Survey Infrastructure Preservation and Upgrade: Trigonometrical Stations in NSW

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ABSTRACT

Land and Property Information (LPI) is the custodian of the geodetic infrastructure in New South Wales, which incorporates approximately 6,000 traditional trigonometric stations that formed the backbone of the survey control network before the introduction of more than 160 CORSnet-NSW stations. Keeping the ageing passive geodetic infrastructure current and ready for utilisation requires regular maintenance such as fit-for-purpose assessments, verification of owner records, contact details, access details, and (most importantly) recent, time-stamped Global Navigation Satellite System (GNSS) observations. As this level of maintenance is neither viable nor justifiable for the entire network of trig stations in the modern era, LPI has selected a subset of 'high-scoring' trig stations based upon a number of factors including a 'TrigStar' rating, monument quality and significance within the contexts of survey network, local community and heritage. After the successful completion of a campaign-style pilot project in the Central West, and subsequent campaigns on the South Coast, in Northern NSW and in Southern NSW, LPI continues to carry out this trig rationalisation and targeted upgrade across the State. LPI plans to complete its first pass of trig maintenance and upgrade before the realisation of the nation's next-generation datum in 2015. This paper outlines how this method provides an effective strategy to maintain geodetic infrastructure across NSW, connect traditional survey infrastructure with modern-day satellite-based positioning and contribute new GNSS observations towards the next-generation Australian datum.

KEYWORDS: *Survey infrastructure, trig stations, preservation, maintenance, AUSPOS, datum improvement.*

1 INTRODUCTION

Land and Property Information (LPI) is the custodian of the survey control network in New South Wales (NSW). Currently, some 250,000 marks are managed within the Survey Control Information Management System (SCIMS), the State's survey control database (Kinlyside, 2013). This includes approximately 6,000 traditional 'passive' trigonometric (trig) stations and more than 160 'active' trig stations referred to as Global Navigation Satellite System

(GNSS) Continuously Operating Reference Stations (CORS) as part of CORSnet-NSW (e.g. Janssen et al., 2013; Janssen, 2014).

In this context, it is useful to briefly summarise the history of the geodetic network in NSW (Rassaby, 1980). The Trigonometrical Survey of New South Wales, as it was then known, commenced in 1867 with the selection of the first baseline at Lake George and continued with little interruption for almost 50 years until it was suspended for reasons of economy and war in 1916. By then, about one third of the State (mainly in the south-east) had been covered by a series of well-conditioned triangles of first and lower orders. The survey was resumed intermittently between the two World Wars with much of its progress attributable to the Royal Australian Survey Corps, particularly the connections to the Victorian and Queensland networks, and along the North Coast.

The Division of National Mapping extended the first-order networks eastwards through Broken Hill from South Australia to Cobar (1955-56) and north of Broken Hill into Queensland (1961). Other networks were established by the NSW Department of Lands between Tamworth and Condobolin (1956-57), Cobar and Ivanhoe (1964), and around Narrabri (1957). Together with the first-order traverses performed by the Royal Australian Survey Corps, prior to the national adjustment of 1966, the geodetic network had extended to approximately half of the State – this had taken 100 years.

A turning point in the geodetic survey network was reached in 1973 with the formulation of a plan to update, revise and complete the network to acceptable standards. This systematic rationalisation commenced in the Sydney-Newcastle-Wollongong region and continued through the coastal belt and then westwards. It was found that many of the stations listed in the old County Registers had disappeared as a result of the type of marking used and the difficulty of protection. Wherever possible, the old-style cairn and pole stations were replaced by a concrete pillar with demountable mast and vane, allowing constrained centring of theodolite and distance measuring equipment.

Looking after the State's survey control network is in everyone's interest because survey marks support billions of dollars of investment, property rights and infrastructure. Loss of marks can significantly degrade the integrity of legal property boundaries and spatial infrastructure. LPI champions the preservation of survey marks through its "Survey Marks: All About Protecting Them" campaign (LPI, 2012) and Surveyor Generals Direction No. 11: "Preservation of Survey Infrastructure" (LPI, 2004). This effort is everybody's responsibility.

However, keeping the substantial geodetic component of the survey control network current and ready for utilisation requires a different approach. Regular maintenance such as fit-for-purpose assessments, verification of owner records, contact details, access details, and recent, time-stamped GNSS observations are primarily an LPI responsibility. This paper outlines the campaign-style trig station upgrade methods employed by LPI, providing an effective strategy to preserve the most fundamental component of the survey control network across NSW, connect traditional survey infrastructure with modern-day satellite-based positioning and contribute new GNSS observations towards the next-generation Australian datum.

1.1 What Makes a Trig Station?

Trig stations are the traditional backbone of a classical survey control network and form the primary or highest-order network, from which all other surveys are controlled. Trig stations

come in a variety of forms and structures and usually consist of a primary monument or standpoint surrounded by witness or eccentric marks. The primary monument can take on a multitude of forms, ranging from survey pillars (concrete or steel) to plugs in stone underneath rock cairns or in rare cases galvanised iron pipes or stainless steel rods in soil. It should be noted that all CORSnet-NSW stations are also trig stations – these are known as 'active' trigs. Figure 1 illustrates the large variety of traditional trig station monuments in the NSW survey control network. Sometimes these marks have very high historical significance and are usually located in very prominent locations. Lighthouses, church spires, radio masts and tall towers are other forms of trig stations that are sometimes encountered.

Figure 1: Trig station monuments in NSW. Clockwise from top left: Steel pillar, cairn and astro pillar, concrete pillar, obelisk, concrete pillar on grand cairn, and stonework veneer on concrete pillar.

When the first major GNSS campaigns were initiated in the western part of NSW, the Geodetic Control Register (GCR) and SCIMS were maintained as separate databases. This necessitated the inclusion of occupied Permanent Marks (PMs) and State Survey Marks (SSMs) into the GCR such that those locations could be elevated to the status of trig station – commensurate with the importance of those sites and the technical functionality of the GCR. This creation of new trig station sites also included some original State border survey marks being the remains of wooden posts (e.g. TS7344 Mile Post 181 East).

However, a trig station is often more than just the physical infrastructure. It often includes the entire site or surrounding area, which may cover a significant portion of ground (up to a few hectares) and include remnants of cleared lanes to other distant trigs or marks, and permanent tenure and restrictions over the site to protect it. Trig stations usually occupy the highest and most prominent point in the local area, e.g. a hilltop, tall building or silo. While LPI (or its

predecessors) may have been the first occupant of these areas since white settlement, they are now of prime interest and value to other parties, primarily landowners, developers and telecommunication operators.

Table 1 emphasises the vast variety of trig stations across the State. Almost two thirds of all trig stations consist of a pillar or ground mark located on *private land*. Only one third of trig stations are located on government land, illustrating the importance of having a good relationship with landowners. In order to ensure that this key survey infrastructure is valued and protected by landowners, careful relationship management, face-to-face interaction and active trig maintenance are required by LPI. For one in ten trig stations, the mark type is currently unknown or uncertain, which could easily be rectified through a site visit if it is decided to maintain the trig in question.

Table 1: Selected NSW trig station metadata (categories are non-exclusive and percentages do not sum to 100).

Trig Monument Type	**% of Total**
Pillars	36.1
Pins/plugs/pipes	31.5
Unknown	9.8
Reservoirs	3.9
CORS	2.5
Other SCIMS marks	1.0
Towers	0.9
Lighthouses	0.4
Obelisks	0.2
Silos	0.2
Trig Tenure Type	**% of Total**
Private land	61.9
National parks	14.7
Crown reserves	14.6
Not in NSW	2.7
State forest	2.5
Misc. reserves	0.1
DP Connections	**% of Total**
1	9.0
2	4.6
>2	11.9

The witness or eccentric marks are connected to the primary station through a supplementary 3-dimensional terrestrial survey (Figure 2) and are occupied if it is either not possible or inconvenient to occupy the primary standpoint. For example, unpiling any rock cairn generally introduces lengthy time delays and Work Health and Safety (WHS) issues. Eccentric marks can also be used to monitor any potential movement of the main mark, although this is rarely, if ever done. Often, these marks physically consist of different objects, e.g. expended rifle cartridge in concrete, galvanised iron pipe, rod or numbered/unnumbered SSMs. On a side note, the issue of numbered SSMs that are eccentric to trig stations having two sets of coordinates and metadata in SCIMS (i.e. one as an eccentric mark and another as a unique SSM) is known to LPI and is being corrected.

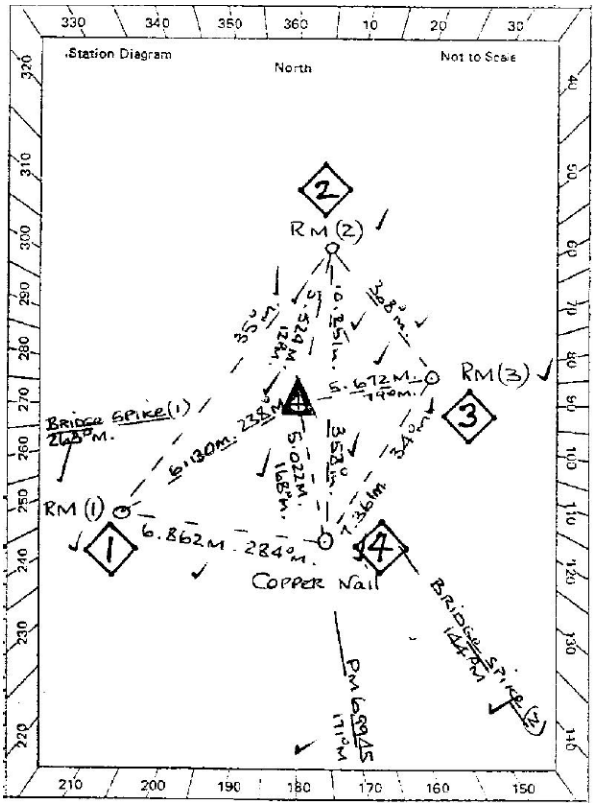

Figure 2: Trig station and witness mark sketch for TS4350 Thoolabool.

1.2 Why Maintain Trig Stations?

Under the Surveying and Spatial Information Act 2002 (NSW Legislation, 2015), by default, the Surveyor General is responsible for maintenance of survey marks:

> *9 Maintenance and repair of permanent survey marks*
>
> *(1) The Surveyor-General may, from time to time, cause notice to be given to any public authority of the location of any permanent survey marks that are located on land that is subject to the authority's control or management.*
>
> *(2) A public authority to which such a notice is given must ensure that all permanent survey marks identified in the notice are kept in good condition and repair.*
>
> *(3) On the application of a public authority to which such a notice is given, the Minister may direct that it is the duty of the Surveyor-General, and not the public authority, to keep any or all of the permanent survey marks concerned in good condition and repair.*

The Surveyor General may delegate maintenance of survey marks on public lands to the relevant public authority, but in practice this does not occur. Instead, LPI acts on behalf of the Surveyor General to carry out maintenance of survey marks, in cooperation with other public authorities where applicable.

Historically, trig stations were built and maintained by LPI staff (i.e. Piling Overseers) on an ongoing day-to-day basis. The last Piling Overseer retired towards the end of the 20th century and since that time trig stations have received minimal or no maintenance, except those close to regional offices or by special request on an ad-hoc basis. However, the ongoing

maintenance of trig stations is of particular importance due to their significant structures and placement in what are usually high-profile locations (e.g. lookouts and hilltops). Such marks in the public eye would reflect poorly on the surveying profession if they were to be indefinitely kept in a state of disrepair. Furthermore, it is critical to show landowners that the survey infrastructure located on their land is valued and maintained by LPI – this provides an incentive for landowners to identify with 'their' trig and maybe help look after it, as is sometimes done in the United Kingdom.

It is also important to maintain trig stations in order to keep LPI's records contemporary. Regular visits will keep track of changes in land ownership, variations to access paths, such as fire trails or 4WD tracks and any new structures or improvements near the site. Up-to-date information is often required to help evaluate the importance of an existing trig station, which may be competing with proposed telecommunication infrastructure or other development. Furthermore, as indicated earlier, active maintenance practically demonstrates the State's and authority's continued interest in a site.

However, it is recognised that it is neither viable nor justifiable for the entire network of trig stations to be maintained in the modern era, particularly in light of the increasing number of active trig stations being installed as part of the ongoing expansion of CORSnet-NSW. Recalling that it took 100 years to cover almost half of NSW with a large number of passive trig stations by the 1960s, it is worth noting that it took only 5 years to cover more than two thirds of NSW with 150 active trig stations via CORSnet-NSW (Janssen, 2014), which are also much easier to maintain.

1.3 Technological Developments

Over the years, the rapid uptake of GNSS technology amongst the surveying profession has seen the perceived importance of passive trig stations wane as surveyors became less dependent upon line-of-sight to propagate datum. The establishment of CORSnet-NSW (Figure 3) has compounded this effect as new, more time-efficient positioning services such as Network Real Time Kinematic (NRTK) and Virtual RINEX are now available across most of the State (e.g. Janssen and Haasdyk, 2011; Janssen, 2013). Since CORSnet-NSW provides accurate, reliable and easy-to-use access to fundamental positioning infrastructure in real time, surveyors are generally no longer willing or desirous to visit passive trig stations to connect to datum.

LPI recognises that the trig station network is now mainly for its own internal use only. Trig stations can be located in remote areas and are often difficult and time-consuming to access and therefore have low appeal to external surveyors, when contrasted with the easy access and suitable quality of marks located along roads and urban corridors. Isolated trig stations are protected from road works and other development activities, which have destroyed many survey marks (PMs and SSMs) across NSW (e.g. de Belin, 2012; Ward, 2014), and as such are expected to have a perpetual lifespan. Thus, trig stations serve as the profession's 'insurance' policy, and LPI guards the vital links in the chain to current and previous realisations and propagations of datums.

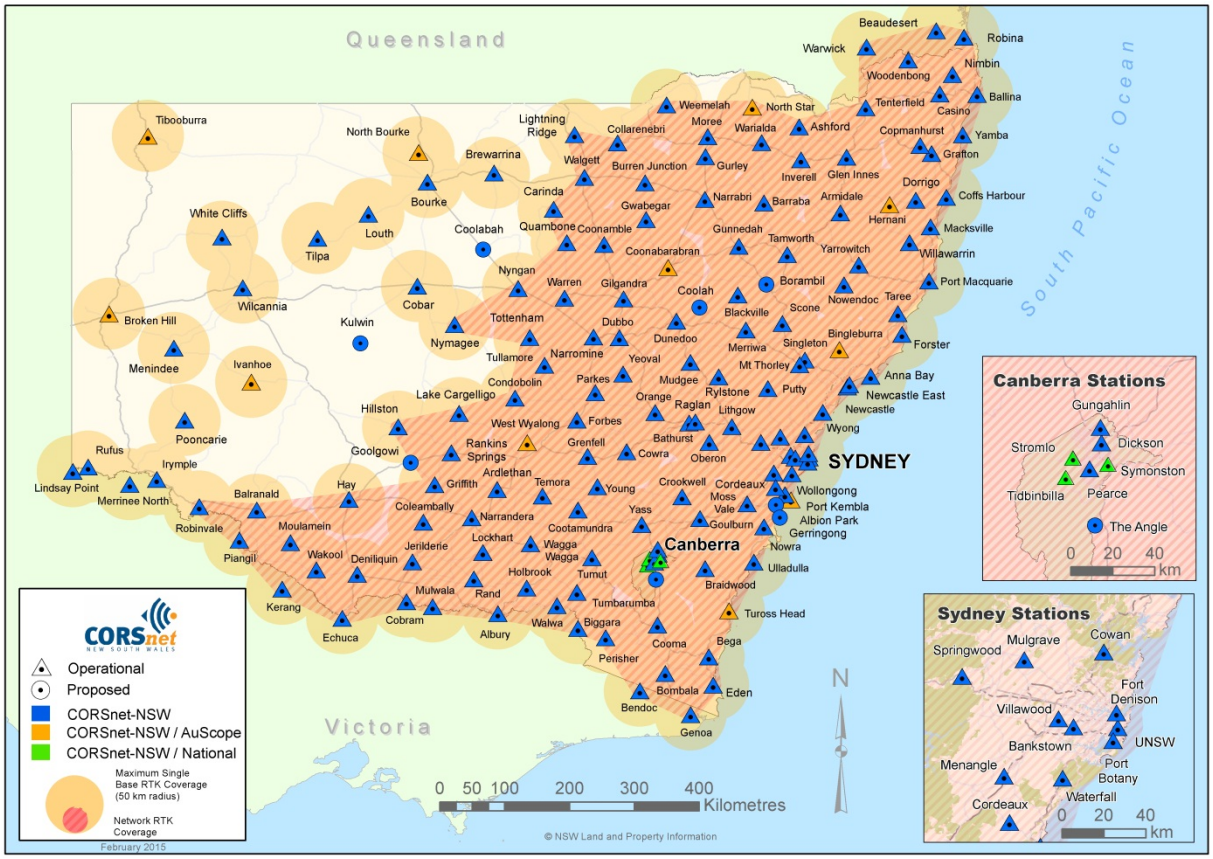

Figure 3: CORSnet-NSW coverage map as of February 2015 (LPI, 2015).

2 METHODOLOGY

2.1 Why Campaigns?

LPI has now adopted a campaign-style or project approach to carry out maintenance and upgrade of trig stations. This has originated from necessity as day-to-day survey operations place an increasing emphasis on doing ‘more with less’. The tempo of lean, highly mobile operations is often rapid and often simple, but important things like trig maintenance and upgrade are placed low on the priority list and cannot be done on a best-effort ‘while you are there’ basis. Gone are the days of survey teams, often with many staff, carrying heavy bulky equipment to trigs, occupying them for multiple days as round after round of observations were made or there was time available while staff waited for the best observing conditions or times to occur.

Targeted campaign-style maintenance programs allow numerous trig stations in a geographic area to be visited, maintained and have their metadata records updated at a common epoch (generally during a 2-week time window). However, in today’s prudent fiscal environment combined with technological advances, maintenance of the entire network of about 6,000 traditional trig stations in NSW is neither justifiable nor viable and therefore a targeted subset of the most important or desirable trig stations must be selected to direct preservation efforts towards.

2.2 TrigStar

Understandably, all trig stations are not equal. LPI's motivation to preserve and maintain trig stations can vary with regard to several criteria including:

- Previous survey work performed (e.g. number of terrestrial and GNSS observations).
- Prominence within the survey network.
- Ease of access.
- Suitability for GNSS observations.
- Suitability for further survey work (e.g. vegetation level, towers or structures, security).
- Historical significance (e.g. TS Kosciuszko, TS Cameron Corner and TS Barringun Zero Obelisk both on the NSW/QLD border).
- Local community identification (e.g. lookouts, public visits).
- Land ownership (e.g. trig reserve, state forest, national park, private land).
- Monument quality (e.g. survey pillar, trig plug and cairn, obelisk, GI nail in remains of wooden post).
- Condition of monument (e.g. decaying pillar, unpiled cairn, plug missing).
- Uniqueness of structure (e.g. concrete pillar on grand cairn, stone veneer vs. standard concrete pillar).
- Number of Deposited Plans connected to the trig station.

These criteria are used to assess each trig station across NSW and calculate a 'TrigStar' score out of 100 and a corresponding rating out of 5 stars (Figure 4). LPI has decided as a general rule to maintain the top 500-700 (i.e. about one in ten) passive trig stations with a rating of 4 or 5 stars. A similar process of rationalisation and upgrade was conducted in the 1970s and 1980s when trig stations not meeting certain standards in regards to permanence, capacity for occupation and usefulness for surveys were eliminated, while others were upgraded to concrete pillars (Rassaby, 1980).

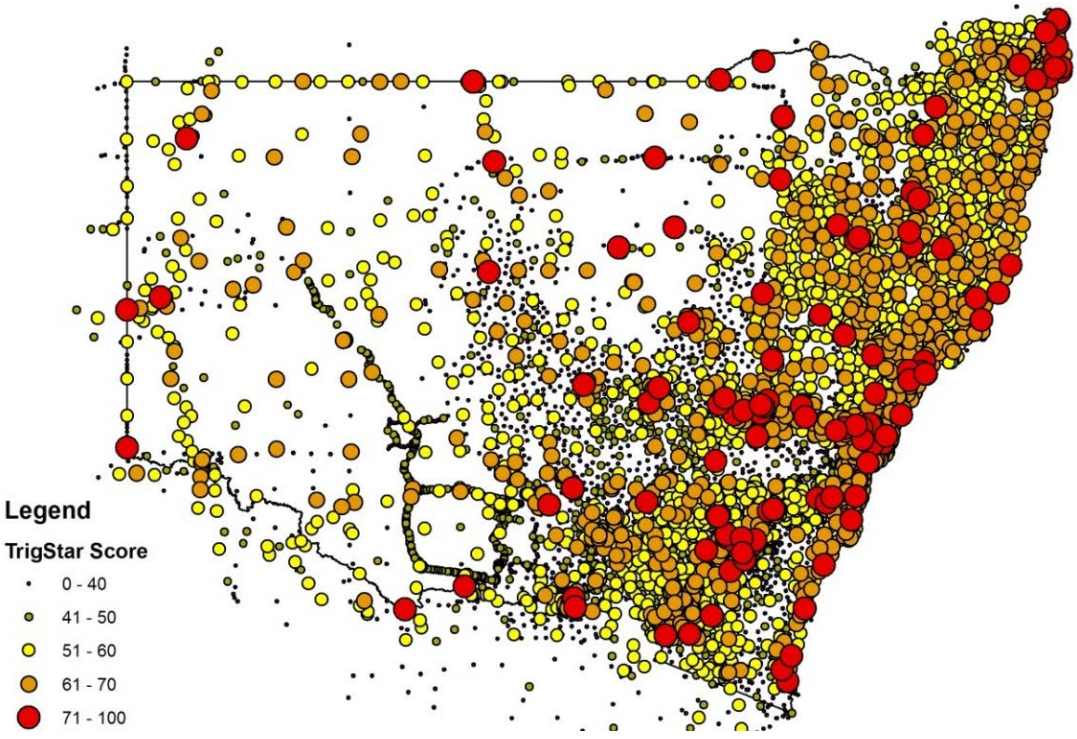

Figure 4: TrigStar scores across NSW (as of December 2014).

Initial TrigStar evaluations were conducted via an office desktop reconnaissance only, with records and imagery being searched to list potential candidates. In many instances, records were found wanting, missing, incomplete or completely out of date (i.e. 20+ years old). Generally, the trig stations with a score of 61 and above (i.e. a rating of 4 stars or higher) are selected as candidates for maintenance and upgrade in survey campaign planning. However, such a procedure failed to ensure a homogeneous coverage of suitable marks across the State. Hence additional candidates are often included, based mainly on geographical location.

In this context, it is worth noting that TS778 Lake George South Base (recall where the Trigonometrical Survey of New South Wales started all those years ago in 1867) is currently the highest-scoring trig station in NSW (Table 2). Obviously, the ranking is influenced by recent maintenance visits (all the listed trig stations but the destroyed have recently been visited) and therefore of a fluctuating nature. Currently about 115 trig stations are rated 5 stars, while about 870 trig stations occupy a 4-star rating. LPI aims to maintain approximately two thirds of all these trig stations.

Table 2: Current top-ranking trig stations in NSW according to TrigStar.

Rank	Trig Number	Trig Name	TrigStar Score
1	TS778	Lake George South Base	84
2	TS5816	Tarella	81
3	TS5566	Sutton Forest	80
4	TS3604	Observatory (destroyed)	79
5	TS2761	Kosciuszko	78
	TS5517	Mulley	78
	TS6424	Beelera	78
	TS6705	Cobar	78
	TS7065	Warral	78
	TS7273	Eden Breakwater	78
	TS7305	Burns	78
	TS7383	Westdale	78

2.3 Maintaining Geodetic Infrastructure

Keeping the State's geodetic infrastructure current and ready for utilisation requires regular maintenance and upgrade. At LPI, this currently involves the following actions:

1. Completion of a new TrigStar form. Many of the initial TrigStar assessments were completed at the office desk rather than on site, which is prone to incomplete and inaccurate information.
2. Capture of new and fully digital photographic records. This allows for quick future use assessments with regards to condition of monument including eccentrics, suitability for GNSS survey, vegetation regrowth, etc. A historical record of the site at the epoch of the photograph is also captured.
3. Verification or update of landowner details and contact information. Changes in property ownership and contact details are noted and recorded for future use. Time invested in discussions with owners strengthens relationships with local hosts, helps reduce access issues for future users and helps promote an interest in (and hopefully a watchful eye on) the asset on their land.
4. Observation of at least 6 hours of dual-frequency GNSS data (preferably overnight).
5. Audit of eccentric marks.
6. Update of the access record. Many of the existing access details were recorded in the 1970s and are outdated. LPI continues with the traditional 'chainage-and-event' based access records but has added a new GPS Exchange Format (GPX) plot, based upon the

tracklog from a vehicular GNSS unit. This spatially referenced file can be imported into a Geographic Information System (GIS), overlaid on imagery and imported back into handheld GNSS units to aid navigation to the site.

7. Update of the visitation log. LPI's records show when the station was last visited, noting the purpose and any other major details arising from the visit.
8. Painting of the monument and repair if necessary. This is the aspect most visible to the public. Trig stations that are well maintained and without graffiti or damage demonstrate to landowners, hosts and the public that they are a valuable and important asset which is still in active use. Their condition also reflects on the image of the surveying profession.
9. Clearing of light regrowth vegetation. Maintaining trig stations includes keeping them in a condition that allows future GNSS observations. Light regrowth is therefore cleared to preserve the monument's usability.

Figure 5 shows a trig station before and after station maintenance was performed. Often the concrete base is also painted white to increase visibility in aerial images (and potentially allow the trig station to be used as ground control). Figure 6 illustrates a GPX access trail overlaid on aerial imagery, clearly demonstrating the benefit of generating visual access details. An example of the traditional visitation log and access entries available through SCIMS is shown in Figure 7.

It should be noted that not all trig stations are considered in these campaigns. GNSS CORS and reservoir trig stations are considered out of scope. LPI has a separate maintenance program for CORS, and reservoirs are now excluded due to WHS concerns and general poor monument quality related to mark movement caused by variation in water levels and seasons. In areas of low trig station density, silos were occasionally visited as a last resort where WHS requirements could be satisfied. Alternatively, selected PMs may be visited in lieu of low-scoring trig stations in order to allow a sufficient geometric spread of AUSPOS datasets (see section 2.4) across the area of interest.

Figure 5: TS1730 Cumber before and after trig maintenance.

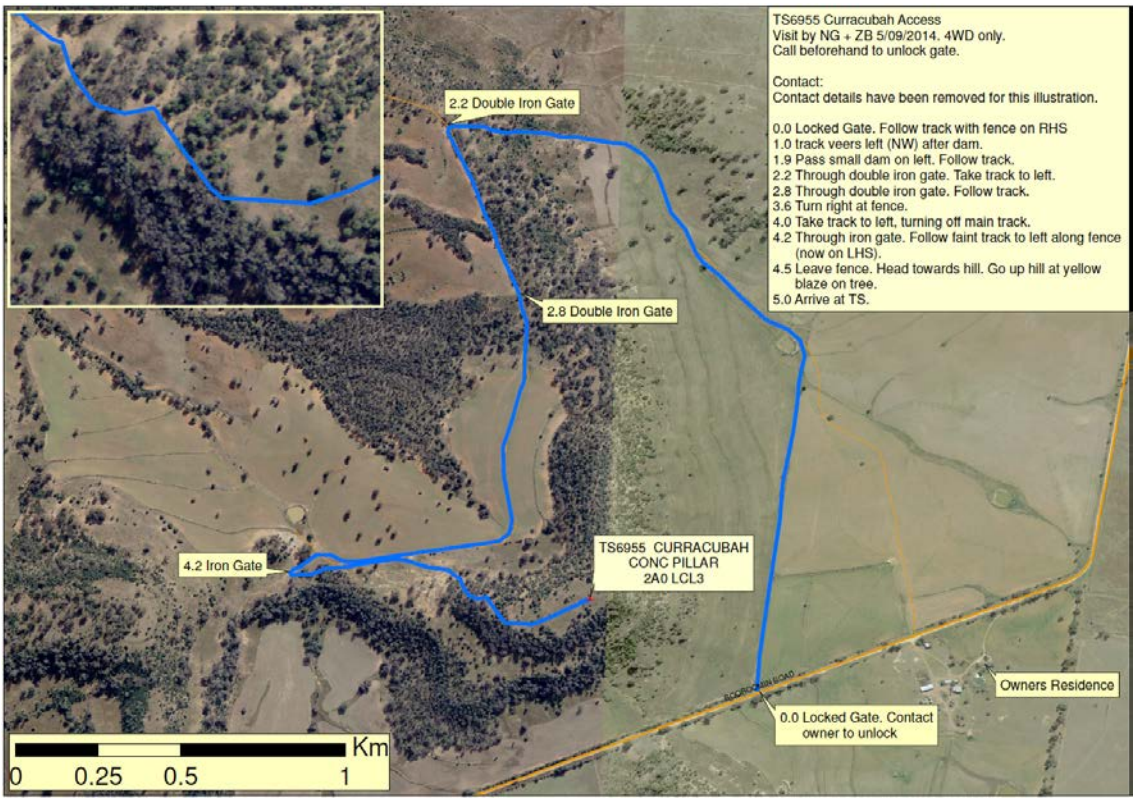

Figure 6: TS6955 Curracubah access including GPX trail overlaid on aerial imagery.

VISITATION LOG

Date	Organisation	Comments
1-NOV-2013	LAND & PROPERTY INFORMATION - BATHURST	STATION VISITED FOR MAINTENANCE AND GNSS SURVEY. GOOD VISIBILITY FOR GNSS. PILLAR, MAST AND VANES PAINTED
10-JUN-1992	LAND & PROPERTY INFORMATION - BATHURST	STATION VISITED FOR GPS SURVEY ON NUMEROUS OCCASIONS AROUND THIS DATE .
15-OCT-1980	n/a	NEW MAST AND VANES PLACED. NEW ACCESS.
2-JUN-1980	n/a	NEW MAST AND VANES PLACED PILLAR PAINTED.
20-DEC-1979	n/a	NEW MAST AND VANES PLACED
15-JUL-1976	DEPARTMENT OF MAIN ROADS	STEEL PILLAR FD.
29-JAN-1976	n/a	NEW MAST AND VANES PLACED.
19-NOV-1974	n/a	STEEL ROOF TOP PILLAR PLACED CONCENTRIC TO OLD TRIG PLUG. CANNOT CONFIRM CONCENTRICITY. MAST AND VANES PARTLY GONE CAIRN INTACT.
1-JAN-1969	n/a	
1-JAN-1892	DEPARTMENT OF LANDS	STATION ESTABLISHED PLUG IN ROCK MAST AND VANES, STONE CAIRN.

ACCESS

Date	Vehicle Access	Walk Time (min)
1-NOV-2013	NONE	60

Description

Allow 20 minutes (drive) plus 60 minutes (walk).
0.0 From WOODBURN ROAD, turn onto CLYDE RIDGE ROAD at sign ?Pigeon House Mountain 14 km?.
1.6 Pass THREE FALLS ROAD on LHS. Pass sign ?Flat Rock State Forest?.
5.9 Pass McMAHONS ROAD on LHS.
7.7 Turn right onto YADBORO ROAD at sign ?Pigeon House Mountain, Yadboro?.
9.3 Pass sign ?Yadboro State Forest?.
12.0 Turn right onto PIGEON HOUSE ROAD at sign ?Morton National Park?.
13.2 Leave vehicle at car park and follow steep walking track to TS (60 minute walk).
16.3 Arrive at TS.

Note also that CLYDE RIDGE ROAD offers good access from other Trigs to the South of Pigeon House.

Figure 7: SCIMS visitation log and access for TS3737 Pigeon House ('?' indicates quotation marks in the original document, caused by computer interface glitches).

2.4 Improving Geodetic Infrastructure via AUSPOS and a Next-Generation Datum

Monument condition and metadata are not the only features that stale with age. Of paramount importance in a geodetic survey network are modern (i.e. at least dual-constellation), time-stamped, long-session GNSS observations. This enables time series analysis of mark movement and the ability to reprocess old raw data as algorithms improve. Such results may be later displayed on the web, much like currently done for CORSnet-NSW stations. As part of the next-generation datum project, LPI is currently retrieving up to 20-year-old GPS data sessions of 3 hours or more for reprocessing using modern tools.

It is well known that systematic distortions of up to 0.2 m horizontally and 0.3 m vertically exist in NSW between the legal coordinate system as realised by SCIMS, i.e. GDA94(1997), and observations in the more homogenous GDA94(2010) realisation of the national datum as provided by CORSnet-NSW and AUSPOS (e.g. Haasdyk et al., 2010; Janssen and McElroy, 2010; Gowans and Grinter, 2013). As an example, Figure 8 illustrates these distortions across the Central West. However, the exact extent of such distortions is not fully known. Test points are required throughout the State, with higher densities in the most affected areas, and trig stations provide the best standpoint for such observations, now and into the future.

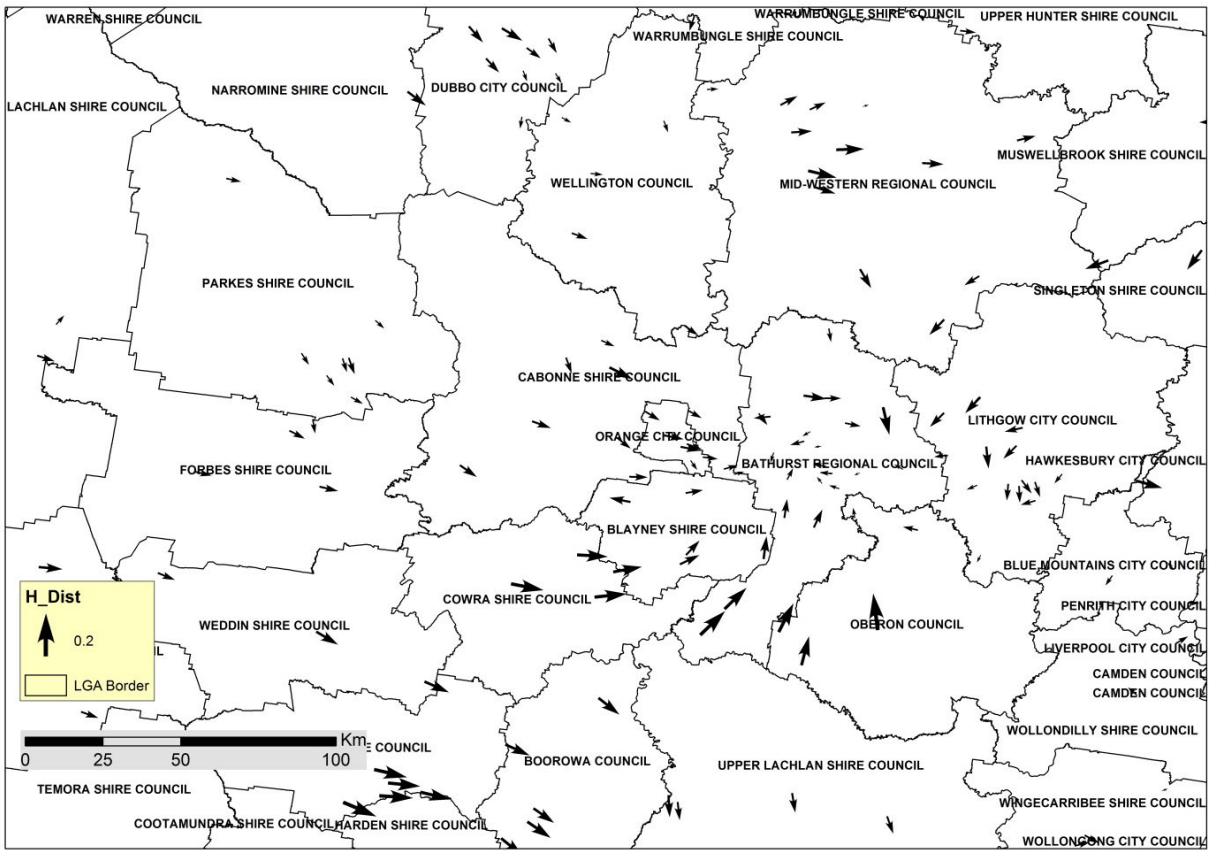

Figure 8: GDA94(1997) to GDA94(2010) distortion vectors across the Central West.

Removing these distortions between local control in GDA94(1997) and coordinates in GDA94(2010) requires a re-adjustment of the entire NSW network, without a hierarchy of fixed control, which will occur as part of the national adjustment to produce a next-generation datum for Australia (Haasdyk et al., 2014b). In the interim, a site transformation is required to relate CORS-derived positions to the local (and legally accepted) ground control available

in NSW via SCIMS (Haasdyk and Janssen, 2012). Trig stations are the logical sites to occupy and measure distortions, as this is where the original distortion originated in the first place.

In this context, it should be noted that LPI also carries out local tie surveys to connect each CORSnet-NSW station to the surrounding ground survey control (Gowans and Grinter, 2013), of which connections to passive trig stations typically form more than half of the overall survey effort. 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. However, 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 (GA, 2015c) outward to the ground survey network, via passive trig stations, as part of the next-generation Australian datum.

As part of the aforementioned list of actions completed during a trig station maintenance visit (see section 2.3), extended GNSS observations (in excess of 6 hours, often overnight and up to 24 hours) are captured to be utilised in the next-generation datum adjustment. These datasets are processed via AUSPOS (GA, 2015b) for validation and internal analysis before being submitted for inclusion in the national survey network adjustment to form the new national datum. These observations form a significant part of a greater effort currently underway by LPI towards datum improvement (Haasdyk et al., 2014a).

With the densification of CORSnet-NSW and its inclusion in AUSPOS processing, LPI is moving towards position-based results becoming increasingly utilised in place of the traditional survey network composed of GNSS baselines. These positions will constrain the traditional GNSS baselines in the next-generation datum adjustment, providing a homogeneous datum realisation by removing existing distortions. Figure 9 illustrates LPI's current database of AUSPOS datasets across NSW.

The benefit of constrained centring offered by concrete or steel pillared trig stations helps minimise or remove some errors, however small. This should in turn help authorities achieve their ambitious goal of achieving an Australian datum realisation of better than 20 mm.

Often remote trig stations only have AHD71 heights derived from trigonometrical heighting, which is accurate to about 0.5 m. The occupation of such stations by GNSS and derivation of AHD71 heights from ellipsoidal heights and AUSGeoid09 (GA, 2015a) has the potential to produce values far better than those that currently exist, provided that the limitations in this methodology are remembered.

Long GNSS sessions, at homogenous points distributed across the State, will also help ensure that suitable transformation grids and tools (e.g. National Transformation Version 2 grids) can be developed, which will have to be used initially for transforming up to about 90% of marks in SCIMS to the next-generation datum.

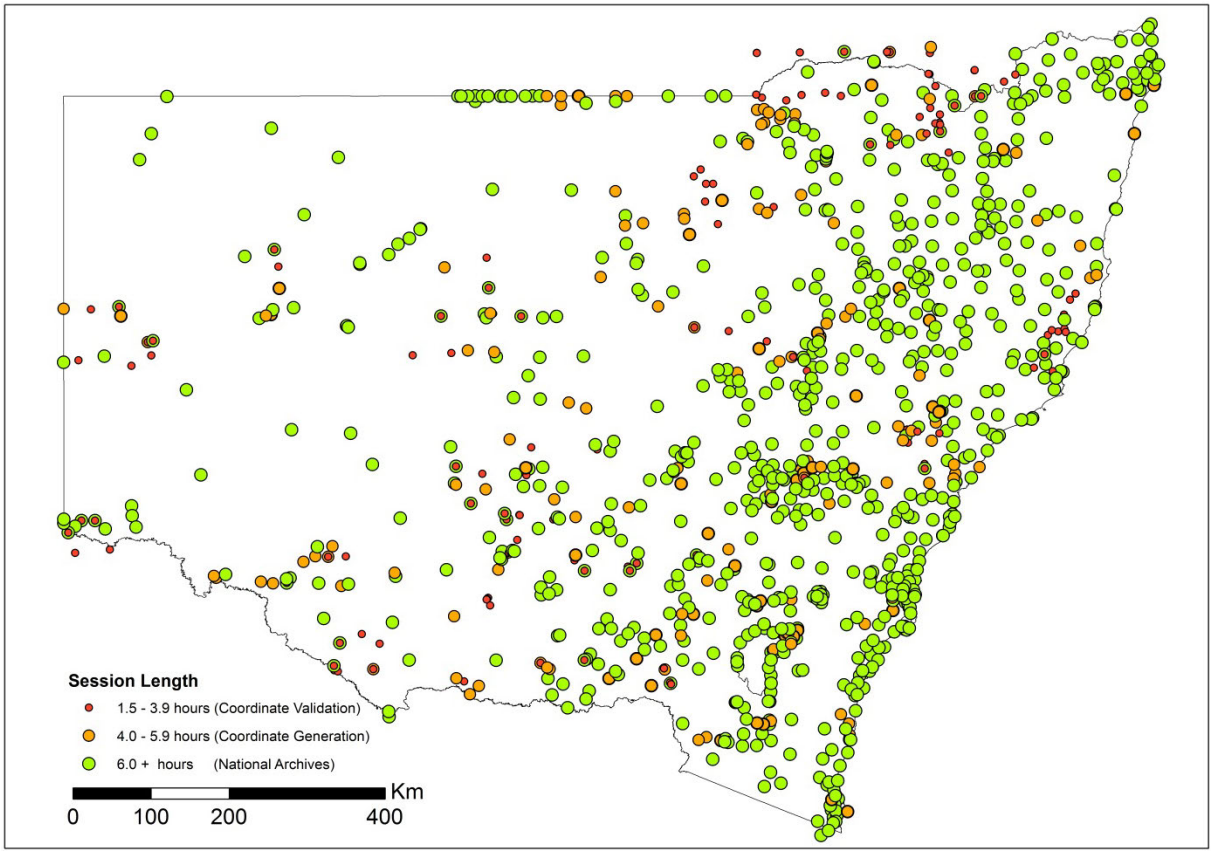

Figure 9: LPI's current AUSPOS dataset collection (as of January 2015).

2.5 Work Practices

Resources and time are limited and require careful planning to successfully complete a trig maintenance campaign. Once the campaign's sites have been selected based on TrigStar rating and geographical distribution, those chosen are divided into Local Government Areas (LGAs) and allocated to individual LPI survey teams. Each LGA is then broken into daily work plans, and each day is typically split into two parts. The first part involves revisiting sites from the previous day to collect the GNSS receivers that observed overnight, while the second consists of visiting and upgrading new sites. From experience, it is generally feasible for one survey crew to visit and occupy six sites in a standard 10-hour field day.

Considerations must be made with regards to distance between sites, organising access with landowners, keeping batteries charged, difficulty of access, technical 4WD skills required and most importantly getting home safely at the end of each day.

Work Health and Safety (WHS) considerations must come before all others – Safety First is LPI's motto. Related practices ensuring a safe working environment include:

- Two-person field parties operating in 'buddy' mode for safety.
- Remote and/or senior first aid training for staff.
- 4WD vehicles equipped with long-range tanks, driving lights, HF radios, spare tyres and recovery gear.
- 'Grab bags' for sites that require a walk to.
- Call-in and call-out procedures to notify the project manager of start and finish times and expected work to be completed each day.

- EPIRB (Emergency Position Indicating Radio Beacon) devices for use in emergency situations.
- Safe Work Method Statements (SWMS) and risk assessments.

3 SUMMARY OF RESULTS AND LESSONS LEARNED

LPI has so far completed four campaigns utilising this approach towards trig station maintenance in NSW (Figure 10). Campaign 1 was a pilot focussing on the Central West (May 2013), campaign 2 concentrated on the South Coast and ACT border (October 2013), campaign 3 focussed on the Mid North (September 2014), and campaign 4 concentrated on Southern NSW (February 2015).

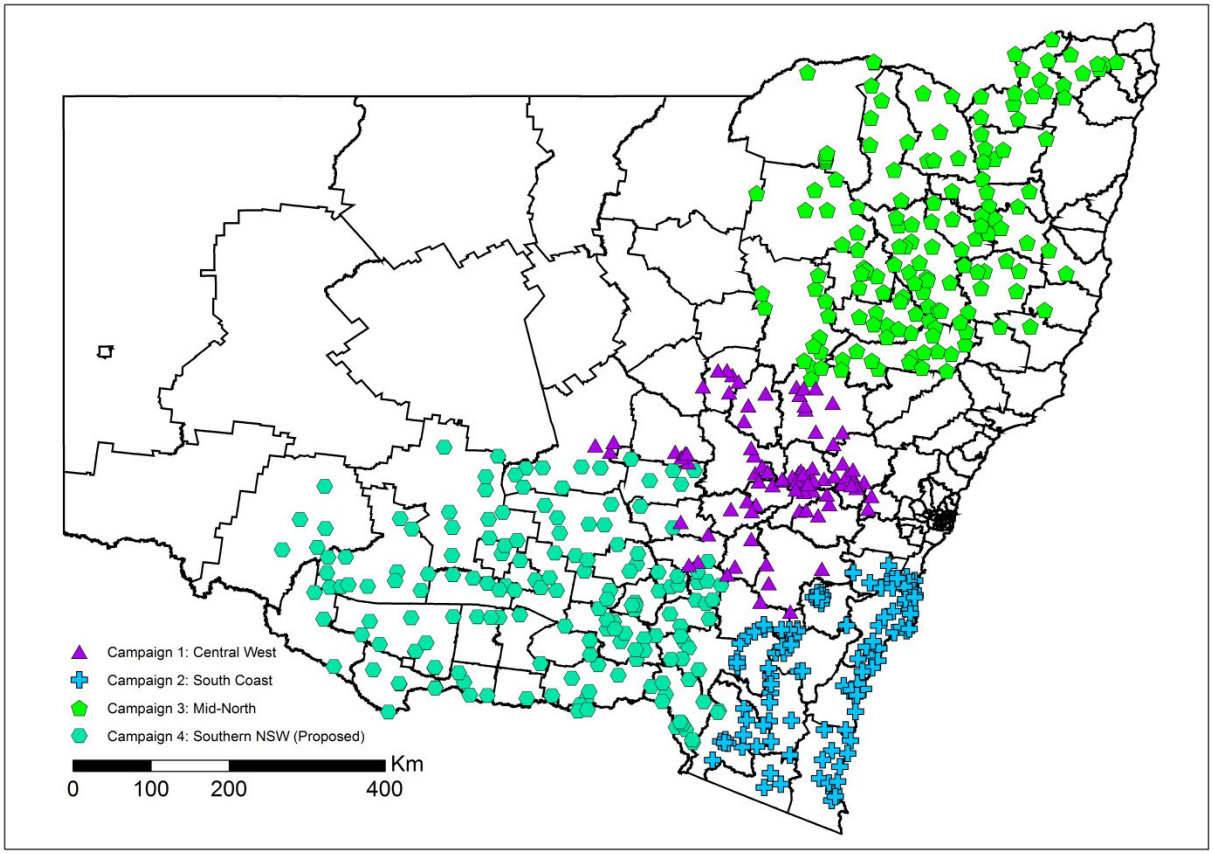

Figure 10: AUSPOS datasets gathered from trig maintenance campaigns in NSW to date.

Relevant metadata for each campaign conducted to date is summarised in Table 3. The significant amount of deliverables achieved with these targeted survey campaigns is clearly evident from the data shown. The campaigns have proven to be a very efficient and effective way to maintain and upgrade the State's geodetic infrastructure and collect valuable data for the adjustment of the next-generation Australian datum. After three campaigns, 350 trig stations have been maintained in this way, with a fourth campaign accounting for an additional 130 or so sites.

Table 3: Trig maintenance campaign details to date (proposed values for campaign 4 shown).

Campaign	**1**	**2**	**3**	**4**
Area of Operation	Central West	South Coast	Mid-North	Southern NSW
Epoch	May 2013	October 2013	September 2014	February 2015
AUSPOS Sessions	80	120	150	140
LGAs covered	13	12	16	31
Crews	3	5	6	5
GNSS receivers	18	25	25	25

The outlined process has been steadily refined and improved from one campaign to another. For example, following feedback obtained from field staff during the first campaign, the TrigStar assessment form was improved to take into account additional factors such as site security and presence of other structures (and RF interference) at the site. In later campaigns, the concrete base of trig pillars was often painted for use as aerial mapping targets, noting the height difference from the pillar plate to the concrete base. Some campaigns required an additional week of 'mopping-up' work for a team to visit stations that were initially missed due to inclement weather, time constraints or other unforseen delays that occur in the field.

4 FUTURE PLANS

It is anticipated that in the spirit of ongoing maintenance and upgrade, LPI will repeat one campaign annually (with a complete cycle taking approximately 5-7 years) in an effort to keep a contemporary set of GNSS observations and records for two thirds of its 4-5 star trigs. Sydney and regional LPI survey offices will continue to maintain and upgrade similar trig stations via day trips on an 'as needs' basis, of no less than a 5-7 year cycle.

Following the significant efforts undertaken towards trig station preservation and upgrade, and the next-generation Australian datum, LPI proposes a similar campaign-style project, called "Saving AHD", to maintain and upgrade the State's fundamental levelling infrastructure. It is anticipated that some 600-800 original 1970s Australian National Levelling Network (ANLN) marks (i.e. a minimum of three marks per level run) will be preserved and upgraded to meet current and future requirements.

5 CONCLUDING REMARKS

On behalf of the Surveyor General, LPI has a legislative, regulative responsibility to maintain the geodetic control network in NSW. As such, LPI is the custodian of some 250,000 marks in SCIMS, which includes about 6,000 traditional 'passive' trig stations as well as more than 160 'active' GNSS CORS. Keeping the geodetic component of the survey control network current and ready for utilisation requires regular maintenance and upgrade. Considering that it is neither feasible nor justifiable to maintain all passive trig stations across NSW in the modern era, particularly in light of the continuing expansion and increasing use of CORSnet-NSW, LPI has introduced a campaign-style trig station rationalisation, maintenance and upgrade program to maintain about 500-700 trig stations of high significance.

This paper has outlined an effective strategy to preserve geodetic infrastructure across NSW, connect traditional survey infrastructure with modern-day satellite-based positioning technology and contribute new GNSS observations towards the next-generation Australian datum. The results of conducting four such campaigns have proven that this method is able to

efficiently maintain the physical trig station infrastructure and associated metadata while capturing new, time-stamped, high-accuracy GNSS observations. These improvements will not only have a significant and lasting effect in regards to the next-generation Australian datum but also help increase the general public's appreciation of the surveying profession in general and the importance of survey infrastructure and its preservation in particular.

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