# GDA2020

## uncertainty values on the public record in NSW

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The Geocentric Datum of Australia 2020 (GDA2020) is now our official national datum, and Australian states and territories are in various stages of transitioning from GDA94 to GDA2020. The provision of rigorous uncertainty values was a key component, advantage and driver for datum modernisation and is the focus of this article.

We explain the migration rules and philosophical decisions applied by NSW Spatial Services to report GDA2020 and AHD uncertainty values on public record in the Survey Control Information Management System (SCIMS).

SCIMS is the State's database containing about 250,000 survey marks, including coordinates, heights, accuracy classifications and other metadata. We also provide initial user tips for dealing with SCIMS uncertainty values in NSW.

### GDA94 vs. GDA2020

GDA94 remains the legal datum in NSW, until it is replaced by GDA2020 following the required change in legislation. This will probably happen on or after 1 January 2020.

Since July 2019, SCIMS provides coordinate values in both datums. This will continue for the foreseeable future as users transition from GDA94 to GDA2020.

The Australian Height Datum (AHD) remains the legal datum for physical heights. All existing AHD heights in SCIMS have been retained and migrated unchanged.

### PU and LU

In 2002, the Intergovernmental Committee on Surveying and Mapping (ICSM) adopted Positional Uncertainty (PU) and Local Uncertainty (LU) as new methods to classify the accuracy of coordinates. LU replaced Order, while Class remained unchanged. This was documented in the Standards and Practices for Control Surveys (SP1, current version 1.7).

PU is the total uncertainty propagated from the Australian Fiducial Network (AFN) comprising 109 Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS), based on a constrained least squares network adjustment.

For AHD heights, PU is the total uncertainty propagated from the Australian National Levelling Network (ANLN) Junction Points (where level runs join).

LU is an average measure of the Relative Uncertainty (RU) of a point with respect to the survey connections to adjacent points in the datum (Figure 1), calculated from the error ellipses (or standard deviations for height).

Basically, PU and LU are the 'currency of positioning'. They allow simple, comparative statements describing position quality, e.g. "this position is better than a 20 or 50 cent piece" or "this height is better than the length of a wine cork or shovel blade". Conceptually, horizontal PU and LU in SCIMS are error ellipses that have been squeezed into a circle of best fit.

### Uncertainties in SCIMS

In 2013, ICSM released the Standard for the Australian Survey Control Network (SP1, current version 2.1), aiming to complete the transition from Class and Order to uncertainty as the basis for evaluating and expressing the quality of measurements and positions.

To make GDA2020 coordinates and uncertainties available on public record in SCIMS, NSW Spatial Services has modified existing database systems. After extensive internal research, we decided to continue with the philosophy outlined in SP1 v1.7 rather than SP1 v2.1. We are currently investigating further upgrades to SCIMS, including the option of a potential national solution.

Initially SCIMS includes Class, Horizontal Positional Uncertainty (HPU), Vertical Positional Uncertainty (VPU), Horizontal Local Uncertainty (HLU) and Vertical Local Uncertainty (VLU).

AHD-PU and AHD-LU are provided for levelled marks belonging to the ANLN, i.e. the original realisation of AHD71, excluding all subsequent levelling. We are still reviewing the best way to deliver PU and LU of GNSS-derived AHD heights.

Table 1 summarises the uncertainty values currently available in SCIMS. Uncertainties are only provided for marks included in the NSW state adjustments.

NSW continues to use Class instead of Survey Uncertainty (SU) defined in SP1 v2.1 because it is an existing, mandatory attribute of SCIMS and deemed to describe survey network quality in a more practical manner.

SU is purely a statistical metric quantifying internal network quality based on a minimally constrained least squares network adjustment, and results vary depending on network size and location of the (arbitrary) 'fixed' point. In SCIMS, Class also considers information that cannot be quantified via an adjustment (e.g. quality of monumentation).

NSW currently prefers LU over Relative Uncertainty (RU) defined in SP1 v2.1 because it provides, at a glance, a single summary measure of how well the subject mark fits into the existing local network. LU accounts for the relative uncertainty in relation to several surrounding marks, while RU only considers the uncertainty between any two marks.

Whilst SP1 allows authorities to estimate PU and LU, NSW Spatial Services has adopted a more rigorous approach and only populates SCIMS with calculated PU and LU values. These are stored to the nearest millimetre, but the significant figures shown to users are commensurate with their

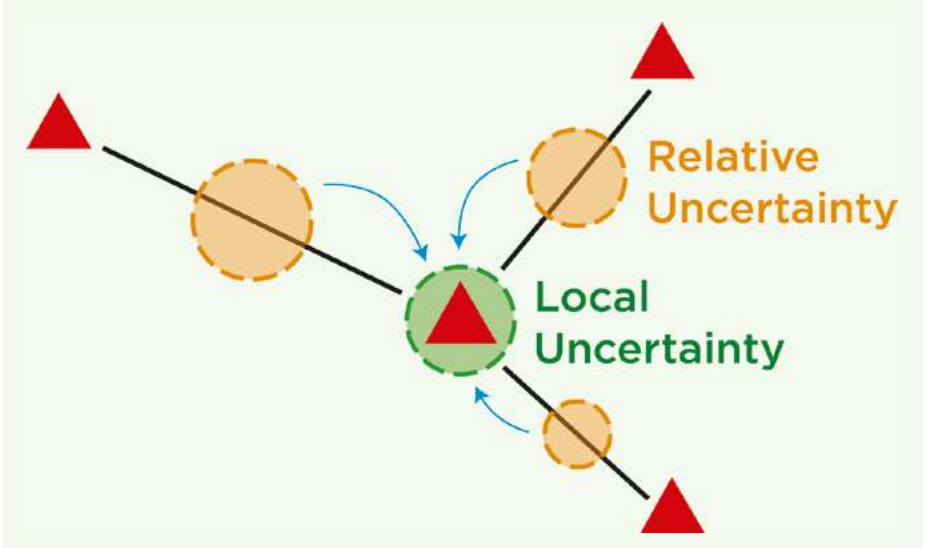


Figure 1: Calculating LU using the RUs between the subject mark and adjacent marks.

| | GDA94 | GDA2020 |
|---|---|---|
| HPU | Y ('spine' & sub-metre DGPS marks only) | Y |
| VPU | N | Y |
| HLU | N | Y |
| VLU | N | Y |
| AHD-PU (levelled) | Y (ANLN marks only) | Y (ANLN marks only) |
| AHD-LU (levelled) | N | Y (ANLN marks only) |
| AHD-PU (derived) | N | N (under investigation) |
| AHD-LU (derived) | N | N (under investigation) |

Table 1: Uncertainty values currently available in SCIMS (Y = yes, N = no).

magnitude and always rounded up: to the nearest centimetre for values less than 1 metre, to the nearest decimetre for values between 1 and 10 metres, and to the nearest metre for values greater than 10 metres.

SCIMS coordinates and uncertainties may improve with each running of the state adjustment, which is run by NSW Spatial Services and constrained to the AFN. A suitable subset of observations contributes to the national adjustment run by Geoscience Australia.

## PU in SCIMS

For horizontal positions, the radius of a 95% circle of uncertainty is calculated from the standard (1σ) error ellipse produced by common adjustment software. However, as PU refers to the national datum (not just the local control for a particular survey), the error ellipse must also consider the uncertainty of the AFN.

The PU of a height is a linear quantity and obtained by scaling the standard deviation (1σ) by 1.96 to convert it to 95% confidence. Again, this standard deviation must be in terms of the national datum, i.e. GDA2020 for ellipsoidal heights and AHD for physical heights.

The PU of AHD heights for levelled marks is computed from a least squares network adjustment of the ANLN, with Junction Points constrained to a standard deviation of 0.005m. The original tide gauges were not constrained. This approach was chosen based on testing undertaken in NSW, following earlier adoption of the same principles in Victoria.

Figure 2 illustrates the distribution of HPU (30,438 values) and VPU (28,872 values) based on the NSW state adjustment and levelled AHD-PU (10,299 values) based on the ANLN adjustment (as at 01/07/2019), along with the median and mean of the data.

It is evident that the PU values are not normally distributed, but instead present as a skewed, right-tailed distribution. For such a skewed distribution, the median provides a more robust measure of central tendency than the mean. It is also far less susceptible to outliers.

Median values of 0.018m (HPU) and 0.027m (VPU) for the horizontal and vertical GDA2020 coordinate components in the NSW state adjustment indicate a very good result. As such, users will often see PU values of 0.02m and 0.03m in SCIMS, due to rounding up and displaying these values to the nearest centimetre.

Pleasingly, 73.4% of all HPU values in the state adjustment are 0.02m or better (91.1% are 0.03m or better), i.e. these survey marks have a horizontal accuracy of a little larger than the size of a 50-cent piece (1.6cm radius). Similarly, 95.6% of all VPU values are 0.05m or better (97.4% are 0.06m or better), which is a little larger than the average height of a wine cork (4.5cm).

To users, this has a huge and immediate impact. Our best-quality survey control is now more readily available (greater quantity, more accessible locations), compared to the days of connecting to 6,400 trigonometrical (trig) stations located on distant hilltops.

In fact, the PU of a typical NSW survey mark is now superior to that of the fiducial marks originally used to realise the superseded GDA94 two decades ago (PU of 0.03m for the Australian National Network).

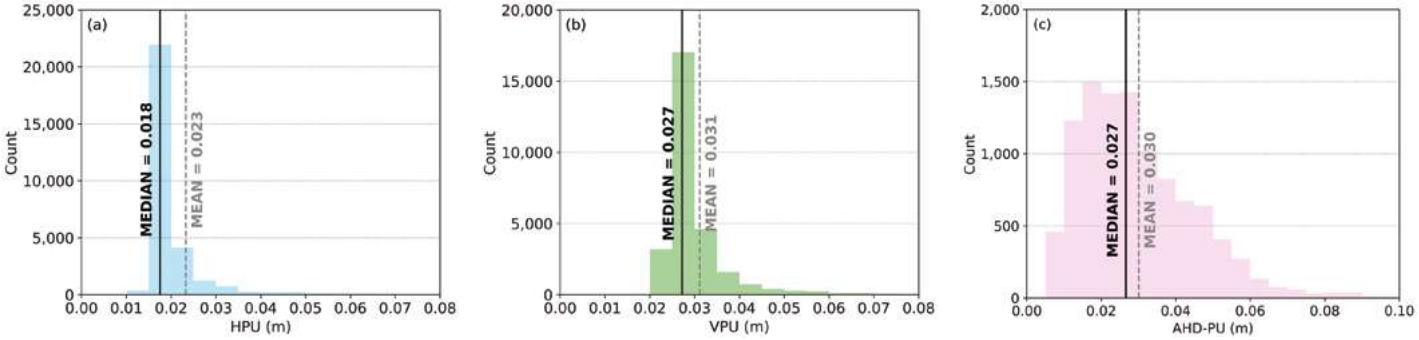


Figure 2: Distribution of (a) HPU, (b) VPU and (c) levelled AHD-PU values in SCIMS, based on the NSW state adjustments as at 01/07/2019.

For AHD heights, 89.3% of levelled AHD-PU values are 0.05m (height of a wine cork) or better (95.9% are 0.06m or better) – another great achievement.

## Class in SCIMS

To limit the impact on surveyors, the existing Class of established survey marks and all levelled marks was simply migrated and fully retained in the initial population of SCIMS with GDA2020 coordinates.

For unestablished marks, we introduced a new generic rule to assign Class based on PU (Table 2). This delivered:

- 27,450 marks assigned GDA2020 ellipsoidal heights.
- 650 new marks added: Control Points (CPs) and eccentric witness marks.
- 2,732 new/existing marks upgraded to 'established', mainly based on 6+ hour AUSPOS sessions.

In assigning Class D, we acted in accordance with Surveyor General's Direction No. 12 (Control Surveys and SCIMS) when the survey methodology delivered positions or heights accurate to several centimetres but involved unchecked radiations or single occupations.

## LU in SCIMS

NSW Spatial Services is exclusively responsible for calculating LU for the NSW survey control network. Only marks in the state adjustment are considered.

In the LU computation, we use the median RU (being the determination of a medial estimate, i.e. the "average" as defined in SP1 v1.7) because the RUs of a network are not normally distributed but present as a skewed, right-tailed distribution.

HLU is computed as the median horizontal relative uncertainty circular confidence region between the subject point and the 15 nearest SCIMS marks within the adjustment, including direct and indirect connections (see Figure 1). This excludes transformed marks, RTK/NRTK and AUSPOS point observations, but may include RTK/NRTK and AUSPOS observations expressed as baselines.

| Class | PU Range |
|---|---|
| Horizontal Class D | HPU (95% CL) ≤ 0.1 m |
| Horizontal Class E | 0.1 m < HPU (95% CL) ≤ 1 m |
| Horizontal Class U | HPU (95% CL) > 1 m |
| Vertical (EHGT) Class D | VPU (95% CL) ≤ 0.1 m |
| Vertical (EHGT) Class E | 0.1 m < VPU (95% CL) ≤ 1 m |
| Vertical (EHGT) Class U | VPU (95% CL) > 1 m |
| N | N (under investigation) |
| N | N (under investigation) |

**Table 2: Assigning Class for unestablished marks, based on Positional Uncertainty.**

The era of estimating uncertainty via sensible judgement according to statistical (empirical) data and professional knowledge is over. Uncertainty can now be rigorously calculated

Accordingly, VLU is the median vertical relative uncertainty between the subject point and the 15 nearest SCIMS marks within the adjustment (including direct and indirect connections). Marks without vertical measurements have a null VLU, and marks without horizontal measurements have a null HLU.

The AHD-LU for levelled marks only considers marks within the ANLN adjustment, i.e. ignoring in-fill levelling and GNSS-derived AHD heights. The AHD-RU/LU values for levelled and GNSS-derived AHD are not meaningfully related because they are determined from separate adjustments (ANLN vs. GDA2020).

Figure 3 illustrates the distribution of HLU (30,438 values) and VLU (28,872 values) based on the NSW state adjustment and levelled AHD-LU (10,299 values) based on the ANLN adjustment (as at 01/07/2019), along with the median and mean of the data.

The LU values also present as a skewed, right-tailed distribution. Hence the median is again a more suitable measure of central tendency and far less susceptible to outliers. Median values of 0.024m (HLU) and 0.038m (VLU) for the GDA2020 coordinate components in the NSW state adjustment deliver a very good result for the average 'local fit'.

This is supported by 83.0% of all HLU values being 0.03m or better (91.5% are 0.04m or better) and 90.0% of all VLU values being 0.05m or better (94.5% are 0.06m or better). For AHD heights, 69.2% of levelled AHD-LU values are 0.05m or better (80.0% are 0.06m or better). These statistics reflect the high quality of the two network adjustments used to populate SCIMS.

At a given point in the NSW state network, LU is typically larger than PU. This is because the RU computation between any two stations is driven by PU at both stations along with their correlation, which tends to be comparatively small in well-constrained networks.

## Uncertainties of transformed GDA2020 marks

The GDA2020 state adjustment currently incorporates about 30,000 survey control marks, i.e. 12% of all marks in SCIMS. Consequently, 88% of SCIMS marks are transformed from GDA94 to GDA2020 using the 'conformal and distortion' NTv2 transformation grid (see *Position* 100, April 2019).

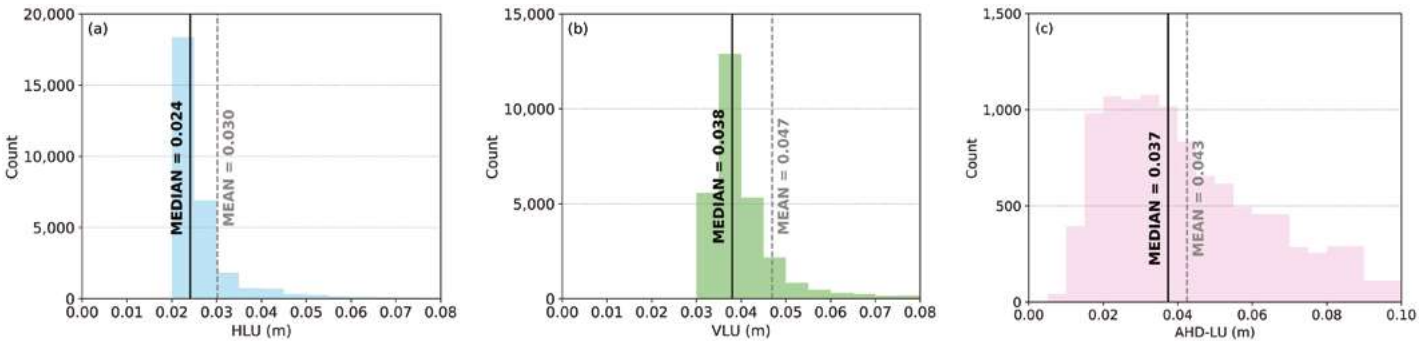


**Figure 3: Distribution of (a) HLU, (b) VLU and (c) levelled AHD-LU values in SCIMS, based on the NSW state adjustments as at 01/07/2019.**

Uncertainties of transformed GDA2020 coordinates are given null values until these are calculated via inclusion in the state adjustment. Caution should be used when mixing adjusted and transformed survey control.

To date, significant street-corner-level traversing datasets in the Sydney region have been prepared and tested (about 20,000 marks) in preparation for later inclusion. Promising results with good PU and LU are emerging.

## More user tips

- PU and LU may be better than displayed (0.011m calculated vs. 0.02m displayed).
- PU can be initially assigned by the authority undertaking the 'general' survey.
- Initial PU may be significantly improved when we include the survey data in the state adjustment.
- PU and LU appear more generous than Class and Order because they are expressed at the 95% confidence level (Class and Order were at the 68% confidence level).
- HPU and HLU are expressed as circular confidence regions and hence well suited to satellite-based positioning (GNSS techniques consistently produce circular error ellipses).
- The smallest PU or 'least uncertainty' in SCIMS is 0.01m (HPU) and 0.02m (VPU). These values occur at CORS and are the smallest uncertainty to be realistically expected under ideal conditions.
- Investigating typical PU regarding mark type, PMs and SSMs have the best PU (generally observed by NSW Spatial Services using GNSS best practice). Trig stations have the poorest PU (due to number of intersected stations or solely relying on 50-year-old terrestrial observations).
- Investigating typical PU regarding survey technique, AUSPOS consistently delivers HPU at the 0.02-0.03m level. PU deteriorates with increasing baseline length for single-base RTK. In terrestrial traversing, network geometry significantly affects PU and LU.
- PU and LU empower users to be innovative and use new tools and techniques, encouraging a shift from prescriptive, rigid methodologies to outcomes.
- We encourage surveyors to submit suitable observations, particularly AUSPOS data and reports, for potential update of SCIMS (https://www.spatial.nsw.gov.au/surveying/surveying_services/forms_and_applications/auspos_submission). Observations can be added to the state/national adjustment, supporting survey infrastructure into the future.
- From 1 July 2019, GDA94 information in SCIMS is no longer updated.

The era of estimating uncertainty via sensible judgement according to statistical (empirical) data and professional knowledge is over. Uncertainty can now be rigorously calculated, while traditional passive and modern active survey control networks (ground marks vs. CORS) are seamlessly working together. However, due diligence is still required.

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