Removing the uncertainty surrounding **Positional Uncertainty** and **Local Uncertainty** in SCIMS

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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.

Whilst accuracy definitions and formulae in technical manuals appear black and white, their application in the real world leads to subtle variations in interpretation. Hence, to remove some of the 'uncertainty' surrounding the newly reported uncertainty values, we also provide initial user tips for dealing with SCIMS uncertainty values in NSW.

GDA94 vs. GDA2020

GDA94 currently remains the ***legal*** datum in NSW, until it is replaced by GDA2020 following the required change in legislation. It is envisioned that this will 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.

The metre and sub-metre differences between GDA94 and GDA2020 coordinate values (horizontal shift of about 1.5 m and decrease of ellipsoidal height by about 0.095 m in NSW) may cause confusion. SCIMS Online therefore uses 'ochre' and 'blue' coloured schemes to differentiate the two datums, based on the GDA94 and GDA2020 logo colours, respectively.

SP1 v1.7 Class, PU & LU

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

Class is defined as a function of the precision of a survey network, reflecting observation precision as well as the suitability of network design, survey methods, instruments and reduction techniques. It is verified by analysing the minimally constrained least squares network adjustment.

PU is defined as the uncertainty of the horizontal and/or vertical (ellipsoidal/physical) coordinates of a point, in metres at the 95% confidence level, with respect to the defined reference frame (datum). It is reported as 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 fully constrained least squares network adjustment. Computationally, these values are largely driven by the original surveys' input a-priori observation weighting and the uncertainty of AFN station constraints.

For AHD heights, PU is the total uncertainty propagated from the Australian National Levelling Network (ANLN) Junction Points (JPs, i.e. where level runs join). Computationally, these values are largely driven by the distance from the JPs and the quality of the levelling.

LU is defined as the average measure, in metres at the 95% confidence level, of the Relative Uncertainty (RU) of the horizontal and/or vertical (ellipsoidal/physical) coordinates of a point, with respect to the survey connections to adjacent points in the defined reference frame (datum). LU is calculated from the error ellipse (or standard deviation in the case of height) between two points, or the average of those from the subject point to adjacent points in the network (Figure 1).

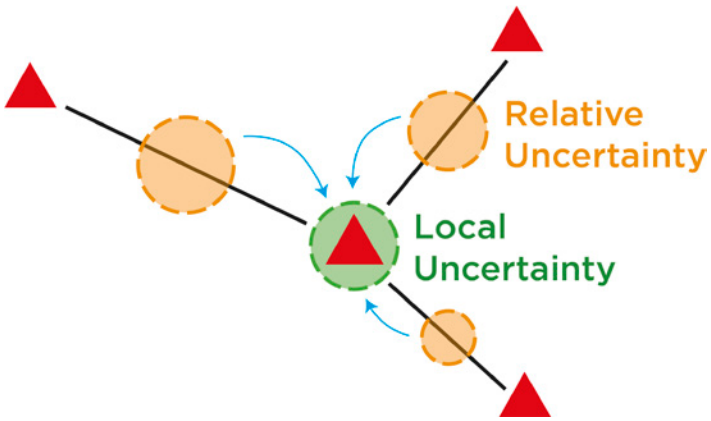

Figure 1: Calculating LU using the RUs between the subject mark and adjacent marks.

PU and LU provide a consistent way of directly comparing the quality of positions regardless of observation technique and

are compatible with international (ISO) and metrology (GUM) standards. Now the user can easily compare an RTK position with that from a smart phone, LiDAR sensor or digitised cadastral map.

Basically, PU and LU are the 'currency of positioning'. They allow simple, comparative statements describing the quality of a position, e.g. "this position is better than a 10, 20 or 50 cent piece" or "this height is better than the length of a wine cork, shovel blade or pogo stick". Conceptually, horizontal PU and LU, as reported 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 in SCIMS, NSW Spatial Services has modified existing database systems. After extensive internal research, it was 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, which excludes all other 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 Online. Note that uncertainties are only provided for marks included in the NSW state adjustments.

	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 Online (Y = yes, N = no).

In NSW, Class continues to be used instead of Survey Uncertainty (SU) as defined in SP1 v2.1 because it is an existing, mandatory attribute of SCIMS and deemed to describe the quality of survey networks in a more practical manner. SU is purely a statistical metric quantifying the internal quality of a network 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).

In NSW, LU is currently preferred over Relative Uncertainty (RU) as 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 is able to account 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 magnitude: rounded up to the nearest centimetre for values less than 1 metre, rounded up to the nearest decimetre for values between 1 and 10 metres, and rounded up to the nearest metre for values greater than 10 metres.

As a SCIMS Online user, it is important to confirm that you are using the latest coordinates and uncertainties as these may improve with each running of the state adjustment. SCIMS is populated via the state adjustment run by NSW Spatial Services, constrained to the AFN. A suitable subset of observations also 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 0.005 m. 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.

Table 2 presents descriptive statistics for HPU and VPU based on the NSW state adjustment and levelled AHD-PU based on the ANLN adjustment (as at 01/07/2019). Figure 2 provides a graphical view of the distribution of these values, along with the median and mean of the data.

	Min (m)	Max (m)	Median (m)	Mean (m)	Count
HPU	0.007	0.831	0.018	0.023	30,438
VPU	0.012	0.601	0.027	0.031	28,872
AHD-PU (levelled)	0.004	0.148	0.027	0.030	10,299

Table 2: Descriptive statistics for HPU and VPU in the NSW state adjustment and levelled AHD-PU in the ANLN adjustment, as at 01/07/2019 (provided through SCIMS Online).

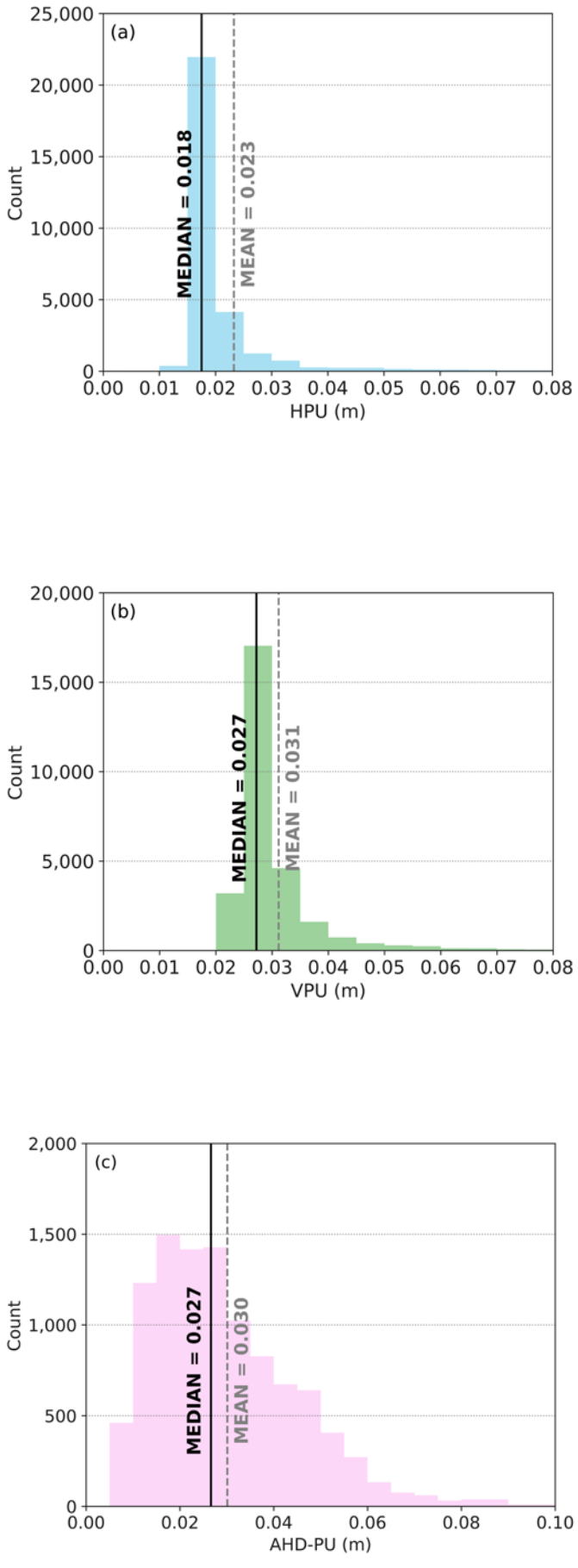

Figure 2: Distribution of (a) HPU, (b) VPU and (c) levelled AHD-PU values in SCIMS Online, based on the NSW state adjustments as at 01/07/2019.

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

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

To the user, this has a huge and immediate impact. Our best-quality survey control is now more readily available, in greater quantities, in more regions and in 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 that were originally used to realise the superseded GDA94 datum two decades ago (PU of 0.03 m for the Australian National Network).

For AHD heights, 89.3% of levelled AHD-PU values are 0.05 m (height of a wine cork) or better (95.9% are 0.06 m 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. Hence the Class of a mark in the context of the state network may now be substantially better than reported, especially if it has been observed in multiple surveys.

For unestablished marks, we introduced a new generic rule to assign Class based on PU (Table 3), allowing us to deliver the following:

- 27,450 marks were assigned GDA2020 ellipsoidal heights.
- 650 new marks were added to SCIMS, mostly Control Points (CPs) with the rest being eccentric witness marks.
- 2,732 new or existing marks were upgraded to 'established', predominately based on AUSPOS sessions of at least 6 hours duration.

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

Table 3: Assigning Class for unestablished marks, based on Positional Uncertainty.

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 computation of LU, 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***.

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. in-fill levelling and GNSS-derived AHD heights are ignored). 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).

Table 4 presents descriptive statistics for HLU and VLU based on the NSW state adjustment and levelled AHD-LU based on the ANLN adjustment (as at 01/07/2019). Figure 3 provides a graphical view of the distribution of these values, along with the median and mean of the data.

	Min (m)	Max (m)	Median (m)	Mean (m)	Count
HLU	0.017	0.833	0.024	0.030	30,438
VLU	0.028	1.952	0.038	0.047	28,872
AHD-LU (levelled)	0.008	0.208	0.037	0.043	10,299

Table 4: Descriptive statistics for HLU and VLU in the NSW state adjustment and levelled AHD-LU in the ANLN adjustment, as at 01/07/2019 (provided through SCIMS Online).

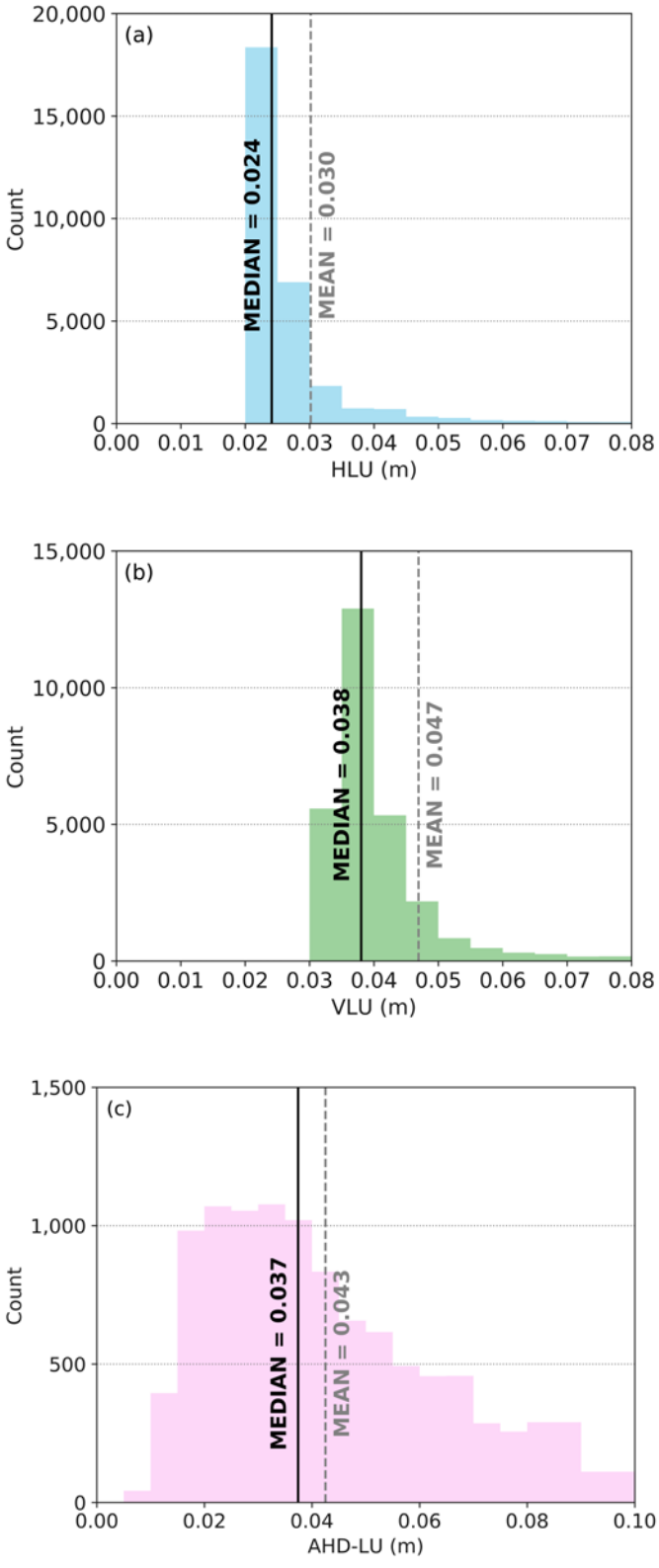

Figure 3: Distribution of (a) HLU, (b) VLU and (c) levelled AHD-LU values in SCIMS Online, based on the NSW state adjustments as at 01/07/2019.

The LU values also present as a skewed, right-tailed distribution. Hence the median is again a more suitable measure of central tendency, which is also far less susceptible to outliers. Median values of 0.024 m (HLU) and 0.038 m (VLU) for the horizontal and vertical 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 0.03 m or

better (91.5% are 0.04 m or better). In the vertical component, 90.0% of all VLU values are 0.05 m or better (94.5% are 0.06 m or better). For AHD heights, 69.2% of levelled AHD-LU values are 0.05 m or better (80.0% are 0.06 m 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, for any pair of stations, the relative uncertainty computation 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 approximately 30,000 survey control marks, i.e. 12% of all marks in SCIMS. Consequently, 88% of the marks in SCIMS are transformed from GDA94(1997) to GDA2020 using the 'conformal and distortion' NTv2 transformation grid (see Azimuth 58(3), April 2019). Uncertainties of transformed GDA2020 coordinates are given null values until these are calculated via inclusion in the state adjustment.

SCIMS will always retain a significant proportion of transformed coordinates, typically for those marks coordinated by external organisations, where only the final survey results and not the raw data or observations were supplied to NSW Spatial Services. Users should use caution when mixing adjusted and transformed survey control.

We have begun the task of including all our street-corner-level traversing data into the state adjustment. To date significant 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 values are emerging.

More User Tips

The following additional tips are provided to assist SCIMS Online users in the transition to GDA2020:

- Uncertainty values in SCIMS are calculated via a pathway from constrained AFN CORS. They are correct at the time of survey but may change due to mark movement.
- PU and LU values may be better than those displayed (e.g. 0.011 m calculated vs. 0.02 m displayed).
- PU can be initially assigned by the authority undertaking the 'general' survey or by Commonwealth or State authorities specifically designing 'datum' surveys for network densification.
- Initial PU values may be significantly improved by NSW Spatial Services, when the survey data is included 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).
- Horizontal PU and LU are expressed as circular confidence regions and as such are well suited to satellite-based positioning because GNSS techniques consistently produce circular error ellipses.
- The smallest PU or 'least uncertainty' displayed in SCIMS is 0.01 m (HPU) and 0.02 m (VPU). These values occur at CORS (which realise the datum) and are the smallest uncertainty of measurement that can realistically be expected under ideal conditions.
- Investigating typical PU values with regards to mark type, PMs and SSMs tend to have the best PU, as these were generally observed by NSW Spatial Services using GNSS best practice. Trig stations have the poorest PU, a direct result of the number of intersected stations or historical stations still solely relying on 50-year-old terrestrial observations.
- Investigating typical PU values with regards to survey technique, AUSPOS consistently delivers horizontal PU at the 0.02-0.03 m 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 the profession to submit suitable observations, particularly AUSPOS data and reports, to NSW Spatial Services 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, thereby supporting the State's 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 (i.e. ground marks vs. CORS) are seamlessly working together. However, due diligence is still required.

More information

More information can be found in Surveyor General's Direction No. 4 (Interpreting SCIMS) and the SCIMS Online Support Guide, available from the NSW Spatial Services website.

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