# Tying It All Together: CORSnet-NSW Local Tie Surveys

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## ABSTRACT

*Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) in the CORSnet-NSW network are coordinated via Regulation 13 certification, providing a recognised value standard and a legally traceable connection to GDA94. These coordinates are propagated directly from the Australian Regional GNSS Network (ARGN) and consequently may not 'fit' well with those of the surrounding ground control network (i.e. those marks in the Survey Control Information Management System, SCIMS), which has been through a large number of cascading adjustments over many years. Therefore, Land and Property Information (LPI) carries out local tie surveys in order to provide 'local-fit' coordinates for each CORSnet-NSW station that will be consistent with existing local ground control for use in applications when a connection to SCIMS marks is required. These coordinates are determined through a GNSS field survey connecting to the surrounding GDA94 and AHD71 ground control, followed by a constrained least squares adjustment with AHD71 propagated from ground control via AUSGeoid09. By nature, these surveys tend to highlight distortions in the existing ground survey network. Although the initial aim of these surveys is to provide 'local-fit' coordinates for each CORSnet-NSW station that are consistent with the (distorted) existing ground survey network, the ultimate goal is the opposite. These local tie survey observations will be used to propagate the Regulation 13 derived coordinates of the CORSnet-NSW network outward to the ground control network in the adjustment for the next generation Australian datum. This paper outlines how these local tie surveys are performed at LPI.*

**KEYWORDS**: *CORS, Regulation 13, datum distortions, GDA94(1997), GDA94(2010), next generation Australian datum.*

## 1 INTRODUCTION

CORSnet-NSW is a rapidly growing network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use (Janssen et al., 2011; LPI, 2013a). CORSnet-NSW currently consists of 117 CORS tracking multiple satellite constellations, and efforts are underway to expand the network to over 150 stations by the end of 2013 (Figure 1). Currently, 53% of the area of NSW (and 97% of the population) is covered by the single-base Real Time Kinematic (RTK) service, while Network RTK is available to 33% of the area of NSW (and 93% of the population).

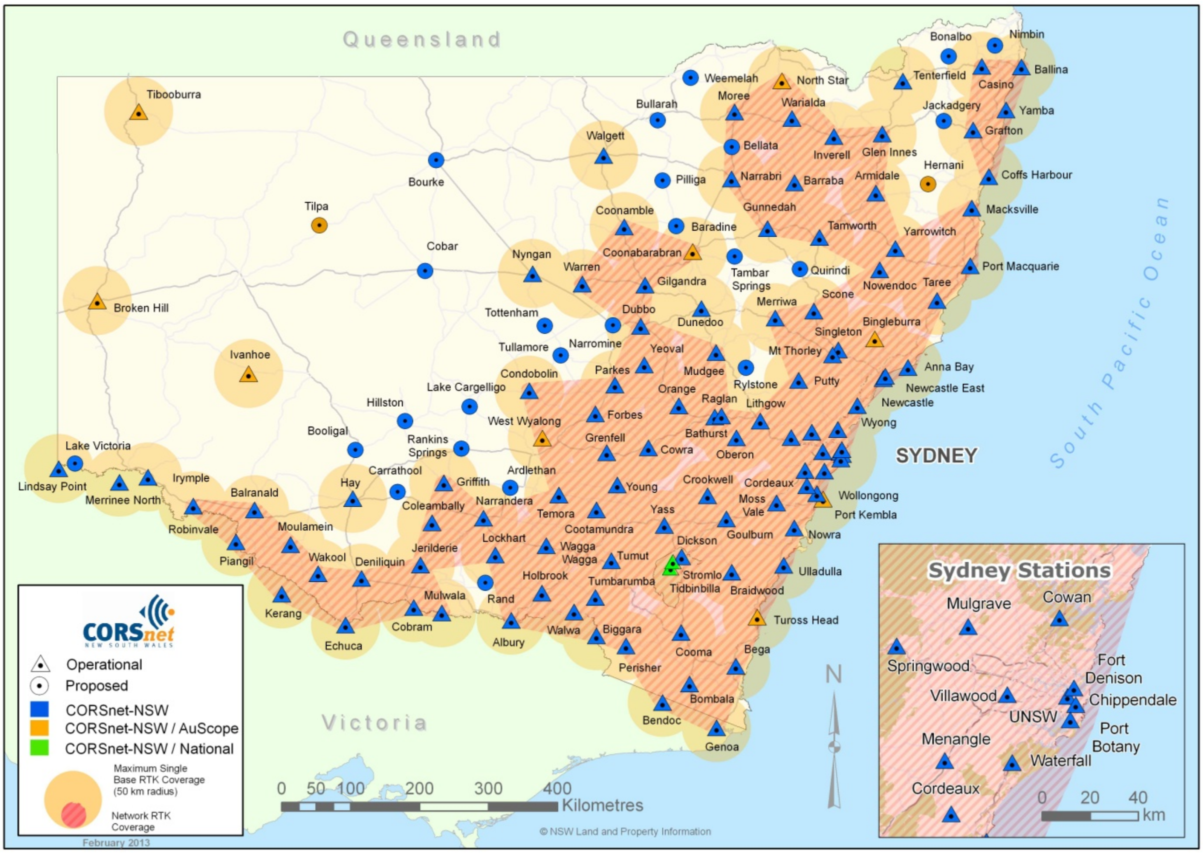


Figure 1: Current coverage of CORSnet-NSW (February 2013).

An operational requirement of CORSnet-NSW is that its reference stations are coordinated to an accuracy of better than 15 mm (Ramm and Hale, 2004). This is due to the nature of distant dependent error modelling across the network (particularly important for the Network RTK service) that affects ambiguity resolution within the network. However, GDA94 is known to contain distortions in the order of up to 0.3 m in NSW and is therefore not suitable for this purpose. For these reasons, an ad-hoc realisation of the national datum, GDA94(2010), was introduced by LPI for CORSnet-NSW, which is consistent with Regulation 13 certification (GA, 2012a) and Geoscience Australia's AUSPOS service (GA, 2012b). In order to avoid confusion, the original definition of GDA94 is now referred to as GDA94(1997) in NSW. CORSnet-NSW reference stations are initially coordinated on GDA94(2010) through a 24-hour AUSPOS solution until Regulation 13 certification is obtained. For further reading on GDA94(1997) vs. GDA94(2010), the reader is referred to Janssen and McElroy (2010).

LPI carries out local tie surveys to connect the CORSnet-NSW station to the ground survey network, bridging the gap between GDA94(1997) and GDA94(2010). The immediate goal of each tie survey is to propagate the local distortions in GDA94(1997) and AHD71 to the CORSnet-NSW station, producing a best 'local-fit' position. These coordinates can then be used by surveyors who are required to connect to local survey control.

Providing two separate realisations of the national datum concurrently is not an ideal solution. Conversely, the ultimate goal is the opposite, i.e. re-adjusting the entire state survey control network and propagating the Regulation 13 CORSnet-NSW station coordinates outward to the ground survey network in the next Australian datum.

In a local tie survey campaign, often additional observations are made for improvements to NSW geodetic infrastructure, usually in the form of long static GNSS observation sessions (e.g. for use in AUSPOS to improve the state-wide and national survey infrastructure or on authoritative levelled marks to assist national geoid modelling efforts). In addition, GNSS 'island' adjustments (i.e. standalone GNSS survey networks not connected to any other GNSS survey networks in SCIMS) are identified and connected to the CORS. This paper outlines how these local tie surveys are performed at LPI.

## 2 METHODOLOGY

This section details the approach taken by LPI to perform CORSnet-NSW local tie surveys. A brief additional discussion related to this topic can be found in LPI (2012).

### 2.1 Network Design

Tie surveys aim to connect to existing survey control in SCIMS (LPI, 2013b), such as the 2A0 'spine' network (Figure 2) and the A1 sub-spine networks. The NSW 'spine' network refers to the original 1997 adjustment of GDA at epoch 1994.0. This adjustment was a mixture of GPS-only baselines along with terrestrial distance and direction (DDS) observations of varying quality. For a recent discussion of the terms class and order, the reader is referred to Dickson (2012). Tie surveys traditionally incorporate two stages of survey, i.e. GNSS connection to 2A0 horizontal GDA94(1997) control (far array) and GNSS connection to AHD71 control (local array).

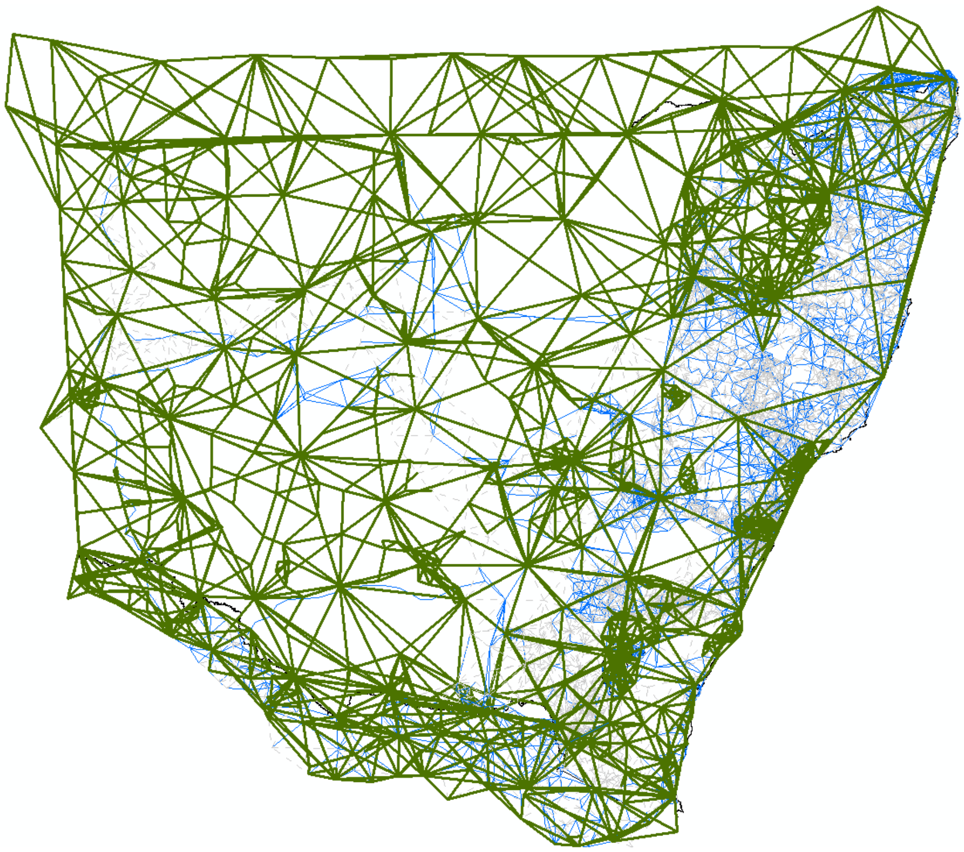

Figure 2: GDA94(1997) NSW spine network composed of GPS (green) and terrestrial (blue/grey) observations.

Local tie survey networks are radial in terms of their geometry design, with the CORSnet-NSW station at the centre. This technique was originally developed for replacing a single trigonometric station within an established survey network and is not considered best practice for typical surveys. Figure 3 shows a typical tie survey composed of its connection to the 2A0 spine network (far array) and the connection to the local survey marks (local array).

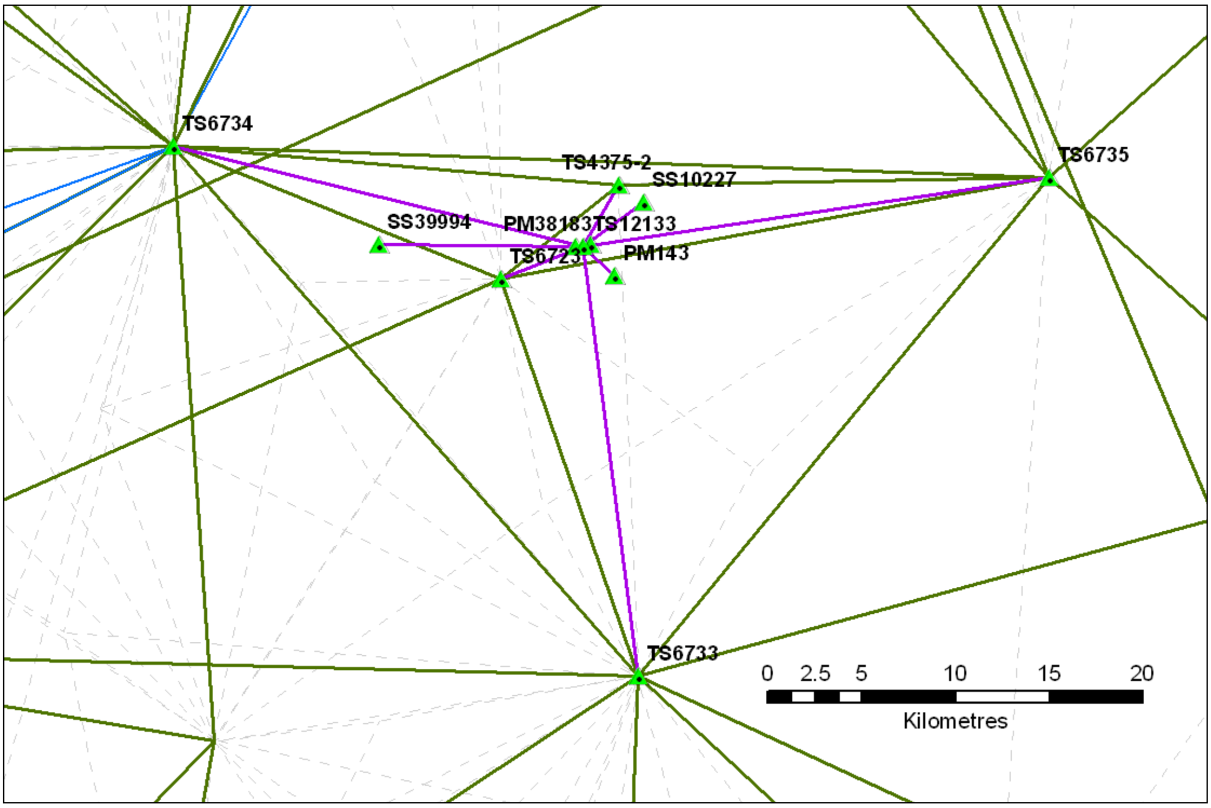


Figure 3: A typical far array network (here for Cooma CORS), showing the tie survey baselines (purple) along with the existing GPS spine (green) and DDS spine (blue/grey).

Observing the lines between fixed stations is usually not practiced for several reasons:

1. These lines have mostly been measured already in LPI's spine network (see Figure 2) and other subsequent adjustments.
2. This would add considerably to staffing and time resources. Usually, field operations are completed by a one/two-person field party with a single survey vehicle.
3. Marks are double-occupied, which provides a check on gross errors. Survey pillars may be single-occupied as long overnight sessions, typically 18-24 hours long, due to the reduced centring error. Field survey procedures check for height of instrument errors and mark identification issues.
4. The intent of these surveys is to provide 'local' coordinates that will match the realised distortions in GDA94(1997) and not to identify potential spine issues.

### *2.1.1 Connection to GDA94(1997) 2A0 Horizontal Network (Far Array)*

The purpose of the far array segment is to provide a predominantly horizontal connection to high-order marks established in GDA94(1997). These marks are usually trigonometric stations with horizontal class '2A' and order '0'. On occasion, where connection to the 2A0 network may not be feasible due a very sparse network and/or very difficult access, an A1 network will be considered suitable for this purpose. For a detailed discussion on the allocation of class and order, see section 4.

Marks are selected according to their:
- Coordinate quality in SCIMS, with a preference towards GNSS derived marks.
- GNSS suitability (e.g. low multipath, clear sky view, Work Health & Safety).
- Network geometry (spread evenly about the CORS).
- Local or historical significance.
- Frequency of use.
- Monument quality.
- Ease of access.
- Suitability for future use.
- Security for overnight observation sessions.

These marks are observed as sessions lasting a minimum of 2 hours with double occupations and at a sampling rate of 10 seconds. Alternatively, survey pillars may be observed as a single overnight session, due to the reduced centring error, if the site is suitable in terms of security. These sessions usually span between 18-24 hours and are added to LPI's AUSPOS database for validation purposes as well as submitted to the national archives to be used in the next generation datum adjustment.

#### *2.1.2 Connection to GDA94(1997) and AHD71 (Local Array)*

Connection to AHD71 is considered the primary purpose of the local array (Figure 4). Orthometrically levelled marks (i.e. LCL3 or better) are selected according to similar traits to those listed in section 2.1.1, as well as a preference towards levelling marks that have been established in the Australian National Levelling Network (ANLN). The marks selected are also assessed on their GDA94(1997) coordinate quality and the amount of GNSS observations to the mark in previous survey adjustments. Marks forming part of the local sub-spine are highly desirable.

These observations are double-occupied, using observation session lengths of at least 1 hour and at a sampling rate of 10 seconds. As the distances are usually quite short (less than 5 km), the relatively long observation sessions provide an increased precision of measurement and a better height solution.

#### *2.1.3 Planning*

LPI uses ArcMap as a graphical interface for its spatial datasets, such as SCIMS, the Digital Cadastral Data Base (DCDB), imagery, the spine network and other survey adjustments. 2A0 survey marks can be assessed on observation and coordinate quality based on their connection in the spine network and chosen accordingly, i.e. a preference towards marks in the spine network derived from GPS/GNSS rather than terrestrial DDS measurements.

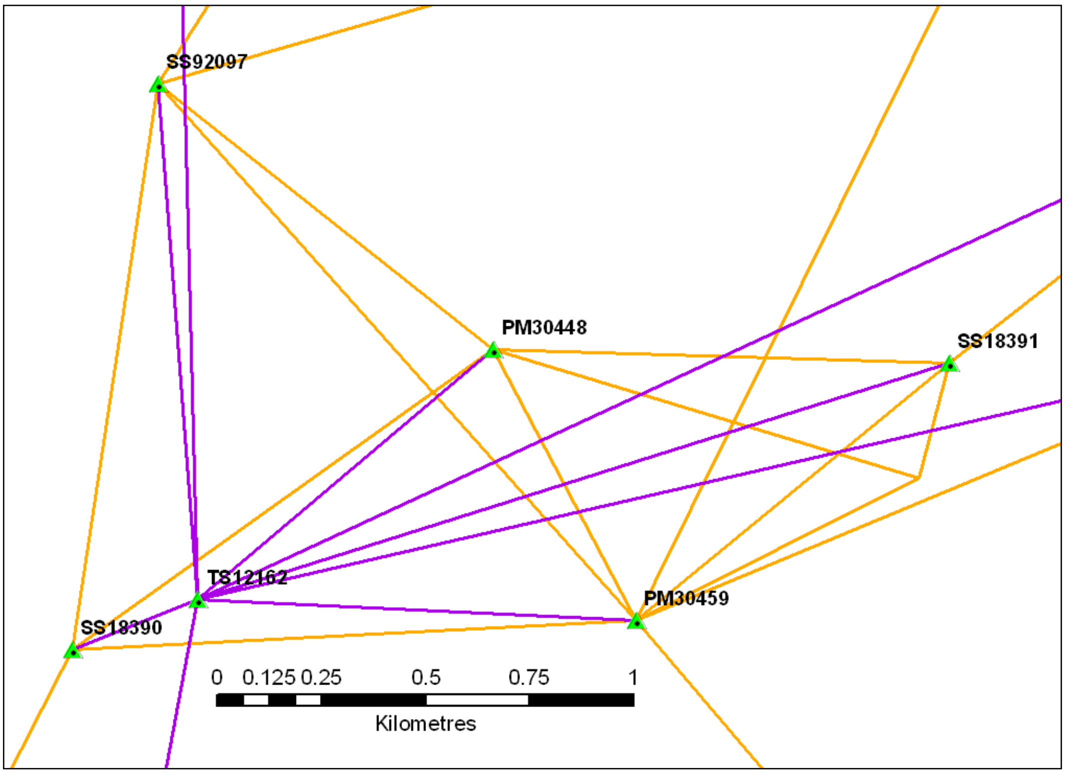


Figure 4: A typical local array network (here for Lockhart CORS), showing the tie survey baselines (purple) along with the existing A1 sub-spine (orange).

### 2.2 Processing, Reduction and Adjustment

The GNSS baselines observed between the CORSnet-NSW station and ground survey marks are processed using commercial software (currently Trimble Business Centre). In order to ensure best results, the data are processed using IGS final precise orbits and the current IGS absolute antenna models (IGS, 2013).

The baselines are adjusted in GeoLab, a commercial least squares adjustment package. A minimally constrained least squares adjustment is initially performed, which provides some error checking for the double-observed stations, somewhat limited by the radial nature of the survey network. Following the completion of the minimally constrained adjustment, a fully constrained adjustment is performed, with rigorous examination of the residuals to note the effect of any network distortions. Each constraint is introduced in a drip-feed fashion. By introducing constraints one at a time, the effect on the resultant coordinates of the CORSnet-NSW station can be analysed. This drip-feed process of introducing local coordinates into the network adjustment can reveal existing distortions in GDA94(1997) (see section 3.2).

#### *2.2.1 Transfer of Height from AHD71 Ground Control*

The height origin for the CORSnet-NSW local tie survey is based on the surrounding AHD71 survey marks. A constrained least squares drip-feed analysis is performed on the local array and height is transferred from the constrained ground marks to the CORSnet-NSW station using the most current AUSGeoid model, currently AUSGeoid09 (Brown et al., 2011). This can also be useful for outlier detection in the constrained adjustment by comparing the observed N-value from the minimally constrained adjustment (i.e. ellipsoidal height – AHD71 height) with the computed AUSGeoid09 N-value.

Orthometrically levelled marks (i.e. LCL3 or better) are chosen as the origin of height in order to propagate AHD71. Marks that have been established in height with GNSS techniques are avoided where possible in order to avoid any biases that may have been present in the geoid model applied at the time of adjustment as well as due to the lack of height precision inherent in GNSS measurements. Trigonometric station heights are usually ignored, due to a tendency to be problematic (e.g. caused by geoid anomalies or systematic levelling errors).

Height is transferred by GNSS survey due to the impracticalities and time constraints associated with spirit levelling. Many CORSnet-NSW stations are not suitable for spirit levelling, i.e. they do not have a bench mark, nor are they mounted in a position conducive to spirit levelling and would require the removal of the antenna to measure to the antenna reference point. Fuller et al. (2011) outline an alternative method of AHD71 height transfer without the use of a geoid model for the purpose of improving geoid models. However, the approach varies in its interpolation method depending on the network geometry and is therefore not used by LPI.

## 3 CASE STUDIES

### 3.1 Parkes CORS: Close Agreement Between Spine and Sub-Spine Networks

Parkes CORS (TS12158) is a Tier 3 CORSnet-NSW station, not to be confused with Parkes Radio Telescope CORS. It is situated in a dense 2A0 GPS spine network and a dense A1 sub-spine network that coincides with LCL3 AHD71. For an explanation of the hierarchy of CORS tiers in Australia and NSW, the reader is referred to Rizos and Satirapod (2011) and LPI (2012). Figure 5 illustrates the extent of the local tie survey and the connections into the 2A0 spine and A1 sub-spine networks. PM8912 is a B2 mark and was connected to for LCL3 AHD71 control to the northeast of Parkes CORS.

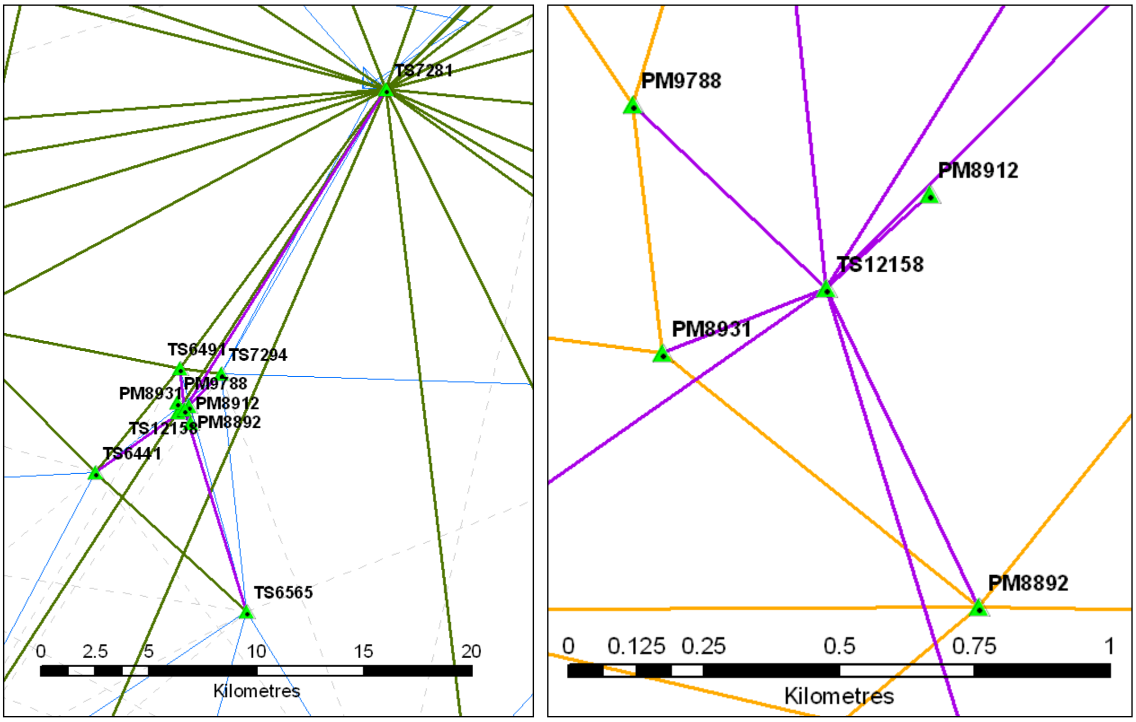


Figure 5: Parkes CORS (TS12158) local tie survey (purple) amongst GPS spine (green), DDS spine (grey/blue) and A1 sub-spine (orange).

After completion of the field work and baseline processing/reduction, the drip-feed least squares adjustment showed a very good agreement between spine and sub-spine networks (Table 1). The difference between the 2A0-only solution and the 2A0+A1 solution is only (ΔN: 0.002 m, ΔE: 0.002 m). PM8912 (B2) was temporarily held fixed in horizontal only for analysis purposes and found to agree very well with the higher order networks.

Table 1: Horizontal drip-feed for Parkes CORS (TS12158) local tie survey.

| Fully Constrained GDA94 | | | Coordinates for TS12158. PM8892 (LCL3) Constrained for AHD71 | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Fixed** | **Class** | **Order** | **VF** | **Northing (m)** | **Easting (m)** | **AHD71 (m)** | **ΔN (m)** | **ΔE (m)** |
| TS6491 | 2A | 0 | 0.07 | 6333160.014 | 609735.999 | 345.111 | 0 | 0 |
| +TS6441 | 2A | 0 | 0.13 | 6333160.011 | 609735.998 | 345.111 | -0.003 | -0.001 |
| +TS6565 | 2A | 0 | 0.40 | 6333160.008 | 609735.997 | 345.111 | -0.003 | -0.001 |
| +TS7281 | 2A | 0 | 0.39 | 6333160.007 | 609735.998 | 345.111 | -0.001 | 0.001 |
| +TS7294 | 2A | 0 | 0.80 | 6333160.012 | 609736.000 | 345.111 | 0.005 | 0.002 |
| +PM8892 | A | 1 | 0.92 | 6333160.014 | 609736.001 | 345.111 | 0.002 | 0.001 |
| +PM8931 | A | 1 | 0.88 | 6333160.015 | 609736.001 | 345.111 | 0.001 | 0.000 |
| +PM9788 | A | 1 | 0.90 | 6333160.014 | 609736.002 | 345.111 | -0.001 | 0.001 |
| +PM8912 | B | 2 | 0.89 | 6333160.014 | 609736.003 | 345.111 | 0.000 | 0.001 |

The horizontal difference between the Regulation 13 and the local tie survey coordinates for Parkes CORS is (ΔN: +0.028 m, ΔE: -0.003 m), being indicative of the minor local distortions between GDA94(1997) and GDA94(2010) in Parkes.

Upon the completion of the GDA94(1997) constraints, the drip-feed adjustment of the AHD71 values is performed. Again, all marks showed very good agreement, only changing the coordinates of Parkes CORS by a few millimetres at a time (Table 2). This case study provides an example of a CORSnet-NSW local tie survey with a straight forward adjustment due to a close agreement between the spine and sub-spine networks.

Table 2: Vertical drip-feed for Parkes CORS (TS12158) local tie survey.

| Fully Constrained AHD71 | | | | | |
|---|---|---|---|---|---|
| **Constrained** | **Class** | **Order** | **VF** | **AHD71 (m)** | **ΔAHD71 (m)** |
| PM8892 | LC | L3 | 0.90 | 345.111 | - |
| +PM8912 | LC | L3 | 0.88 | 345.113 | 0.002 |
| +PM8931 | LC | L3 | 0.89 | 345.108 | -0.005 |
| +PM9788 | LC | L3 | 0.88 | 345.109 | 0.001 |

### 3.2 Lockhart CORS: An Abrupt Shift from Spine to Sub-Spine

Lockhart CORS (TS12162) is a Tier 3 CORSnet-NSW station approximately 55 km away from the nearest GPS spine station. There is very little spine control available and the closer DDS spine marks are very difficult to access. The decision was made to connect to the three closest GPS spine stations, which were spread around the CORSnet-NSW station. These baseline distances ranged from 56 km to 59 km (Figure 6).

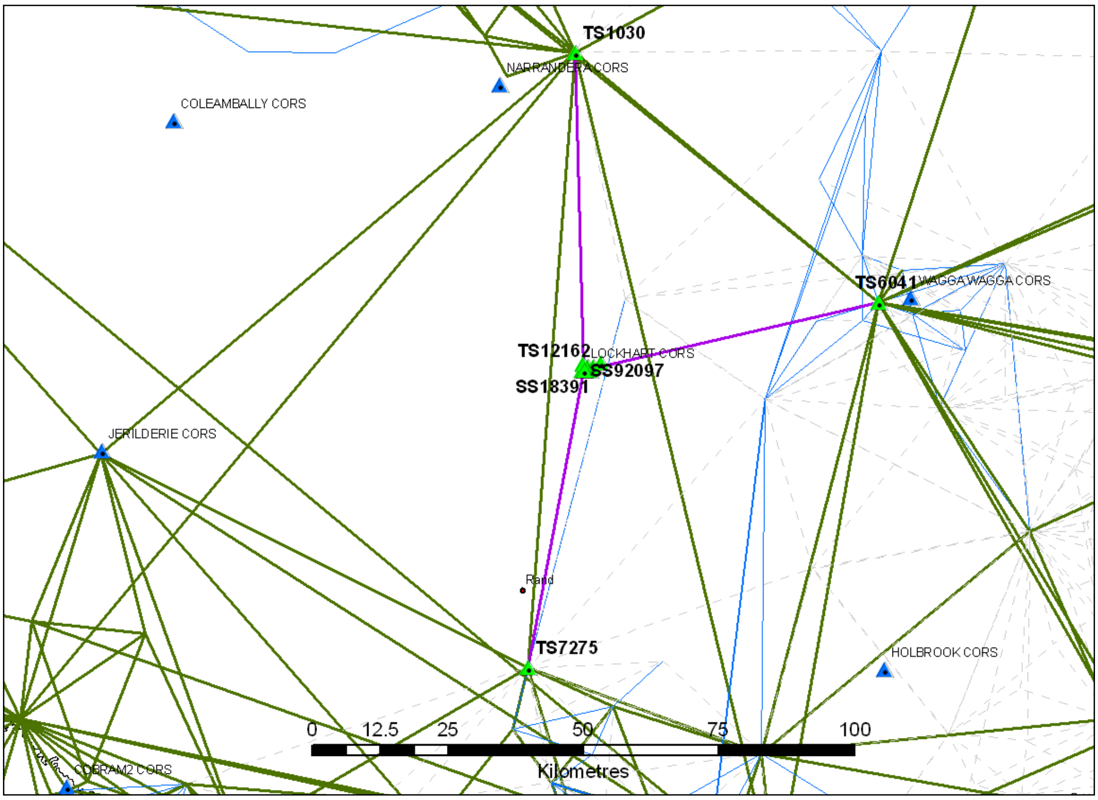


Figure 6: Lockhart CORS (TS12162) local tie survey (purple) amongst GPS spine (green) and DDS spine (grey/blue).

While Lockhart has a well established sub-spine network (Figure 7), only limited AHD71 control is available – along the main road in and out of town, established from a single AHD71 levelling adjustment. Marks with AHD71 values derived from separate adjustments are often connected to for additional checking, but this was not possible in this case. Many of the marks are not suitable for GNSS measurements (mainly due to tree coverage) or have been destroyed since they were placed. Three suitable LAL1 marks (i.e. SS18390, SS18391 and SS18392) were located and observed to determine the AHD71 value at Lockhart CORS. Three additional marks in the A1 sub-spine (i.e. SS92097, PM30448 and PM30459) were also connected to because they were desirable for the horizontal adjustment of the tie survey, i.e. for matching the distortions of the local control.

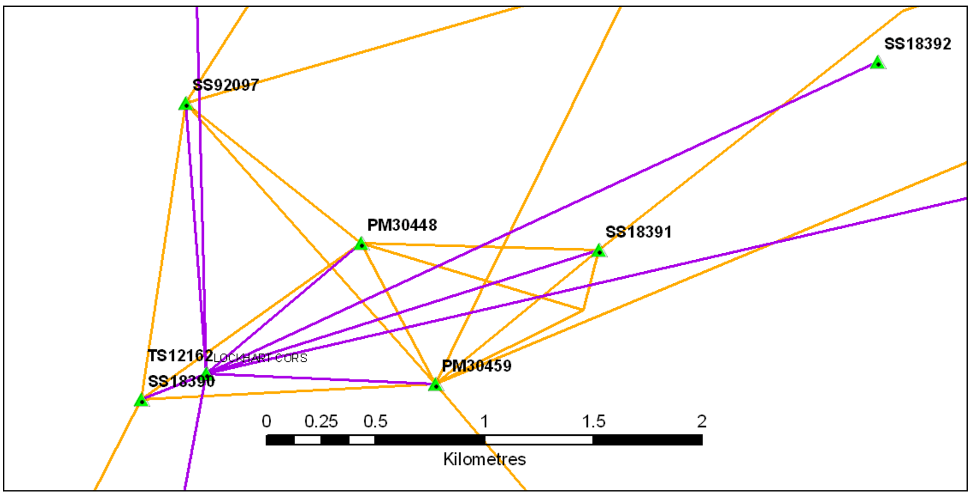


Figure 7: Lockhart CORS (TS12162) local tie survey (purple) amongst A1 sub-spine (orange).

As mentioned earlier, introducing constraints one at a time allows the effect on the resultant coordinates of the CORSnet-NSW station to be analysed. In this case, the adjustment began by drip-feeding constraints from the 2A0 network down to the A1 network. The 2A0 marks showed very good agreement. However, the introduction of the A1 network constraints to the adjustment caused an abrupt shift in the coordinate of the CORSnet-NSW station as the survey began to pair the 2A0 and A1 control networks (Table 3). However, it is important to note that the residuals to the 2A0 marks are less than 2 ppm, which satisfies the precision requirements of GNSS measurements for a class 2A survey.

Table 3: Horizontal drip-feed for Lockhart CORS (TS12162) local tie survey.

| **Fully Constrained GDA94** | | | **Coordinates for TS12162. SS18390 (LAL1) Constrained for AHD71** | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Fixed** | **Class** | **Order** | **VF** | **Northing (m)** | **Easting (m)** | **AHD71 (m)** | **ΔN (m)** | **ΔE (m)** |
| TS6041 | 2A | 0 | 0.11 | 6101713.906 | 473229.638 | 156.051 | 0.000 | 0.000 |
| +TS1030 | 2A | 0 | 0.11 | 6101713.908 | 473229.633 | 156.051 | 0.002 | -0.005 |
| +TS7275 | 2A | 0 | 0.11 | 6101713.913 | 473229.629 | 156.051 | 0.005 | -0.004 |
| **+PM30448** | **A** | **1** | **1.12** | **6101713.962** | **473229.532** | **156.051** | **0.049** | **-0.097** |
| +PM30459 | A | 1 | 1.19 | 6101713.967 | 473229.535 | 156.051 | 0.005 | 0.003 |
| +SS18390 | A | 1 | 1.38 | 6101713.963 | 473229.532 | 156.051 | -0.004 | -0.003 |
| +SS18391 | A | 1 | 1.62 | 6101713.964 | 473229.528 | 156.051 | 0.001 | -0.004 |
| +SS92097 | A | 1 | 1.61 | 6101713.963 | 473229.529 | 156.051 | -0.001 | 0.001 |

The horizontal difference between the Regulation 13 and the local tie survey coordinates for Lockhart CORS is (ΔN: +0.088 m, ΔE: -0.082 m), which is indicative of the higher level of distortion between GDA94(1997) and GDA94(2010) in Lockhart.

The vertical drip-feed adjustment showed a very good agreement between the three levelled marks occupied, with changes of less than 0.005 m the AHD71 value of Lockhart CORS (Table 4). This adjustment demonstrates that for the purpose of the survey (i.e. creating a local-fit coordinate) the A1 sub-spine must be allowed to overpower the 2A0 spine where necessary. This is further discussed in section 4.

Table 4: Vertical drip-feed for Lockhart CORS (TS12162) local tie survey.

| **Fully Constrained AHD71** | | | | | |
|---|---|---|---|---|---|
| **Constrained** | **Class** | **Order** | **VF** | **AHD71 (m)** | **ΔAHD71 (m)** |
| SS18390 | LA | L1 | 1.61 | 156.051 | - |
| +SS18391 | LA | L1 | 1.58 | 156.047 | -0.004 |
| +SS18392 | LA | L1 | 1.54 | 156.048 | 0.001 |

### 3.3 Bingleburra CORS: High Precision Observations within a Low Precision Network

Bingleburra CORS (TS12166) is a Tier 2 CORSnet-NSW station situated 90 m from TS5600 Richardson (2A0) in an area of 2A0 DDS spine with only one GPS spine mark within 30 km. Established AHD71 is only available to the southeast, some 10 km away. This was a difficult adjustment due to the lack of GNSS-derived horizontal control (such as GPS spine or sub-spine networks) and the long distance to AHD71 control (Figure 8).

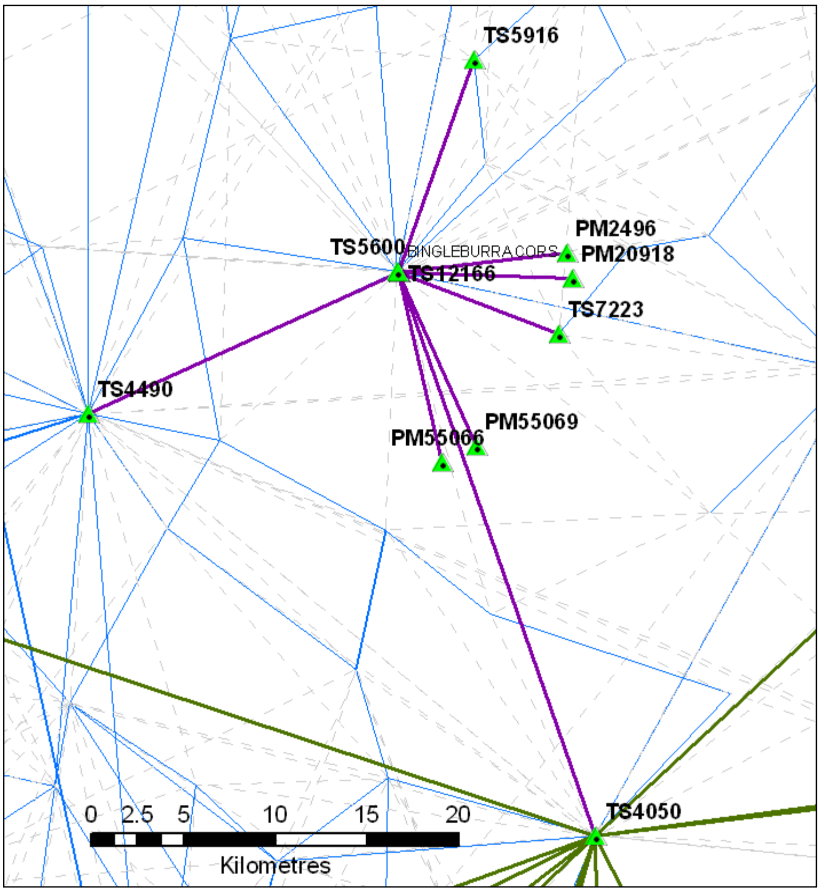


Figure 8: Bingleburra CORS (TS12166) local tie survey (purple) amongst GPS spine (green) and DDS spine (blue/grey).

LPI routinely performs reference mark (RM) monitoring surveys for Tier 2 CORSnet-NSW sites, involving sub-millimetre measurements with a precise total station (Janssen, 2009). TS5600 was connected to from Bingleburra CORS during the RM survey and these selected total station observations (a mean of 5 rounds for zenith angle and slope distance) were included in the adjustment, along with the usual GNSS baselines to TS5600.

The constrained adjustment yielded several outliers with residuals in the order of a few centimetres (or about 3 ppm). By varying the control held fixed, the adjusted coordinates of the CORS fluctuated at the centimetre level. Initially this seems excessive, however, the DDS network design accuracy for this area was 15 ppm, and residuals of this size are quite good in comparison to the design accuracy. The decision was made to better fit the coordinates of Bingleburra CORS to match TS5600 by realistically weighting the precise total station observations with a standard deviation of 0.5” and 0.5 mm. This caused the coordinates of the CORS to be consistent with the immediate 2A0 control provided by TS5600.

The final horizontal difference between the Regulation 13 and the local tie survey coordinates for Bingleburra CORS is (ΔN: +0.044 m, ΔE: +0.064 m). This coordinate difference can only be taken as a general indication of distortion between GDA94(1997) and GDA94(2010) for the immediate area around the CORS due to the large ppm design accuracy of the larger area. This level of distortion is more a reflection of the distortions apparent specifically at TS5600 Richardson, and not throughout the surrounding network.

The marks along the western extent of the existing sub-spine network (Figure 9) had to be 'jumped over' in order to connect to marks with orthometrically levelled AHD71 heights. The vertical drip-feed analysis showed a change in the AHD71 value of -0.017 m at Bingleburra CORS (Table 5).

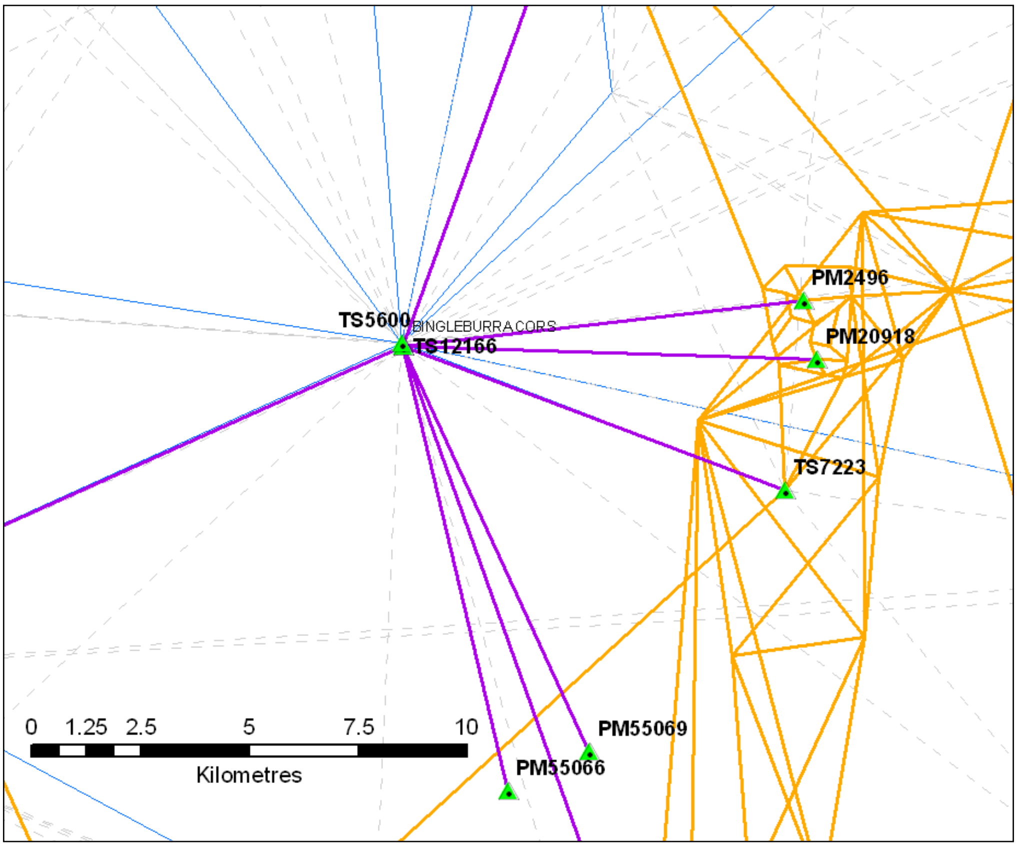


Figure 9: Bingleburra CORS (TS12166) local tie survey (purple) amongst regional sub-spine (orange) and DDS spine (blue/grey).

Table 5: Vertical drip-feed for Bingleburra CORS (TS12166) local tie survey.

| 234950 Fully Constrained AHD71 | | | | | |
|---|---|---|---|---|---|
| **Constrained** | **Class** | **Order** | **VF** | **AHD71 (m)** | **ΔAHD71 (m)** |
| PM2496 | LB | L2 | 2.47 | 458.949 | - |
| +PM20918 | LB | L2 | 2.41 | 458.942 | -0.007 |
| +PM55066 | LB | L2 | 2.40 | 458.932 | -0.010 |
| +PM55069 | LB | L2 | 2.31 | 458.932 | 0.000 |

Analysing this change from the perspective of SP1 version 1.7 (ICSM, 2007), the accuracy of LCL3 levelling is dependent on the rule $12\sqrt{k}$, where k is the distance in kilometres. At a distance of 10 km, this gives a misclose allowance of around 0.038 m, showing the agreement between marks is within this tolerance. At this distance, the requirement for a class A height with GNSS techniques is for an observation with a standard deviation equal to or less than 0.076 m (based on the equation given in section 4.1), confirming that the observations and adjustment are within the desired precision. It should be noted that spirit levelling connections were not feasible due to time, staffing and budget constraints.

## 4 ALLOCATION OF CLASS AND ORDER TO CORSnet-NSW STATIONS

At the time of writing, SP1 is in the process of being updated. All discussions in this section refer to SP1 version 1.7 (ICSM, 2007). It is recognised that some argue this methodology should not produce horizontal coordinates that are allocated class 2A and order 0.

### 4.1 Class

SP1 defines class as a function of the planned and achieved precision of a survey network that is dependent upon the following components:

- Network design.
- Survey practices adopted.
- Equipment and instruments used.
- Reduction techniques employed.

The allocation of class 2A for the local tie survey could be disputed due to the radial network geometry. While the authors agree that observing the closing lines of the network would add confidence to the result of the survey, the quality of the data can be supported by other factors, e.g. its agreement with the existing survey network (of a known quality), validation via AUSPOS and dual occupations. There is also an element of redundancy through the sheer amount of radiations into the established survey network.

However, SP1 elaborates on the allocation of class (referring to Table 6): "*The allocation of class to a survey on the basis of the results of a successful minimally constrained least squares adjustment may generally be achieved by assessing whether the semi-major axis of each relative standard error ellipse or ellipsoid (i.e. one sigma), is less than or equal to the length of the maximum allowable semi-major axis (r) using the following formula*

$$r = c\,(\,d + 0.2\,)$$

*where* $r$ *= length of maximum allowable semi-major axis in mm.*
$c$ *= an empirically derived factor represented by historically accepted precision for a particular standard of survey.*
$d$ *= distance to any station in km.*"

Table 6: Classification of horizontal control surveys from SP1.

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

The distance from the CORSnet-NSW station to the nearest mark in the local tie survey can range from less than 100 m to 20 km or more. Applying said values into the above formula yields an $r$ value which can vary from 0.9 mm to more than 60 mm! It is clear that this sort of analysis is irrelevant to the purpose of CORS local tie surveys.

Furthermore, SP1 stipulates that the adoption of the aforementioned formula as one element in the determination of class will generally provide these specifications with the flexibility necessary to accommodate survey networks containing control stations that are closely spaced, widely spaced or with variable spacing. However, it is recognised that the nature of survey adjustments is such that it is not always possible to fully describe the results of a survey simply by considering the statistical output of the adjustment. Part of the assessment of the quality of a survey is also dependent upon a subjective analysis of both the adjustment and of the survey itself. Most importantly, SP1 specifically states: "*The ultimate responsibility for the assignment of a class to the stations of the survey network must remain within the subjective judgement of the geodesists of the relevant authority*."

It is impossible to satisfy the above equation when a CORS is placed within a dense ground control network. Consequently, the effect of any station within one kilometre of the CORSnet-NSW station is ignored. The allocation of class 2A also follows from the intent of the CORS mark. CORSnet-NSW stations are active survey marks, enabling centimetre-level positioning for a wide range of applications across multiple industries. In time, the CORSnet-NSW stations will realise the fundamental datum for NSW (and contribute to the realisation of the national datum). Survey marks with such a high value in terms of not only cost, but also monument quality, productivity and frequency of use should have a hierarchical rating to reflect this appropriately.

### 4.2 Order

SP1 defines order as "*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*." As stated earlier, the immediate goal of CORSnet-NSW local tie surveys is to produce 'local-fit' coordinates, and this is usually achieved by holding the A1 sub-spine control fixed in addition to the 2A0 spine control.

SP1 continues to state that the order assigned to the stations in a new survey network following constraint of that network to the existing coordinate set may be (a) not higher than the order of existing stations constraining that network, and (b) not higher than the class assigned to that survey. This is a standard rule of SP1 that is broken by CORSnet-NSW local tie surveys. By holding first order, such as an A1 sub-spine, marks constrained, SP1 limits the allocated order of the CORSnet-NSW station to be only first order and not order 0.

However, as with class, SP1 recognises that the assessment of the quality of a network following a constrained adjustment remains dependent upon a subjective analysis of the adjustment, the survey, and the ties to the existing survey control. SP1 again specifically states: "*The ultimate responsibility for the assignment of order to the stations in a survey network must remain within the subjective judgement of the geodesists of the relevant authority.*"

The subject of CORSnet-NSW local tie surveys is a classic example where the relevant authority (i.e. LPI) is allowed the liberty of allocations of class and order that do not satisfy the standard rules of SP1. Inserting a CORSnet-NSW station (essentially a modern spine station) into a dense survey ground network means a sub-mm error ellipse would be required to satisfy the standard rules of SP1. Even if the allocation was downgraded to A1, this would result in a required error ellipse of less than a few millimetres over short distances. This is impossible to achieve with standard survey GNSS observations. Therefore, taking into account the intent of the mark, LPI will issue a class and order allocation for CORS of 2A0 as a business rule when deemed appropriate. However, in areas of particularly notable distortions or exhibiting a lack of available control, this allocation may be downgraded to A1, or even B2, at the discretion of an LPI Senior Surveyor. For example, Ballina CORS has been allocated horizontal class A and order 2.

## 5 TOWARDS A NEW DATUM ADJUSTMENT

The ultimate goal of local tie surveys is for reverse propagation in the next datum adjustment, i.e. a means to propagate the Regulation 13 derived CORSnet-NSW station coordinates outward to the ground survey network.

Since the GDA94(1997) adjustment, there has been over a decade worth of GNSS observations and adjustments that can be harvested for use in a national adjustment. As SCIMS has been extended and updated over the years, it now contains significantly more GNSS connections between marks than were available for the GDA94(1997) adjustment. Haasdyk and Watson (2013) explain the methodology by which this GNSS baseline repository is currently being data-mined, cleaned and prepared at LPI for use in any future improved national datum.

The adjustment of the next generation Australian datum will be strongly supported in NSW by constraining the Regulation 13 certified CORSnet-NSW stations. The GNSS baselines observed as part of the CORSnet-NSW local tie surveys will be crucial to propagate these Regulation 13 coordinates outward into and through the existing survey ground control networks. This will provide a homogeneous national datum realisation across NSW, thereby significantly improving the State’s geodetic infrastructure for years to come.

## 6 CONCLUDING REMARKS

CORSnet-NSW local tie surveys provide an efficient and rigorous method of survey to obtain ‘local-fit’ coordinates in GDA94(1997) using the GNSS survey and least squares adjustment techniques outlined in this paper. As a side goal, many multi-hour AUSPOS datasets are captured, and GNSS ‘island adjustments’ are connected into the existing state-wide fabric. Most importantly, local tie surveys provide a consistent and rigorous method of connecting the CORSnet-NSW stations to existing ground control networks in support of the realisation of the next generation Australian datum in NSW. Through these local tie surveys, LPI can effectively transfer datum from the CORSnet-NSW network to the ground marks, providing a homogeneous datum adjustment and significantly improving the State’s survey infrastructure. LPI encourages other jurisdictions and commercial CORS network providers to adopt a similar approach in order to connect CORS to the existing surrounding survey control.

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