Densification of the Greater Sydney Subspine Network for Roads and Maritime Services Western Sydney Infrastructure Plan Projects

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ABSTRACT

Spatial Services, a unit of the Department of Finance, Services and Innovation (SS-DFSI) has developed a network of Class A survey marks covering the Greater Sydney area. Known as the Greater Sydney Subspine Network (GSSN), it assists design, construction and maintenance of road and rail infrastructure projects covering large, linear areas. Roads and Maritime has broken down this network utilising static Global Navigation Satellite System (GNSS) methods to Class B standard in order to provide a control framework for multiple road upgrade projects in western Sydney. Given the unprecedented growth predicted in western Sydney over the coming decades and the thousands of direct and indirect jobs for the region created by the opening of the western Sydney airport at Badgerys Creek, Roads and Maritime has developed the Western Sydney Infrastructure Plan (WSIP), a 10-year plan to provide improved road transport capacity ahead of future traffic demand. Control surveys undertaken by Roads and Maritime, several by working with private industry from Roads and Maritime's panel of specialist providers, support this plan by providing a control framework that will be utilised throughout the various stages of each project, including ground modelling, utility investigations, construction and boundary surveys, and subsequent asset maintenance activities. The control framework provides a number of additional benefits, including preservation and reinstatement of survey control infrastructure, and a legacy control framework to benefit the greater community. Given the GSSN will be used to define GDA2020, Roads and Maritime control networks provide a direct linkage to GDA2020, allowing a very accurate set of transformation parameters to be developed. Future surveys connecting to Roads and Maritime networks, including those by traditional methods, will also provide a link to GDA2020. This paper outlines the extent of surveys undertaken by Roads and Maritime, the extent of the GSSN and plans for the development of regional subspine networks, and demonstrates the benefits of this approach now and into the future.

KEYWORDS: *Survey control, GNSS, GDA2020, GSSN, WSIP.*

1 INTRODUCTION

The Greater Sydney Subspine Network (GSSN) was established by Spatial Services, a unit of the Department of Finance, Services and Innovation (SS-DFSI). The network provides over 300 Class A marks coordinated via a single static Global Navigation Satellite System (GNSS) adjustment extending throughout the Greater Sydney area. Coordinates are based on the GDA94(1997) realisation of the Geocentric Datum of Australia 1994 (for more details see Janssen and McElroy, 2010) with readjusted values published in the Survey Control Information Management System (SCIMS – see Kinlyside, 2013) in June 2013.

GNSS control surveys established for large road and rail infrastructure projects can connect to and break down the GSSN to provide a highly accurate network over the project area. A major benefit of this are site-specific adjustments that are not subject to localised distortions which can occur when establishing a datum based on connection to local permanent survey marks spanning multiple SCIMS adjustments.

Throughout 2015 and 2016, the Roads and Maritime Surveying Section established an extensive network of large scale GNSS control surveys in western Sydney connected to the GSSN. These surveys provide a control framework for many Western Sydney Infrastructure Plan (WSIP) projects. WSIP is Roads and Maritime's 10-year plan to provide improved road capacity by building many new and upgraded arterial roads in western Sydney to meet anticipated future demand (Roads and Maritime, 2017).

Although undertaken in isolation, many WSIP projects overlapped and were reliant on a consistent set of coordinates on common marks. Connection to an overarching framework of highly accurate control marks ensured a smooth transition between adjacent projects.

Survey control networks established for each WSIP project are used throughout the project life cycle, from initial ground modelling and utility location surveys, through to construction and boundary surveys, and subsequent asset maintenance activities. The resulting network provides a legacy for all future surveys and land development projects. Networks similar to the GSSN are being established by SS-DFSI throughout regional NSW to service areas with a high volume of infrastructure development. The methods utilised by the Roads and Maritime Surveying Section in Sydney may be applied to regional projects.

This paper provides an overview of the GSSN utilised by Roads and Maritime. It also shows the extent of the many survey control networks undertaken to service the WSIP projects. The paper highlights Roads and Maritime's specialised knowledge in high-order control surveys, its ability to work collaboratively with private industry to deliver results, application of Surveyor General's Direction No. 12 (DFSI Spatial Services, 2012) to ensure recognition in the SCIMS database and the future expansion of subspine networks throughout NSW.

2 GREATER SYDNEY SUBSPINE NETWORK (GSSN)

The GSSN was developed by SS-DFSI to address the need for a homogeneous network of Class A marks covering the Greater Sydney area to service large scale infrastructure projects. The network provides over 300 Class A marks coordinated via a single static GNSS adjustment. Coordinates are based on GDA94(1997) with readjusted values published in SCIMS in June 2013.

Observations forming the GSSN were used to define GDA2020, however the release of preliminary coordinates pre-date those that will be published in GDA2020. The network is made up of a combination of existing SCIMS marks and marks placed especially for the purpose of the subspine network. All marks have been specifically selected or placed based on fulfilling the requirements for accessibility, GNSS suitability, safety (i.e. high road traffic areas) and survey station density.

At the time of writing this paper, it was not possible to search explicitly for GSSN marks. However SS-DFSI proposes to incorporate an 'infrastructure layer' within SCIMS containing

subspine marks both in Sydney and regional NSW. A KML file appears the most logical way to publicly distribute this information. However, if a particular GSSN mark is known, the coordinates are readily available through SCIMS. As an example, the SCIMS search for GSSN mark PM42445 is shown in Figure 1.

SURVEY MARK

Mark	Name	Alias
PM 42445		n/a

Status	Date	Comments
	n/a	n/a

Location	Monument	Date Placed	Placed By
GROUND LEVEL	UNKNOWN	n/a	0

GDA94

Easting	Northing	Zone	Latitude	Longitude
295246.438	6261562.394	56	-33° 45' 58.58036"	150° 47' 20.57838"

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
A	1	n/a	n/a	18-FEB-2014

Source	Type	Method	Date issued	Issued By
235356	ADJUSTMENT	GEOLAB	28-JUN-2013	MICHAEL LONDON

Previous Reference	Location	File Number
n/a	n/a	n/a

Comments

GREATER SYDNEY SUBSPINE TRANSACTION #100093

MGA Combined Scale Factor	MGA Convergence
1.000106	-1° 13' 45.44"

AusGeoid09

23.442

AHD71

Height

41.494

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
B	2	n/a	n/a	18-FEB-2014

Source	Type	Method	Date issued	Issued By
235356	ADJUSTMENT	GEOLAB	28-JUN-2013	MICHAEL LONDON

Previous Reference	Location	File Number
n/a	n/a	n/a

Comments

GREATER SYDNEY SUBSPINE TRANSACTION #100093

Figure 1: SCIMS search for Greater Sydney Subspine Network (GSSN) mark PM42445.

SS-DFSI is developing additional Class A subspine networks in regional NSW to support areas with a high volume of infrastructure development. SS-DFSI will also support regional infrastructure projects by creating ad-hoc networks (see section 5).

The GSSN network established during the period of Roads and Maritime control surveys is shown in Figure 2.

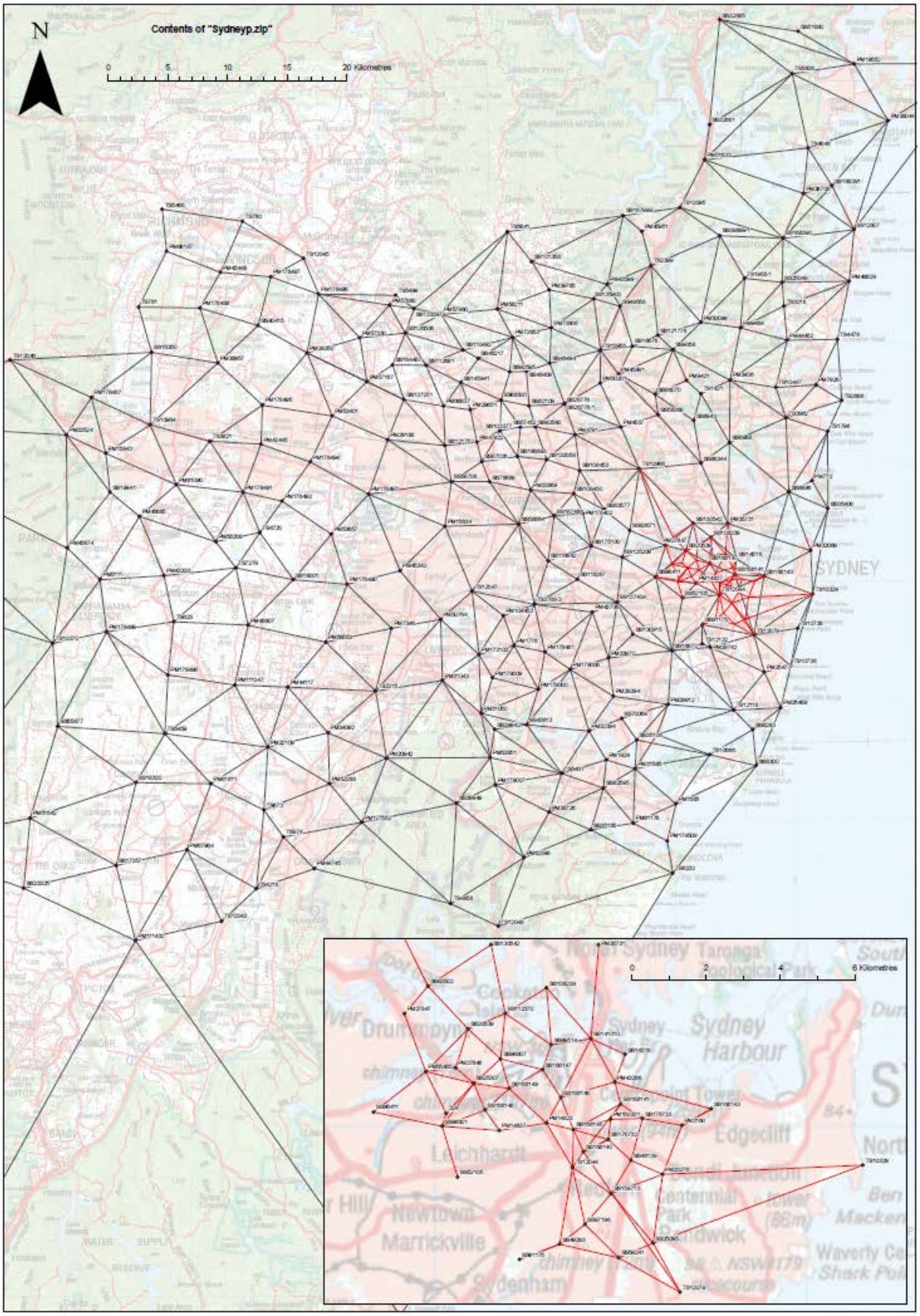

Figure 2: Greater Sydney Subspine Network (November 2016).

The network incorporates several CORSnet-NSW stations (Janssen et al., 2016; DFSI Spatial Services, 2017). While the GDA94(2010) coordinate values for these Continuously Operating Reference Stations (CORS) obtained via Regulation 13 certification currently do not match those published in SCIMS (Janssen and McElroy, 2010), the modernised Australian datum (GDA2020) will provide a homogenous set of coordinates for both CORS and ground control marks. The current differences in coordinate values between SCIMS and CORSnet-NSW are shown in Table 1 and agree with the known distortions across the State (e.g. Haasdyk et al., 2014; Janssen et al., 2016).

Table 1: Coordinate comparisons of CORSnet-NSW stations vs. SCIMS.

		Coordinates – MGA Zone 56					Difference: SCIMS - CORS	
Mark	**Name**	**Easting (m)**	**Northing (m)**	**C**	**O**	**Source**	**ΔE (mm)**	**ΔN (mm)**
TS12043	Menangle	291928.734	6221563.023	A	1	235356	-2	-51
TS12044	Chippendale	333655.813	6248928.970	A	1	235356	+21	-33
TS12045	Mulgrave	298805.017	6277143.353	A	1	235356	+18	-11
TS12046	Springwood	274216.880	6268603.676	A	1	235356	-19	+11
TS12047	Villawood	312919.848	6249236.646	A	1	235356	+18	-23
TS12048	Waterfall	315117.373	6221146.449	A	1	235356	+20	-27
TS12079	UNSW	336547.298	6245564.220	A	1	235356	+28	-39
TS12095	Cowan II	330336.155	6281393.630	A	1	235356	+25	-22
TS12118	Port Botany	334826.525	6239282.703	A	1	235356	+20	-47

The GSSN was developed ahead of GDA2020 in order to address the need for a homogeneous network of Class A marks covering the Greater Sydney area to serve large scale infrastructure projects. Roads and Maritime surveys continually found excellent agreement between the published SCIMS values of all GSSN marks. Table 2 shows coordinate differences when all WSIP control surveys were merged into a single minimally constrained adjustment.

Table 2: Coordinate comparisons of western Sydney GSSN stations in a minimally constrained adjustment.

Mark	**C**	**O**	**ΔE (mm)**	**ΔN (mm)**	**Mark**	**C**	**O**	**ΔE (mm)**	**ΔN (mm)**
TS623	A	1	-4	-8	**PM45685**	A	1	+11	-6
TS2215	A	1	+5	+4	**PM48807**	A	1	Fixed	Fixed
TS3821	A	1	+23	-7	**PM53657**	A	1	+23	+6
TS4720	A	1	+2	+3	**PM55208**	A	1	+14	+4
TS5459	A	1	+18	-16	**PM56553**	A	1	-4	+3
TS7279	A	1	+3	+10	**PM57330**	A	1	+9	-9
TS10964	A	1	+28	-13	**PM57880**	A	1	-4	+6
TS12045	A	1	Fixed	Fixed	**PM61090**	A	1	+19	-5
PM7346	A	1	-2	-1	**PM81811**	A	1	+5	-13
PM8111	A	1	+5	-15	**PM111047**	A	1	+13	0
PM15843	A	1	+22	-3	**PM178490**	A	1	+16	+3
PM20942	A	1	+6	-6	**PM178491**	A	1	+12	-3
PM22109	A	1	+27	+2	**PM178492**	A	1	+9	+3
PM29250	A	1	+3	-15	**PM178493**	A	1	+7	-5
PM31043	A	1	+6	+4	**PM178494**	A	1	+9	+4
PM31050	A	1	+16	+13	**PM178496**	A	1	+12	-7
PM34092	A	1	+12	-13	**PM178498**	A	1	+5	-8
PM42445	A	1	+18	+2	**PM178499**	A	1	0	-12
PM43333	A	1	+10	-10	**SS16001**	A	1	+9	+7
PM44117	A	1	+3	+6	**SS18320**	A	1	+13	-13
PM45342	A	1	+9	+8	**SS19941**	A	1	+17	-9
					SS40415	A	1	+14	-14

3 ROADS AND MARITIME CONTROL SURVEYS

3.1 Application of Surveyor General's Direction No. 12 and General Roads and Maritime Procedure

Roads and Maritime has undertaken many GNSS control surveys for western Sydney infrastructure projects. A sample survey is provided in section 3.2. The compilation of all western Sydney control surveys is outlined in section 3.3.

Ultimately, all marks surveyed by static GNSS will be recognised in the SCIMS database at Class B standard. In order to ensure this standard of recognition, all of the procedures outlined in Surveyor General's Directions No. 12 – Control Surveys and SCIMS (SGD12 – see DFSI Spatial Services, 2012) are followed. SGD12 provides a guide as to what SS-DFSI requires before control survey information can be placed on public record in the SCIMS database.

The initial planning stage involves a comprehensive search of the SCIMS database within the project extent. At this point, reference is also made to the Greater Sydney Subspine Network (GSSN) to determine suitable marks to be included in the survey. A field reconnaissance is undertaken by Roads and Maritime. The status of marks destroyed or disturbed is reported via SS-DFSI's *Survey Mark Status Report Form*.

SGD12 emphasises the importance of consultation with SS-DFSI regarding selection and placement of marks, network design, station density, observation and processing techniques, levels of redundancy, equipment and presentation of results. These are all critical if the network is to be recognised to the desired Class in SCIMS. Roads and Maritime control surveys aim for and achieve horizontal Class B status. The requirements outlined in ICSM's Standards and Practices for Control Surveys (SP1), version 1.7 (ICSM, 2007) for static GNSS surveys are fulfilled.

When selecting the GSSN marks, the principle of working from the whole to the part is imperative. GSSN marks are selected such that the project is wholly contained within a polygon joining adjacent GSSN marks surrounding the project area. Figure 3 shows the marks selected for survey supporting the proposed upgrade of a section of Cambridge Avenue and Moorebank Avenue, Casula to Moorebank. The survey extents are shown in red.

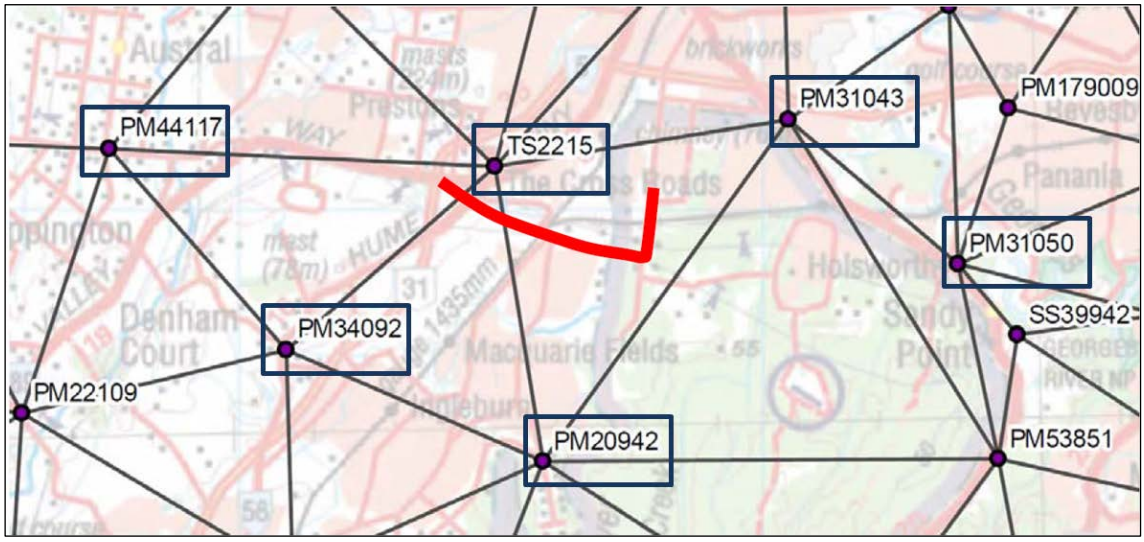

Figure 3: Greater Sydney Subspine Network marks selected for survey of Cambridge Ave and Moorebank Ave.

Network design requires a balanced connection to the GSSN marks surrounding the network. Baselines join all adjacent marks. Redundancy exists within each network, however the network is not over-observed.

Some control surveys have been undertaken internally by Roads and Maritime survey teams. However, closer collaboration with the private sector has allowed Roads and Maritime to utilise a larger pool of resources and build up the industry's capability in this area of specialisation. Private industry partners performing static GNSS control surveys initially work under the direction of Roads and Maritime's Senior Surveyor (Control Surveys). This ensures private industry partners are aware of the field and office procedures to fulfil the requirements of both SGD12 and SP1 to achieve Class B results. RINEX format data has been used where a combination of GNSS manufacturer's equipment is employed.

A minimally constrained least squares network adjustment is the first step in any network adjustment with one GSSN mark held fixed in position and level (height), followed by an assessment of the integrity of the network. Baselines with large residuals may be reprocessed in the GNSS processing software in an attempt to improve the quality of the baseline before being retested in the unconstrained network adjustment.

The minimally constrained adjustment tests the statistical Class of the survey by analysis of the relative error ellipses between marks. Adjustment software such as Compnet used by Roads and Maritime will perform a Class test at each selected Class. However, as far as recognition in the SCIMS database is concerned, the statistical Class result is meaningless if procedures outlined in SP1 regarding field procedures, equipment and processing techniques have not been fulfilled.

Once the minimally constrained adjustment has been completed, a comparison is made to the GSSN marks. It is often useful to apply a standard deviation to the Easting, Northing and level (height) values to determine a 'best-fit' to the marks. Roads and Maritime surveys have revealed excellent agreement between GSSN marks (see Table 2). All GSSN marks are held fixed in the final constrained adjustment.

Infill traverse surveys undertaken during ground modelling surveys include differential levelling throughout the project extents. Thus the definition of the vertical datum at the GNSS control survey stage is not critical. However, the final constrained GNSS adjustment holds fixed levelled, established marks, showing general agreement.

Investigation surveys for Roads and Maritime are undertaken under Specification G73 *Detail Survey*. The recently released Edition 3 contains detailed requirements and checklists to ensure control surveys are undertaken to achieve Class C and differential levelling achieves Class LC standards as defined by SP1 version 1.7.

Furthermore, Roads and Maritime Specification G71 *Construction Surveys* (currently under review) establishes a Survey Mark Register for all control and cadastral reference marks. This register tracks the status of all marks within the construction zone. Ground modelling surveys populate this register with control marks prior to construction.

Critical to acceptance of the survey in SCIMS is the Survey Report with a template located on the SS-DFSI website. The Survey Report includes the checklist provided in SGD12 and is accompanied by all survey data relating to the project.

3.2 Sample Survey: The Northern Road (Stage 4), Luddenham to South Penrith

The Northern Road is being upgraded to a dual carriageway major arterial road between Oran Park and South Penrith. Control surveys have been undertaken over four sections to date. The northern-most section between Luddenham and south Penrith involved a survey undertaken by Roads and Maritime surveyors with infill traversing and levelling performed by several Roads and Maritime private industry partners. The GNSS control network extent is shown in Figure 4. GSSN marks selected to define the datum are highlighted.

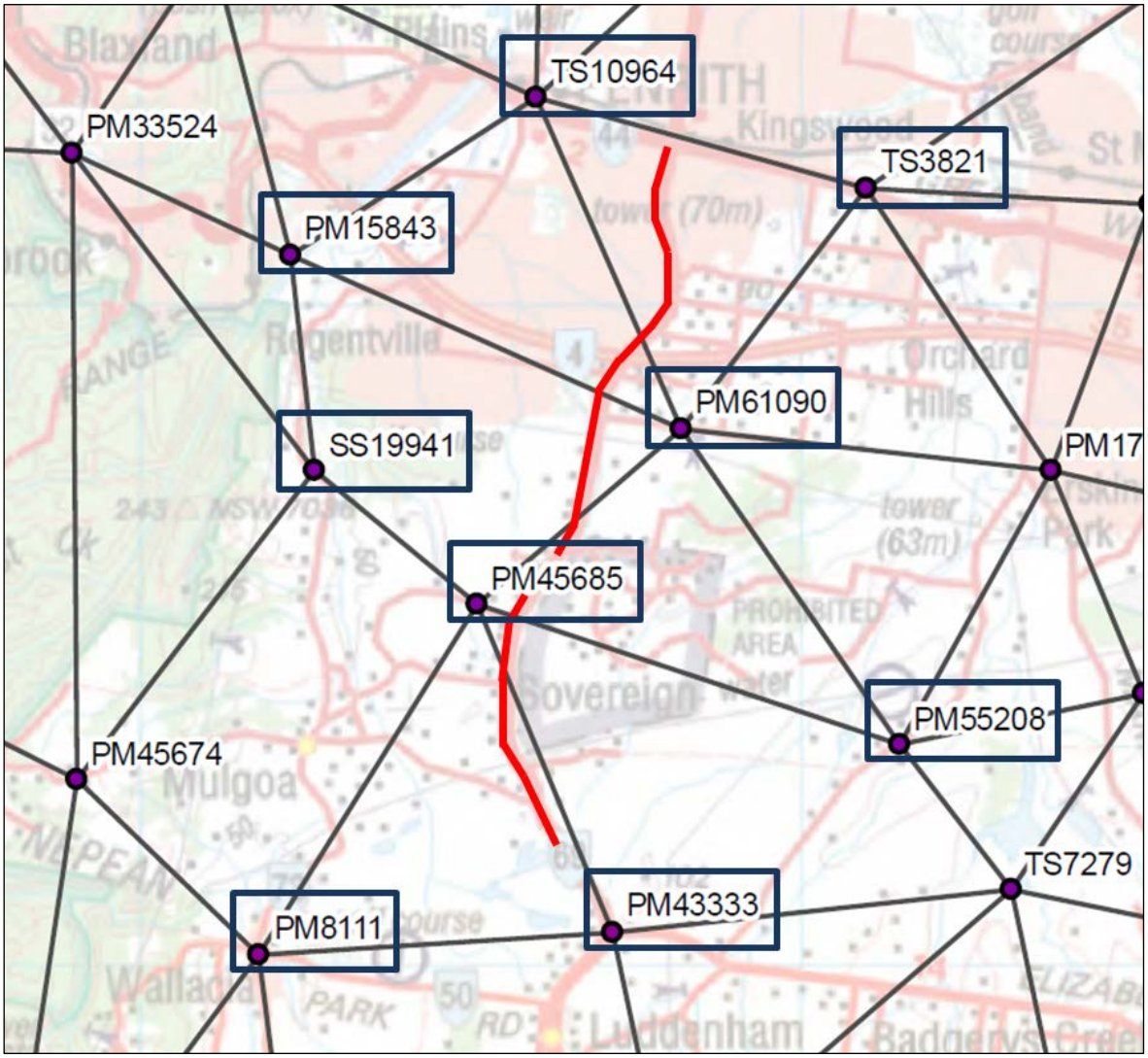

Figure 4: Static GNSS control survey network for The Northern Road, Luddenham to South Penrith.

The static GNSS control survey network, approved by SS-DFSI and surveyed by Roads and Maritime is shown in Figure 5. It should be noted that there are no baselines observed between GSSN marks, which is as per SS-DFSI instruction. Whilst these baselines may improve the statistical analysis of the unconstrained adjustment, their absence makes no difference to the final coordinates when all GSSN marks are held fixed. This network provides the framework on which all subsequent surveys will be based.

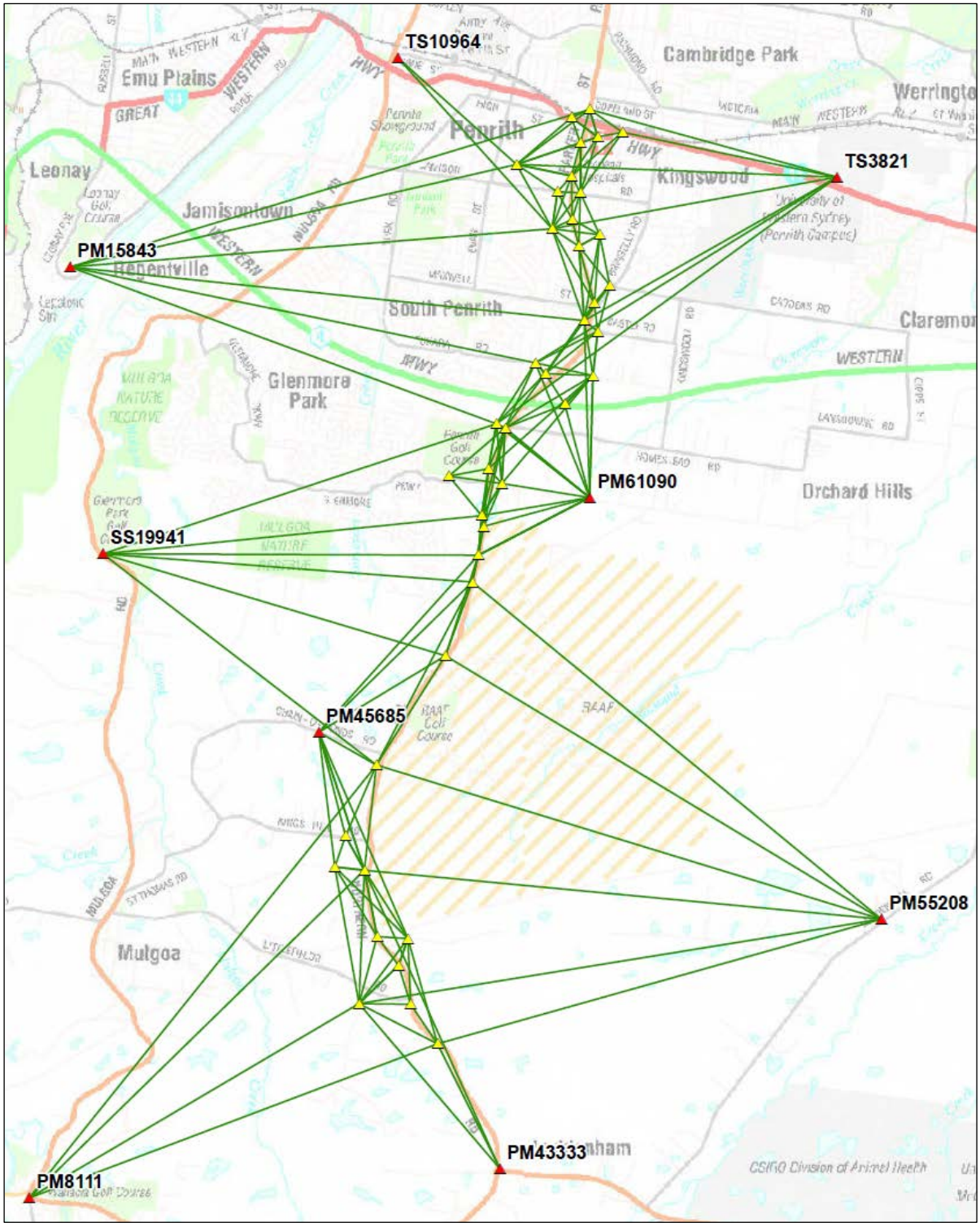

Figure 5: Static GNSS control survey network for The Northern Road, Luddenham to South Penrith.

The network was densified by traversing during the ground modelling survey. The traverse adjustment holds fixed for position only those marks coordinated by the GNSS adjustment. All other SCIMS marks, regardless of their Class and Order, are floated in the adjustment. All new traverse stations were differentially levelled with 2-way levelling runs to Class LC standard. The vertical adjustment is based on a best fit to local SCIMS values. The infilled traverse network is shown in Figure 6. Marks from the static GNSS adjustment are marked.

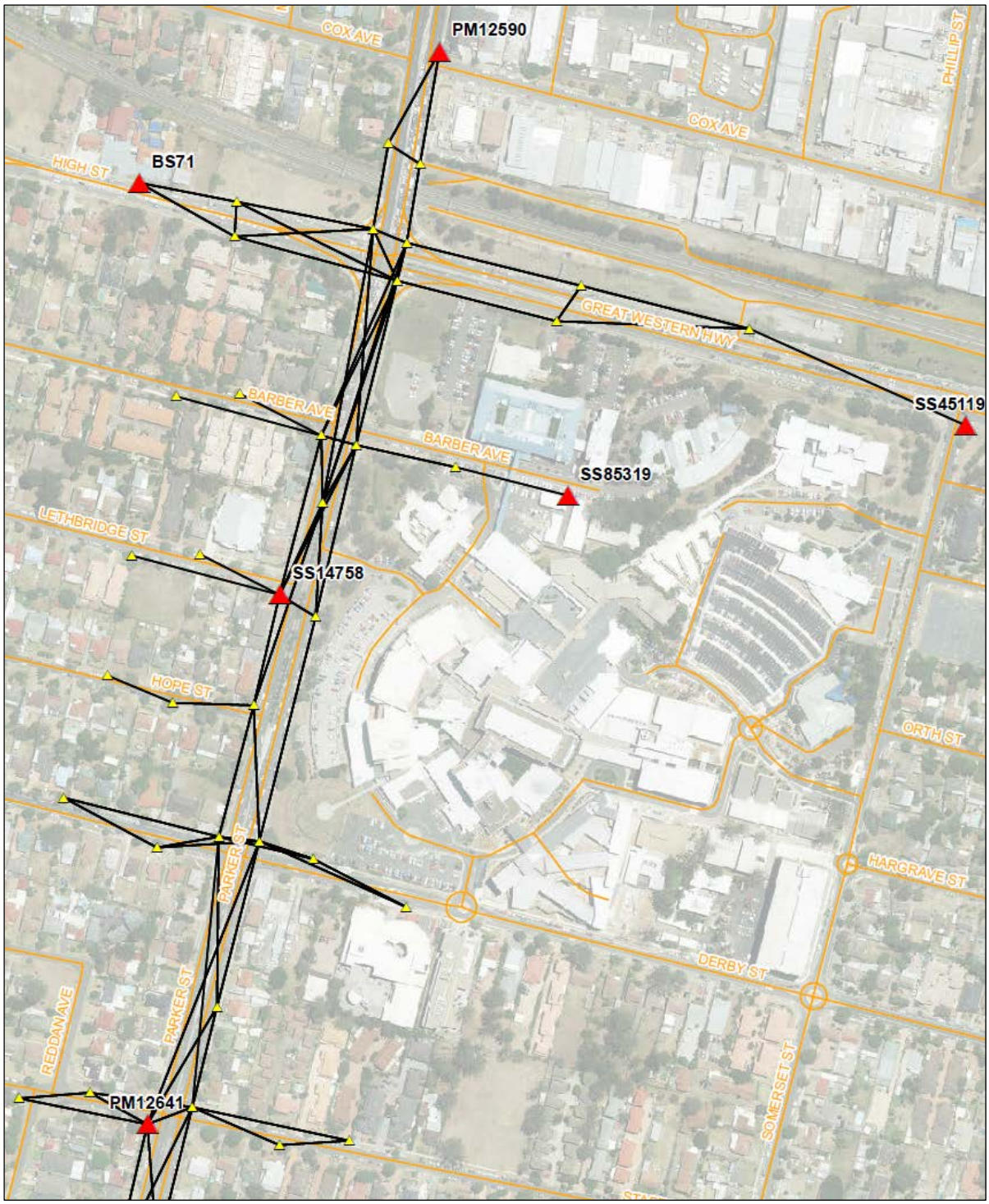

Figure 6: A section of infill traverse control for The Northern Road at South Penrith.

3.3 Combined Roads and Maritime Networks

The case study outlined in section 3.2 is one of many control surveys undertaken by Roads and Maritime in western Sydney with each survey following the same process, and several of these surveys overlapping. Connection to, and adoption of, the homogeneous GSSN meant a smooth transition between projects, free of the distortions and steps that often occur when networks adopt local SCIMS control across multiple adjustments.

Roads and Maritime has to date completed the following static GNSS networks across western Sydney linked to the GSSN:

- The Northern Road, Stages 1-4, Oran Park to South Penrith.
- Mamre Road, Kemps Creek to Claremont Meadows.
- The Horsley Drive, Horsley Park to Bossley Park.
- Archbold Road, Minchinbury to Horsley Park.
- Bandon Road, Vineyard.
- Fifteenth Avenue, Austral to Hoxton Park.
- Cambridge Avenue, Casula to Moorebank.

Figure 7 shows the combined static GNSS surveys undertaken and managed by Roads and Maritime supporting the Western Sydney Infrastructure Plan, with connection to the GSSN. At the time of writing this paper, the M12 Motorway joining the M7 Motorway to The Northern Road, incorporating an upgrade to Elizabeth Drive, has been announced. A proposed network has been approved by SS-DFSI and is included in Figure 7. This network will be surveyed in early 2017.

As demonstrated above, many GSSN marks are common between projects with an overlap on some projects, including Mamre Road and the proposed M12 Motorway/Elizabeth Drive surveys, and the four stages of The Northern Road. Some statistics regarding the 10 survey networks shown in Figure 7 include:

- Number of GSSN marks utilised: 43.
- Number of SCIMS marks coordinated by GNSS relative to GSSN: 220.
- Number of additional construction-quality marks coordinated by GNSS relative to GSSN: 40.
- Number of SCIMS marks proposed to be coordinated on M12 survey: 49.
- Number of approved survey marks to be placed and coordinated on M12 survey: 23.

At the time of writing, all surveys with the exception of M12 Motorway/Elizabeth Drive have been submitted to SS-DFSI. An update of the SCIMS database will most likely take place following the release of GDA2020.

Unlike the GSSN observations undertaken by SS-DFSI, Roads and Maritime GNSS observations have not been utilised to define GDA2020. However, the surveys now provide a direct linkage to GDA2020 and allow an accurate set of transformation parameters to be developed. This is also the case for the infill traversing marks that have further broken down the static GNSS control networks.

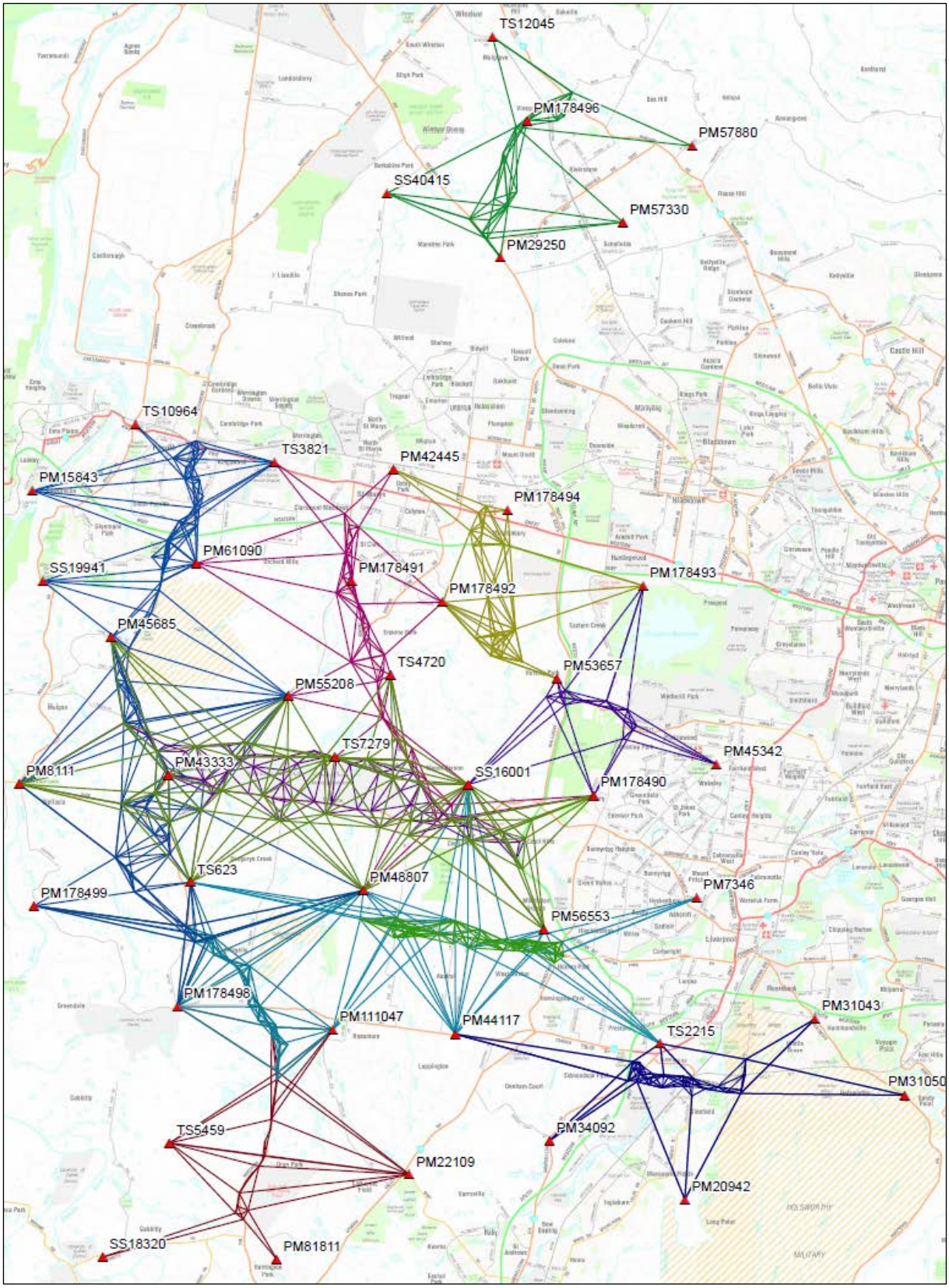

Figure 7: Combined static GNSS surveys connecting to the GSSN to support WSIP projects.

4 BENEFITS OF THIS APPROACH

There are many benefits to the approach taken by Roads and Maritime in western Sydney. Firstly, a homogeneous dataset of control coordinates exists across western Sydney, which is used as the basis for multiple infrastructure projects. Each network connects to the local datum, but each is free from the distortions that exist across multiple adjustments. Projects that overlap have a seamless transition between coordinates adopted at each site which is especially critical during the construction stages of these projects.

Secondly, it is anticipated that many survey control marks will be destroyed during construction. Roads and Maritime treats the preservation of survey infrastructure very seriously and has worked extensively with SS-DFSI to develop procedures in this regard. Having the original control marks directly linked to the overall GSSN will allow replacement control marks to be coordinated relative to the same datum, thus maintaining the integrity of the post-construction network.

Thirdly, all future surveys that link to the extensive network of marks will have a direct link to the marks used to define GDA2020. Whilst the construction phase of each project will maintain the coordinate system established during the initial stage of the project, SS-DFSI will eventually upgrade all SCIMS marks to GDA2020 coordinates. The marks coordinated by Roads and Maritime will have very accurate GDA2020 coordinates.

Finally, Roads and Maritime will leave a legacy framework following construction of these projects that will be used for future asset maintenance activities, future land use projects and will benefit the greater surveying community.

5 REGIONAL SUBSPINE NETWORKS

SS-DFSI is developing additional Class A subspine networks in regional NSW to support areas with a high volume of transport infrastructure development. SS-DFSI is also able to support regional projects on an ad-hoc basis. For example, south of Sydney observations for the South Coast A1 network from Sydney to the Victorian border have been reduced and adjusted by SS-DFSI. The results of this survey will soon be released publicly.

North of Sydney the network expands through the Central Coast and Hunter region. Observations are still being collected with an adjustment pending. Eventually the network will extend through the North Coast to the Queensland border. Figure 8 shows the network covering the NSW Central Coast.

Eventually the subspine network will cover much of the state of NSW, with the density of marks being the greatest in metropolitan areas. The release of GDA2020 will mean all subspine network marks will have homogeneous coordinates compatible with the CORSnet-NSW network. CORS may then be considered part of the subspine network. Increased station density will provide greater redundancy when breaking down the subspine network, leading to increased accuracy. The added bonus for surveyors is that they will not need to occupy CORSnet-NSW sites – GNSS RINEX data for each CORSnet-NSW site during the observation periods may be downloaded upon returning to the office.

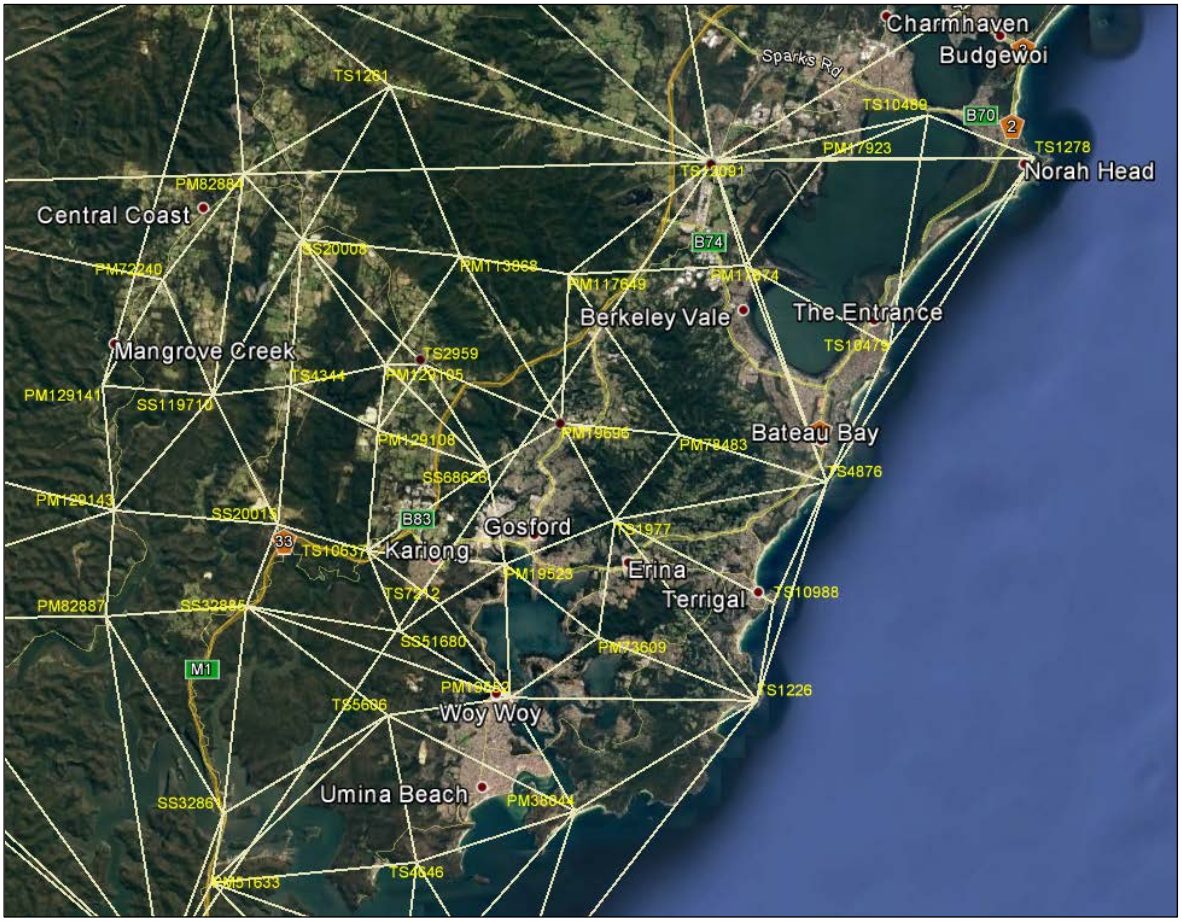

Figure 8: Class A subspine network throughout the Central Coast.

The methodology described in this paper may be used as a template for future large road or rail infrastructure projects. As the subspine network expands to cover much of NSW, a similar approach may be taken for regional projects over large areas or in areas with little survey control infrastructure.

6 CONCLUDING REMARKS

The GSSN is a fantastic initiative by SS-DFSI. Released prior to GDA2020 and based on a single adjustment, it provides the foundation for control survey networks established for large scale infrastructure projects. The Roads and Maritime Surveying Section has utilised this network for projects falling under Roads and Maritime's Western Sydney Infrastructure Plan, developed to address the unprecedented growth predicted in western Sydney over the coming decades and subsequent infrastructure upgrades.

Roads and Maritime has broken down the subspine network by static GNSS observations and adjustment to Class B standard to provide a homogeneous network of control marks for each WSIP project. Projects that are developed in stages, such as The Northern Road, and projects sharing common extents benefit from this approach as a common set of coordinates between projects is established.

Roads and Maritime has undertaken much of the control surveys using internal resources. However, Roads and Maritime has also engaged with private industry specialist partners to

deliver these projects. Working in collaboration with Roads and Maritime, companies have a clear set of procedures fulfilling the requirements of SGD12, which may be applied on future projects. SGD12 has been an invaluable tool for ensuring SS-DFSI is consulted throughout the planning and execution of these control surveys, allowing the surveys to be eventually recognised in the SCIMS database to the desired Class.

Roads and Maritime is aware of its responsibilities to maintain the integrity of survey control infrastructure throughout the construction stages of projects. By coordinating new and existing survey control marks relative to the subspine network at the start of a project, any marks that are destroyed may eventually be replaced with approved survey marks coordinated relative to the overall network.

By coordinating a large network of survey marks relative to the subspine network, a very accurate set of GDA2020 transformation parameters can be established. All future surveys that connect to Roads and Maritime surveys will benefit from these initial surveys. Networks established by Roads and Maritime provide a legacy framework for the greater community. These networks may be utilised for future land development projects, cadastral surveys and many more applications.

The future state-wide expansion of subspine networks will provide benefits to regional infrastructure projects as has been realised in western Sydney. The approach for western Sydney projects may be used as a guide for the establishment of control survey networks for future regional infrastructure projects.

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