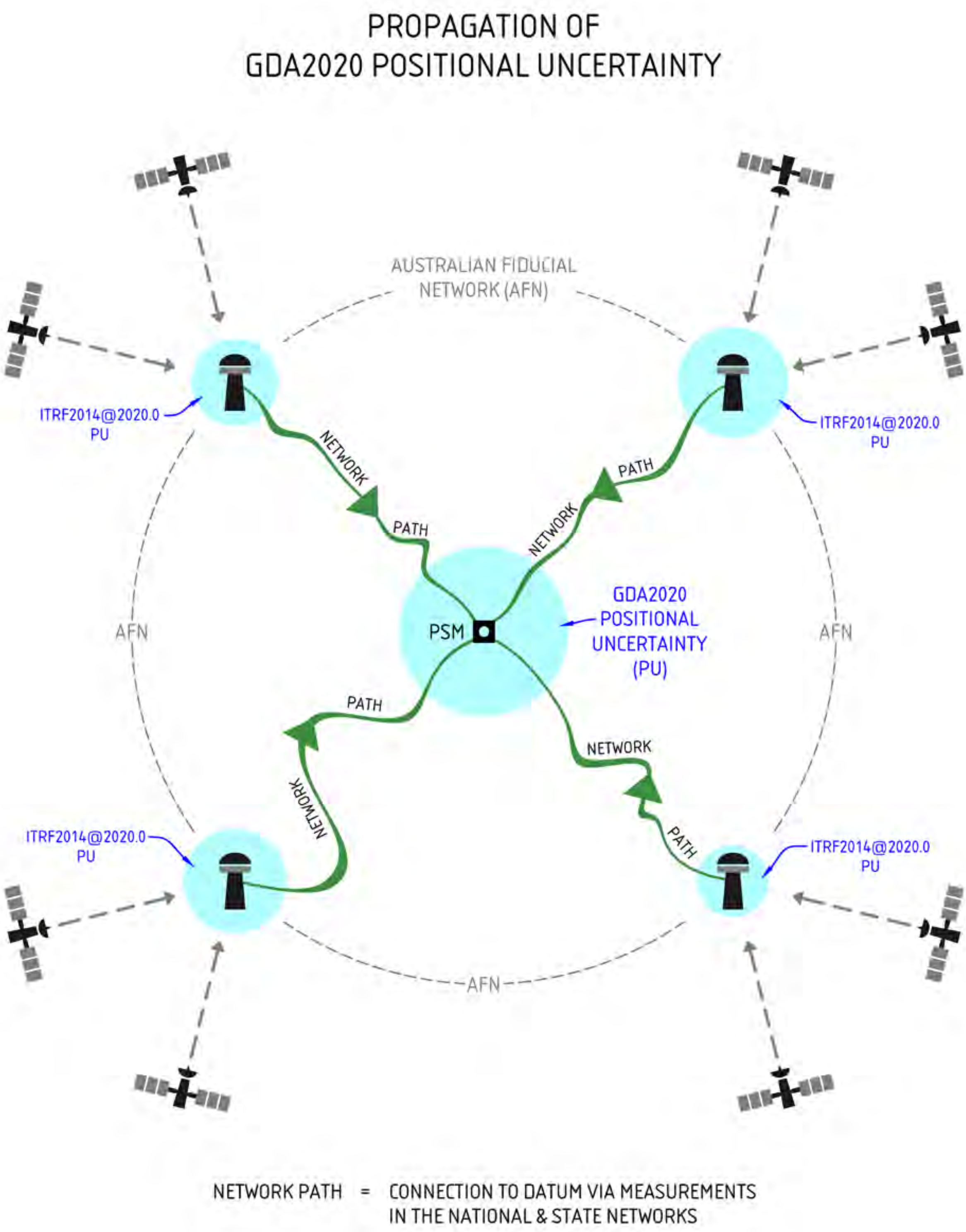

Figure 1: GDA2020 Positional Uncertainty reported as the total uncertainty propagated from the Australian Fiducial Network (AFN). The network path indicates a survey mark's connection to the AFN which may be direct (e.g. using AUSPOS) or indirect (i.e. connecting into survey marks in the State Control Survey Network that have existing PU).

PU and Class are not always complementary. Class is a measure of the quality of the control survey itself, whereas PU is a measure of the quality of the connection of a survey mark to the defined datum.

To illustrate this, a 6hr+ AUSPOS solution will generally achieve a small PU due to its direct connection to the AFN and therefore the GDA2020 datum. However, a control survey consisting entirely of AUSPOS solutions will only be allocated a maximum Class D, reflecting the lack of redundancy in the network design. Conversely, a well-designed traverse with good redundancy may be allocated a Class B but will have a larger PU due to its extended connection to the AFN (represented by the network path in **Figure 1**).

Positional Uncertainty is determined through the State Adjustment, which is run periodically as new survey information becomes available. SCIMS reports Horizontal Positional Uncertainty (HPU) and Vertical Positional Uncertainty (VPU) for GDA2020 coordinates, and AHD Positional Uncertainty for levelled survey marks (AHD-PU).

For a control survey to propagate PU, it must be connected to survey marks that have existing PU in SCIMS. **Section 8** details the control strategy and network design requirements to facilitate this.

Spatial Services is exclusively responsible for the calculation of PU. However, if users have the capability, they are encouraged to determine their own provisional PU in order to determine if their control survey is fit-for-purpose, see **Sections 5.2.1** and **5.2.2**.

5.2.1 Calculating Horizontal Positional Uncertainty

For horizontal coordinates, the radius of a 95% (two sigma) circle of uncertainty can be calculated from the results of a constrained least squares adjustment. Using the point error ellipse of a survey mark (at one sigma), the radius of the 95% circle of uncertainty (PU) is calculated as follows (ICSM, 2007):

$$\mathbf{C = b / a}$$

$$\mathbf{K = q_0 + q_1\,C + q_2C^2 + q_3C^3} \qquad \mathbf{(3)}$$

$$\mathbf{Radius\ (PU) = aK}$$

where

a = semi-major axis of the standard point error ellipse

b = semi-minor axis of the standard point error ellipse

$\mathbf{q_0}$ = 1.960790

$\mathbf{q_1}$ = 0.004071

$\mathbf{q_2}$ = 0.114276

$\mathbf{q_3}$ = 0.371625

Note: In order to calculate PU, the least squares output **must** be at one sigma.

5.2.2 Calculating Vertical Positional Uncertainty

The Positional Uncertainty of heights is a linear quantity that is calculated by scaling the standard deviation (one sigma) by the one-dimensional expansion factor to convert it to the 95% confidence level (see **Section 5.1**). The standard deviation of the height must be with respect to the datum used (GDA2020 or AHD71).

Spatial Services employs the same method for calculating VPU for GDA2020 Ellipsoidal Heights and AHD-PU for AHD71 heights.

5.3 Local Uncertainty

Local Uncertainty (LU) is the average measure of the relative uncertainty of the coordinates (or height) of a survey mark, with respect to the survey connections to the nearest adjacent survey marks in the defined reference frame (datum). LU is reported in metres at the 95% confidence level.

In the context of SCIMS, LU provides a single summary of how well a survey mark fits compared to adjacent survey marks with existing uncertainty in the State Control Survey Network. LU supersedes Order with the adoption of GDA2020 in NSW.

Spatial Services uses two separate approaches to calculate LU, depending on the datum.

To calculate GDA2020 LU, the Relative Uncertainty (RU) is calculated between the subject survey mark and the 15 nearest survey marks within the State Adjustment. These survey marks may be connected either directly or indirectly to the subject survey mark. LU for the subject mark is the *median* RU of this set. This strategy is employed for both the calculation of Horizontal Local Uncertainty (HLU) and Vertical Local Uncertainty (VLU). **Figure 2** provides an illustrative example of how HLU is calculated.

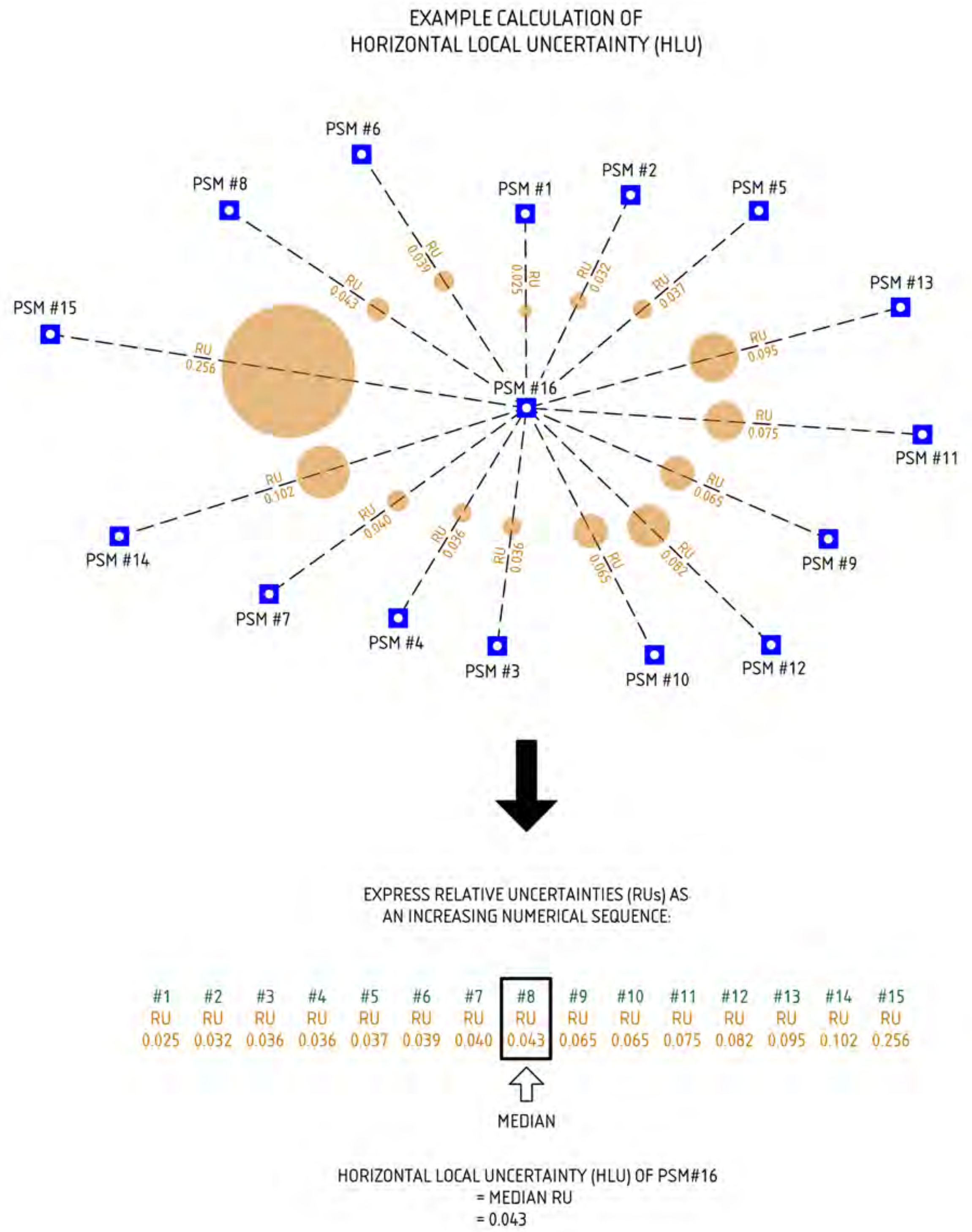

Figure 2: Example calculation of GDA2020 Horizontal Local Uncertainty.

To calculate AHD Local Uncertainty (AHD-LU), the RU is calculated between the subject survey mark and the 5 nearest survey marks within the AHD71 component of the State Adjustment. As above, LU for the subject mark is the *median* RU of this set.

Spatial Services uses the *median* to calculate LU as it is considered a more robust indicator of central tendency in the State Adjustment (see Janssen et al., 2019).

As for PU, LU as reported in SCIMS is determined through the State Adjustment, which is run periodically as new survey information becomes available. SCIMS reports Horizontal Local Uncertainty (HLU) and Vertical Local Uncertainty (VLU) for GDA2020, and AHD-LU for AHD71. Survey marks that are not in the State Adjustment have a NULL LU value assigned in SCIMS. Therefore, it is important to understand that **LU only relates to adjacent survey marks with a published LU value**.

Spatial Services is exclusively responsible for calculating LU for the State Control Survey Network and SCIMS.

5.4 Order

Order is an estimation of the derived coordinate quality and is a function of the overall fit with surrounding survey control. It is a function of:

- the Class of a survey,
- the conformity of the new survey data with an existing network coordinate set, and
- the precision of any transformation process required to convert results from one datum to another.

Order is no longer used or shown in SCIMS for GDA2020 or AHD71, having been superseded by Local Uncertainty. Legacy values are still provided for GDA94 coordinates but are no longer supported by Spatial Services.

For further information regarding Order, see SP1 v1.7 and Dickson (2012).

6. Survey Monumentation and Mark Placement

Survey marks realise the physical component of a control survey and the approved reference frame which it connects to, such as GDA2020 and AHD71. The form and style of survey marks in SCIMS are prescribed by Clause 27 and Schedules 1–4 of the Regulation. When designing a control survey, it is important to consider the stability, longevity and suitability of a survey mark for the environment in which it is being placed. Mark monumentation, placement and setting are not strictly captured in the Class of a survey but are important components in ensuring that only suitable survey marks are placed and used. This section outlines some general rules and principles Spatial Services uses in determining the correct form and style of a survey mark with respect to the intended outcome and purpose of the control survey.

Survey marks must be placed, installed and recorded according to the Regulation and relevant Surveyor-General's Directions to be accepted into SCIMS.

- *Surveyor-General's Direction No. 1 – Approved Permanent Survey Marks* (SGD1) provides information on how to construct and install the various approved survey marks that are to be included in the State Control Survey Network. Special attention to how a survey mark is installed, what materials are used and the location in which it is placed must be given to ensure its long-term durability.
- *Surveyor-General's Direction No. 2 – Preparation of Locality Sketch Plans* (SGD2) outlines the requirements for information to be shown on Locality Sketch Plans (LSPs) for all placed survey marks required under Clause 43 of the Regulation. Special attention to the mark type and mark number must be given to ensure the correct survey mark is identified and located for future users.
- *Surveyor-General's Direction No. 4 – Interpreting the Survey Control Information Management System (SCIMS)* (SGD4) provides users with information on how to identify the various types of survey marks within SCIMS including their terminology, symbology and associated metadata.

Survey marks are to be placed with special consideration for Work Health and Safety (WHS) issues regarding access, pedestrians, cyclists and vehicle movement. Generally, all survey marks should be publicly accessible and avoid being placed in restricted environments such as railway corridors, high-speed roadways and private property. Where possible, locations selected should be GNSS friendly, exhibiting a clear sky view with minimal obstruction and/or multipath obstructions. Consideration must also be given to intervisibility to adjacent survey marks to assist in the propagation and design of the State Control Survey Network. Survey marks must be placed in a position that is unlikely to be disturbed by future activities such as construction, maintenance or general land use.

Survey mark placement and monumentation must support the long-term stability of the coordinates and/or height assigned to it and therefore its corresponding uncertainty. It is important to factor in the structure and environment, such as geology and location (e.g. black soil, acid sulphates), and how this may affect the long-term durability of the survey mark and its ability to confidently deliver coordinates over time. The stability of the survey mark is derived from the structure to which it is attached or the setting in which it is installed, and is therefore as equally important as the mark type itself. As such, control surveys delivering high-quality coordinates need to be supported by appropriate survey mark monumentation and mark type.

Spatial Services considers survey mark type, monumentation and placement when assessing Class and reserves the right to downgrade a survey if the monumentation does not meet the long-term intent of the control survey and SCIMS. In certain circumstances other public authorities may stipulate, in agreement with Spatial Services, specific mark types when carrying out control survey work. For surveys of critical importance, users should contact Spatial Services to determine what survey mark type and monumentation is appropriate.

7. Best Practice Surveying Techniques and Standards

Spatial Services accepts the following observation types for update of SCIMS:

- **Terrestrial Observations**
- **GNSS Observations**

As detailed in **Section 1**, Spatial Services has developed the *Technical Specifications for NSW Secondary Control Surveys* to assist surveyors in achieving a certain Class for a 'secondary control survey' for update of SCIMS. This document is based on SP1 v1.7 and has been updated in key sections to reflect the advancements in survey technology to ensure that current best practice surveying standards are adopted throughout NSW. Any survey defined as a 'secondary control survey' in the context of this Direction must adopt and demonstrate compliance with this document. Surveyors may only use the document within its applicable scope as shown in **Table 4** in conjunction with SGD12.

Table 4: Approved survey techniques and applicable Class for secondary control surveys.

Survey Technique	Achievable Horizontal Class	Achievable Vertical Class	Applicable Conditions
Traversing	B, C, D	D	Measurement lines must be less than 1 km in length
Trigonometric Heighting	N/A	B, C	
Differential Levelling	N/A	LB, LC, LD	
GNSS Static	A, B, C, D	A, B, C, D	
GNSS RTK	D	D	
AUSPOS	D	D	

Surveys or survey techniques that are not included in **Table 4**, **must** instead adopt SP1 v1.7 and consult Spatial Services for update of SCIMS.

All surveys conducted in GDA2020 must be capable of delivering three-dimensional coordinates (easting, northing, MGA zone and ellipsoidal height) to be included in the State Adjustment for update of SCIMS. **Unless specified, Spatial Services does not require the height component of a three-dimensional GDA2020 survey to be observed to the same Class as the horizontal component**, e.g. users are not required to survey to Class B vertically when carrying out a horizontal Class B traverse.

A digital copy of survey observations and supporting documents must be included in the submission as detailed in **Section 11**.

7.1 Terrestrial Observations

Spatial Services supports the following terrestrial surveying techniques:

- Total station traversing
- Trigonometrical heighting
- Differential levelling

Spatial Services distinguishes between heights derived from total station traversing and those derived from trigonometric heighting because the latter technique is specifically intended for the derivation of accurate heights. Additional specifications apply in order to derive accurate heights using a total station, as detailed in the *Technical Specifications for NSW Secondary Control Surveys*.

Independent of Class, all total station traverse surveys must be capable of delivering three-dimensional GDA2020 coordinates for update of SCIMS. This requires traverse measurements to record distance, horizontal and vertical angles as well as instrument and target heights to the nearest millimetre at each set-up.

All total station instruments and ancillary equipment must be calibrated and checked in accordance with the Regulation and as detailed in *Surveyor-General's Direction No. 5 – Calibration of Electronic Distance (EDM) Equipment* (SGD5). Details of verification and calibration along with other metadata such as instrument serial numbers and checking details (e.g. tribrachs, verticality of bipods and staves, collimation checks, thermometers and barometers) must be submitted as detailed in **Section 11**.

7.2 GNSS Observations

Spatial Services supports the use of the following GNSS surveying techniques:

- **Post-Processed Static GNSS (GNSS Static)** – where static GNSS observations are made in the field and baseline vectors between stations are computed using processing software.
- **Real Time Kinematic GNSS (RTK)** – which is further categorised into **single-base RTK**, where the roving receiver computes its position from a single reference (base) station using data transmitted via a communication link in real time, and **Network RTK (NRTK)**, where the roving receiver computes its position based on connections to multiple reference stations surrounding the user in real time.
- **AUSPOS** – where static GPS observations are processed through Geoscience Australia's free online GPS processing service to derive accurate 3D positions using CORSnet-NSW stations together with International GNSS Service (IGS) stations and products, independent of the local datum.

There are limitations to the achievable Class using GNSS techniques, particularly when the distance between adjacent survey marks is reduced (see **Table 2**). As an example, when observing survey control for a cadastral survey, GNSS techniques may be challenged due to factors such as measurement precision and station density. Therefore, it may be appropriate to add in terrestrial observations (with sufficient redundancy such as direct connection or closed loops) to strengthen the network and achieve the desired Class of survey.

All GNSS equipment must be verified annually or after instrument servicing which may include a firmware upgrade (whichever comes first), see *Surveyor-General's Direction No. 9 – GNSS for Cadastral Surveys* (SGD9). Specific to RTK surveys, a site validation and transformation (if applicable) must be performed to validate the Class of survey and account for any potential local datum distortions. Details of verification and validation, along with other metadata such as instrument serial numbers and checking details, must be provided to Spatial Services as detailed in **Section 11**.

Spatial Services uses coordinates from AUSPOS solutions for quality assurance and improvement of the existing State Control Survey Network and ingests the raw data into the State Adjustment to fix local datum distortions. Spatial Services therefore encourages the submission of raw data (RINEX files) for long (2hr+) GNSS occupations without a site transformation applied for any existing and newly placed survey mark in SCIMS.

Spatial Services requires the following items to be submitted (if applicable) for a GNSS survey to update SCIMS:

- Raw GNSS observations in both native and 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.

7.2.1 Site Validation and Transformations

When carrying out RTK surveys (both single-base and NRTK), a site validation **must** be performed to confirm the outcome of the survey and Class, as well as a site transformation (if applicable) to correct for potential local distortions in the GDA2020 and/or AHD71 datum.

A site validation is a basic three-dimensional (easting, northing, MGA zone, height) check against SCIMS using a minimum of 3 well-configured survey control marks. A site validation provides users with valuable equipment, systems and field checks to give confidence in the outcome of the RTK survey and validate the proposed Class. As a guide, the site validation is considered acceptable if it falls within the expected precision of RTK.

A site transformation is applied to RTK surveys for proof of position, to correct for distance-dependent biases, and to account for potential local GDA2020 and/or AHD71 datum distortions. In NSW, GDA2020 site transformation parameters are expected to be relatively small and often within the measuring precision of RTK. AHD71 still contains distortions which can vary across the State and are not influenced by the adoption of GDA2020. Site transformation parameters should only be applied if they are deemed statistically significant. Depending on the size and scope of the survey, Spatial Services generally recommends that users apply a simple block shift if performing a site transformation, see Haasdyk & Janssen (2012) for more information.

To enable a site validation and transformation, Spatial Services requires that all RTK surveys **must** connect to a:

- **Minimum 3 x GDA2020 Class D or better survey marks with best available PU, and**
- **Minimum 3 x AHD71 Class B / LD or better survey marks with best available PU.**

The number of survey control marks must be increased for larger surveys to ensure that the site validation/transformation parameters are fit-for-purpose and appropriate for the size and scope of the survey. Principles of good network design apply as detailed in **Section 8**.

For RTK surveys spanning significant areas (e.g. local government areas or large State infrastructure projects), or where site validation/transformation parameters are found to be significant, please contact Spatial Services for further advice.

Dickson (2012) provides further useful information on RTK surveys and their relationship to Class.

8. Network Design and Control Strategy

For control surveys to be included in the State Control Survey Network for update of SCIMS, the following conditions must be satisfied:

1. The **Network Design** is fit-for-purpose and commensurate with the proposed Class of survey as detailed in **Section 8.1**, and
2. Datum (GDA2020 and/or AHD71) is established by adopting the **Control Strategy** outlined in **Section 8.2** to propagate accurate coordinates/heights and uncertainty.

It is strongly recommended that Spatial Services is consulted before carrying out a control survey to ensure that the proposed network is of an appropriate design and standard. Spatial Services reserves the right to downgrade surveys in Class based on poor network design or reject submissions altogether if they do not meet a satisfactory standard.

A network diagram must be included as part of any data submission, clearly demonstrating the control strategy and network design adopted in compliance with this Direction.

8.1 Network Design

When assessing Class, Spatial Services considers how appropriate the network design of a control survey is, factoring in:

- the intent of the survey,
- the proposed Class,
- the adopted survey technique, and
- the current framework of the State Control Survey Network in a particular area.

To assist in the design of a control survey network, Spatial Services considers the following principles when assessing the Class of a survey (note this list is not exhaustive):

- *The network geometry is fit-for-purpose and commensurate with the proposed Class*. Strong network geometry includes sufficient redundancy, closed figures and avoiding radiations. Multiple observations to the same set-up over a survey mark are considered radiations, and redundancy is only achieved by a new set-up. Good network design avoids duplication of infrastructure and does not extrapolate any coordinates or heights, i.e. the survey is contained within the surrounding survey control.
- *The control survey has been designed and optimised for its intent and is not over-observed*. Strong control survey networks are characterised by connections between adjacent survey marks and good geometry of survey observations. Measurements which span the extent of the survey may be redundant and contribute little to the determination of coordinates, but instead may exaggerate the statistics in a least squares adjustment and propagate distortions throughout the survey network.
- *The adopted survey technique is appropriate for the proposed Class and station density of the control survey network*. It is important that a survey technique that is appropriate for the station density is used noting an instrument's achievable measurement precision (see **Section 5.1.1**). This is particularly evident in the local survey environment where techniques such as total station traversing and differential levelling are more appropriate for propagating survey control and improving Class. Conversely, techniques such as GNSS Static and AUSPOS are more appropriate for surveys of larger sizes (e.g. where distances are greater than 500 m) considering the propagation of errors and the distances that survey control needs to be densified from (see **Table 2**).
- *The network design is appropriate for establishing datum (GDA2020 and/or AHD71)*. Control

surveys must establish datum in compliance with **Section 8.2**. Good survey control practice is to work from the whole to the part by observing a primary control network to establish and interpolate datum from, then infill other survey control as necessary using the most appropriate survey technique considering station density.

- *The proposed network connects into survey control within and adjacent to the survey*. Control surveys must connect into local adjacent survey marks and avoid skipping survey control. For example, a GNSS Static control survey must not connect solely to the nearest CORS if there are suitable survey marks available closer by (see **Section 8.2**). Similarly, surveys of a long linear nature such as a level run or traverse that are common along street corridors, must connect into survey control on either side to avoid stretching or warping the resultant least squares statistics. Spatial Services will automatically downgrade the Class of the survey if scenarios such as these occur.

Network design examples for a variety of survey techniques are provided in the SGD12 Resource Pack.

8.2 Control Strategy

For a control survey to be included in SCIMS, the following control strategy **must** be adopted regardless of Class or survey technique. A control survey must:

1. Connect the proposed network into a sufficient number of existing **survey control marks containing the equivalent or better Class**, e.g. a Class B survey network must contain adequate Class B or better survey control, and
2. Establish datum (GDA2020 and/or AHD71) by connecting into existing **survey control marks containing Positional Uncertainty** (PU), or **incorporate an approved survey technique to enable the propagation of PU**, e.g. GNSS connection to CORS or AUSPOS, and
3. Adopt any **additional best practice specifications** as detailed in the *Technical Specifications for NSW Secondary Control Surveys* and, if applicable, **SP1 v1.7**, e.g. the minimum number of survey control marks required to achieve a Class for a differential levelling run.

All survey control used must be from SCIMS and should be in agreement in order to successfully establish datum. Survey marks may have moved or there may exist local datum distortions within the State Control Survey Network that will impact the proposed Class and uncertainty of a survey. This may only become evident in the processing/adjustment stage of the survey; therefore, it is important that enough redundancy has been designed into a survey to deal with this.

9. Computation and Adjustment Strategy

For a control survey to be accepted for update in SCIMS, Spatial Services requires that:

1. **An assessment of Class is made** by performing and analysing a successful minimally constrained least squares adjustment and demonstrating rigorous compliance with the standards and specifications outlined in this Direction.
2. **Provisional coordinates are determined** by performing a successful fully constrained least squares adjustment and establishing datum (GDA2020 and/or AHD71).

All of which **must** be clearly outlined in a supporting survey report as detailed in **Section 10**.

Information on appropriate processing, computation and least squares adjustment strategies are provided below.

9.1 Processing and Reduction

In preparation for the least squares adjustment, all necessary reduction and processing corrections outlined in **Section 7** must be applied to the survey observations. Observations must be submitted in an organised and unambiguous digital format that assists in the adjustment process and facilitates the ingestion of survey information into the State Adjustment. Further information on data submission requirements are provided in **Section 11**.

Before an adjustment is performed, the following processing and reduction requirements must be satisfied where applicable (note this list is not exhaustive).

For terrestrial surveys:

- *All sets of observations are appropriately reduced* – All angles, distances and heights must be reduced or abstracted where applicable, i.e. meaned distances, reduced arcs etc. Distances must be reduced to the ellipsoid, while height differences must be reduced between survey marks (not change points). Class is assessed on the characteristics of reduced data, not the evaluation of individual pointings which can bias statistics. Outlier observations or dubious data should either be re-observed or removed.
- *Observation standard deviations meet the proposed Class of survey* – The standard deviations of observations must comply with **Section 7** in terms of range, mean and residuals of multiple pointings.
- *All necessary corrections are applied* – Depending on the survey technique and Class, corrections may need to be applied, e.g. horizontal distances determined using a total station must be reduced to ellipsoidal distances and have appropriate atmospheric corrections applied.

For GNSS surveys:

- Baselines achieve ambiguity resolution and have noisy satellite data removed.
- Correct IGS antenna models, orbits and transformation datasets (if applicable) are applied/used (see **Section 7**).
- GNSS Static baseline solutions are processed accounting for baseline length, receiver type and ionospheric effects.
- No trivial baselines are processed. Trivial baselines skew the results of a least squares adjustment and influence the assessment of Class and calculation of uncertainty. Spatial Services may reject surveys if it suspects trivial baselines are included.
- GNSS Static baselines are processed from a known starting point with accurate GDA2020 horizontal coordinates and ellipsoidal height with all baseline vectors processed outwards from

this point (also known as 'seeding' a network).

9.2 Adjustment Strategy

Both a minimally constrained and a fully constrained least squares adjustment are required to validate the outcome of the control survey, assess Class, and determine provisional coordinates.

If GDA2020 coordinates are required, a three-dimensional least squares adjustment must be performed using ellipsoidal heights as vertical constraints. If AHD71 heights are required, then a separate adjustment must be performed, using AHD71 heights as vertical constraints.

Fundamental to the adjustment are the input standard deviations applied to observations. These values must be clearly stated for both the minimally constrained and fully constrained adjustment with reasoning provided. **Input standard deviations should be a true reflection of the estimated measurement, survey and instrument precision**, rather than selected for the sake of passing a statistically 'clean' adjustment. Analysis of some measurements may require using a different input standard deviation for a particular measurement so as to not distort surrounding survey marks. Ill-fitting measurements must be removed and either re-observed or the Class downgraded accordingly. Input standard deviations have a direct effect on the determination of Class and therefore must be realistic and carefully selected, see **Section 5.1**.

9.3 Minimally Constrained Adjustment

An assessment of Class **must** be made by performing a successful minimally constrained least squares adjustment and confirming the survey meets the proposed Class as instructed in **Section 5.1**.

All statistics including residuals, variance factors and error ellipses must be checked to ensure they pass successfully and meet the proposed Class. Spatial Services also recommends taking the difference in adjusted coordinates to what is currently in SCIMS in order to make an assessment of datum by checking for potential mark movement and/or local datum distortions.

Explanation and justification are 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.
- Scaling of error ellipses.

All the above must be addressed in a survey report as detailed in **Section 10**.

9.4 Fully Constrained Adjustment

Provisional coordinates must be determined by performing a successful fully constrained least squares adjustment and establishing datum (GDA2020 and/or AHD71). All coordinates (and data) submitted to Spatial Services are considered 'provisional' as they may undergo changes before update of SCIMS.

The fully constrained adjustment should be commensurate with the control strategy identified in **Section 8** so long as all survey control agrees. Spatial Services recommends that a fully constrained least squares adjustment is performed using the PU values of survey control (as published in SCIMS) as horizontal and vertical constraints. If users do not have the capability to do so, then a conventional 'fixed' adjustment (applying zero values to the weightings for survey control, i.e. 'fixing') is acceptable for submission.

The same adjustment analysis as required for the minimally constrained adjustment **must** be performed (see **Section 9.3**) and included in a survey report. Users must check agreement between survey control marks in order to accurately make an assessment of datum and meet any necessary specifications as outlined in **Sections 7** and **8**.

Spatial Services **does not** require users to calculate Positional Uncertainty for their control survey as this will be determined in the State Adjustment. However, if users have the capability, they are encouraged to do so as a check to see if their control survey is fit-for-purpose. Local Uncertainty can only be determined through the State Adjustment.

10. Survey Report and Checklist

Spatial Services requires a survey report and checklist to be submitted, covering the control survey and demonstrating compliance with the standards outlined in this Direction. These documents are used as the basis of assessing whether a control survey is fit-for-purpose and meets the requirements for update of SCIMS.

A survey report containing a description of the following components is required:

- The overall job, including purpose, background and intent.
- A summary of the survey and adjustment, including survey technique, type of adjustment, datum to be established and proposed Class of survey.
- 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. This is required for both the minimally constrained and fully constrained adjustment.
- Recommendations for Class based on the results of the minimally constrained adjustment and demonstrating compliance with the standards outlined in this Direction.
- Determination of provisional coordinates.
- Data archive, presentation and formats.
- Any formal communication from Spatial Services for permission to deviate from this Direction (if applicable).
- Submission statement.

Template survey reports and checklists are provided by Spatial Services in the SGD12 Resource Pack and must be used to show compliance with this Direction.

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

Spatial Services will not approve a survey for update into SCIMS unless a satisfactory survey report and all items in the survey checklist are submitted as a whole in a timely and professional manner.

11. Data Submission

Survey data and accompanying information must be presented in a professional, unambiguous and clear manner that facilitates the update of SCIMS. Spatial Services expects the following items (where applicable) when submitting survey data:

- Raw data (in digital format).
- Edited raw data (in digital format).
- Field notes, log sheets, survey plans, observation session diagrams etc (signed).
- Locality Sketch Plans (LSPs).
- Processing and reduction files.
- Least squares adjustment input and output files, including results.
- Survey report and checklist(s).
- Photos of survey marks, observation conditions, sites etc.

Any ancillary information that is required under the Regulation and other Surveyor-General's Directions such as Locality Sketch Plans must also be submitted.

Details on the data submission process including standards, formats and items can be found on the Spatial Services website. For large control surveys (e.g. State-level infrastructure projects), users should contact Spatial Services for advice on the most appropriate method of data submission.

Spatial Services reserves the right to contact a user for any missing, incomplete or incorrect items of a control survey. It is the responsibility of the user to ensure that all data is properly archived to facilitate this.

12. References and Recommended Reading

Australian Government (2017) *National Measurement (Recognized-Value Standard of Measurement of Position) Determination 2017*, https://www.legislation.gov.au/Details/F2017L01352 (accessed April 2021).

Dickson G. (2012) *Control Surveys: Why things are the way they are and not the way you think they should be!* Proceedings of Association of Public Authority Surveyors Conference (APAS2012), 19-21 March, Wollongong, Australia, 12-28.

Geoscience Australia (2021a) *AUSGeoid2020*, http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/ahdgm/ausgeoid2020 (accessed April 2021).

Geoscience Australia (2021b) *AUSPOS*, https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos (accessed April 2021).

Geoscience Australia (2021c) *Australian Height Datum*, https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/datums-projections/australian-height-datum-ahd (accessed April 2021).

Gowans N. (2017) *GDA2020 in NSW*, Proceedings of Association of Public Authority Surveyors Conference (APAS2017), 20-22 March, Shoal Bay, Australia, 21-31.

Gowans N. (2018) *Which GDA94-GDA2020 transformation grid should NSW surveyors use: Where, when and why?* Proceedings of Association of Public Authority Surveyors Conference (APAS2018), 9-11 April, Jindabyne, Australia, 33-48.

Gowans N. and Grinter T. (2013) *Tying it all together: CORSnet-NSW local tie surveys*, Proceedings of Association of Public Authority Surveyors Conference (APAS2013), 12-14 March, Canberra, Australia, 104-119.

Intergovernmental Committee on Surveying and Mapping (ICSM) (2007) *Standards and Practices for Control Surveys (SP1)*, Version 1.7, https://www.icsm.gov.au/publications/archived-version-17-september-2007 (accessed April 2021).

Intergovernmental Committee on Surveying and Mapping (ICSM) (2014) *Geocentric Datum of Australia 1994 Technical Manual*, Version 2.4, https://www.icsm.gov.au/gda2020-and-gda94-technical-manuals (accessed April 2021).

Intergovernmental Committee on Surveying and Mapping (ICSM) (2020a) *Standard for the Australian Survey Control Network (SP1)*, Version 2.2, https://www.icsm.gov.au/publications/standard-australian-survey-control-network-special-publication-1-sp1 (accessed April 2021).

Intergovernmental Committee on Surveying and Mapping (ICSM) (2020b) *Geocentric Datum of Australia 2020 Technical Manual*, Version 1.5, https://www.icsm.gov.au/gda2020-and-gda94-technical-manuals (accessed April 2021).

Intergovernmental Committee on Surveying and Mapping (ICSM) (2021a) *The Australian Geospatial Reference System*, https://www.icsm.gov.au/australian-geospatial-reference-system (accessed April 2021).

Intergovernmental Committee on Surveying and Mapping (ICSM) (2021b) *Australian Geodetic Datum 1966/84 (AGD)*, https://www.icsm.gov.au/datum/australian-geodetic-datum-196684-agd (accessed April 2021).

Intergovernmental Committee on Surveying and Mapping (ICSM) (2021c) *Australian Vertical Working Surface*, https://www.icsm.gov.au/australian-vertical-working-surface (accessed April 2021).

Haasdyk J. and Janssen V. (2012) *Site transformations: A block shift in thinking*, Proceedings of Association of Public Authority Surveyors Conference (APAS2012), 19-21 March, Wollongong, Australia, 29-47.

Janssen V. (2017) *GDA2020, AUSGeoid2020 and ATRF: An introduction*, Proceedings of Association of Public Authority Surveyors Conference (APAS2017), 20-22 March, Shoal Bay, Australia, 3-20.

Janssen V., Gowans N., Hine S. and McElroy S. (2019) *Removing the uncertainty surrounding Positional Uncertainty and Local Uncertainty in SCIMS*, Azimuth, 58(8), 28-32.

Janssen V. and McElroy S. (2020) *Evaluating the performance of AUSPOS solutions in NSW*, Proceedings of APAS Webinar Series 2020 (AWS2020), 5 May – 30 June, 3-19.

Janssen V. and Watson T. (2018) *Evaluating the performance of AUSGeoid2020 in NSW*, Proceedings of Association of Public Authority Surveyors Conference (APAS2018), 9-11 April, Jindabyne, Australia, 3-18.

NSW Legislation (2021a) *Surveying and Spatial Information Act 2002*, https://www.legislation.nsw.gov.au/#/view/act/2002/83 (accessed April 2021).

NSW Legislation (2021b) *Surveying and Spatial Information Regulation 2017*, https://www.legislation.nsw.gov.au/#/view/regulation/2017/486 (accessed April 2021).

Rapp R. H. (1961) *The orthometric height*, Dissertation, The Ohio State University, Columbus.

Roelse A., Granger H.W. and Graham J.W. (1975) *The adjustment of the Australian Levelling Survey 1970-1971*, National Mapping Technical Report No. 12, 2nd edition. Canberra, Department of National Development.

Spatial Services (2021a) *CORSnet-NSW*, http://corsnet.nsw.gov.au/ (accessed April 2021).

Spatial Services (2021b) *SCIMS Online*, https://www.spatial.nsw.gov.au/surveying/scims_online (accessed April 2021).

Spatial Services (2021c) *Surveyor-General's Directions*, https://www.spatial.nsw.gov.au/surveying/surveyor_generals_directions (accessed April 2021).

13. Appendices

13.1 Appendix A – Example of Calculating Horizontal Class

Appendix A provides a modified example from SP1 v1.7 showing the implementation of **Equation (1)** in the process of assessing Class for a control survey:

'A network of survey observations, obtained using Class A instrumentation and techniques, is adjusted in a minimally constrained least squares process which satisfies the a posteriori statistical tests.

In the adjustment output, standard (one sigma) line error ellipses (relative error ellipses) are generated between adjacent points in the network. The allowable limit for the assumed Class A is calculated for each of these lines and compared to the ellipse's semi-major axis.

If all line error ellipses are less than or equal to their limit for the proposed Class, then the hypothesis is true and the network may be adopted as Class A.

If all the line ellipses are greater than the limit for the proposed Class, then the hypothesis is false and the network should be tested for a lower Class.

If most of the ellipses are less than the limit for the proposed Class, but a few are greater, then professional experience must be used to decide whether to downgrade the whole network, part of the network, or to check and possibly re-observe certain sections of the control network.

Referring to **Table 5**, *all relative error ellipses (REEs) on lines connected to station 1 are within the allowable Class A limits, e.g. between stations 1 and 2 where the REE is 0.230 m < 0.248 m. All relative error ellipses on lines within the network pass for Class A, except on the line from station 3 to 4. As only this line is affected in the network, the user must exercise professional diligence in deciding to downgrade the whole or part of the network to a Class that passes (e.g. Class B), or alternatively re-observing that particular line within the network.'*

Table 5: Example – Results of a minimally constrained adjustment that is being tested for Class A standards.

From	To	Semi-major Axis	Distance	Class A allowable limit	Pass for Class A?
1	2	0.230 m	33 km	7.5(33+0.2) = 0.248 m	Pass
1	3	0.050 m	10 km	7.5(10+0.2) = 0.077 m	Pass
1	4	0.035 m	5 km	7.5(5+0.2) = 0.039 m	Pass
2	3	0.100 m	15 km	7.5(15+0.2) = 0.114 m	Pass
3	4	0.030 m	2 km	7.5(2+0.2) = 0.017m	Fail

For any externally submitted data, unless appropriate supporting documentation and reasoning is provided (e.g. survey report), Spatial Services will generally choose to collectively downgrade the entire survey before SCIMS is updated if a scenario similar to the example above occurs. Spatial Services will not re-observe sections of an externally submitted control survey to ensure it passes for Class. As such, any applicants wishing to have their control surveys put on public record at a particular Class need to ensure that they have carried out the appropriate Class assessment tests or provided reasoning why their survey should meet the desired Class.

13.2 Appendix B – Example of Calculating Vertical Class for Differential Levelling Surveys

Appendix B outlines the mathematical process of determining and assigning vertical Class for a differential levelling survey, assuming the criteria outlined in **Section 5.1** have been met. The process is shown through the following example in **Figure 3**:

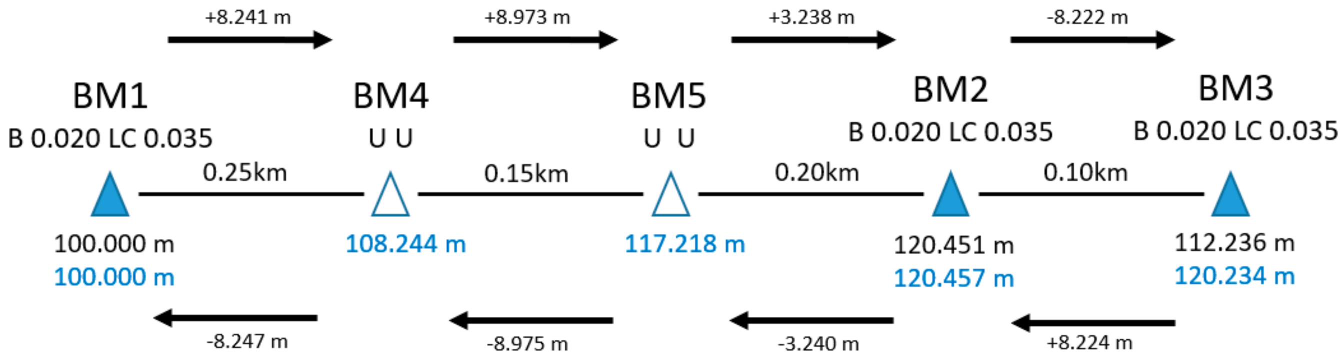

Figure 3: Example – A two-way Class LC differential levelling run carried out between 5 survey marks, 3 of which contain accurate Class LC AHD71 heights in SCIMS (shown by the blue triangles). Associated metadata such as AHD71 height, Class, PU and distance between survey marks is also shown. SCIMS AHD17 values are shown in black.

Referring to **Figure 3**, a minimally constrained adjustment is run holding constrained BM1 in AHD71 and propagating datum throughout the level run (adjusted reduced levels (RLs) are shown in blue). **Table 6** shows the process of determining Class based on:

- the misclose between the forward and return section of a level run between consecutive survey marks, and
- the misclose between the terminals of a level run.

In this case, the terminals are the survey control marks that have been connected into to establish AHD71 datum, i.e. BM1, BM2 and BM3. While the misclose between each consecutive survey mark passes for Class LC, the accumulated misclose between the terminals of the level run fails between BM1 and BM2. As such the survey does not pass for Class LC and the user must exercise professional diligence in deciding to either test whether the survey passes for a lower Class (e.g. LD) or to re-observe some of the sections of the level run that have relatively large miscloses (e.g. between BM1 and BM4).

Table 6: Example – Process of testing a level run for Class based on the misclose between consecutive survey marks and the terminals of the level run.

From	To	Distance	Total Distance	Difference in Elevation (∆H)		Forward / Backward Run Misclose Evalation				
				Forward Run	Backward Run	Misclose per Bay (mean ∆H)	Allowable Misclose LC (12√d)	Misclose Accumulated	Allowable Misclose Accumulated	Pass Overall for LC
		km	km	m	m	m	mm	m	mm	
BM1	BM4	0.25	0.25	8.241	-8.247	-0.006	6.0	-0.006	6.0	Pass
BM4	BM5	0.15	0.40	8.973	-8.975	-0.002	4.6	-0.008	7.6	Fail
BM5	BM2	0.20	0.60	3.238	-3.240	-0.002	5.4	-0.010	9.3	Fail
BM2	BM3	0.10	0.70	-8.222	8.224	0.002	3.8	-0.008	10.0	Pass

Having made an initial determination of Class, the level run must be checked to ensure there is sufficient agreement between survey control marks in order to verify and adopt the AHD71 datum. In this case, the level run must be checked for agreement between BM1, BM2 and BM3 to ensure it meets Class LC tolerances.

Table 7 shows this process by taking the difference in adjusted height to what is currently in SCIMS, and testing whether that section passes for Class. The misclose for section BM2 to BM3 does not pass for Class LC, meaning there are not three AHD71 survey control marks in agreement within the level run and therefore datum cannot be verified.

Table 7: Example – Process of adopting and verifying AHD71 datum in the assessment of Class for a level run.

From	To	Distance	△H in SCIMS	△H in Adjustment	Difference in △H (SCIMS - Adj)	Allowable Misclose	Pass / Fail Overall for LC
		km	m	m	m	mm	
BM1	BM2	0.6	20.451	20.457	0.006	9.3	Pass
BM2	BM3	0.1	-8.215	-8.223	-0.008	3.8	Fail
BM1	BM3	0.7	12.236	12.234	-0.002	10.0	Pass

In this case, Spatial Services would either require:

- Specific sections of the level run to be re-observed to improve the misclose, or
- The level run to either be extended until another Class LC or better AHD71 mark is found to be in agreement to Class LC tolerances, or
- Downgrade the survey to a lower Class for update of SCIMS, e.g. Class LD.

It should be noted that BM2 might not have necessarily moved, instead the inter-station distance of 100 m is quite short and does not meet agreement to Class LC tolerances.

This example highlights that for differential levelling surveys, Class is not only assessed on the individual fit of the level run and the technical specifications adopted, but also on the agreement in the AHD71 datum. Spatial Services recommends that surveyors check for this agreement whilst in the field to avoid the need to potentially carry out further survey work in the future.

End of Direction