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Editorial

These proceedings contain the papers presented at the Association of Public Authority Surveyors Conference (APAS2018), held in Jindabyne, NSW, Australia, on 9-11 April 2018. Papers were not peer-reviewed but have been subject to changes made by the Editor. The Editor would like to thank all authors for their contributions covering a wide range of topics relevant to the surveying and spatial information community, thus ensuring an exciting and informative conference.

Authors are welcome to make their paper, as it appears in these conference proceedings, available online on their personal and/or their institution's website, provided it is clearly stated that the paper was originally published in these proceedings. Papers should be referenced according to the following template:

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Evaluating the Performance of AUSGeoid2020 in NSW

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ABSTRACT

Presently, Australia is transitioning to a modernised national datum in order to meet the increasing demands placed by modern satellite-based positioning technology on the underlying geodetic framework. The much improved Geocentric Datum of Australia 2020 (GDA2020) was gazetted in October 2017 and is to replace the current national datum (GDA94) in practice by 2020. This also includes a new quasigeoid model, AUSGeoid2020, to provide an improved connection between ellipsoidal heights derived from Global Navigation Satellite System (GNSS) observations and the Australian Height Datum (AHD). In September 2017, Geoscience Australia finalised the release version of AUSGeoid2020. As NSW is preparing to enable GDA2020, this paper quantifies the expected improvement of using AUSGeoid2020 in conjunction with GDA2020 ellipsoidal heights over using the current AUSGeoid09 in conjunction with GDA94 ellipsoidal heights to access AHD. Three tests are performed in order to investigate how well the two quasigeoid models fit known AHD heights across the State, based on (1) 138 CORSnet-NSW sites, (2) seven GNSS-based adjustments of varying extent and size, and (3) numerous height control points from these adjustments. It is found that the AUSGeoid2020 product provides a considerably improved fit to AHD across NSW when compared to its predecessor. However, the rigorous uncertainty values provided with AUSGeoid2020 appear to be overly conservative, resulting in the AUSGeoid2020 uncertainty grid having only limited practical value at this stage.

KEYWORDS: *AUSGeoid2020, GDA2020, Australian Height Datum, CORSnet-NSW, datum modernisation.*

1 INTRODUCTION

The Geocentric Datum of Australia 1994 (GDA94) has been our national datum since its adoption in 2000, providing fundamental positioning infrastructure for Australia (ICSM, 2014a). Significant improvements in positioning technology in the recent past now enable centimetre-level positioning capability via Global Navigation Satellite System (GNSS) techniques such as Network Real Time Kinematic (NRTK) and Precise Point Positioning (PPP) (e.g. Janssen and Haasdyk, 2011; Rizos et al., 2012), while decimetre-level accuracy will soon be available to the mass-market. These developments have revealed that GDA94 is not capable of providing the required quality of datum into the future. Consequently, Federal, State and Territory Governments have worked towards modernising Australia's datum for some time. In the context of NSW, progress made in this regard has been reported on many

occasions during recent years (e.g. Haasdyk and Roberts, 2013; Haasdyk and Watson, 2013; Haasdyk et al., 2014; Gowans et al., 2015). These efforts are now becoming reality as Australia is transitioning to a modernised national datum in order to meet the increasing demands placed on the geodetic framework by modern satellite-based positioning technology (e.g. Gowans, 2017; Janssen, 2017).

The Geocentric Datum of Australia 2020 (GDA2020) is a new, much improved Australian national datum that is based on a single, nationwide least squares network adjustment and rigorously propagates uncertainty (ICSM, 2018). GDA2020 is defined in the current state-of-the-art global International Terrestrial Reference Frame 2014 (ITRF2014 – see Altamimi et al., 2016) at epoch 2020.0. The coordinates are extrapolated into the future to 1 January 2020 in order to extend the lifespan of the datum. In October 2017, GDA2020 was realised by gazetting an expanded Australian Fiducial Network (AFN) consisting of 109 GNSS Continuously Operating Reference Stations (CORS) contributing to the Australian Regional GNSS Network (ARGN) and the AuScope network (NMI, 2017; ICSM, 2018). The move from GDA94 to GDA2020 causes the horizontal coordinates of a mark to shift by up to 1.8 m to the north-east (due to tectonic motion of the Australian plate from 1994 to 2020), while the ellipsoidal height decreases by about 0.09 m (due to improvements from ITRF92 to ITRF2014 to better define the shape of the Earth). GDA2020 is expected to replace GDA94 in practice by 1 January 2020.

Vertical coordinates continue to be referred to the Australian Height Datum (AHD) (Roelse et al., 1975). It is well known that shortcomings in the AHD realisation (AHD71 for mainland Australia and AHD83 for Tasmania) resulted in considerable distortions of up to about 1.5 m into AHD across Australia, which is therefore considered a third-order datum (e.g. Morgan, 1992; Featherstone and Filmer, 2012; Watkins et al., 2017). However, in the immediate future AHD continues to be a practical height datum or working surface that provides a sufficient approximation of the geoid for many surveying and engineering applications. In the longer term, the Intergovernmental Committee on Surveying and Mapping (ICSM) will consider updating AHD or replacing it potentially with a new national gravity-based vertical reference frame (Filmer and Featherstone, 2012). Geoscience Australia plans to lead the development of a new vertical working surface as an alternative to AHD (Brown et al., 2018).

In order to connect to AHD via GDA2020 ellipsoidal heights, a new quasigeoid model (AUSGeoid2020) has been produced (Featherstone et al., 2018; ICSM, 2018; Brown et al., in prep.). Due to the aforementioned 0.09 m difference in ellipsoidal heights between GDA94 and GDA2020, it is crucial for users to apply AUSGeoid2020 *only* to GDA2020 ellipsoidal heights, while its predecessor AUSGeoid09 *must* be used to convert GDA94 ellipsoidal heights.

In September 2017, Geoscience Australia finalised the release version of AUSGeoid2020. As NSW is preparing to enable GDA2020, this paper aims to quantify the expected improvement of using AUSGeoid2020 in conjunction with GDA2020 ellipsoidal heights over using the current AUSGeoid09 in conjunction with GDA94 ellipsoidal heights to access AHD in NSW. Three tests are performed in order to evaluate how well the two quasigeoid models fit known AHD heights across the State, based on (1) 138 CORSnet-NSW sites, (2) seven GNSS-based network adjustments of varying extent and size, and (3) numerous height control points from these adjustments.

2 RECENT QUASIGEOID MODELS IN AUSTRALIA

The geoid is defined as the equipotential surface that best approximates mean sea level and is the basis for orthometric heights, while the quasigeoid is the non-equipotential surface that normal heights refer to (e.g. Vaniček et al., 2012; Sjöberg, 2013). The Australian Height Datum can be thought of as a hybrid of these two vertical surfaces because normal gravity, referenced to a mean Earth ellipsoid, was used in the orthometric correction formulae instead of observed gravity (Roelse et al., 1975). The AHD is therefore sometimes called a normal-orthometric height datum. Estimates of the quasigeoid-to-geoid separation over Australia were found to be small enough to assume geoid and quasigeoid to be coincident for the determination of AHD heights from GNSS observations (Featherstone and Kirby, 1998).

Over many years, the use of quasigeoid models has helped GNSS users to compute AHD heights (H_{AHD}) from ellipsoidal heights (h) by applying the ellipsoid-to-AHD separation (N_{AHD}) (e.g. Featherstone and Kuhn, 2006; Janssen, 2009):

$$H_{AHD} = h - N_{AHD} \tag{1}$$

Figure 1 illustrates this relationship between GNSS-derived ellipsoidal heights and AHD heights.

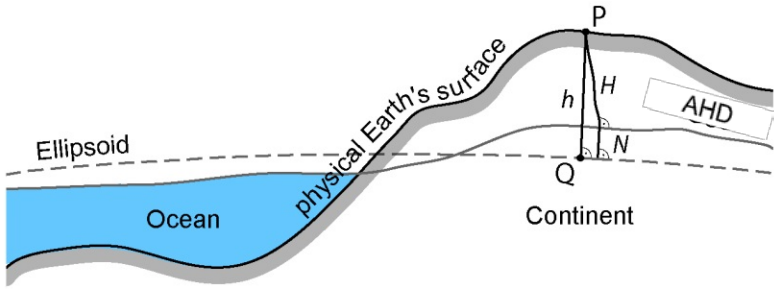

Figure 1: Relationship between ellipsoidal height (h), AHD height (H) and ellipsoid-to-AHD separation (N), courtesy of M. Kuhn, Curtin University of Technology.

The first version of AUSGeoid, AUSGeoid91, was released in 1991, followed by AUSGeoid93 and AUSGeoid98 (e.g. Kearsley, 1988; Kearsley and Steed, 1995; Featherstone et al., 2001). This section briefly describes the two most recent versions, AUSGeoid09 and AUSGeoid2020.

2.1 AUSGeoid09

In March 2011, AUSGeoid98 was replaced by AUSGeoid09, the first combined gravimetric-geometric quasigeoid model for Australia (Brown et al., 2011; Featherstone et al., 2011). AUSGeoid09 has the same extent as its predecessor (between 108ºE and 160ºE longitude and 8ºS and 46ºS latitude) but is given on a 1’ by 1’ grid (about 1.8 by 1.8 km), making it four times denser.

Previous versions of AUSGeoid were predominantly gravimetric-only quasigeoids, and it was assumed that these were sufficiently close approximations of AHD – an assumption we now know to be incorrect. In contrast, AUSGeoid09 is a combined gravimetric-geometric quasigeoid, providing a direct connection to AHD and thereby allowing a more reliable determination of AHD heights from GNSS observations.

The gravimetric component of AUSGeoid09 is the Australian Gravimetric Quasigeoid 2009 (AGQG09) (Featherstone et al., 2011). It provides the gridded ellipsoid-quasigeoid separation and is a product far better than the one used in AUSGeoid98, mainly due to a larger amount of input data and improved modelling.

The geometric component of AUSGeoid09 delivers a grid of quasigeoid-AHD separation values, derived from an empirical dataset of collocated GNSS ellipsoidal heights and AHD heights. It accounts for the offset between AHD and the quasigeoid, ranging from about -0.5 m (AHD below quasigeoid) in the south-west of Australia to about +0.5 m (AHD above quasigeoid) in the north-east of Australia (-0.3 m to +0.2 m across NSW). This offset is predominantly caused by the AHD definition not taking into account sea surface topography including the differential heating of the oceans. The warmer or less dense water off the coast of northern Australia is approximately 1 m higher than the cooler or denser water off the coast of southern Australia. By constraining each of the 30 tide gauges used in the definition of AHD to zero without considering the differences in mean sea level, these effects were propagated into the adjustment (Brown et al., 2011). The introduction of the geometric component takes care of most of this 1-metre trend across Australia (0.5-metre trend across NSW), thereby providing a better overall fit to AHD. Across NSW, the geometric component of AUSGeoid09 is based on 100 control points (Figure 2).

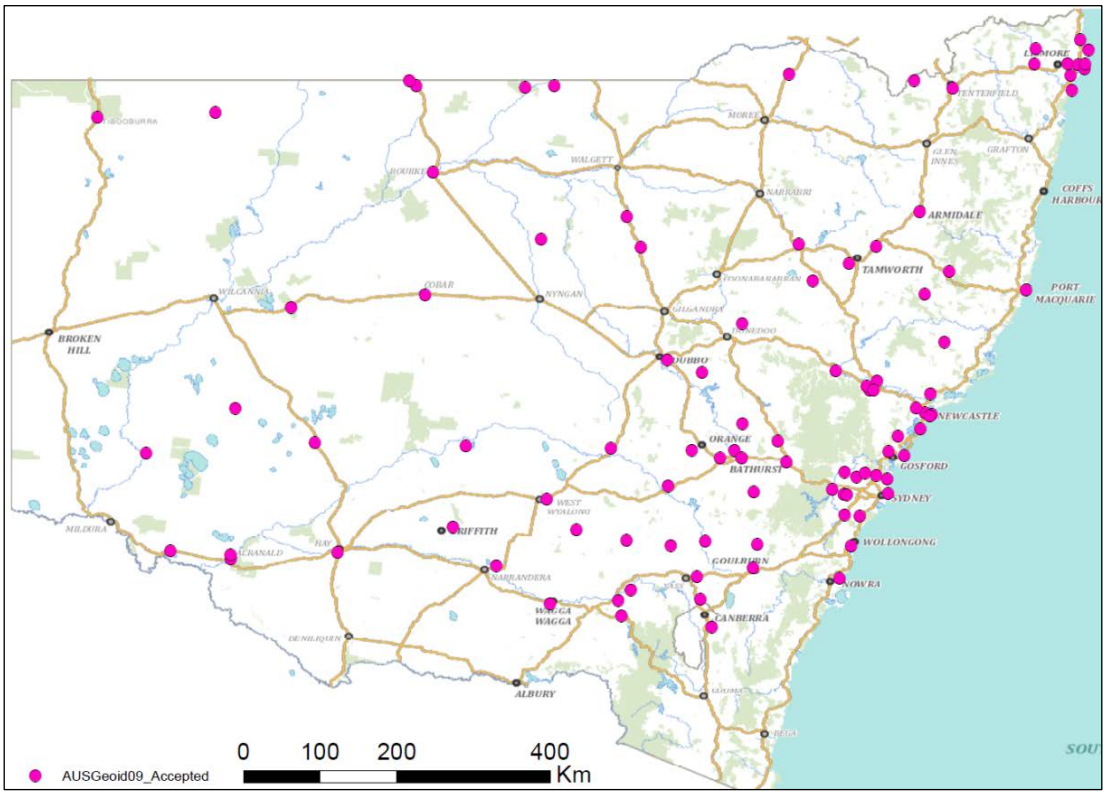

Figure 2: Levelled marks observed by GNSS and providing control for AUSGeoid09.

AUSGeoid09 was found to provide connection to AHD at the ±0.05 m uncertainty level (1 sigma) across most of Australia, although the uncertainty can exceed a decimetre in some areas due to errors in the ageing levelling network, land subsidence, geoid anomalies or data deficiency (e.g. Janssen and Watson, 2010, 2011; Brown et al., 2011; Sussanna et al., 2014, 2016; Allerton et al., 2015).

2.2 AUSGeoid2020

In September 2017, Geoscience Australia finalised the release version of AUSGeoid2020 (version 08/09/2017). AUSGeoid2020 is also a combined gravimetric-geometric quasigeoid model. The gravimetric component is a 1' by 1' grid of improved ellipsoid-quasigeoid separation values created using data from satellite gravity missions (e.g. GRACE and GOCE), re-tracked satellite altimetry, localised airborne gravity, land gravity data from the Australian national gravity database and a Digital Elevation Model to apply terrain corrections. This gravimetric component is known as the Australian Gravimetric Quasigeoid 2017 (AGQG2017 – see Featherstone et al., 2018 for details on its input data and computation).

The geometric component is basically a 1' by 1' grid of improved quasigeoid-AHD separation values, derived from a much larger dataset of collocated GNSS ellipsoidal heights and AHD heights across Australia, accounting for the offset between AHD and the quasigeoid. It should be noted that only a single grid of ellipsoid-AHD separation values is made available to users.

While AUSGeoid2020 has the same extent (albeit with a larger computation area during its generation) and density as its predecessor AUSGeoid09, it is based on a much larger and much more homogeneous dataset. For example, DFSI Spatial Services has collected over 2,500 extended GNSS datasets (at least 6 hours but generally 12-24 hours duration) on levelled benchmarks across NSW as part of its 'Saving AHD' project (Figure 3). These datasets inform the geometric component of AUSGeoid2020, thereby helping to provide a much improved connection to AHD for GDA2020 ellipsoidal heights across the State.

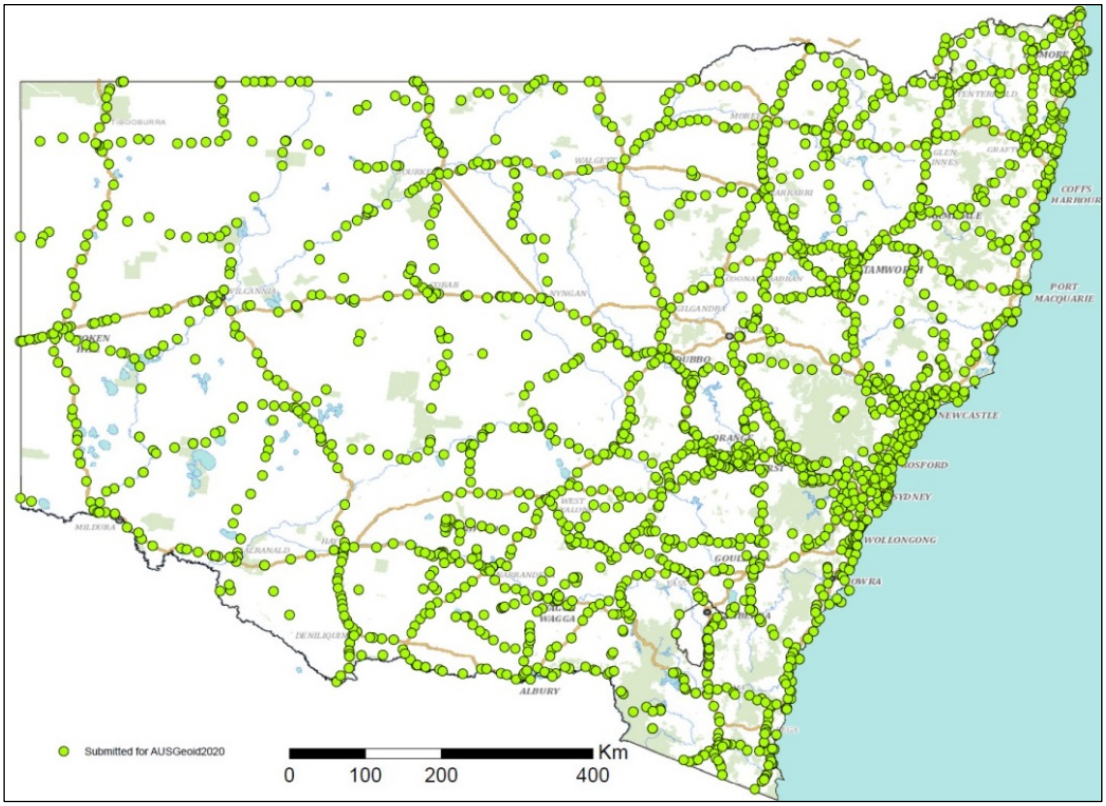

Figure 3: GNSS datasets (6+ hour duration) observed on levelled marks by DFSI Spatial Services, contributing to AUSGeoid2020.

AUSGeoid2020 provides a rigorous uncertainty value associated with the separation between the ellipsoid and AHD, varying as a function of location (Featherstone et al., 2018; ICSM, 2018; Brown et al., in prep.). In contrast, AUSGeoid09 only provides a constant uncertainty estimate (Brown et al., 2011). Consequently, AUSGeoid2020 users are expected to benefit from more realistic uncertainty information, particularly in the coastal zone where offshore data is included in the model computation and mountainous regions or other areas exhibiting sparser input datasets.

3 PERFORMANCE OF AUSGeoid2020 IN NSW

NSW is currently preparing to enable GDA2020. The move from GDA94 to GDA2020 causes the horizontal coordinates of a mark to shift by up to 1.8 m to the north-east and the ellipsoidal height to decrease by about 0.09 m. Consequently, a comparison between AUSGeoid09 and AUSGeoid2020 necessitates the availability of both GDA94 and GDA2020 coordinates for the test points utilised in order to quantify the expected improvement in the connection to AHD, as realised by known AHD heights of sufficient quality (class and order) on public record in the Survey Control Information Management System (SCIMS).

SCIMS is the State's database containing about 250,000 survey marks across NSW, including coordinates, heights and metadata (Kinlyside, 2013). For a discussion of the terms class and order, the reader is referred to ICSM (2007) and Dickson (2012). While it is acknowledged that ICSM (2007) has recently been superseded by ICSM (2014b), this update does not affect the outcome of the analysis presented in this paper.

Since it is necessary to consider coordinate differences of opposite signs, the Root Mean Square (RMS) is deemed appropriate to quantify the average agreement to AHD. The following sections describe the three tests performed and outline the results obtained.

3.1 Test 1: Analysis Based on CORSnet-NSW Sites

CORSnet-NSW is Australia's largest state-owned and operated network of permanent GNSS reference stations. It is built, owned and operated by Spatial Services, a unit of the NSW Department of Finance, Services and Innovation (DFSI) (e.g. Janssen et al., 2016; DFSI Spatial Services, 2018). As of March 2018, the network consists of 200 reference stations, providing fundamental positioning infrastructure that is authorative, accurate, reliable and easy-to-use for a wide range of applications across NSW (Figure 4). Upon completion, CORSnet-NSW is planned to include 220 CORS.

138 of these CORSnet-NSW sites, i.e. those that had both Regulation 13 certified GDA94 coordinates (GA, 2018) and a locally 'established' SCIMS AHD height (albeit obtained by DFSI Spatial Services through an A1 class/order GNSS-based local tie survey – see Gowans and Grinter, 2013), were selected for comparable test calculations. The GDA2020 coordinates of these sites were obtained directly from the national GDA2020 adjustment.

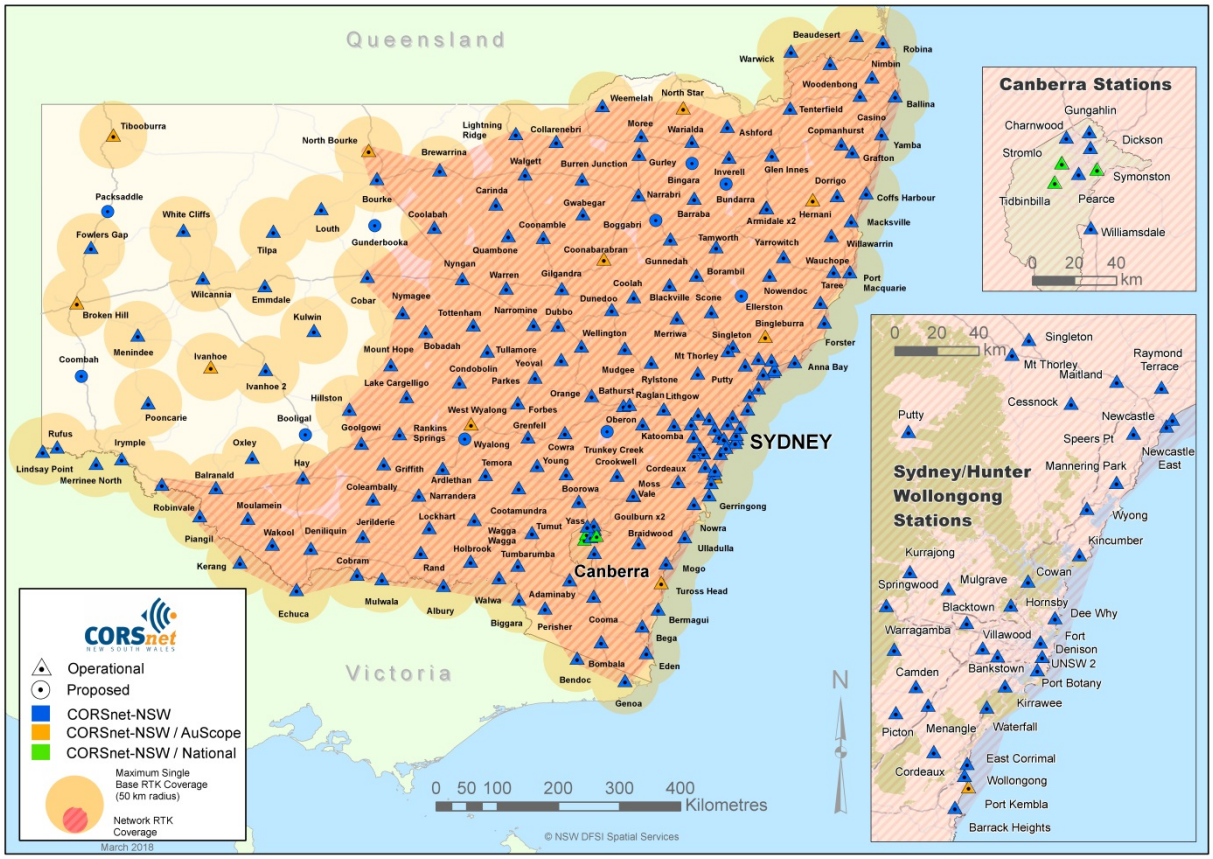

Figure 4: CORSnet-NSW network map as of March 2018 (DFSI Spatial Services, 2018).

Applying AUSGeoid2020 to GDA2020 national-adjustment derived ellipsoidal heights as opposed to applying AUSGeoid09 to Regulation 13 GDA94 ellipsoidal heights revealed an improvement by a factor of 2.3 in the agreement to AHD with the RMS dropping from 0.056 m to 0.024 m. The range of residuals for this dataset decreased from 0.33 m (-0.185 m to +0.142 m) to 0.22 m (-0.158 m to +0.063 m), improving by a factor of 1.5. It is also interesting to note that the number of absolute differences from AHD greater than 0.1 m decreased from 12 to 1. The only remaining misfit in excess of 0.1 m occurs at GURL CORS (-0.158 m).

GURL CORS is located in ‘black soil’ country, which is well known for reactive soils that cause significant ground movement. These problems were clearly evident when processing both the CORS tie survey for GURL, which connected the CORS to the surrounding ground control network, and from DFSI Spatial Services’ continuous daily station monitoring using the Bernese software (Haasdyk et al., 2010) – see Figure 5. Consequently, in SCIMS, GURL CORS was assigned class/order E5 for its AHD height, so the larger difference was expected. It should be noted that the height difference to SCIMS is even larger when using AUSGeoid09 (-0.185 m).

If GURL CORS is excluded from the analysis, the improvement achieved is even more pronounced. Using AUSGeoid2020 provides an improvement by a factor of 2.7 in the agreement to AHD with the RMS dropping from 0.054 m to 0.020 m. The range of residuals decreases from 0.25 m (-0.107 m to +0.142 m) to 0.12 m (-0.053 m to +0.063 m), improving by a factor of 2.2.

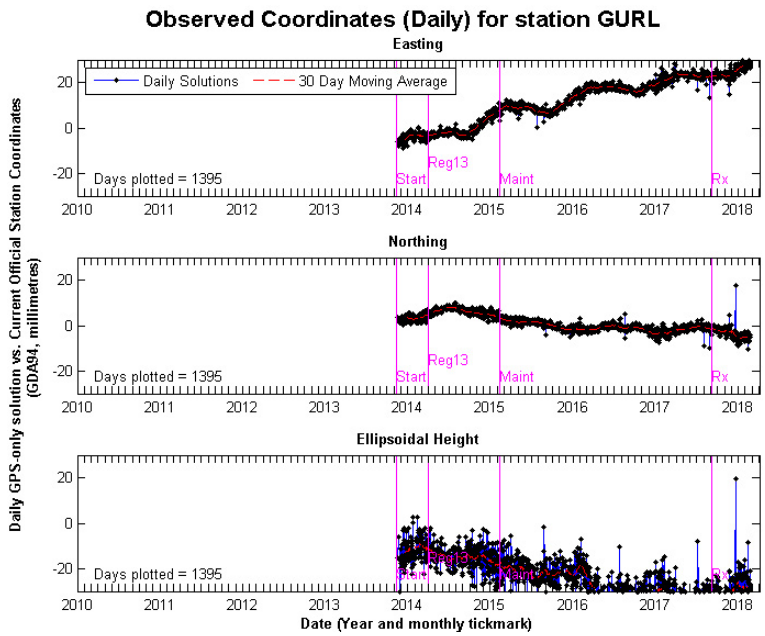

Figure 5: Coordinate time series for GURL CORS, based on daily Bernese processing (DFSI Spatial Services, 2018).

In summary, it is evident from the 138 CORSnet-NSW sites analysed that AUSGeoid2020 provides a considerably better fit to AHD across NSW than its predecessor AUSGeoid09.

3.2 Test 2: Constrained 3D Network Adjustment (Overall Fit)

In order to get an indication of the performance of the new quasigeoid model in practice with regards to GNSS-based adjustments in NSW, seven 3-dimensional GeoLab (BitWise Ideas, 2018) network adjustments were run using AUSGeoid09 in conjunction with GDA94 and AUSGeoid2020 in conjunction with GDA2020. The original quasigeoid files were converted to GeoLab geoid files using software developed in-house, which has been tested and validated over 20 years.

Height control points used for these adjustments had accurate (i.e. LCL3 or B2, or better), predominantly levelled AHD height values that were converted to ellipsoidal values before the adjustment using the selected quasigeoid model. All heights known accurately were tightly constrained in the adjustment and the resulting variance factor and flagged residuals were inspected to get an indication of the overall fit of the adjustment to AHD across NSW.

The following seven GNSS-based adjustment datasets were examined, increasing in size, extent and height variation from small to a state-wide network:

1. South Coast, a small adjustment covering a small area with a small variation in height.
2. Oxley Highway, a small adjustment covering a small area and showing a large variation in height.
3. Singleton, a large adjustment covering a small area with a moderate variation in height.
4. Bellingen, a large adjustment covering a small area with a large variation in height.
5. Bland, a large adjustment covering a moderately sized area and exhibiting a moderate variation in height.
6. South-west NSW, a large adjustment covering a quarter of the State with a moderate variation in height. Most of the observations are also included in the state-wide NSW adjustment (see below).

7. NSW, a large state-wide adjustment, extending to all borders of the State. It exhibits a large variation in height and is constrained by 11 Australian National Network (ANN) stations.

Table 1 summarises relevant information about these adjustments, while Figure 6 illustrates their location and extent in NSW. It should be noted that each baseline component is represented as a separate observation.

Table 1: Summary of the GNSS-based adjustment datasets used in this study.

Adjustment	Extent (km)	Height Range (m)	Number of Sites	Number of Obs	Number of Hgt Constraints	Baseline Length (km)	Average Bsl Length (km)
1: South Coast	21 x 18	7 – 296	18	159	12 (67%)	0.4 – 12	5
2: Oxley Hwy	53 x 35	116 – 1,208	13	108	6 (46%)	0.03 – 53	16
3: Singleton	33 x 42	30 – 442	87	631	55 (63%)	0.6 – 30	5
4: Bellingen	40 x 27	2 – 1,041	107	565	63 (59%)	0.3 – 23	2
5: Bland	212 x 162	167 – 544	155	1,075	70 (45%)	0.1 – 67	12
6: SW NSW	633 x 553	20 – 645	34	752	26 (76%)	8 – 270	128
7: NSW	1,000 x 800	2 – 2,229	89	1,721	11 (12%)	3 – 393	130

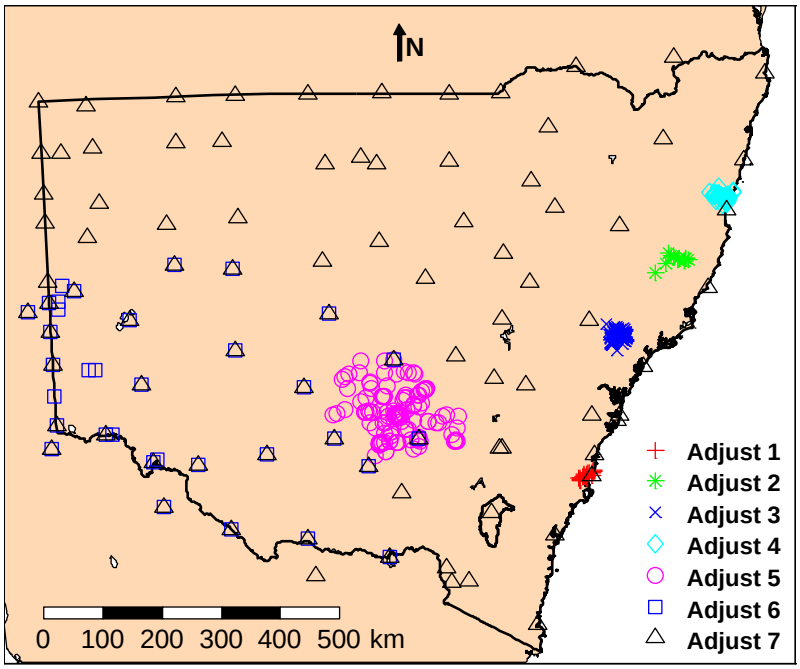

Figure 6: Location and extent of the GNSS-based adjustment datasets investigated.

In general, the utilisation of AUSGeoid2020 improved the variance factor (Table 2) and resulted in a comparable number of flagged residuals (Table 3), indicating a better adjustment result in comparison to using AUSGeoid09. The largest improvement was gained in adjustment 5, with the variance factor improving by a factor of 2.3, while the number of flagged residuals was reduced from 1 to 0. This adjustment covers a moderately sized area and exhibits a moderate variation in height, illustrating the positive effect AUSGeoid2020 can have on GNSS-based height transfer in NSW.

In one case, adjustment 2 (a small adjustment exhibiting a large variation in height), the variance factor increased slightly, bringing it a little closer to unity, while the number of flagged residuals increased from 0 to 2. However, this does not necessarily mean that AUSGeoid2020 performs worse than AUSGeoid09 in this case, but simply that previously hidden outliers are now detectable.

In this context, it should be noted that generally a variance factor of unity is desired to ensure that the uncertainties correctly represent the quality of the observations. However, in practice, DFSI Spatial Services does generally not modify uncertainties if the resulting variance factor is smaller than unity (i.e. the uncertainties could be tightened because the observation quality is actually better than that stated by the a-priori values). Consequently, for the purpose of this comparison, a lower variance factor is interpreted as a better result.

Table 2: Variance factors obtained for the adjustments investigated.

Adjustment	AUSGeoid09	AUSGeoid2020	Improvement Factor
1: South Coast	1.19	1.16	1.0
2: Oxley Hwy	0.54	0.71	0.8
3: Singleton	1.05	0.59	1.8
4: Bellingen	1.12	0.93	1.2
5: Bland	1.00	0.43	2.3
6: SW NSW	0.24	0.22	1.1
7: NSW	0.63	0.60	1.1

Table 3: Number of flagged residuals obtained for the adjustments investigated.

Adjustment	AUSGeoid09	AUSGeoid2020	Change
1: South Coast	2	2	0
2: Oxley Hwy	0	2	+2
3: Singleton	0	0	0
4: Bellingen	1	1	0
5: Bland	1	0	-1
6: SW NSW	0	0	0
7: NSW	1	2	+1

Adjustments 3 and 4 cover equally small areas and contain rather short baseline lengths. However, the improvement gained by using AUSGeoid2020 is much more pronounced for adjustment 3, which exhibits a moderate variation in height (variance factor improving by a factor of 1.8). For adjustment 4, which incorporates a large variation in height, the variance factor improves by a factor of 1.2, suggesting that most improvement is gained in areas exhibiting moderate height variations. Intuitively, this makes sense as input data density for AUSGeoid modelling is routinely lower at higher elevations.

The overall fit of the large adjustments (6 and 7) also improved but only slightly. These adjustments cover very large areas with average baseline lengths of 130 km, reaching up to 270 km and 390 km respectively. It can therefore be expected that distance-dependent error sources mask the improvement achieved by using AUSGeoid2020 to some degree.

While 76% of the marks included in adjustment 6 are tightly constrained to their known AHD heights, only 12% of sites are constrained in the state-wide adjustment 7. The other five adjustments include height constraints on 45% – 63% of the marks involved. From the limited amount of data analysed here, no correlation is evident between the number of constrained AHD heights included in the adjustment and the improvement gained by utilising AUSGeoid2020.

In summary, based on these seven adjustments, further evidence is given that AUSGeoid2020 considerably improves access to AHD compared to AUSGeoid09 across NSW.

3.3 Test 3: Minimally Constrained 3D Network Adjustment (Height Observation Residuals)

In a further attempt to evaluate the performance of AUSGeoid2020 in practice, a third test was performed, based on the seven adjustments mentioned above. In this analysis, only one observed AHD height was held fixed (located in the centre of the adjustment area), while the others were introduced as observations and allowed to float. Therefore, the adjustment was minimally constrained in height. For the marks that had accurately known AHD heights, the adjusted heights (obtained by applying AUSGeoid09 to GDA94 ellipsoidal heights or AUSGeoid2020 to GDA2020 ellipsoidal heights) were compared against their known AHD values by analysing the residuals of the height observations after the adjustment. The values of these residuals indicate how well the quasigeoid model fits the AHD heights.

For each of the adjustment datasets described above, the height observation residuals for each quasigeoid model are summarised in Table 4. It is evident that the use of AUSGeoid2020 considerably improves the residuals in most cases with improvement factors generally around 1.4. By far the largest improvement is achieved for adjustment 5 with improvement factors of 1.8 for the RMS and 2.4 for the range of the residuals.

Table 4: Results of the height observation residual analysis.

Adjustment	Parameter	AUSGeoid09	AUSGeoid2020	Improvement Factor
1: South Coast (11 marks)	**RMS (m)**	0.024	0.022	1.1
	Range (m)	0.070	0.059	1.2
2: Oxley Hwy (5 marks)	**RMS (m)**	0.034	0.038	0.9
	Range (m)	0.050	0.076	0.7
3: Singleton (53 marks)	**RMS (m)**	0.029	0.021	1.4
	Range (m)	0.104	0.076	1.4
4: Bellingen (60 marks)	**RMS (m)**	0.053	0.044	1.2
	Range (m)	0.340	0.246	1.4
5: Bland (68 marks)	**RMS (m)**	0.049	0.027	1.8
	Range (m)	0.281	0.115	2.4
6: SW NSW (24 marks)	**RMS (m)**	0.087	0.061	1.4
	Range (m)	0.408	0.234	1.7
7: NSW (9 marks)	**RMS (m)**	0.144	0.071	2.0
	Range (m)	0.411	0.231	1.8

In most cases, the RMS values of the AUSGeoid2020 results show significant improvement and fall well within ±0.05 m, i.e. the accuracy estimate stated by Brown et al. (2011) and verified by Janssen and Watson (2010, 2011) for AUSGeoid09, although the range of residuals remains rather large in some cases. However, adjustments 6 and 7 show larger RMS values. This was expected because these two adjustments cover large areas and contain relatively long average baseline lengths of 130 km. On the positive side, the range of residuals is significantly reduced in these two cases (by factors of 1.7 and 1.8 respectively).

Only adjustment 2 shows no improvement over AUSGeoid09, with both the RMS and range of residuals increasing slightly. Considering that the sample size is very small and this adjustment exhibits a large variation in height, this result needs to be taken with caution as it is not representative of the general trend seen in the other adjustments. It should also be remembered that errors in the AHD and GNSS heights at the analysed points contribute cumulatively to the overall error in the residual comparison of these adjustments.

In summary, all three tests have shown that AUSGeoid2020 substantially improves access to AHD for GNSS-based height transfer in NSW. Furthermore, our results agree with absolute testing performed nationally. Brown et al. (in prep.) report standard deviations (1 sigma) of 0.038 m for about 7,600 GPS-levelling test points across Australia using the cross validation method and 0.027 m for about 8,400 independent GPS-levelling points across NSW, Victoria and Western Australia.

3.4 Rigorous Propagation of AUSGeoid2020 Uncertainty

As mentioned in section 2.2, AUSGeoid2020 provides a rigorous uncertainty value associated with the separation between the ellipsoid and AHD, varying as a function of location. AUSGeoid2020 users are therefore expected to benefit from more realistic uncertainty information, particularly in the coastal zone where offshore data is included in the model computation and mountainous regions or other areas exhibiting sparser input datasets. Unfortunately, at the time of writing, detailed information about the calculation of the AUSGeoid2020 uncertainty grid and the processing philosophy followed was not available to the authors. Consequently, this section can only provide a general examination of the AUSGeoid2020 uncertainty grid.

In order to briefly investigate the practical usefulness of the new uncertainty component of the AUSGeoid product, absolute uncertainty values were calculated for each survey mark in this study (approx. 610 in total). About 70% of the AHD heights used are independent of the data used to compute AUSGeoid2020. The resulting absolute (1 sigma) uncertainty values were determined via bi-cubic interpolation and ranged from about 0.07 m to 0.11 m, with a mean of 0.086 m. Figure 7 illustrates the distribution of AUSGeoid2020 uncertainty across the State, as obtained from the official AUSGeoid product. The location of levelled benchmarks along major roads, observed via GNSS by DFSI Spatial Services in preparation for the AUSGeoid2020 product, is clearly visible (cf. Figure 3).

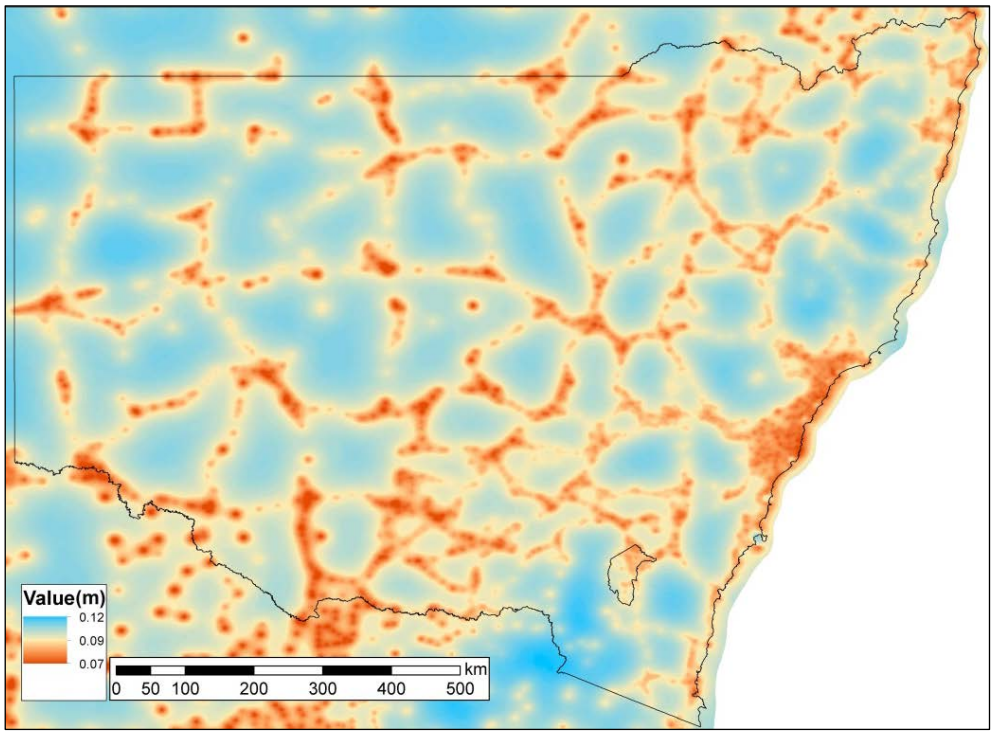

Figure 7: Distribution of absolute AUSGeoid2020 uncertainty across NSW.

Judging from the results presented in this paper, and those reported by Brown et al. (in prep.), it is apparent that these uncertainty values are overly conservative. Furthermore, the smallest rigorously propagated uncertainty value (0.07 m) is larger than the (constant) ±0.05 m accuracy estimate stated (and verified) for the previous product (AUSGeoid09), although the new product is based on much improved input datasets and modelling. Consequently, the AUSGeoid2020 uncertainty grid currently has only limited practical value. It should be noted that the relative uncertainties of the AUSGeoid2020 uncertainty grid (between marks) were not investigated as part of this study.

It is important to emphasise that the comparison of uncertainty values presented here can only provide a general assessment of the rigorously calculated AUSGeoid2020 uncertainties. Once more information about the generation of the AUSGeoid2020 uncertainty grid becomes available, a more thorough investigation will be possible.

4 CONCLUDING REMARKS

In September 2017, Geoscience Australia finalised the release version of AUSGeoid2020 (version 08/09/2017), which is to be used in conjunction with Australia's new national datum, GDA2020 (gazetted in October 2017), in order to connect GNSS-derived ellipsoidal heights to the Australian Height Datum. As NSW is preparing to enable GDA2020, this paper has shown that the AUSGeoid2020 product provides a considerably improved fit to AHD across NSW when compared to its predecessor.

Analysis based on 138 CORSnet-NSW sites showed that AUSGeoid2020 substantially enhances the quality of GNSS-based determination of AHD heights in NSW. The RMS of residuals improved by a factor of 2.3, while the range of the height residuals improved by a factor of 1.5 (2.7 and 2.2 respectively, if GURL CORS is excluded).

An investigation of several GNSS-based adjustments, incorporating various ranges in elevation and adjustment area sizes, revealed that the utilisation of AUSGeoid2020 generally improved the overall adjustment fit. This was evidenced by improved variance factors and comparable numbers of flagged residuals, although this improvement was smaller for larger adjustments covering large areas. The residuals of the height observations stemming from these adjustments were also analysed and showed that AUSGeoid2020 improved the residuals, generally by a factor of about 1.4, reaching maximum values of 2.0 for the RMS and 2.4 for the range of the residuals.

In most cases the AUSGeoid2020 results fall well within ±0.05 m of the known AHD heights on public record, considering the existence of errors in both AHD and GNSS heights at the analysed points. However, the rigorous, location-based uncertainty values provided with the AUSGeoid2020 product appear to be overly conservative (ranging from 0.07 m to 0.11 m, with a mean of 0.086 m) and are therefore of limited practical use, apart from blunder detection. Once more information about the generation of the AUSGeoid2020 uncertainty grid becomes available, a more thorough investigation will be necessary.

The improvement achieved with AUSGeoid2020 can be explained mainly by the larger, denser and higher-quality input dataset and improved modelling. Users who derive their initial ellipsoidal heights using AHD and a quasigeoid model can expect that AUSGeoid2020 will serve them very well and the elevation products will represent local AHD much better

than in the past. However, it must be remembered that AUSGeoid2020 can *only* be used in conjunction with GDA2020 ellipsoidal heights, while AUSGeoid09 *must* be used to convert GDA94 ellipsoidal heights to AHD.

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Using an Avalanche of Measurements to Improve National Datums

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ABSTRACT

Within the next decade, Global Navigation Satellite Systems (GNSS), with corrections from internet or satellite communications, will permit national coverage of positioning services with several centimetre or better accuracy in real-time. Given that location-based data can only be as accurate as the datum to which it is aligned, there is a widespread need for a millimetre-level accurate national datum that disparate, high-accuracy datasets can be aligned to. The new national datum, the Geocentric Datum of Australia 2020 (GDA2020) and national geoid model, AUSGeoid2020, go a long way to meeting the requirements of many users seeking to geo-reference spatial information accurately and precisely. The respective improvements from their predecessors (GDA94 and AUSGeoid09) are in large part due to the increased number of high-quality observations, and software capable of analysing and combining them. The national adjustment to produce GDA2020 was developed using approximately two million measurements to rigorously propagate coordinates and uncertainties to ~250,000 points across Australia. AUSGeoid2020 is a by-product of the national adjustment, developed using ~7,500 collocated GNSS-levelling points, 1.75 million land gravity observations and a global gravity model. This paper describes the new techniques applied to develop GDA2020 and AUSGeoid2020 in a rigorous manner. Furthermore, it explores the future of Australian datums and time dependent reference frames from which to commence discussion about the requirements of future users of positioning, including those from new and emerging industries (e.g. intelligent transport services and precision agriculture) to improve productivity, efficiency and safety, and those from fields of science (e.g. climate change) to improve our understanding of the Earth and to assist with making important decisions. This paper also explores how the ever increasing number of observations from the expanding community of users of spatial data can be best used to feed back into the development of time-dependent reference frames.

KEYWORDS: *National datums, GDA2020, AUSGeoid2020, emerging industries, future requirements of positioning.*

1 INTRODUCTION

The use of positioning data and applications is no longer limited to spatial professionals. By 2023, location based services (e.g. augmented reality and emergency services) and intelligent transport services (road, rail, maritime and aviation) are expected to account for 93.5% of Global Navigation Satellite System (GNSS) chipset sales. In contrast, the traditional GNSS chipset market of precision agriculture, surveying and timing is expected to only account for 6.5% (GSA, 2015).

This growing user base of non-spatial users expects real-time, accurate, high-integrity positioning services and applications. They should be abstracted from the complexities of coordinate transformations, coordinate conversions, datums and geoid models. The challenge for governments and spatial professionals is to develop high-quality, robust infrastructure, tools, services and communication services, which will enable industry, scientists and the public to capitalise on this technology and maximise its benefit.

Evidence of this changing and diverse user base is demonstrated by the projects currently being tested under the National Positioning Infrastructure Capability (NPIC) Satellite-Based Augmentation System (SBAS) trial in Australia and New Zealand. This 2-year trial is testing the advantages of precise positioning from corrections over the internet and space-based communications at the centimetre-level in a range of industries and mass-market applications such as marine, agriculture and smart cities. To enable the best use of this emerging precise positioning technology, Australia requires datums or reference frames which are more accurate than the data, closely aligned to the global coordinate reference frame and, in some cases, time-dependent.

2 DEVELOPING GDA2020 FROM AN AVALANCHE OF OBSERVATIONS

2.1 Drivers for an Update to the National Geometric Datum

The key driver for a new national geometric datum is the expectation that centimetre-level mobile positioning technology will be available within the next decade. The advent of this technological advancement follows many changes within the geospatial industry including the regeneration or launch of satellite navigation constellations such as GLONASS (Russia), Galileo (Europe), QZSS (Japan), BeiDou (China) and IRNSS (India) in addition to GPS (UNOOSA, 2016). Australia is well placed both geographically and strategically to take advantage of these systems including the regional networks from Japan and India. Given that there is a growing number of users and applications reliant on GNSS for positioning, navigation and timing, there is also a clear driver to be more closely aligned to the International Terrestrial Reference System (ITRS), the international standard for positioning in which GNSS and precise positioning services inherently operate.

A further reason to modernise the national geometric datum stems from the fact that we are attempting to measure things more accurately. As a result, we can no longer make the assumption that we live in a static environment. The Earth is stressed and strained by numerous geophysical processes such as plate tectonic motion of ~7 cm/yr (Dawson and Woods, 2010), hydrological cycles (Brown and Tregoning, 2010), earthquakes (Tregoning et al., 2013) and post-glacial rebound (Thomas et al., 2011). As we attempt to measure these geophysical processes with greater precision, we need to continually improve the datum to

which our observations are referenced. The previous Australian datum, the Geocentric Datum of Australia 1994 (GDA94), was unable meet this requirement for some current and future users.

GDA94 was based on the International Terrestrial Reference Frame 1992 (ITRF92) and constrained to eight Australian Fiducial Network (AFN) marks. Since then there have been many revisions and improvements to ITRF which better define the shape of the Earth. For example, between ITRF92 (GDA94 was based on the realisation of ITRF92 at epoch 1994.0) and ITRF2014 (GDA2020 was based on the realisation of ITRF2014 at epoch 2020.0) there is ~9 cm change in ellipsoidal heights in Australia (GDA2020 heights are ~9 cm less than GDA94 ellipsoidal heights).

A further issue with GDA94 was the lack of rigour in uncertainty propagation caused by performing a hierarchical adjustment. For example, to compute Australian National Network (ANN) coordinates at 78 sites across Australia, the AFN sites were held fixed (zero positional uncertainty) in the adjustment (Figure 1). The ANN sites were then held fixed in the combined state/territory adjustments and so on. As a result, state and territory survey control marks lower in the hierarchy have an unrealistic uncertainty value (Haasdyk and Watson, 2013).

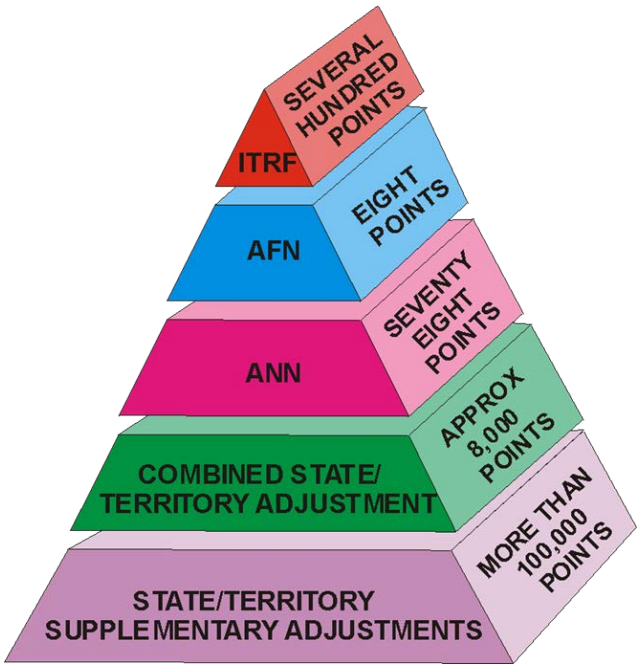

Figure 1: Constraint was not rigorously applied to the least squares adjustment of coordinates for GDA94.

To overcome this issue, the Intergovernmental Committee on Surveying and Mapping's (ICSM's) Permanent Committee on Geodesy (PCG) adopted the use of least squares adjustment software (DynaNet – see Fraser et al., 2017) capable of performing a continental-scale rigorous adjustment of all GNSS and terrestrial data from Commonwealth, state and territory governments (see section 2.2). Since the development of GDA94, there has been significant investment in infrastructure including the construction of the AuScope Continuously Operating Reference Station (CORS) network (GA, 2018b), state and territory government CORS networks, privately operated CORS networks and improvements in GNSS hardware and analysis including absolute antenna modelling (Riddell et al., 2015). These infrastructure and technological developments have led to higher-quality geodetic

measurements and improved realisations of the ITRS which cannot be accurately modelled with a transformation from ITRF to GDA94.

2.2 How GDA2020 Was Developed

GDA2020 coordinates were computed using a rigorous, 3D Cartesian network adjustment of all available GNSS and terrestrial data from Commonwealth, state and territory jurisdictional archives. This adjustment enables the determination of GDA2020 coordinates and supports the computation of positional uncertainty and relative uncertainty between any survey control marks in Australia. The national GDA2020 network adjustment was undertaken by Geoscience Australia with input from geodetic specialist representatives from all jurisdictional survey organisations.

The GDA2020 network adjustment involved a rigorous least squares adjustment of all data. In the past, adjustments were undertaken with higher-order data being held fixed in lower-order adjustments. This resulted in distortions in the datum that have become more apparent when compared with high-accuracy GNSS data observed in ITRF2008 or ITRF2014 and transformed back to 1994 using a 7-parameter similarity transformation. By performing a single, national, rigorous adjustment, these distortions have been reduced and relative uncertainty can be computed for any given points on the datum.

The national GDA2020 network adjustment includes all available GNSS and terrestrial data from the jurisdictional archives, constrained using the Asia-Pacific Reference Frame (APREF) time series combination solution. This solution is calculated weekly by Geoscience Australia for approximately 450 APREF stations within Australia's jurisdiction and provides a link between ITRF2014 and GDA2020. The development of GDA2020 has also seen the creation of the National GNSS Campaign Archive (NGCA) stored at Geoscience Australia. This archive contains all GNSS observations provided by state and territory jurisdictions that are greater than 6 hours in duration. The data were processed (and will continue to be processed as new data becomes available) by Geoscience Australia to create a national high-quality GNSS network.

To define GDA2020, International Terrestrial Reference Frame 2014 (ITRF2014) coordinates and velocities of the 109 Australian Fiducial Network (AFN) stations were mapped forward to the epoch of 1 January 2020 using a plate motion model (explained in detail in section 3). The plate motion model can be expressed as a 3-parameter Euler plate model expressed as a 14-parameter transformation with only rates of change for the rotation components (Table 1; ICSM, 2018).

Table 1: Transformation parameters for ITRF2014 to GDA2020 along with their one-sigma uncertainties (1σ). Units are in metres (m) and m/yr for the translation and their rates, respectively, parts-per-million (ppm) and ppm/yr for scale and its rate, respectively, and arcseconds and arcseconds/yr for rotations and their rates, respectively. The reference epoch t_0 is 2020.0.

	$t_x, \dot{t}_x$	$t_y, \dot{t}_y$	$t_z, \dot{t}_z$	$s_c, \dot{s}_c$	$r_x, \dot{r}_x$	$r_y, \dot{r}_y$	$r_z, \dot{r}_z$
	0.00	0.00	0.00	0.00	0.00	0.00	0.00
uncertainty	0.00	0.00	0.00	0.00	0.00	0.00	0.00
rates	0.00	0.00	0.00	0.00	0.00150379	0.00118346	0.00120716
uncertainty	0.00	0.00	0.00	0.00	0.00000417	0.00000401	0.00000370

The production of GDA2020 and its associated products (AUSGeoid2020 and the GDA94-GDA2020 transformation grids) were the result of an iterative process that spanned more than four years. This iterative process was necessitated by the fact that AUSGeoid2020 was developed in parallel with GDA2020, which required the results from one process being input into the other process, and vice versa. It was crucial for the development of the national adjustment as it allowed measurement blunders to be identified and corrected, as well as ensuring every station had a single, unique name.

Each development cycle consisted of several steps: GNSS baseline processing (NGCA), jurisdictional adjustments, a combined national adjustment and product development (AUSGeoid2020 and transformation grids). Following each iteration, quality assurance was carried out by members of the PCG Adjustment Working Group (AWG).

The NGCA contains all the high-quality GNSS observations that are used to densify the APREF network and serve as the backbone of the national geodetic network. Data submitted to this archive are RINEX files between 6-48 hours in duration and sampled at 30-second epochs. The NGCA data from each state or territory are currently processed individually to avoid cross-border issues which are dealt with later in the process. Given the large number of submitted RINEX files, they are arranged into clusters for processing based on the overlap in observation times. Processing of the data is then undertaken using a modified version of the AUSPOS software (GA, 2018a).

The output from the AUSPOS analysis is a SINEX file for each cluster which is then converted to a GNSS baseline cluster. Each GNSS baseline cluster is a set of relative baselines, i.e. the datum constraint on the baselines is removed. Constraint in the national least squares adjustment (performed using DynaNet) is provided by the APREF solution. The output of the combined APREF and NGCA adjustment is supplied to the jurisdictions who add their jurisdictional data archive to ensure their data which has not yet been included in the adjustment (e.g. RINEX files less than 6 hours and terrestrial data) fit the APREF and NGCA data. Once jurisdictions are satisfied, the APREF network, NGCA and jurisdictional adjustments were combined in a national adjustment to compute GDA2020.

2.3 DynaNet: Handling Many Observations

While the task of estimating unknown station coordinates and their uncertainties for relatively small survey control networks can be achieved in a matter of seconds using a modern computer, the computation of extremely large geodetic networks (comprising hundreds of thousands of stations and measurements) is a computationally intensive and time-consuming task. In some cases, the size of national and continental networks presents an impenetrable obstacle to network adjustment, which has often led to non-rigorous approaches to their computation.

For this reason, DynaNet was adopted to compute the GDA2020 national adjustment. DynaNet is a rigorous, high-performance least squares adjustment application designed to handle both small and extremely large geodetic networks – whether on a standard desktop or a supercomputer. The means by which DynaNet is able to efficiently manage large geodetic networks, without compromising on the rigour of the solution, is the technique of phased adjustment. In order to simplify the task of running phased adjustments on a network that is continually evolving (with new stations and measurements appearing almost weekly),

DynaNet provides a highly efficient automatic approach to network segmentation – an essential prerequisite task for successful phased adjustment.

On account of the phased adjustment approach used by DynaNet, the maximum network size which can be adjusted is effectively unlimited, other than by the limitations imposed by a computer's processor, physical memory and operating system memory model (Fraser et al., 2017). It follows that by having an automated segmentation procedure which permits the user to quickly and easily segment a geodetic network of almost any size and configuration, DynaNet offers extreme versatility to the ongoing maintenance of the national adjustment. Versatility primarily comes as a result of being able to (a) reproduce the same coordinate estimates and uncertainties despite how the network has been segmented and which stations appear in each block and (b) efficiently re-segment the network at will using different segmentation parameters, or whenever new stations and measurements are introduced to the network.

In addition to these two primary features, DynaNet offers the ability to integrate a diverse range of survey measurement types, manage the rigorous transformation of coordinates and measurements between multiple reference frames, and compute detailed statistical information for all station estimates and adjusted measurements – an essential component for the effective evaluation of the quality of the network and the computed results. The evaluation of uncertainty includes Positional Uncertainty (PU) of all stations across the network, as well as relative uncertainty between two or more stations in the network, as described in the Standards and Practices (SP1) document (ICSM, 2014).

Given the size of the Australian geodetic network (~2 million measurements and ~250,000 stations) it would take days, if not weeks, to perform a single iteration of adjustment on a standard PC. For this reason, the national adjustment was computed on the National Computational Infrastructure (NCI) supercomputer, Raijin. The multi-thread capabilities of DynaNet allowed segments of the national adjustment to be distributed across Raijin and then combined to form a rigorous adjustment. A single iteration of the national adjustment can be performed in less than 2.5 hours, uses eight cores and requires almost 2.8TB of RAM.

3 THE FUTURE OF AUSTRALIA'S GEOMETRIC DATUM

Location-based data can only be as accurate as the datum to which it is aligned. For some applications which require real-time, high-precision positioning aligned to GNSS such as the intelligent transport sector (e.g. autonomous vehicles and mining) and location-based services (e.g. asset management and emergency services), ICSM has endorsed a plan to introduce a time-dependent reference frame in 2020. This time-dependent reference frame will be called the Australian Terrestrial Reference Frame (ATRF). As opposed to GDA2020, which is a static datum (i.e. coordinates are fixed to a given epoch), ATRF coordinates will change with time. This reference frame will be an accurate and densely realised geodetic framework based on continuous observation and analysis of GNSS data and will provide the Australian community with traceable, high-precision coordinates, closely aligned to ITRF and capable of meeting the most demanding positioning requirements.

Time-dependent reference frames are not new – nine International Terrestrial Reference Frame solutions (realisations of the International Terrestrial Reference System, ITRS) have been developed with the first in 1992. The origin of the reference frames are the centre of the

mass of the Earth and the X, Y, Z axes co-rotate with the Earth (Petit and Luzum, 2010; Altamimi et al., 2016). As the tectonic plates move on the Earth (e.g. the Australian plate moves ~7 cm/yr to the NNE), the coordinates of points change with time to reflect this motion. With each new ITRF realisation, new and improved models, analysis strategies and geodetic techniques are applied to improve the realisation of the size and orientation of the Earth.

3.1 Difference Between ITRF and ATRF

There will be very close alignment between ATRF and ITRF – in fact the 13 Australian sites that contributed to ITRF2014 will be a subset of the reference sites constrained in ATRF (see section 3.2). The increased number of reference sites will provide a denser and more representative reference frame and velocity field for a more robust positioning capability and improved interoperability of spatial data in Australia. Due to computational limitations, it is not currently possible for countries to submit hundreds of sites to include in analysis and definition of ITRF realisations. Therefore, when countries, continents or regions require denser reference frames, it is necessary to establish regional and national reference frames (e.g. European Terrestrial Reference System 1989, ETRS89).

3.2 Realising ATRF

The National Measurement (Recognized-value Standard of Measurement of Position) Determination 2017 (the Determination) states the coordinates of 109 AFN sites, which are the basis of the Geocentric Datum of Australia 2020 (NMI, 2017). ATRF coordinates are anticipated to be generated in an automated fashion with a new national adjustment being triggered as any new data is detected within Commonwealth, state or territory government databases. The adjustment will run on the National Computational Infrastructure supercomputer using machine-to-machine protocols. Following the operationalisation of the process, it is also expected that spatial professionals will be able to submit data to this national adjustment using a cloud service to have their data used in the definition of the reference frame.

The results of a national adjustment will be new coordinates, coordinate uncertainties, velocities, and velocity uncertainties in GDA2020, which will be projected forward in time using the Australian plate motion model (section 2.2) to be ATRF coordinates at the epoch of the adjustment.

3.3 Legal Traceability of GDA2020 and ATRF

Historically, the recognized-value standard of position of measurement determinations only included coordinates (X, Y, Z), however, the 2017 Determination also includes coordinate uncertainty, coordinate velocity and coordinate velocity uncertainty. Furthermore, it includes equation 1 which enables coordinates of the AFN to be expressed at any epoch t (years) through the application of the following linear model using the coordinates (X, Y, Z) and velocities (V_x, V_y, V_z):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_t = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{2020} + (t - 2020) \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} \tag{1}$$

This model is valid for 15 years either side of 2020: $|t - 2020| \leq 15$.

Internal deformation of the Australian plate is less than 1 mm/yr with the exception of isolated areas of intraplate earthquakes and subsidence (Tregoning et al., 2013). As a result, a rigid plate motion model is appropriate to describe the dynamics experienced by the Australian tectonic plate and is sufficient to maintain compatibility with ITRS realisations in which GNSS operate. The difference between the coordinates computed using velocities described in the Determination and those computed from the Australian plate motion model are within the uncertainty of sites defined in the Determination. The Australian plate motion model can therefore be used to propagate coordinates and maintain traceability to the Determination. The inclusion of the additional parameters in the Determination and equation 1 has established the framework for users to implement the ATRF.

In recognition of the fact that many users do not require a time-dependent reference frame, GDA2020 will continue to be supported for the foreseeable future. As explained above, from a legal traceability perspective, the Determination has been designed to support both GDA2020 and ATRF.

4. THE FUTURE OF AUSTRALIA'S PHYSICAL HEIGHT DATUM

Heights derived from GNSS are precise and efficient. However, they are not always practical. For example, when dealing with water flow for drainage systems or assessing flood risk, it is necessary to use a physical height datum. Geometric height datums, such as the ellipsoid, ignore Earth's gravity field and use straight-line paths (e.g. GNSS). Physical height datums are based on Earth's gravity field and measured along the curved plumbline (e.g. normal-orthometric heights used for AHD), and are often measured relative to mean sea level. As we innovate and improve the geometric reference systems, we need to ensure we also innovate and improve our national height datum and geoid model to enable users to convert ellipsoidal (geometric) heights to physical heights efficiently and accurately.

4.1 AHD and the Geoid

The Australian Height Datum (AHD) is the official national vertical datum for Australia and refers to Australian Height Datum 1971 (AHD71, Australian mainland) and Australian Height Datum (Tasmania) 1983 (AHD-TAS83). Prior to AHD, many local height datums were used in the states and territories. The datum surface passes through mean sea level (MSL) realised between 1966-68 at 30 tide gauges around the Australian mainland and from 1972 at two tide gauges in Tasmania.

AHD heights were derived across Australia via a least squares adjustment of 97,320 km of 'primary' levelling (used in the original adjustment) and 80,000 km of 'supplementary' levelling (applied in a subsequent adjustment) (Roelse et al., 1975). The interconnected network of level sections and junction points was constrained at the tide gauge sites, which were assigned a value of zero AHD. A least squares adjustment was performed to propagate AHD heights across the level network.

A number of known biases and distortions exist within AHD. The primary bias with respect to the geoid is due to the manner in which AHD was realised. In the adjustment of the levelling network data, each of the tide gauge sites was constrained to zero AHD. Due to the effect of

the ocean's time-mean dynamic topography, AHD is ~0.5 m above the geoid in north-east Australia and ~0.5 m below the geoid in south-west Australia (e.g. Featherstone, 2004, 2006; Featherstone and Filmer, 2008). Secondary causes of the difference between AHD and the geoid are uncorrected gross, random and systemic levelling errors in the levelling network data (e.g. Roelse et al., 1975; Morgan, 1992; Filmer and Featherstone, 2009).

4.2 AUSGeoid2020

AUSGeoid2020 enables the determination of AHD height estimates H_{AHD} from GNSS ellipsoidal heights h by providing ellipsoid-to-AHD separation values ζ_{AHD} with uncertainty (Figure 2):

$$H_{AHD} = h - \zeta_{AHD} \tag{2}$$

AUSGeoid2020 is a combined gravimetric-geometric model. The gravimetric component is a $1'$ by $1'$ grid of ellipsoid to Australian Gravimetric Quasigeoid 2017 (AGQG2017 – see Featherstone et al., 2018) separation values and the geometric component is a $1'$ by $1'$ grid of AGQG2017 to AHD separation values computed using a dataset of collocated GNSS ellipsoidal height and AHD heights. The geometric component can be viewed as a correction surface which attempts to account for the biases and distortions in the AHD.

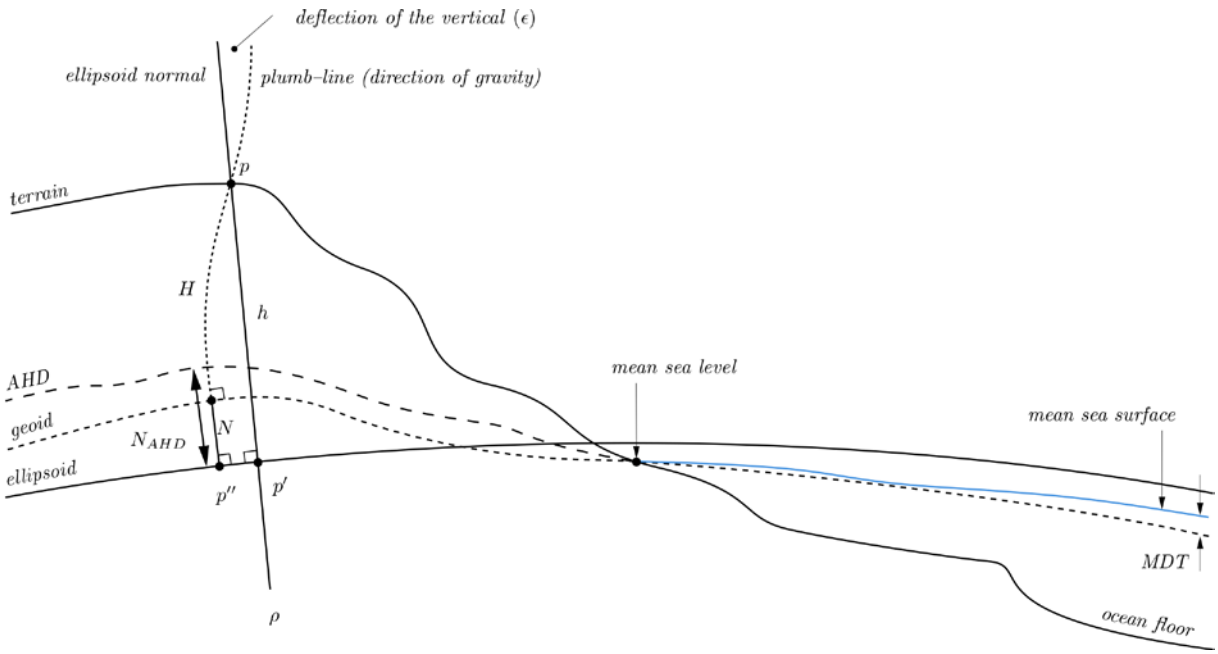

Figure 2: Reference and working surfaces for height in Australia.

4.3 New Australian Vertical Working Surface

A datum needs to meet user requirements for accuracy, integrity and accessibility. Ignoring the primary bias from time-mean dynamic topography, the secondary effects reveal the mean standard error of AHD heights used in the development of AUSGeoid2020 is 0.038 m (Featherstone et al., 2018). For some users, particularly those interested in absolute heighting and scientific and industrial heighting applications on a regional or basin scale, the distortions in the AHD are problematic and make it inadequate for their requirements. One such example of this is converting Light Detection and Ranging (LiDAR) ellipsoidal height data to a physical height datum. The distortions and uncertainty in the AHD make it difficult to

determine if LiDAR data misfits are in the data or the datum. As a result, ICSM guidelines recommend using the smoother AGQG to convert ellipsoidal heights to physical heights.

With respect to accessibility, without performing a levelling connection to the reference points used to define AHD, it is difficult to accurately connect to the datum. AUSGeoid2020 assists with this accessibility issue and provides ellipsoid-to-AHD separation values, however, the uncertainty of AUSGeoid2020 is approximately 10 cm (95% CI) in built-up areas and up to 22 cm (95% CI) in more remote regions of Australia (Brown et al., in prep.). In light of the accuracy, integrity and accessibility challenges for some in the user community, Geoscience Australia plans to lead the development of a new vertical working surface. It is important to note that this is not a new national datum to replace AHD, but an alternative vertical working surface.

The vertical working surface (working title) will provide heights above AQGQ2017. Unlike AHD, it will not be constrained to mean sea level, but instead to AQGQ2017 heights at CORS sites. Following each national adjustment, new ellipsoidal heights will be computed at each of the national CORS sites. At these sites, ellipsoid-to-quasigeoid separation values will be interpolated from AGQG2017 and used to compute the vertical working surface height and uncertainty using equations 3 and 4:

$$H_{VWS} = h - \zeta_{AQGQ2017} \tag{3}$$

$$\sigma_{H_{VWS}} = \sqrt{{\sigma_h}^2 + {\sigma_{\zeta_{AGQG2017}}}^2} \tag{4}$$

The vertical working surface height at CORS sites (and associated uncertainty) will be used as the constraint in a national adjustment of the Australian National Levelling Network (ANLN) which was used to produce AHD. It is anticipated that the ANLN will not be used in its entirety. Instead, work will be undertaken in consultation with the state and territory geodetic agencies to identify which portions of the ANLN are best to include and which can be left out. In regions where no levelling data is available, or levelling data has been removed from the process, the vertical working surface will revert back to AGQG2017.

The vertical working surface will be continually refined as new gravity, levelling and GNSS data become available, and as improved analysis techniques are developed. At this point in time, PCG and ICSM do not see a strong push from the user community to update the national vertical datum. However, the work undertaken on the vertical working surface will benefit the user community as it provides a working surface more closely aligned to the geoid with the bias and some of the distortions in the AHD removed.

It is hoped that the vertical working surface will meet the requirements of users not being met by AHD, while alleviating the fear associated with changing the national height datum. Furthermore, it will continue to promote collaboration between academia, government and industry.

5 FUTURE WORK AND CHALLENGES

5.1 Deformation Models

Surface deformation caused by natural events (e.g. earthquakes – Wright et al., 2004) or anthropogenic activities (e.g. groundwater extraction – Featherstone et al., 2012) can be significant over a small area and is often non-linear. This complex deformation cannot be adequately represented by conventional static datums or monitored using the tools traditionally used in the geodetic surveying community. For example, GNSS data has high temporal resolution but low spatial resolution. In an attempt to overcome these problems, Geoscience Australia is planning to include Interferometric Synthetic Aperture Radar (InSAR) data in the development of 4D national scale deformation model to describe motion of the crust over time.

InSAR is a geodetic remote sensing technique that can identify relative movements of the Earth's surface over large areas (100s of km) with millimetre precision and multiple observations per month. Radar images contain information on the Earth's surface in the form of the amplitude and phase components of the returned energy. The amplitude image records information about the terrain slope and surface roughness, while the phase image records information about the distance between the satellite and the Earth's surface. It is the precision of this phase information which the geodetic community can exploit.

The complimentary GNSS, levelling and InSAR observations can be combined in a least squares adjustment to create displacement estimates in a 3D velocity field with high spatial resolution and accuracy (Fuhrmann, 2016). When combined with the plate motion model to describe the secular motion of the continent, the deformation model will enable ITRF2014 coordinates to be converted to ATRF coordinates for high-accuracy positioning applications (Figure 3).

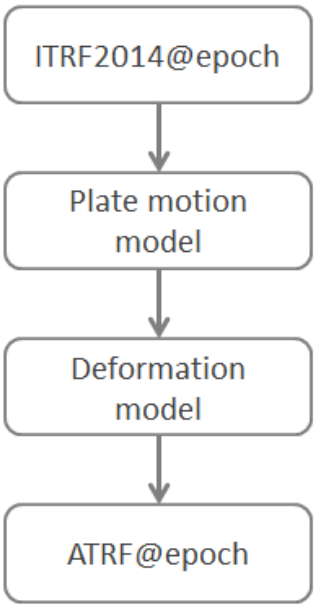

Figure 3: ATRF coordinates computed by applying the secular motion from a plate motion model with the deformation model.

5.2 Standards and Automation

Under this avalanche of observations, there is a growing need for machine-to-machine communication, automated quality checking of data and national adjustments being triggered with the delivery of new data. These processes require significant improvements to the standards and software we use. In an effort to improve our capability for databases to share data and metadata at a machine-to-machine level, the Permanent Committee on Geodesy has been developing the Geodesy Markup Language (GeodesyML) as a standard way of describing (encoding) and sharing geodetic data and metadata. In the same way people from all over the world speak different languages, so do geodesists. For example, some people use the term 'GNSS station' and others use the term 'GNSS site'. GeodesyML is a common language. By mapping your database to GeodesyML, when your data is shared with others, it is easy for the user to discover and combine it with other data.

The geodetic community needs such a standard as it is frequently called upon to provide data, products and services to support a broad spectrum of government, industry, science and societal applications. Coupled with this is the ubiquitous uptake across society of accurate and reliable Positioning, Navigation and Timing (PNT) information. In order to service these user demands in a robust way, geodetic data and the associated metadata need to be standardised, discoverable and interoperable. The continual increase in the volume and complexity of data means that we also need to generate, transfer and use data and metadata via a machine-readable form. In order to achieve these stated goals, it is clear that the time has come to develop a XML-based standard for geodesy. In recognition of these benefits, the IGS Central Bureau, UNAVCO, Geoscience Australia and Australian jurisdictional governments are currently testing machine-to-machine transfer of IGS site logs using GeodesyML.

In years to come, when new data is observed, the objective is to have an end-to-end system developed that will enable new observations from a user to be automatically uploaded, quality-checked and used to trigger the development of a new national adjustment and version of ATRF. This would further trigger the development of new products such as AUSGeoid models, transformation grids and deformation models. Finally, notifications will be sent to subscribers. At that point it becomes a business decision to determine whether the changes are significant to them, whether or not to adopt them, and how to communicate this change with their stakeholders.

6 CONCLUDING REMARKS

Technology, big data, computing power, user requirements and user expectations continue to drive down the uncertainty of positioning data. This in turn highlights the requirement to continually improve the accuracy and integrity of datums and reference frames. This is a new era for the geodetic community – more people than ever are reliant on the work we do, but just as many do not understand it. This is not to say they should understand it – in fact, they should be abstracted from it by spatial professionals. It is our role to improve the technology, understand the user requirements, and meet the user expectations.

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Which GDA94-GDA2020 Transformation Grid Should NSW Surveyors Use: Where, When and Why?

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ABSTRACT

The Geocentric Datum of Australia 2020 (GDA2020) is now the official national datum of Australia, but how should surveyors bring their existing datasets from GDA94 to GDA2020? GDA94-GDA2020 transformation grids, which can be easily obtained online and used with existing software, are expected to be commonly used for this task. The Intergovernmental Committee on Surveying and Mapping (ICSM) recommends the transformation grids as a simple and nationally consistent method for transforming between Australian datums. Two grids have been produced to cater for different realisations of GDA94. With a focus on NSW, this paper explains the composition and purpose of each grid, and identifies accuracy and data origin as the two key factors determining their appropriate use. Performance analysis results indicate that both grids are fit for purpose in NSW when used in the appropriate circumstances. Prior to transformation, users must know if their existing GDA94 dataset is affected by known GDA94 distortions (present in the Survey Control Information Management System, SCIMS), or if those distortions have been removed by other methods.

KEYWORDS: *Datum modernisation, GDA2020, transformation grids, best practice*.

1 INTRODUCTION

In October 2017, the Geocentric Datum of Australia 2020 (GDA2020) was gazetted as Australia's new, improved national datum (Gowans, 2017; Janssen, 2017; NMI, 2017; ICSM, 2018a), succeeding the Geocentric Datum of Australia 1994 (GDA94). When spatial information users wish to adopt the new datum, they may consider transforming their legacy datasets from the now superseded GDA94 to GDA2020.

In recent years, spatial data utilisation has soared, aided by open-source Geographic Information Systems (GIS) and government efforts to deliver open spatial data (e.g. ANZLIC, 2018). As a consequence, the role datum plays in meaningfully aligning data is highlighted. Failure to correctly manage datum across multiple datasets could compromise any analysis. Further, decimetre-accurate or better real-time positioning (e.g. RTK, DGNSS or SBAS-based positioning) now means stamping datasets with appropriate metadata, such as datum and even date observed, has become critical. The user must know their data and know their datum.

In Australia's previous datum modernisation efforts (e.g. AGD66-AGD84 and AGD66-GDA94), transformation grids were utilised as a simple and efficient method for transforming datasets to the new national standard. This strategy has been continued to aid uptake of GDA2020 from GDA94 with the development of two transformation grids and a number of tools, plug-ins and services.

This paper examines the GDA94-GDA2020 transformation grids, provides an explanation of their composition and an evaluation of their performance in NSW, and answers a series of 'Frequently Asked Questions' for new users.

2 TRANSFORMING FROM GDA94 TO GDA2020

2.1 The Hard Way: 7-Parameter Conformal Transformation

A conformal (often called a similarity) transformation can be used to transform between reference frames. This transformation owes its name to its characteristic of preserving shape throughout the process. The 3-dimensional conformal transformation between GDA94 and GDA2020 is described in the GDA2020 technical manual (ICSM, 2018a) and accounts for the difference in scale, rotation and translation between reference frames. This transformation method is suitable for 3D data and requires coordinates to be expressed in an earth-centred Cartesian system. The transformation can be computed using just 7 parameters as in (ICSM, 2018a):

$$\begin{matrix} X'_{GDA2020} \\ Y'_{GDA2020} \\ Z'_{GDA2020} \end{matrix} = \begin{matrix} t_x \\ t_y \\ t_z \end{matrix} + (1 + s_c) \begin{pmatrix} 1 & r_z & -r_y \\ -r_z & 1 & r_x \\ r_y & -r_x & 1 \end{pmatrix} \begin{pmatrix} X_{GDA94} \\ Y_{GDA94} \\ Z_{GDA94} \end{pmatrix} \tag{1}$$

Such a formula can appear daunting to users without a background in geodesy. Furthermore, conformal transformations cannot compensate for localised survey network distortion because this method only accounts for the mathematical differences and plate motion between the frames.

2.2 The Easy Way: Grid Transformation

A grid transformation is a simpler 2-dimensional method of transforming between reference frames and is the Intergovernmental Committee on Surveying and Mapping's (ICSM's) preferred method of transforming between datums (ICSM, 2018a). Here, transformation components (i.e. a series of latitude and longitude shifts across all of Australia) are initially computed across a grid at a set interval. Given a transformation grid, various interpolation methods can then be applied to compute shifts at an exact user-determined location (Figure 1). Often bi-linear interpolation is adopted, but other interpolation strategies are possible. For a detailed explanation on grid interpolation, the reader is referred to Collier (2002). Grid transformation is considered 'reversible', i.e. each transformation can be undone by applying the grid parameters in the opposite direction. It is also 'traceable' and 'reproducible' by all users.

Previous investigation by Collier et al. (1997) concluded the simplest and most effective way to facilitate uptake of a new datum by a wide variety of users was to provide the transformation components, including known datum-to-datum distortions, on a grid. Grid transformation is a well-established methodology and provides a method that is rigorous, simple and reversible. Transformation grids were produced to aid users in the transition from the Australian Geodetic Datum (e.g. AGD66, AGD84) to GDA94. As such, the new GDA94-GDA2020 transformation grids are backwards compatible with any existing software that can accept a user-input grid.

Two GDA94-GDA2020 transformation grids have been developed: 'Conformal only' and 'conformal and distortion'. These are discussed in section 3.

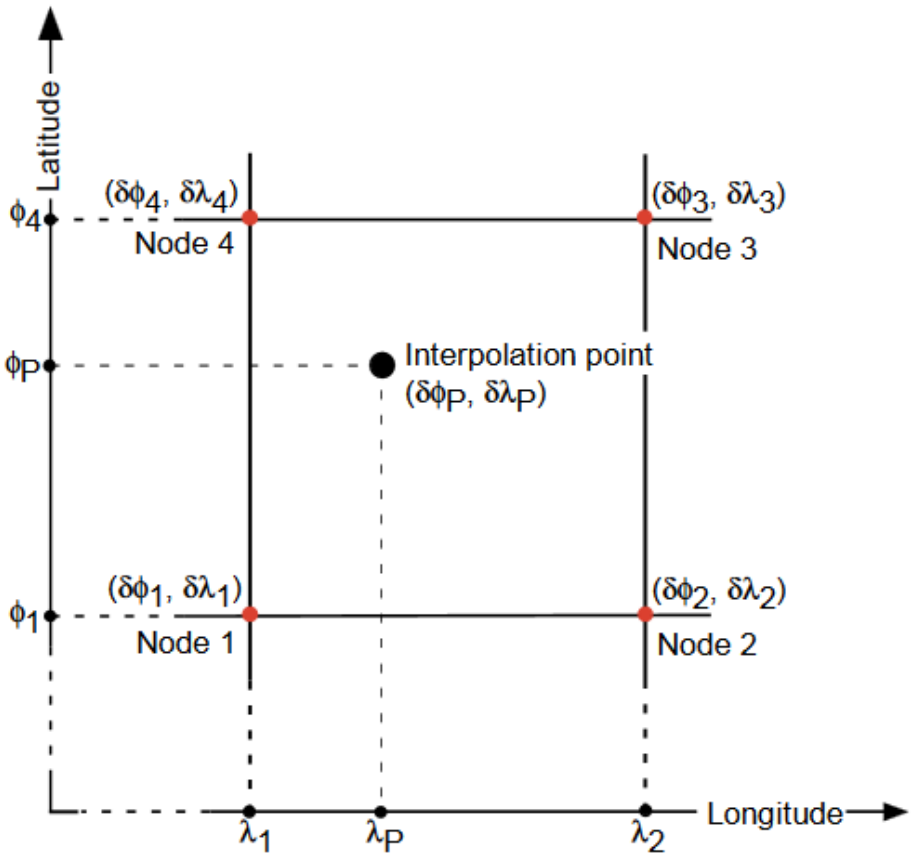

Figure 1: Grid interpolation principle from Collier (2002).

3 TRANSFORMATION GRID PRODUCTS

3.1 Transformation Grids

For some time, DFSI Spatial Services has been simultaneously providing two realisations of GDA94 for use in NSW (Janssen and McElroy, 2010). The first, based on the original GDA94 adjustment, termed GDA94(1997) in NSW, is available via the Survey Control Information Management System (SCIMS – see Kinlyside, 2013) and suffers from the adjustment deficiencies in the original GDA94 definition, and the subsequent accumulation of distortion in further adjustments. The second realisation, based on the most recent national realisation of GDA94, termed GDA94(2010) in NSW, is available via positioning technologies such as CORSnet-NSW (e.g. Janssen et al., 2016; DFSI Spatial Services, 2018a) and AUSPOS (GA, 2018), and is effectively distortion-free. For this reason, the NSW Surveyor General's Directions recommend performing site localisations to align CORSnet-NSW-based surveys to SCIMS (Haasdyk and Janssen, 2012; DFSI Spatial Services, 2012, 2014).

Consequently, two transformation pathways from GDA94 to GDA2020 were required: one which assumes distortion-free input data, i.e. GDA94(2010), and one which compensates for the localised distortions embodied in SCIMS, i.e. GDA94(1997). Background information on coordinate reference systems, datums and transformations can be found in Janssen (2009),

while Gowans (2017) further explains the need for two transformation grids. The reader is also referred to Janssen and McElroy (2010) for a more detailed explanation of GDA94(1997) versus GDA94(2010).

The following should be noted in regards to 'site localisation' versus 'site transformation' terminology: In previous papers, DFSI Spatial Services used the term 'site transformation' to describe the process of matching GDA94(2010) to GDA94(1997), e.g. from CORSnet-NSW to SCIMS. This paper uses the term 'site localisation' to avoid any potential confusion regarding transforming between references frames and transforming a site to match local survey control.

3.1.1 Conformal Only Transformation Grid

The conformal only transformation grid is simply a grid representation of Equation 1. It contains the latitude and longitude shifts between GDA94 and GDA2020 for each grid node, based solely on the 7-parameter similarity transformation parameters.

3.1.2 Conformal and Distortion Transformation Grid

The conformal and distortion grid is designed to compensate for any known localised distortions present in the control survey networks of each state and territory in Australia. In NSW, DFSI Spatial Services has contributed approximately 26,000 marks which are common between the GDA94 and GDA2020 networks in order to compute the localised distortion across NSW (Figure 2).

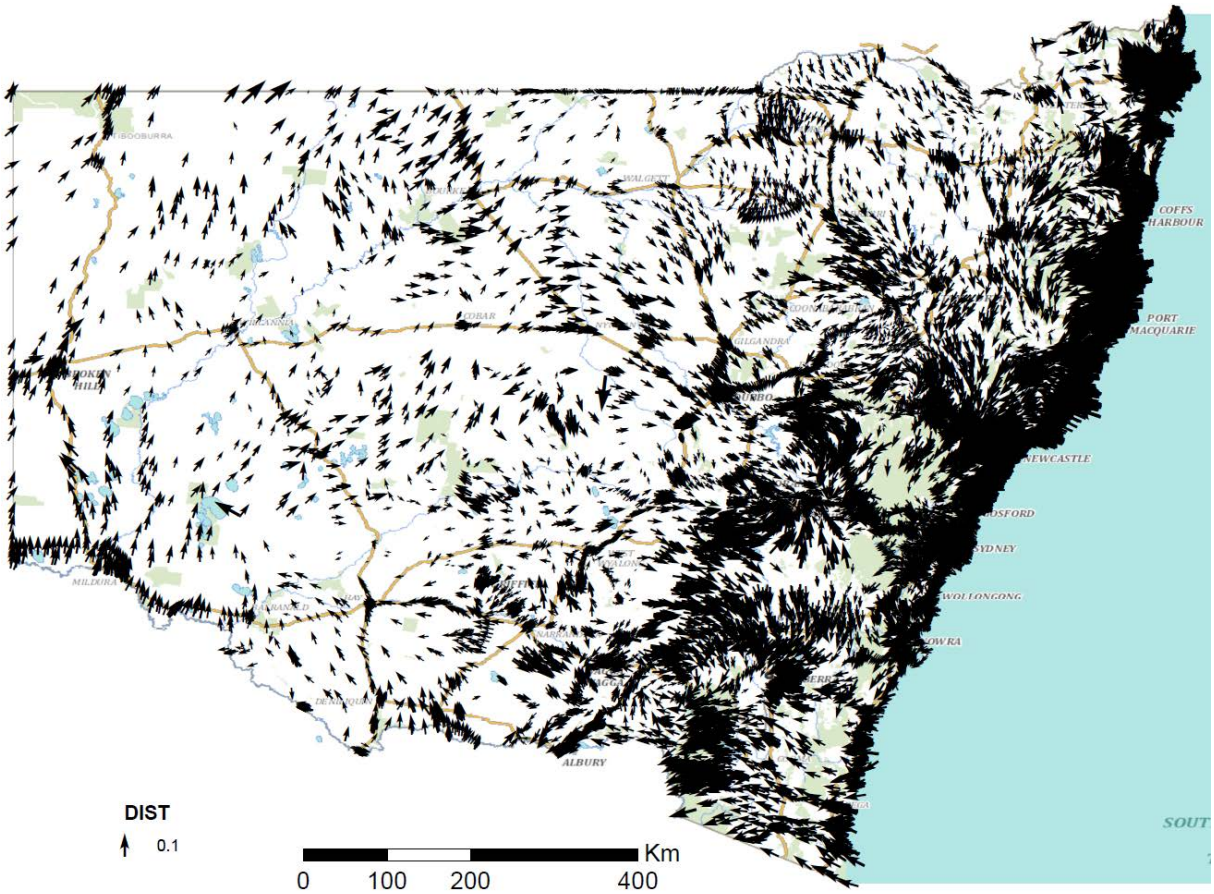

Figure 2: GDA94(1997) to GDA94(2010) distortion vectors from Gowans (2017). Units are in metres.

The distortion component at each grid node has been computed based on the surrounding input data falling within a search radius of 45.5 km. If there are no input data points within this critical distance, the computation reverts to a conformal only solution and no distortion will be apparent.

3.1.3 Composition

Both national transformation grids are divided into five non-overlapping sub-grids (Figure 3, Table 1), each with a grid interval of 54 arc seconds (~1.5 km).

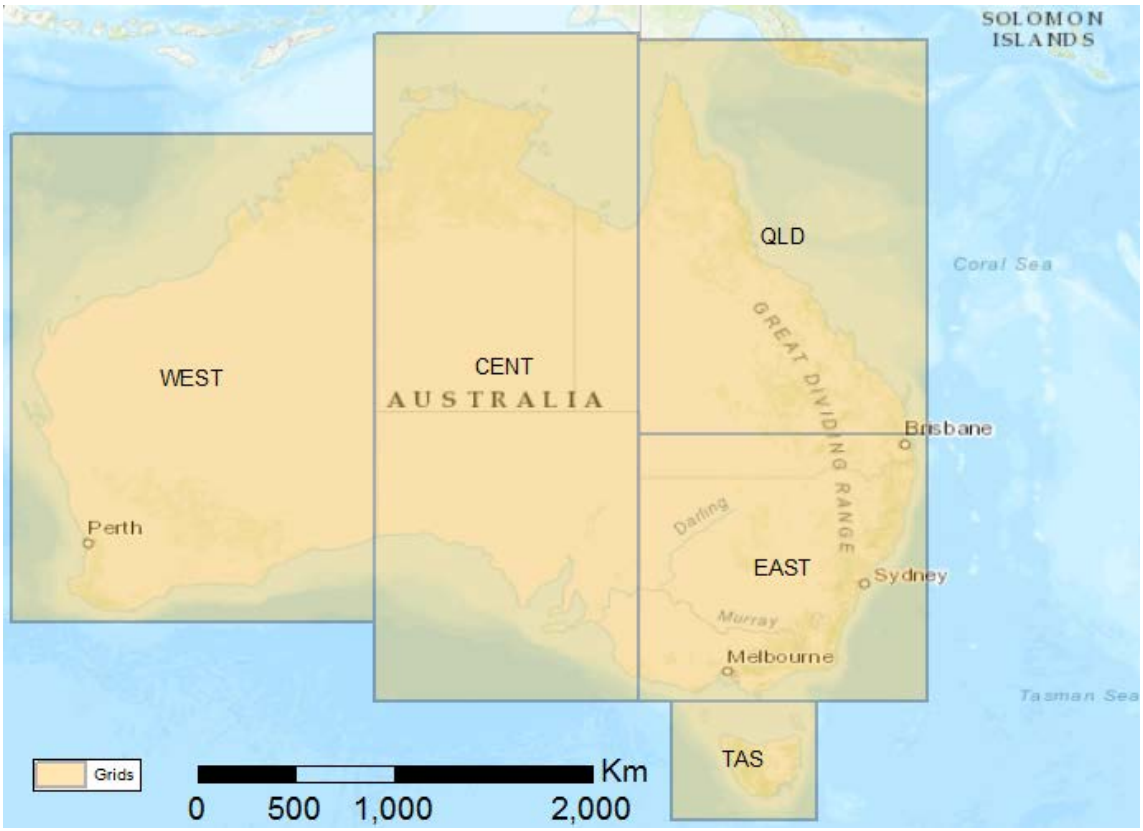

Figure 3: Transformation Grid composition and extents.

Table 1: Transformation grid composition and extents. Note that by NTv2 convention, longitude east of the prime meridian is negative.

Sub Grid Name	Southern Latitude (Decimal Degrees)	Northern Latitude (Decimal Degrees)	Eastern Longitude (Decimal Degrees)	Western Longitude (Decimal Degrees)
WEST	-35.55	-13.35	-128.90	-112.40
CENT	-39.15	-8.70	-140.90	-128.90
QLD	-27.00	-9.00	-154.10	-140.90
EAST	-39.15	-27.00	-154.10	-140.90
TAS	-44.55	-39.15	-149.00	-142.40

Currently, the transformation grids cover mainland Australia and Tasmania. Several offshore territories such as Lord Howe, Norfolk, Christmas and Cocos (Keeling) islands are not included in the provided transformation grids at this time.

3.1.4 NTv2 Format

The National Transformation version 2 (NTv2) format was developed by the Canadian Geodetic Survey of National Resources Canada for the North American Datum transition from NAD27 to NAD83. Since this time, NTv2 has been widely adopted for datum transformations by many international survey organisations and is supported in many GIS software packages. It provides a simple, efficient and comprehensive file structure for storing latitude and longitude shift parameters for each grid node (Figure 4). The file structure is kept relatively small because the coordinates of each grid node are not stored. Instead, the grid extents, grid interval and total number of grid nodes are given, linking the node shifts to their coordinates through a pattern specifying their order of occurrence. The NTv2 format is compatible with sub grids, which can be used to alter the overall coverage area or densify areas with high rates of change.

Sub grid header

```
SUB_NAME     EAST_DC5
PARENT       NONE
CREATED      17102017
UPDATED      21112017
S_LAT       -140940.0
N_LAT        -97200.0
E_LONG      -554760.0
W_LONG      -507240.0
LAT_INC          54.0
LONG_INC         54.0
GS_COUNT       714491
```

Sub grid metadata

Sub grid extents (arc-seconds)

Grid interval (arc-seconds)

Total nodes in sub grid

Sub grid Transformation components (left to right): Latitude shift, Longitude shift, Latitude reliability, Longitude reliability (arc-seconds)

```
    0.047533   -0.022141    0.000471    0.000206
    0.047532   -0.022074    0.000473    0.000137
    0.047536   -0.022083    0.000045    0.000103
    0.047539   -0.022088    0.000046    0.000102
    0.047782   -0.022046   -1.000000   -1.000000
    0.047785   -0.022056   -1.000000   -1.000000
    0.047788   -0.022066   -1.000000   -1.000000
    ...
```

Figure 4: ASCII sample sub grid in NTv2 format. Note: reliability values of -1 denote that no reliability figure could be computed (conformal only solution).

In addition to latitude and longitude shifts, NTv2 provides space to report on the known or estimated accuracy of these shifts. In the GDA94-GDA2020 conformal and distortion transformation grid, this is a measure of the consistency (i.e. reliability) of the distortion surrounding the grid node rather than an absolute accuracy statement. Furthermore, reliability figures can only be computed where distortion is modelled, and hence grid nodes without any distortion influence exhibit a reliability figure of -1. It should be noted that the GDA94-GDA2020 transformation grids are supplied as binary grid shift (.gsb) files and are not human readable unless converted to text.

3.1.5 EAST Sub Grid (Conformal and Distortion) Behaviour

NSW users will be primarily concerned with the performance of the EAST sub grid, which covers the whole of NSW, ACT, Victoria, and some of Queensland and South Australia. The performance of the conformal only grid is uniform (see section 4.1) and does not require further review. The performance of the conformal and distortion transformation grid, however, varies with location. This variation is mapped in Figure 5 and provides a useful indication of the magnitude of distortion across NSW and Victoria.

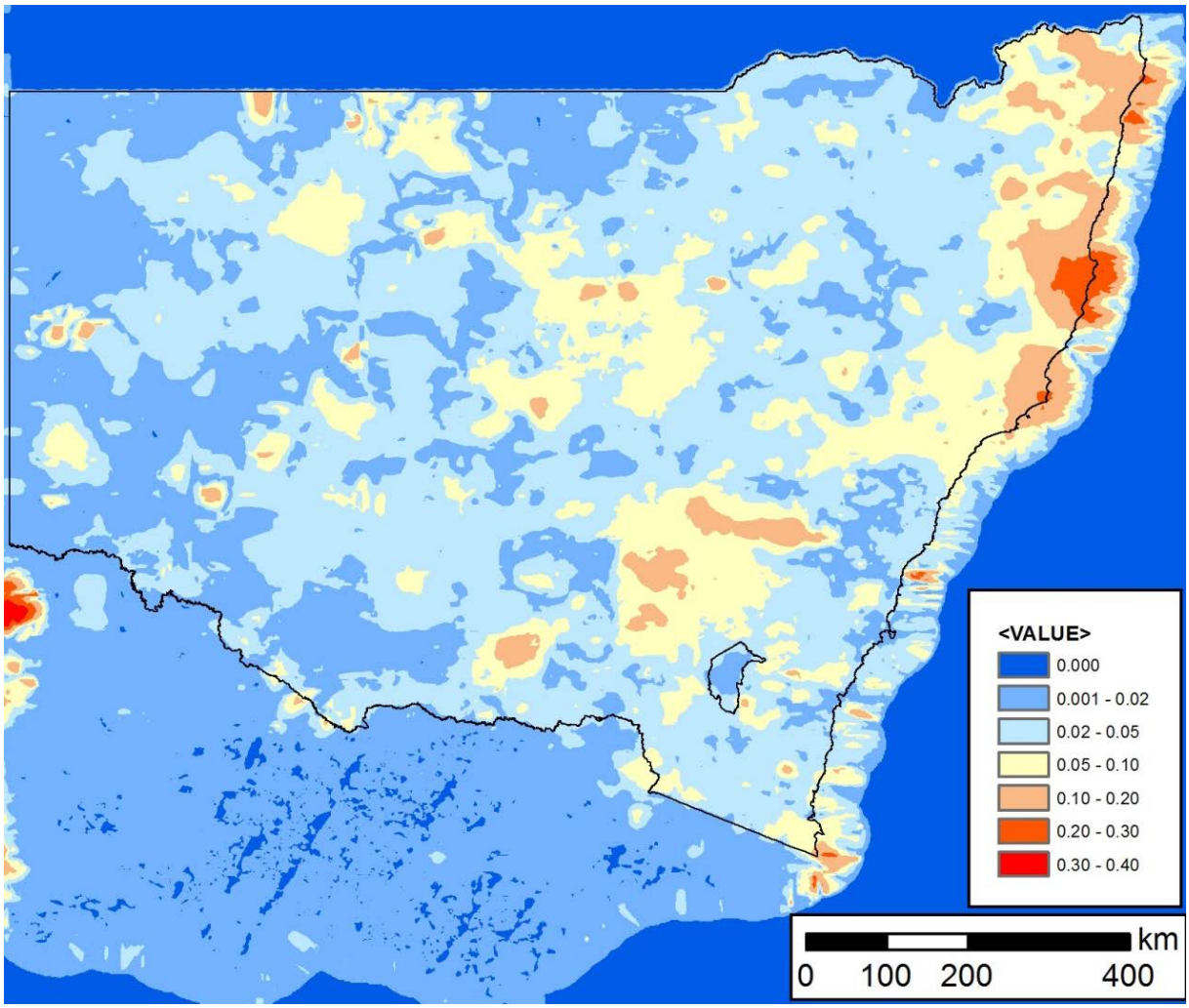

Figure 5: Distortion component across the EAST sub grid. Units are in metres.

Additionally, reliability figures have also been mapped (Figure 6), which indicate the consistency of distortion within each grid node computation.

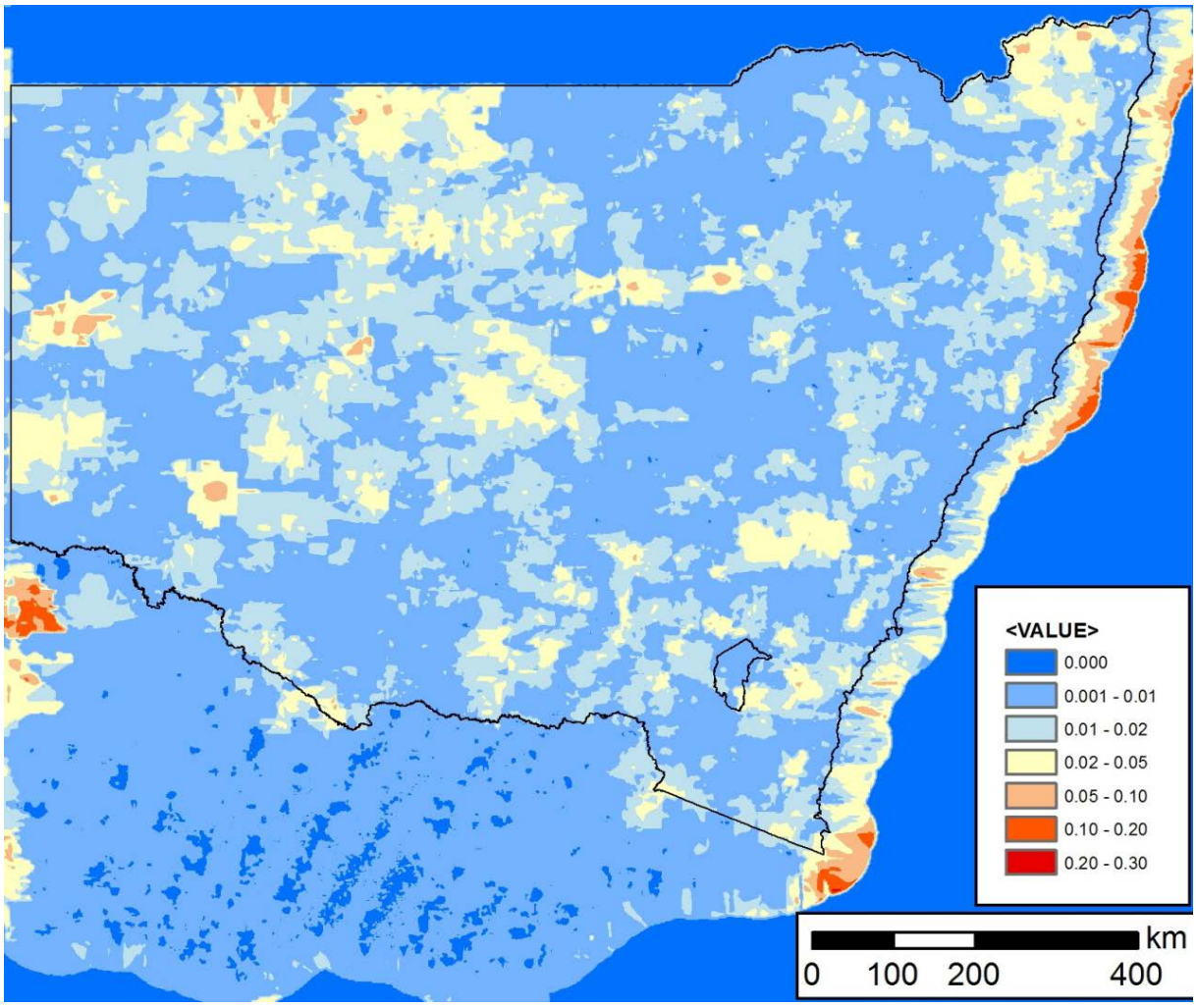

Figure 6: Reliability component across the EAST sub grid. Units are in metres.

3.2 How Can I Access/Apply the Grids?

A suite of transformation products and tools has been published online (ICSM, 2018b). Users are guided towards the grid (.gsb) files, an online transformation service which can be operated with simple 'drag-and-drop' functionality, as well as software and plug-ins.

3.3 Which Grid Should I Use?

The accuracy and the origin (i.e. provenance) of the dataset both need to be considered when applying a transformation grid from GDA94 to GDA2020. The difference between GDA94 and GDA2020 horizontal positons in NSW is about 1.5 m. Therefore, any dataset referenced to GDA94 with an accuracy of worse than a few metres is already GDA2020 compatible and does not require transformation.

In NSW, the largest known horizontal distortions are in the order of about 0.3 m (Haasdyk and Watson, 2013; Gowans, 2017). The conformal only transformation grid is sufficient for any GDA94 data with an accuracy of 0.5 metres (but either grid could be applied at these accuracy-levels). For data more accurate than 0.5 metres, the origin of the data must be considered. If the data is derived from local (SCIMS) survey control, then the conformal and distortion transformation grid is appropriate. If the data is derived directly in GDA94(2010), e.g. from CORSnet-NSW (without a site localisation) or from AUSPOS in GDA94(2010),

then distortions in local survey control are already eliminated and the conformal only transformation grid is appropriate. A decision-making flow chart is provided in Figure 7 to guide NSW users.

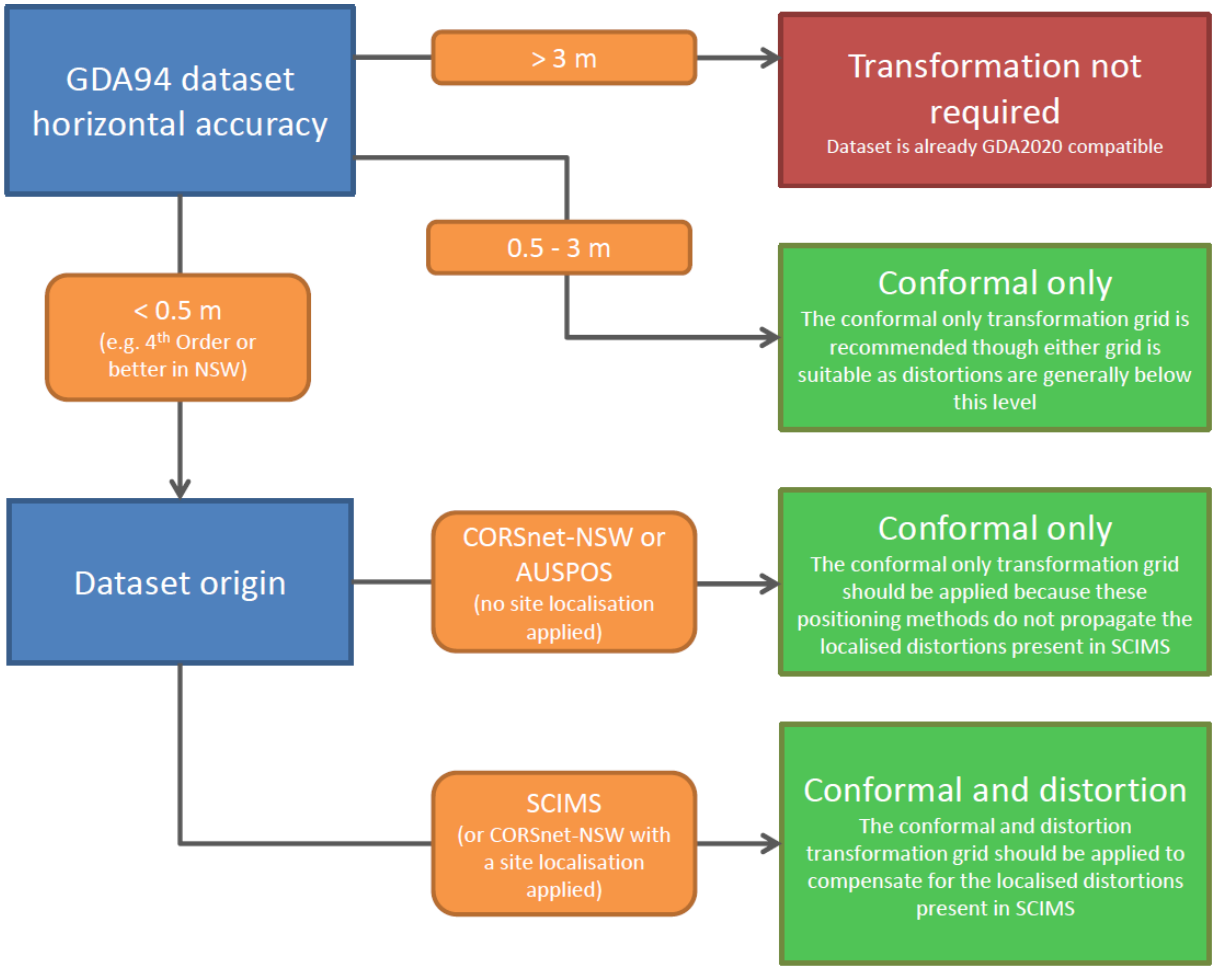

Figure 7: Decision-making flow chart for selecting a GDA94-GDA2020 transformation grid in NSW.

If the origin of a GDA94 dataset is unknown, then it is not possible to transform to GDA2020 and retain a nominal accuracy better than the known local distortions. For this reason, metadata is critical and has been affectionately described as a “love note to the future”.

Where the original survey measurements (with connections to GDA2020 stations) are available, a new least squares network adjustment based on GDA2020 control will provide the most accurate and rigorous solution. However, this can be far more time consuming and is not applicable to point-based datasets.

4 EVALUATION OF THE TRANSFORMATION GRIDS

4.1 Evaluation of the Conformal Only Transformation Grid

The conformal only transformation grid was evaluated by transforming the 250,000 marks across Australia comprising the GDA2020 national adjustment from GDA2020 to GDA94 using the 7-parameter conformal transformation (Equation 1) and then back to GDA2020 with

the conformal only transformation grid. The resulting coordinates were compared against the original GDA2020 coordinates.

The results from this test show that the conformal grid will introduce a negligible amount of computational error when compared to the 7-parameter conformal transformation. The descriptive statistics (Table 2) show a maximum difference in Easting and Northing of ±0.001 m, with standard deviations of 0.0003 m.

Table 3: Descriptive statistics of conformal-only transformation assessment.

	Δ Easting (m)	Δ Northing (m)	Horizontal Distance (m)
Mean	0.0000	0.0000	0.0002
RMS	0.0003	0.0003	0.0004
Std Dev	0.0003	0.0003	0.0004
Minimum	-0.0010	-0.0010	0.0000
Maximum	0.0010	0.0010	0.0014

The conformal only transformation grid is considered fit for purpose for use in NSW and is far simpler to use than the alternative 7-parameter conformal transformation (Equation 1) method.

4.2 Evaluation of the Conformal and Distortion Transformation Grid

4.2.1 Test 1: Common Stations Between SCIMS and GDA2020

The conformal and distortion transformation grid was evaluated by transforming the coordinates of approximately 26,000 SCIMS marks from GDA94 to GDA2020, and comparing against the adjusted GDA2020 coordinates. The chosen marks were part of the GDA2020 national adjustment and required SCIMS coordinates with horizontal order 4 or better and GDA2020 coordinates with horizontal Positional Uncertainty (PU) of 0.1 m or better (1 sigma).

The descriptive statistics (Table 3) and histogram plot (Figure 8) quantify what is a very good result: 86.3%, 96.4% and 99.6% of SCIMS to GDA2020 transformed coordinates are within 0.01 m, 0.02 m and 0.05 m, respectively, of the expected GDA2020 adjusted coordinates with no notable differences between Easting and Northing components.

Differences of up to 0.27 m have been seen at a very small number of the marks analysed (i.e. < 0.1%). However, these rare outliers occur where SCIMS behaves inconsistently, e.g. where a remote trigonometrical station was re-surveyed and its position improved, but its eccentric marks were not updated in SCIMS, altering the relationship between trigonometrical station and eccentric marks.

Table 3: Descriptive statistics of conformal and distortion transformation assessment (SCIMS to GDA2020 transformed vs. GDA2020 adjusted).

	Δ Easting (m)	Δ Northing (m)	Horizontal Distance (m)
Mean	0.000	0.000	0.006
RMS	0.007	0.006	0.010
Std Dev	0.007	0.006	0.008
Minimum	-0.229	-0.267	0.000
Maximum	0.120	0.139	0.271

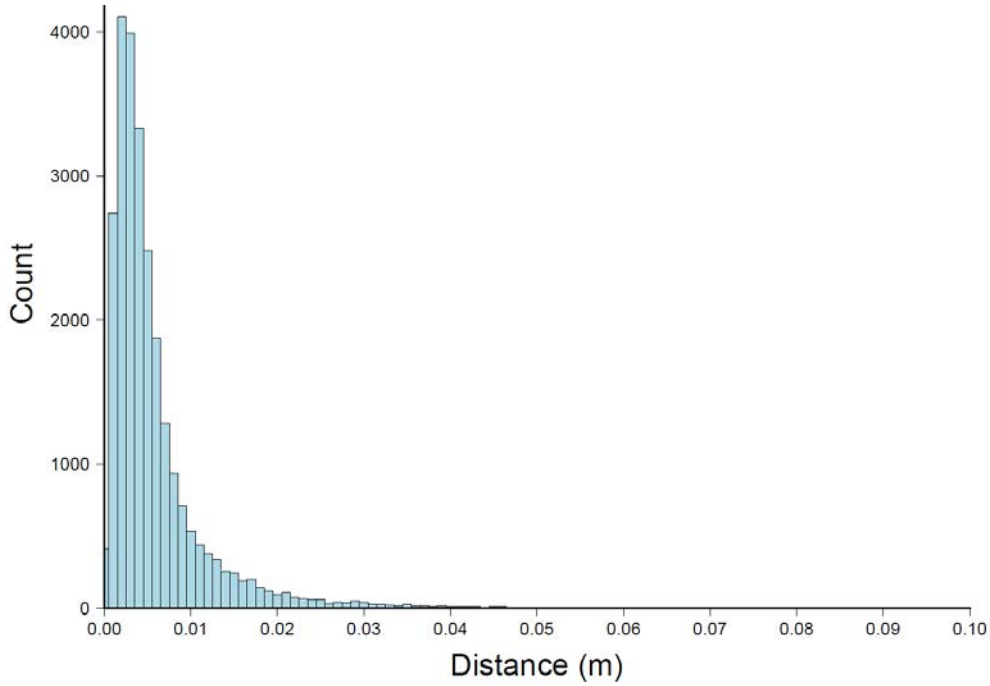

Figure 8: Differences in horizontal distance for SCIMS to GDA2020 transformed vs. GDA2020 adjusted.

4.2.2 Test 2: Independent Data

DFSI Spatial Services is currently preparing to enable GDA2020 in NSW. Some early proof-of-concept studies were carried out in an effort to assess the value in transforming versus readjusting our terrestrial 'street corner' traversing networks, which currently are not in the GDA2020 national adjustment. Survey networks in six NSW towns containing a total of 1,881 direction sets, 4,337 distances and 2,635 height differences at 2,759 stations were examined in this evaluation. Each network was readjusted based on constraints from the national GDA2020 adjustment. The results of the adjustments were compared with the results of transforming the SCIMS coordinates via the conformal and distortion transformation grid.

On average, the difference in horizontal position between the two methods was 0.006 m, with the largest being 0.04 m (Table 4). This analysis provides a high level of assurance that transforming SCIMS control will deliver a result close to the more rigorous (and far more time consuming) method of readjusting.

Table 4: Descriptive statistics of conformal and distortion transformation assessment (SCIMS to GDA2020 transformed vs. GDA2020 adjusted). Note that the values for Vincentia are higher compared to the other sites due to a previous transformation from AGD66 (i.e. SCIMS order U).

Site	RMS ΔE (m)	RMS ΔN (m)	RMS Distance (m)	Mean Distance (m)	Max Distance (m)
Blayney	0.005	0.005	0.007	0.004	0.040
Curlewis	0.004	0.002	0.005	0.004	0.027
East Hills	0.004	0.004	0.006	0.005	0.014
South West Rocks	0.003	0.003	0.004	0.003	0.019
Vincentia	0.012	0.008	0.014	0.011	0.037
Yamba	0.004	0.002	0.008	0.070	0.036

The conformal and distortion transformation grid is considered fit for purpose for use in NSW, and again is far simpler to use than the alternative 7-parameter conformal

transformation (Equation 1) method, which has the additional disadvantage that it cannot compensate for local distortions.

5 FREQUENTLY ASKED QUESTIONS

Why are there two grids?
Separate grids are required for the different realisations of GDA94 used in NSW: GDA94(1997), which is based on SCIMS and includes localised distortions of up to 0.3 m horizontally, and GDA94(2010), which is sympathetic with AUSPOS and CORSnet-NSW and is essentially distortion-free.

How do they differ?
The conformal only transformation grid is the 2D equivalent of the 7-parameter transformation. It accounts for mathematical differences between reference frames and does not compensate for any localised distortions in the state or territory realisations of GDA94. The conformal and distortion transformation grid is composed of the conformal component and a distortion component that will compensate for any known localised distortions in the state and territory realisations of GDA94.

What does conformal mean?
Shape is preserved throughout the transformation, i.e. the 7-paramater transformation accounts for the difference in scale, rotation and translation between each reference frame. The term 'similarity transformation' is often used to describe a conformal transformation.

Do any other jurisdictions besides NSW have distortions?
Yes, to varying extents. Both transformation grids cover all states and territories across mainland Australia and Tasmania.

What happens at the NSW-ACT/QLD/SA/VIC border?
Since the GDA94 adjustment, different jurisdictions have adopted different business rules for maintaining and propagating their survey networks. For example, NSW chose to preserve and hold fixed the original GDA94 adjustment (and its distortions) while Victoria and Queensland have readjusted their networks over time to remove distortions. The grid computation strategy is such that each node is influenced by contributing marks within 45.5 km, weighted according to proximity. This ensures the behaviour of the grid accurately represents the survey networks of each jurisdiction. There is one exception to this rule: Queensland, having periodically readjusted their survey network to remove distortion, opted for zero distortion to be present in *both* transformation grids across Queensland. In effect, this means distortions from NSW, SA and NT were only able to influence the 1st grid node into Queensland. After this point, the grid nodes revert to a conformal only solution.

Is there a difference between using the 7-parameter conformal transformation and the conformal only transformation grid?
There is no significant *horizontal* difference between the conformal only transformation grid and the 7-parameter transformation. However, it is important to note that the 7-parameter transformation provides a 3-dimensional transformation whereas the grid transformation is only 2-dimensional.

How should I transform 3D data?

3-dimensional data can be transformed using the transformation grids provided, but only the latitude and longitude components will be affected, i.e. height will be preserved (remains unchanged). If the height component is referenced to the Australian Height Datum (AHD), no height transformation should be undertaken between GDA94 and GDA2020 anyway.

The 7-parameter transformation can provide a true 3D transformation for data with ellipsoidal heights, but will not compensate for localised distortions. The GDA2020 technical manual (ICSM, 2018a) recommends users with ellipsoidal heights first convert their data to earth-centred Cartesian (XYZ) coordinates, apply the 7-parameter conformal transformation, and then convert back to geodetic or grid coordinates as required. ICSM (2018a) provides the formulae and a number of spreadsheets to perform these computations.

The ellipsoidal height difference from GDA94 to GDA2020 varies across NSW by approximately 0.01 m (i.e. just one centimetre!), from -0.10 m in the north-east to -0.09 m in the south-west (Figure 9). Consequently, it is possible to apply a simple 'block shift' of -0.095 m to transform ellipsoidal heights from GDA94 to GDA2020, but each user will need to assess if this approximation is suitable for their datasets and applications.

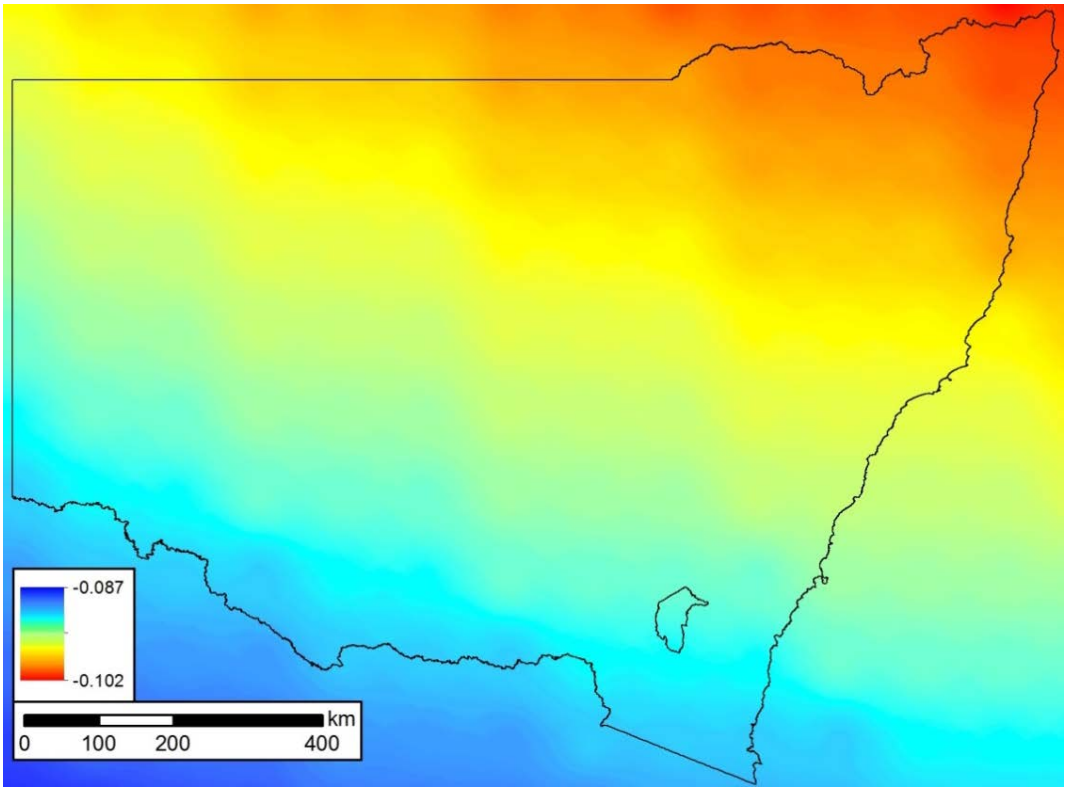

Figure 9: GDA94 to GDA2020 ellipsoidal height differences across NSW. Units are in metres.

Which transformation grid should I use if my GDA94 data is based on … ?

As a general rule, data that is based on absolute positioning technologies such as CORSnet-NSW or AUSPOS should use the conformal only transformation grid, except when a site localisation has been applied to align it to SCIMS. Data that is based on SCIMS should apply the conformal and distortion transformation grid. Table 5 provides a decision-making guide in this regard.

Table 5: Decision-making guide for selecting a transformation grid based on the positioning technology used.

Positioning Technology	Conformal Only	Conformal and Distortion
SCIMS	✗	✓
AUSPOS	✓	✗
CORSnet-NSW (V)RINEX/(N)RTK (without a site localisation)	✓	✗
CORSnet-NSW (V)RINEX/(N)RTK (with a site localisation)	✗	✓

What do I do if I have a problem? This is all too hard, who can I talk to?
There are several communication avenues available. Fact sheets, videos, FAQs and even an online forum have been produced by ICSM (2018a, 2018b, 2018c). Alternatively, your local state or territory geodetic agency may provide assistance. DFSI Spatial Services publishes its technical papers online to assist the profession (DFSI Spatial Services, 2018b).

6 CONCLUDING REMARKS

Since October 2017, GDA2020 is Australia's new, improved national datum. DFSI Spatial Services is currently preparing to enable GDA2020 in NSW. This paper has shown that the GDA94-GDA2020 transformation grids provide a fast, accurate and simple method for spatial professionals to transform their existing datasets from GDA94 to GDA2020. Two transformation grids have been developed to cater for the different realisations of GDA94 currently available to users. Accuracy and data origin have been identified as the two key factors determining their appropriate use.

Prior to transformation, users in NSW must know if their existing GDA94 dataset is affected by known GDA94 distortions (present in SCIMS) or if those distortions have been removed by other methods. Spatial professionals transforming datasets based on SCIMS should use the conformal and distortion transformation grid, while the conformal only transformation grid should be used for datasets based on CORSnet-NSW or AUSPOS services where a site localisation has not been applied.

Each transformation grid has been evaluated across NSW and found to be fit for purpose, with the conformal only transformation grid accurately representing the 7-parameter conformal transformation and the conformal and distortion transformation grid providing centimetre-accuracy in almost all cases. Spatial professionals are encouraged to properly understand the accuracy and lineage of their GDA94 datasets before selecting a transformation grid to transform to GDA2020.

ACKNOWLEDGEMENTS

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Preservation of Survey Infrastructure in NSW

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ABSTRACT

This presentation provides an update of the actions and system developments undertaken by the Collaborative Working Group of DFSI Spatial Services and the Roads and Maritime Services (RMS) Surveying Section. It will discuss the establishment of the strategy and finalisation of the project to ensure compliance with the legislative requirements for the preservation of survey infrastructure. It includes a best practice method for the implementation of Surveyor General's Directions No. 11 (Preservation of Survey Infrastructure) and 12 (Control Surveys and SCIMS), the Surveying and Spatial Information Regulation 2017 and RMS specifications G73 Detail Surveys and G71 Construction Surveys. Several large infrastructure projects and lessons learnt along the way are discussed.

KEYWORDS: *Preservation, survey infrastructure, best practice, collaboration.*

Fast Tracked: V8 Supercars vs. Survey Infrastructure in Newcastle

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ABSTRACT

Last year, in November 2017, the Newcastle 500 motor race was held as part of the Supercars Championship for the first time. In order to enable this event to occur, major infrastructure works were conducted to construct a race circuit through the heart of Newcastle East. Much of the works involved expansion of infrastructure within the entire boundary limit of the existing road corridor. As most survey infrastructure is located in the road corridor, it was paramount to protect and/or relocate this infrastructure during the progress of the construction works along the race circuit. In February 2017, de Witt Consulting Pty Ltd was engaged by project management consultancy iEDM (on behalf of V8 Supercars Australia Pty Ltd) to create and facilitate a survey infrastructure preservation strategy in order to fulfil the responsibilities in accordance with the Surveying and Spatial Information Act 2002. At this time, the draft remake of Surveyor General's Direction No. 11 (Preservation of Survey Infrastructure) had just been released. Having a very short time frame to survey the site before most of the existing survey infrastructure was destroyed was challenging and required some innovative approaches to get across the finish line. This was the first 'major project' to be managed by DFSI Spatial Services in accordance with the new Surveyor General's Direction No. 11. This paper outlines the project, strategies and steps undertaken to ensure the preservation of survey infrastructure at a site with no room to move and a very tight time frame.

KEYWORDS: *Preservation of survey infrastructure, Surveyor General's Direction No. 11, supercar racing.*

1 INTRODUCTION

NSW is currently experiencing an unprecedented amount of large infrastructure projects (Underwood, 2017). Unfortunately the previous version of Surveyor General's Direction No.11 (Preservation of Infrastructure) was not written to address the impacts on the survey infrastructure for large scale projects.

The V8 Supercars Newcastle 500 motor racing circuit is an example of such a large scale project within a densely populated and developed area in Newcastle East (Figures 1 & 2). It can be seen that these large scale projects can consume the entire road corridor. The road corridor is where survey infrastructure is most commonly placed because of the ease of access (being public land) and generally allowing unobstructed sightings to other points of interest for the survey. This project threatened to destroy survey infrastructure along street frontages of several blocks, creating a 'black hole' in survey marks available for applications like mapping and engineering projects or cadastral boundary definition (using cadastral marks

which are fundamental to ensure the integrity of the cadastre). The situation was amplified by this area of Newcastle East containing high property values with large buildings that are located on or near the boundary. The survey marks to be destroyed were placed between the 1950s and the present day, providing important survey control for the area. The extensive survey infrastructure preservation and relocation efforts performed as part of this project will ensure that survey marks in this part of Newcastle East will be maintained for many surveys to come.

Figure 1: View of part of the V8 Supercars Newcastle 500 circuit.

Figure 2: V8 Supercars Newcastle 500 circuit through Newcastle East (de Witt Consulting, 2017).

2 OVERVIEW OF THE REQUIREMENTS UNDER SGD11

With the release of the draft version of the new Surveyor General's Direction No.11 Preservation of Survey Infrastructure (SGD11) in January 2017 (DFSI Spatial Services, 2017), the V8 Supercars Newcastle 500 infrastructure project was about to commence construction in 6 weeks. As de Witt Consulting were engaged at this time, this meant they needed to act quickly to preserve the existing survey infrastructure.

A meeting was held a week later between de Witt Consulting and DFSI Spatial Services to reach agreement on how survey infrastructure preservation was to be implemented using the draft SGD11. This was the first large scale project to test the new (draft) Direction, and (like all projects) some obstacles required special strategies and unique solutions to make it a success.

2.1 Aim

The focus of SGD11 is generally divided into two areas:

1) To preserve the integrity of the state control network by ensuring that sufficient permanent survey marks are available following completion of the project. On completion of works the survey should be of sufficient horizontal and vertical Class to allow existing and/or replacement mark(s) to be coordinated to a similar standard as the mark(s) affected by the works.
2) To preserve sufficient cadastral infrastructure, place additional marks, and provide sufficient measurements in order to re-establish the cadastre at the accuracies specified in the Surveying and Spatial Information Regulation following completion of the works.

2.2 General Requirements

Be it a cadastral mark or a permanent survey mark (such as TSs, PMs and SSMs in the State's Survey Control Information Management System, SCIMS – see Kinlyside, 2013), an application for authorisation to remove or replace a survey mark needs to be made in accordance with clause 90 of the Surveying and Spatial Information Regulation 2017 (NSW Legislation, 2017). The application is to be made at least 14 business days before the proposed removal or replacement of survey marks is carried out (30 business days for large scale projects). An online form can be used for this purpose (Figure 3).

Before the application is made, some preliminary work is required. A visual inspection needs to be conducted to look for all survey marks that are on public record (such as in SCIMS and on Deposited Plans). All the survey marks at risk (and not noted as destroyed on public record) need to be identified and presented in a schedule indicating their status (i.e. found, not found or destroyed).

For large-scale projects a Survey Project Plan also needs to be prepared. This will show the strategy and methodology as to how the preservation of survey infrastructure will be conducted. It will contain a diagram visually showing the proposed works with all survey marks identified in the schedule.

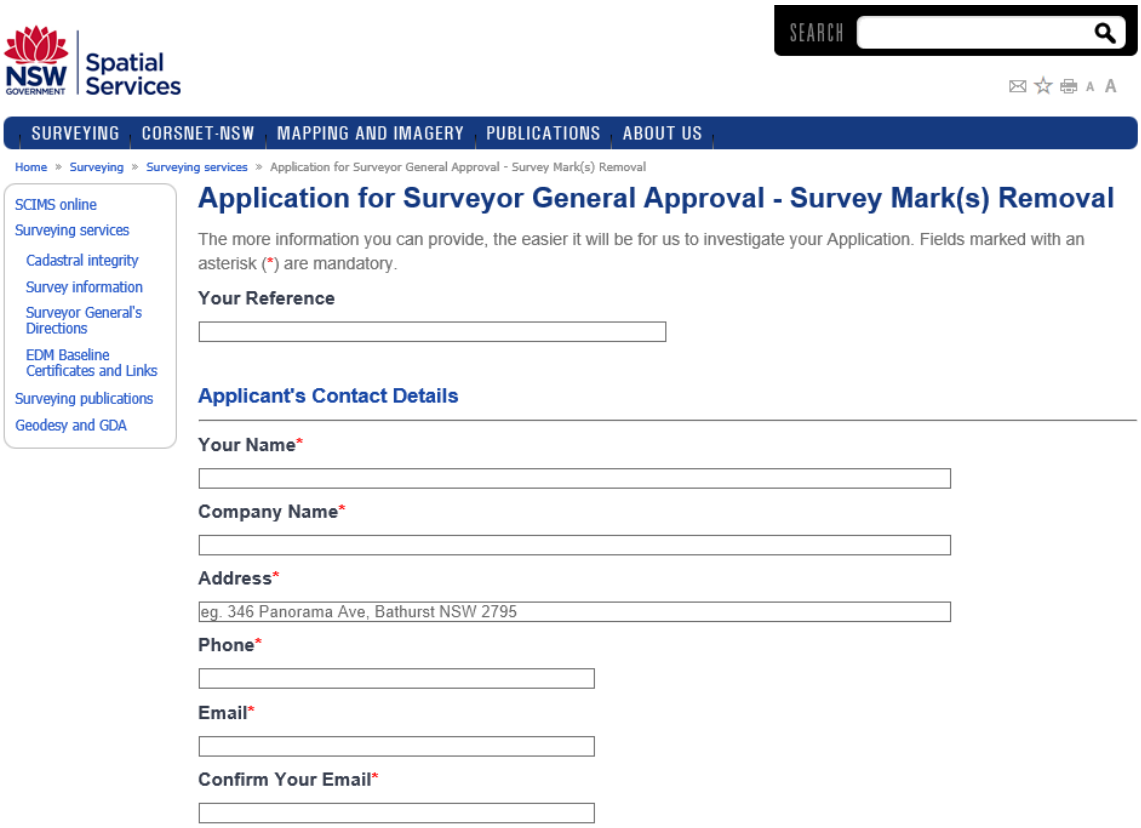

Figure 3: Online application form for survey mark(s) removal (DFSI Spatial Services, 2018).

Approval given for the destruction of survey infrastructure will be subject to specific conditions. In most circumstances a replacement mark has to be placed for the one(s) being destroyed.

In the case of permanent survey marks, at a minimum, a like-for-like approach is used. Where practical, this means if the mark was a type 4 PM, then a type 4 PM should be used to replace it. This like-for-like approach also reflects on the Class and Order of the replacement PM – for a discussion on the terms Class and Order, the reader is referred to ICSM (2007) and Dickson (2012). If the destroyed mark is of Class and Order B2, then the new mark will need to be at the same or a higher standard. This applies to both the horizontal and vertical classification of the permanent survey mark. However, there are some allowances that can be applied for in certain circumstances. One such example is that aiming for a vertical LBL2 or higher replacement mark is quite onerous and a LCL3 mark is generally the highest type of survey that is practically obtainable.

For cadastral marks (which can include cadastral reference marks, cadastral boundary marks, survey monuments, bench marks and PMs) a Plan of Survey Information Only needs to be prepared. This Deposited Plan (DP) needs to show connections from the cadastral marks at risk to marks that will remain undisturbed following the completion of the works. These recovery marks can be existing cadastral marks or permanent survey marks. However, if there are no suitable existing marks, than a survey mark (as described by the Surveying and Spatial Information Act 2002 – see NSW Legislation, 2018) can be placed to suit. The connections created need to be shown by closed survey (no open-ended traverses or unchecked radiations) and should not exceed 30 m in length. This procedure is specifically specified for small-scale projects. It also should be noted that a Plan of Survey Information Only cannot define or redefine cadastral boundaries. The intent is to show redundant measurements from survey

marks that will be destroyed to survey marks that will remain after the completion of works.

If it can be justified that these conditions are not required, they can be changed at the discretion of the authorised approver based on the merits of the argument.

3 ADAPTING SGD11 TO SUIT THE NEWCASTLE V8 SUPERCAR PROJECT

By the time the meeting had taken place with DFSI Spatial Services and de Witt Consulting, there were only 5 weeks (20 business days) left until ground works would commence. There had been no opportunity to conduct a site visit to investigate which survey marks existed for the creation of a Survey Project Plan.

It was agreed that a site mark audit of only the Permanent Marks (PMs) would be performed first and a plan for the control survey would be created to provide sufficient horizontal and vertical replacement marks. The targeted Class for the survey was B for horizontal (GDA94) and LC for vertical (AHD71). The equipment used was a 1” 1 mm Leica TS15 total station for traversing and a Leica DNA03 for levelling.

A desktop study showed that there were some ‘holes’ in the survey control network, created over the years as PMs had been destroyed but not replaced. This actually created an issue for the proposed survey, in that there was no appropriate survey control directly on the site. To assist de Witt, DFSI Spatial Services placed two new type 4 PMs (stainless steel pin in concrete) and surveyed these with static GNSS supported by traversing techniques. This allowed de Witt to focus their survey on their main area and without having to extend the survey drastically to ‘chase’ control. On the other hand, de Witt surveyed other unestablished PMs that were outside the proposed works to strengthen the state control network. The network design and survey practices used supported the desired outcome for the Class, and the control used additionally supported the desired outcome for the Order (Figures 4-6).

Once the survey data and other required information was supplied to DFSI Spatial Services, it was reduced and entered into least squares adjustment packages GeoLab and levadj. Running a successful minimally constrained adjustment proved that the survey was free of gross errors and showed that the desired Class was met. Running a fully constrained adjustment demonstrated that the desired Order had been achieved in a statistical and realistic fashion (Figure 7).

Figure 4: SCIMS marks already destroyed and to be destroyed.

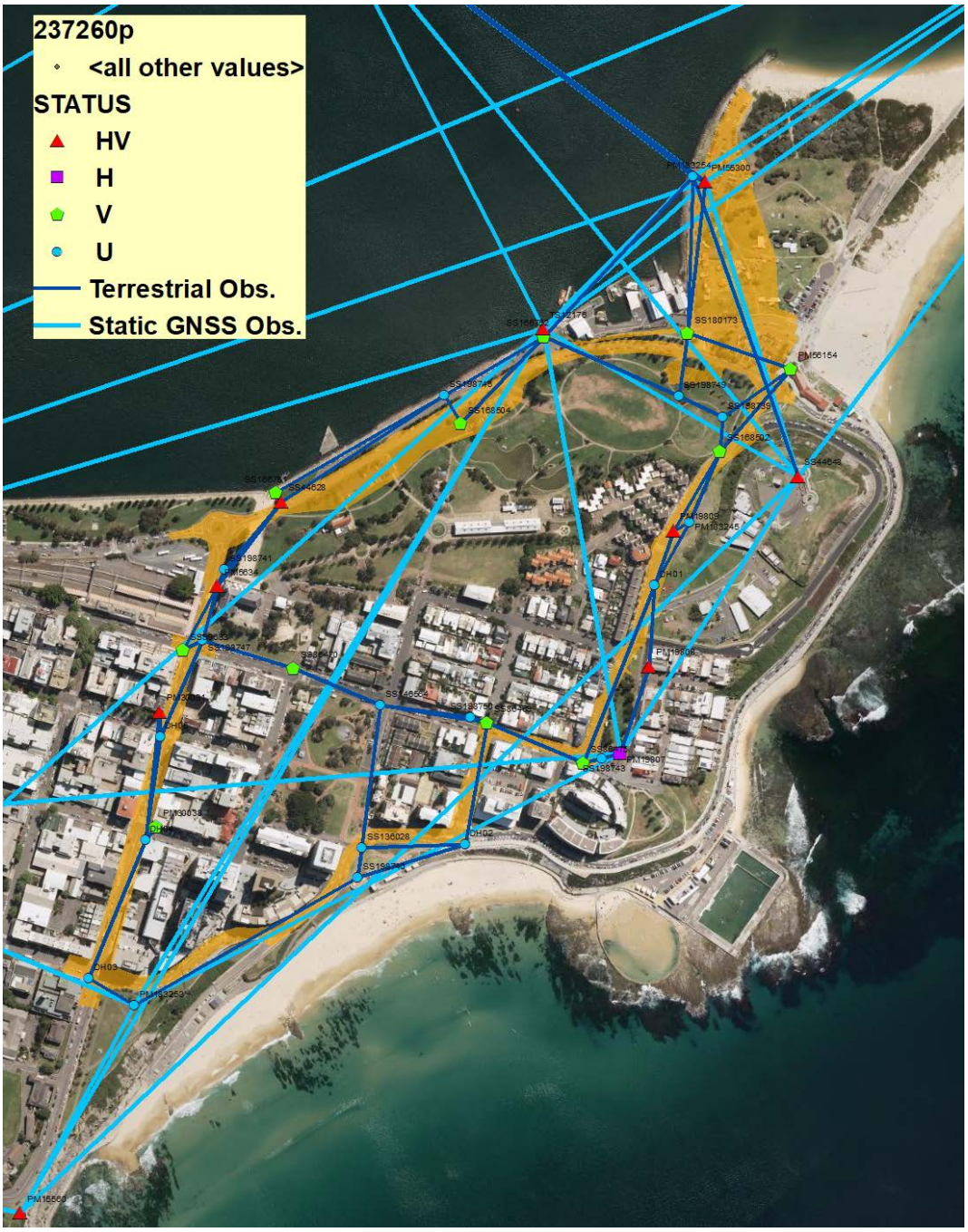

Figure 5: Horizontal GNSS and traversing network.

Figure 6: Vertical levelling network.

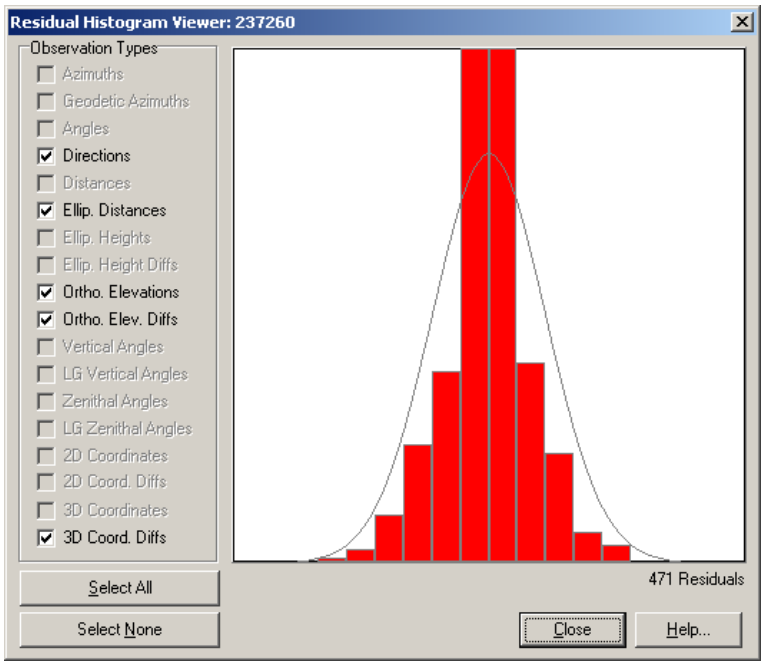

Figure 7: Histogram of traversing and static GNSS survey.

The results from the fully constrained adjustment where then used to produce the coordinates and heights to be entered into SCIMS. The requirements for the results of the survey control for SCIMS were predominantly met (a couple of marks were downgraded in Order due to mark density and extrapolation issues). The final result is that the state control network in Newcastle East is now in a better state than before the project was conducted (Table 1).

Table 1: Comparison of SCIMS marks pre-project to post-project.

SCIMS marks at risk or to be destroyed		**SCIMS marks placed and surveyed**		**Bonus SCIMS marks upgraded**	
Mark No.	**Class & Order**	**Mark No.**	**Class & Order**	**Mark No.**	**Class & Order (original)**
PM55300	A1 LDL4	SS198739	B2 LCL3	SS166752	B2 LCL3 (C3 LDL4)
SS180173	C3 LDL4	SS198740	B2 LCL3	PM56154	B3 LCL3 (C3 LCL3)
SS168504	C3 LDL4	SS198741	B2 LCL3	SS166751	B2 LCL3 (D4 LDL4)
SS168502	C3 LDL4	SS198743	B2 LCL3	SS86470	B2 LCL3 (CU LDL4)
SS44628	B2 LCL3	SS198746	B2 LCL3	SS146564	B3 LCL3 (UU D5)
PM19809	B2 LCL3	SS198747	B2 LCL4	PM19807	B2 LCL3 (B2 UU)
SS99633	CU LBL2	SS198749	B2 LCL3	**TOTAL: 6**	
SS86469	CU B2	SS198750	B2 LCL3		
SS136028	C4 UU	PM183245	B2 LCL3		
PM5634	B2 LBL2	PM183253	B2 LCL4		
SS86475	CU B2	PM183254	B2 LCL4		
TOTAL: 11		**TOTAL: 11**			

With the state control network survey being worked on, a desktop study was conducted by de Witt Consulting for the cadastral marks. By the time the state control survey field work and least squares adjustment were completed, the cadastral investigation was also finished. The cadastral mark survey was now ready to commence by using the minimally constrained adjustment from the state control network survey as control.

Due to time constraints, it was agreed that the Survey Project Plan (with its audit schedule of all cadastral marks) could be created post survey. An initial cadastral mark pickup was conducted with a stakeout of any missing cadastral marks performed soon after. Over the 2.6

km of track, there were 110 cadastral marks located (not including any cadastral SCIMS marks). In the Preservation of Survey Infrastructure (POSI) strategy (de Witt Consulting, 2017), 95 of these cadastral marks were identified as to be destroyed or listed as vulnerable (Figure 8).

This approach left little time to deal with any issues that the verifying authority (i.e. the Surveyor General's representative) may find in regards to survey marks identified or with the proposed strategy in how to mitigate the loss of survey infrastructure. Once the marks are destroyed, there is no going back to add a little more surveying. However, this was unfortunately the best way forward in this project, as risky as it was. Constant communication was paramount for the success of this course of action (Figures 9-10).

Figure 8: Part of the final POSI plan diagram (de Witt Consulting, 2017).

For this project, any mark that was vulnerable, or may potentially be impacted by ground works that extend beyond the original plan, was located and connected to the recovery marks (both for cadastral and permanent survey marks). This little extra work, though arguably not needed, provides greater flexibility and creates safety measures for any unforeseen events. It is well known that large projects may extend the area of works at a moment's notice, and unfortunately the surveyor is not always told this information at the appropriate time.

One of the issues that were identified early was the problem of placing recovery points to show connections to because parts of the infrastructure works encompassed the entire road corridor (building to building). SGD11 indicates that two connections of less than 30 m in length should be shown. This was not practical in this case, as the block lengths were at least 100 m. Consequently, a strategy had to be devised in order to address this issue. It should be

noted that a recovery mark or surviving survey mark can be used more than once to show the required connections. This allows for more efficiency in the surveying and clarity when drafting the DP.

Figure 9: Looking north down Watt Street to the foreshore of the completed works (at the intersection of Shortland Esplanade).

Figure 10: Looking north down Watt Street to the foreshore of the completed works (at the intersection of Hunter Street).

For this project, the 30 m rule was loosened to generally a 60 m maximum distance for connections, but closed connections still needed to be shown. This being the case, a recovery mark could be placed approximately mid-block to allow all the connections to conform to this 60 m allowance. The solution to the preservation of the recovery mark (such as a drill hole & wing, DH&W) was to place these in either the side of buildings, on top of low brick walls or just inside lots in concrete driveways (with the consent of the land owner when appropriate) (Figures 11-13).

While SGD11 explicitly states that connections must be less than 30 m in length for small-scale projects, it does not provide a specific limit for large-scale projects. This is to allow flexibility to the project to adapt an appropriate solution to the circumstances because a blanket rule for large-scale projects will not always be workable. The standards applied to small-scale projects should be used as a guide for large-scale projects whenever possible.

Figure 11: Recovery mark placed in wall (AO from DP).

Figure 12: Recovery mark placed on top of brick wall (O from DP).

In this context, the utilisation of major structures as useful objects to place recovery marks should be considered. For example, Figure 14 shows a navigation target for ships that use the Port of Newcastle. The concrete base of this target is quite significant and will not be disturbed easily. It is designed to last into the future and therefore a good option for hosting a recovery mark.

Selecting such unique locations for placing survey marks increases their chance of survival during construction works and provides easy access to surveyors in the future. Some other structures on which survey marks can be placed on are the edging of large telco and electricity pits (Figure 15).

Figure 13: Recovery mark placed in concrete (FW from DP).

Figure 14: Recovery mark placed in concrete base of ship navigation target (CQ from DP).

Figure 15: State Survey Mark in telco pit, reference mark in pit, and bench mark in pit (de Belin, 2015).

However, as de Belin (2015) states, there is still the risk of the top of the concrete edging to be destroyed during new paving works. As this infrastructure project was focused on creating a roadway that suited a race track, there was no guarantee that an 'untouchable large pit' would stop it from being modified. Consequently, no recovery marks were placed on this type of structure for this project.

In the future, a recovery mark may unfortunately be lost without any preservation works being carried out. However, the use of the redundant measurements (in this case two separate connections from a recovery mark to a destroyed cadastral mark) should allow the secondary mark to be used. There should be less risk of losing groups of these new recovery marks by a single infrastructure or development project, as they have been placed on a diverse range of structures.

The entire project was included in one Plan of Survey Information Only, i.e. DP1233256. This DP contains 6 pages and is presented so that it clearly shows which marks are the recovery marks. These recovery marks are shown by the use of traverse lines. By presenting it in this fashion on the DP, a surveyor will be able to quickly identify the recovery marks they are looking for (Figures 16-18).

The manner, in which the cadastral marks are shown in their true location and not shown at the cadastral corner they reference, also helps the next surveyor to identify which mark it refers to. The addition of stating which DP the mark originates from is very important in assisting future users.

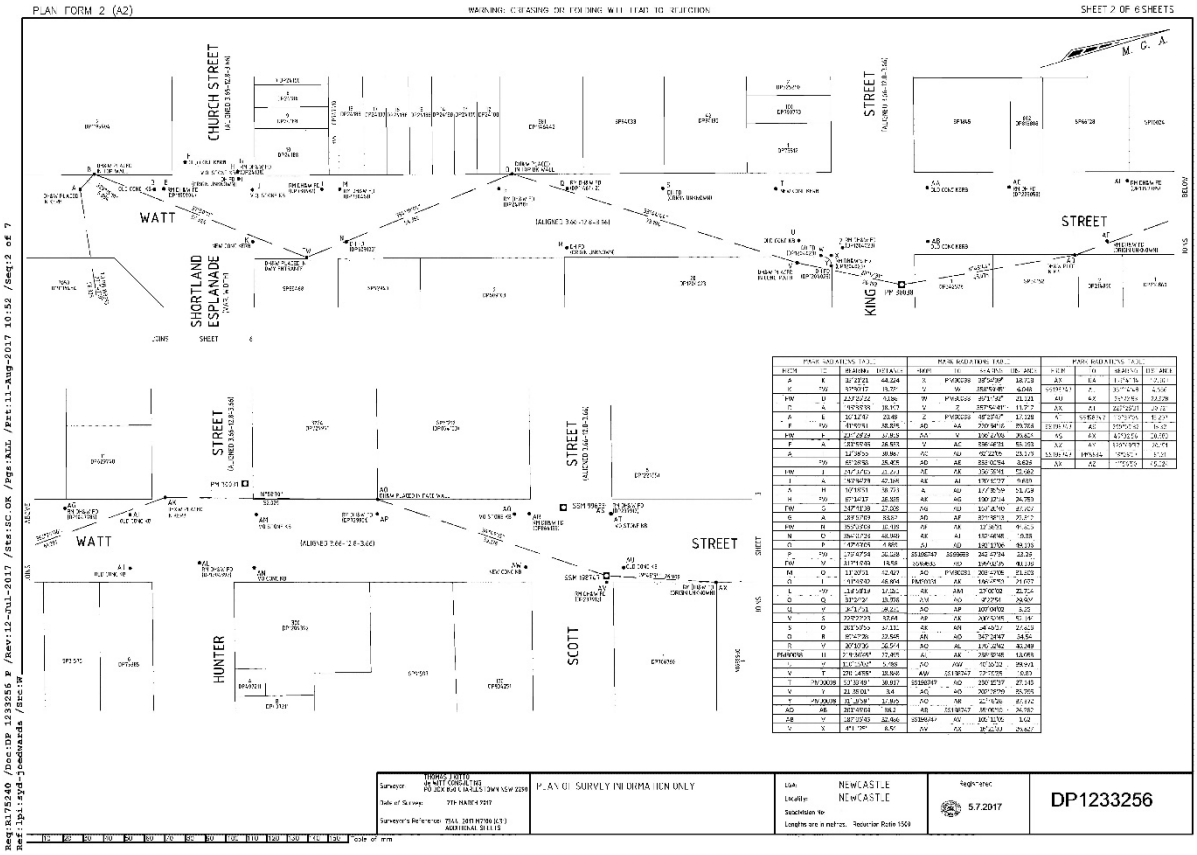

Figure 16: Page 2 of 6, DP1233256.

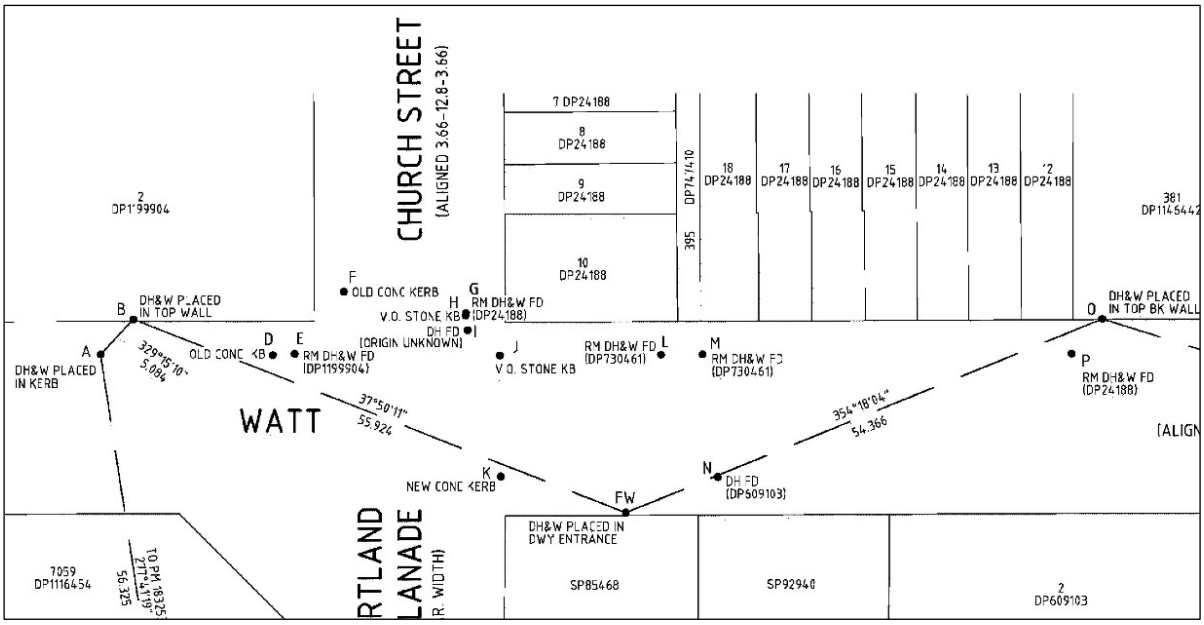

Figure 17: Section of page 2 of 6, DP1233256.

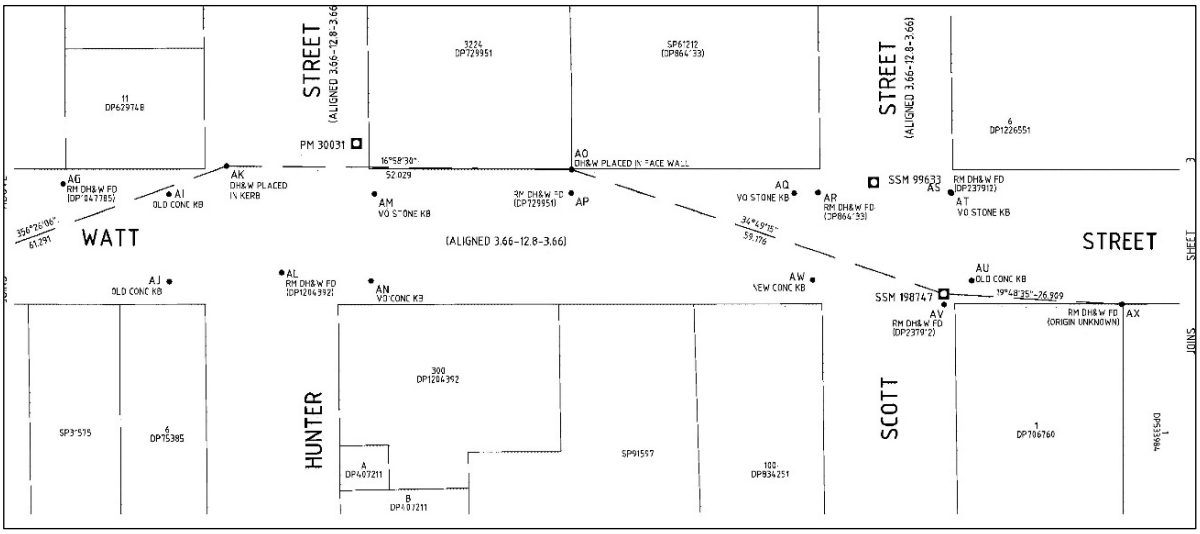

Figure 18: Section of page 2 of 6, DP1233256.

4 FINDING AND USING PLANS OF SURVEY INFORMATION ONLY

Locating more survey marks than needed helps to prevent issues from potential project creep. In this project, some marks have survived the works although they have been recovered. It must be remembered that a Plan of Survey Information Only does not tell future surveyors that the cadastral marks have been destroyed. The intent of this type of plan is to provide valuable survey information on public record that can be used by other surveyors and provides valuable evidence for the relocation of boundaries. Therefore, any future surveyor should still look for the cadastral marks that are shown on any Plan of Survey Information Only and not assume that they are destroyed.

When conducting a Cadastral Record Enquiry (CRE) search in the race track area, DP1233256 will show up, but knowing how to obtain the information from a CRE is sometimes tricky. It is helpful to know when doing a CRE search that the current cadastral

fabric (current titles only) is all that is shown on the map at face value. The dashed lines indicate if there is an underlying or overlying plan that may be of benefit, e.g. acquisition and resumption plans, small easement plans and survey information only plans (Figure 19). These plans can then be found on the notation section of the CRE.

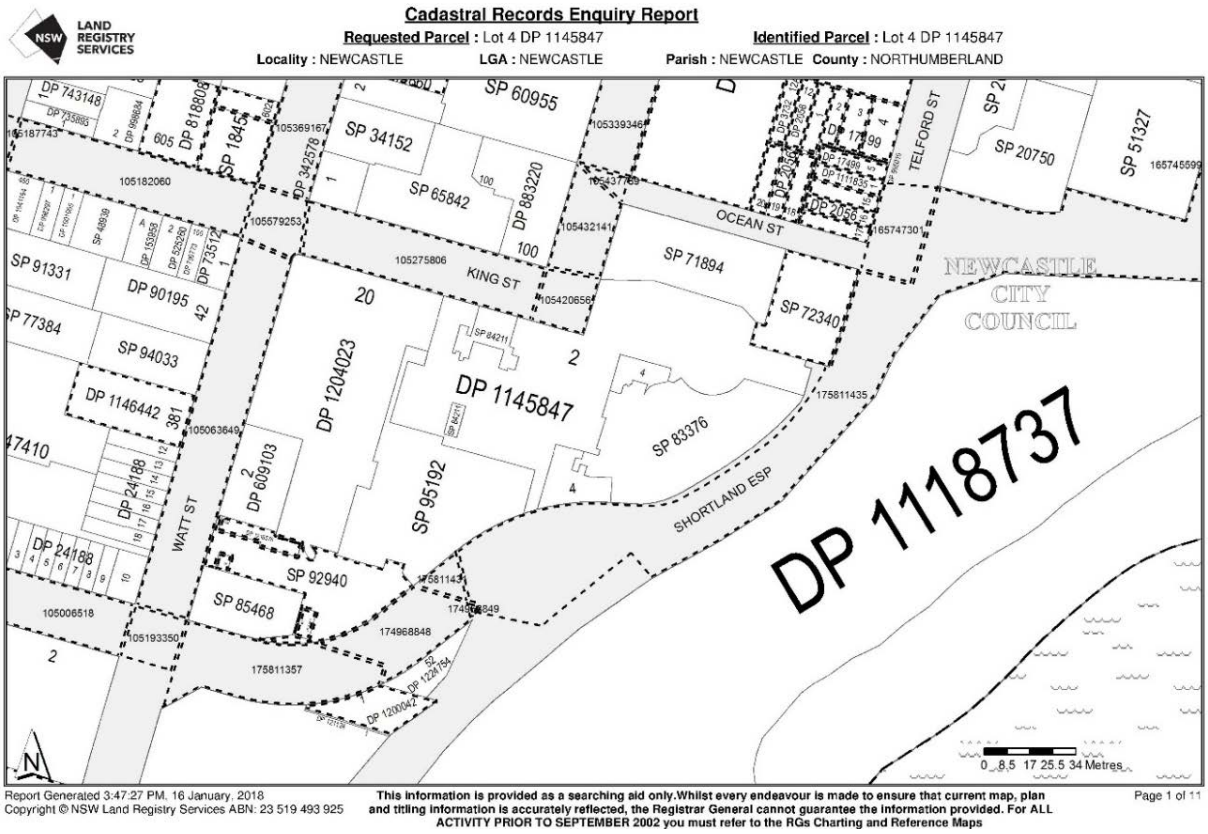

Figure 19: Map of CRE in the Newcastle East area.

If one of these plans from the notation section is on a road reserve, then a polygon ID number is used (as there is no title to refer to) and shown on the map to help refer the user to its location. Large plans, such as DP1233256, may contain multiple polygon IDs, due to the large area it is contained within (Figure 20).

Cadastral Records Enquiry Report

LAND REGISTRY SERVICES

Requested Parcel : Lot 4 DP 1145847 **Identified Parcel** : Lot 4 DP 1145847

Locality : NEWCASTLE **LGA** : NEWCASTLE **Parish** : NEWCASTLE **County** : NORTHUMBERLAND

	Status	Surv/Comp	Purpose
Polygon Id(s): 175811357, 175811431, 175811435			
DP1224752	REGISTERED	SURVEY	RESUMPTION OR ACQUISITION
NSW GAZ. 18-08-2017 ACQUIRED FOR PUBLIC ROAD - LOT 20 DP1224752			Folio : 4491
Polygon Id(s): 174968848, 175811357, 175811431, 175811435			
NSW GAZ. 18-02-2011 ACQUIRED AND DEDICATED PUBLIC ROAD FOR THE PURPOSES OF THE ROADS ACT 1993 - LOT 2 DP1029006. ERRATUM GAZ. 3-6-2011 FOL. 3479 AND GAZ. 17-6-2011 FOL. 4495			Folio : 1218
Polygon Id(s): 105006518, 105063649, 105182060, 105275806, 105339346, 105369167, 105432141, 165745599, 165747301, 174968848, 175811357, 175811431, 175811435			
DP1233256	REGISTERED	SURVEY	SURVEY INFORMATION ONLY

Figure 20: Notations of CRE in the Newcastle East area.

5 CONCLUDING REMARKS

This paper has outlined how the new SGD11 (Preservation of Survey Infrastructure) was practically applied to the Newcastle V8 Supercars – Newcastle 500 large-scale project. It was demonstrated that even on a site with little to no room to place survey marks and under severe time constraints, a good result could be obtained with close collaboration and communication. The new SGD11 has been generated to help guide surveyors and personnel authorised by the Surveyor General to preserve and protect survey infrastructure for future use by tomorrow's surveyors.

ACKNOWLEDGEMENTS

De Witt Consulting are gratefully acknowledged for their professionalism and dedication to see the project through from start to finish, in particular Tom Kitto and John Wilson. Vittorio Sussanna (Senior Surveyor, Survey Operations Metropolitan) is thanked for his guidance, support and trust.

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UAS Photogrammetric Mapping Workflow and Accuracy

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ABSTRACT

Utilising Unmanned Aerial Systems (UAS) for aerial photogrammetric mapping has been advanced in the last few years with available drones, sensors and automated image processing software. It has greatly supplemented and extended conventional surveying technology in many ways. The UAS aerial photogrammetric survey capability has numerous applications for surveying tasks, such as land surveying, mining surveying, construction monitoring, volume estimation and agriculture. Automatic and robust UAS photogrammetric image processing software packages require little surveying professional knowledge or expertise to produce impressive geospatial products, such as textured 3D point clouds, digital surface models, digital terrain models and ortho-mosaic image maps. What is the achievable accuracy of UAS photogrammetric mapping in terms of the 3D coordinates of the point cloud, Digital Terrain Model (DTM) points and the ortho-images? This presentation outlines various UAS mapping experimental projects that were designed with optimised workflow to investigate 3D point cloud accuracy.

KEYWORDS: *UAS, drone, surveying, mapping, photogrammetry, geospatial.*

Surveying and Spatial Information Regulation 2017: GNSS and Plan Requirements

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ABSTRACT

The Surveying and Spatial Information Regulation 2017("the Regulation") came into force on 1 September 2017 and, in certain circumstances, allowed for the usage of approved Global Navigation Satellite System (GNSS) methods to determine the Map Grid of Australia (MGA) position and MGA orientation of a survey. This paper summarises, from a practical perspective, what should be shown on a survey plan to comply with those clauses of the Regulation that apply to GNSS methods and the datum line of orientation of a survey. Examples illustrating what should and should not be shown on a survey plan for compliance with the Regulation are given.

KEYWORDS: *Regulation, GNSS, datum line, position, orientation.*

1 INTRODUCTION

The horizontal datum of a survey plan is a fundamental requirement that defines the orientation of the survey with respect to a known reference frame. Depending on the regulations within the jurisdiction that apply to that survey plan, the horizontal datum requirements might also define the position of the survey with respect to a known reference frame. Establishing a datum, whether horizontal or vertical, is paramount to the reliability, traceability and spatial enablement of a survey (e.g. Janssen, 2009, 2017).

Historically, the majority of survey plans lodged with the New South Wales Registrar-General over the last 180 years or so have not adopted a horizontal datum line orientation aligned with a State or Federal reference frame or map projection. Instead, the datum line orientations adopted have included, amongst others, bearings from magnetic compass observations, bearings from astronomical observations and bearings from survey plans on public record. Typically, the orientation historically adopted is that of a bearing from magnetic compass observations or a bearing from a survey plan on public record that has adopted a bearing from magnetic compass observations.

A datum line orientation, including an orientation that is aligned with a State or Federal reference frame or map projection, does not solely spatially enable the survey. In order to spatially enable the survey, position information is required (i.e. coordinates of the datum line terminals within a State or Federal reference frame or map projection). The position

information should be stated on the survey plan so that the plan is spatially enabled without reference to any external databases, spatial information systems or other plans. That is, the survey plan should be spatially autonomous requiring very little, if any, further research by the end user. Not only are the majority of survey plans lodged with the NSW Registrar-General over the last 180 years or so not aligned with a State or Federal reference frame or map projection, neither do they have position information, thus the spatial enablement of those plans usually requires some considerable research and processing by the end user.

It is estimated that 95% of all current data contains geographical references (Perkins, 2010). As the spatial enablement of society has increased and continues to increase via the use of Global Navigation Satellite System (GNSS) enabled technology coupled with readily available mobile data connection, there is a greater expectation that data available to society will also be spatially enabled. Notably, the United Nations (UN) Resolution 69/266 has recognised "the economic and scientific importance of and the growing demand for an accurate and stable global geodetic reference frame for the Earth … as the basis and reference in location and height for geospatial information" (UN, 2015). The ANZLIC Spatial Information Council, a "peak government body in Australia and New Zealand responsible for spatial information" (ANZLIC, 2018a) has introduced the Foundation Spatial Data Framework (FSDF) initiative which "is a change program on Australia's 'common asset' of location information" (ANZLIC, 2018b) that "provides a common reference for the assembly and maintenance of Australian and New Zealand foundation level spatial data in order to serve the widest possible variety of users" (ANZLIC, 2018c). The FSDF has 10 themes, including 'Positioning' and 'Elevation and Depth', i.e. the fundamental elements required for spatial enablement of data. The NSW state control survey is an example of a dataset contributing to both the FSDF initiative and implementation of UN Resolution 69/266.

To respond to the societal and governmental expectation that publically available data should be spatially enabled, the Surveying and Spatial Information Regulation 2017 (NSW Legislation, 2017) (hereinafter referred to as "the Regulation") that applies within New South Wales introduced reforms for greater spatial enablement of survey plans. Those reforms require the datum line of orientation for the majority of survey plans to be aligned to the Map Grid of Australia (MGA) and report an MGA position to, at a minimum, Class D standard. In particular, *all* rural surveys and the majority of urban surveys must have an MGA orientation and MGA position.

An MGA orientation and MGA position of the datum line can, under the Regulation, be achieved by two methods:

1. Connection to established survey marks of the state control survey, or
2. Use of an approved GNSS method.

Method number 2, i.e. use of an approved GNSS method, has resulted in a number of queries to the Office of the Surveyor-General regarding the correct implementation of such methods and the information to be shown on a survey plan when using an approved GNSS method for datum line orientation and position. Answers to those queries received have often included the explanation of certain geodetic concepts and their application to cadastral surveying. Traditionally, there has been little crossover between cadastral surveying ("that enables people to readily and confidently identify the location and extent of all rights, restrictions and responsibilities related to land and real property" (ICSM, 2015)) and geodetic surveying (that measures and represents the size and shape of the earth). This has, on occasion, caused confusion in practitioners of either of the above branches of surveying as to the methods and

techniques employed by the other. This confusion has latterly been brought into sharp relief by the ready availability of GNSS equipment, being geodetic surveying equipment that natively operates in a geodetic reference frame. The readily available GNSS equipment has been adopted by a majority of cadastral surveyors for use in cadastral surveys that historically, and as regulated, are expressed as bearings and distances on a local horizontal plane projection, being a non-geodetic projection.

In order to address the queries received by the Office of the Surveyor-General from cadastral surveyors, this paper describes certain geodetic concepts, tools available to cadastral surveyors for calculation of geodetic elements, the cases when approved GNSS methods for datum line purposes are to be used, use of approved GNSS methods for datum line purposes and their application to survey plan requirements under the Regulation, with reference to case studies of survey plans.

2 GEODETIC ELEMENTS REQUIRED FOR SURVEY PLANS

2.1 Grid Bearing

Clause 12 of the Regulation is the clause that regulates the adoption of datum lines of orientation for a survey plan. Clause 12, for many cases that might apply to a survey, states a requirement to adopt a grid bearing derived from MGA coordinates for orientation of the datum line.

2.1.1 Grid Bearing Concept

A line observed between two points on the earth's surface can be expressed as a line representing the shortest distance between two points on an ellipsoid, where the ellipsoid might be an equipotential ellipsoid that best represent the earth's size, shape and gravity field (Moritz, 2000) – that shortest line on the ellipsoid is called a geodesic.

For the Geocentric Datum of Australia 1994 (GDA94), the ellipsoid is the GRS80 reference ellipsoid that uses the International Terrestrial Reference Frame 1992 (ITRF92) as the reference frame. For the Geocentric Datum of Australia 2020 (GDA2020), the ellipsoid is also the GRS80 reference ellipsoid. However, GDA2020 uses a different reference frame being the International Terrestrial Reference Frame 2014 (ITRF2014), i.e. GDA94 and GDA2020 use the same reference ellipsoid, GRS80, but the ellipsoid is in slightly different positions for each of the two datums (e.g. Janssen, 2017). The ellipsoidal coordinates for a survey mark will therefore be different depending on what datum (GDA94 or GDA2020) the coordinates are expressed in. It should be noted that the majority of the ellipsoidal coordinate difference between GDA94 and GDA2020 is due to tectonic plate movement.

When a geodesic on the GRS80 reference ellipsoid for either GDA94 or GDA2020 is projected onto MGA, which is a Universal Transverse Mercator (UTM) projection, the geodesic projects as an arc. As an example, a cadastral surveyor working in NSW uses a total station to measure a line between two permanent survey marks, PM#1 and PM#2. The measured line, expressed as a geodesic on the reference ellipsoid (GRS80) for the GDA94 datum and then projected onto MGA will appear on the projection plane as an arc (Figure 1). If GNSS methods were used instead to measure the line, and that line were expressed as a geodesic (noting, though, that measured 3-dimensional GNSS vectors are not usually

expressed as geodesics in measurement processing), the measured line still appears on the projection plane as an arc.

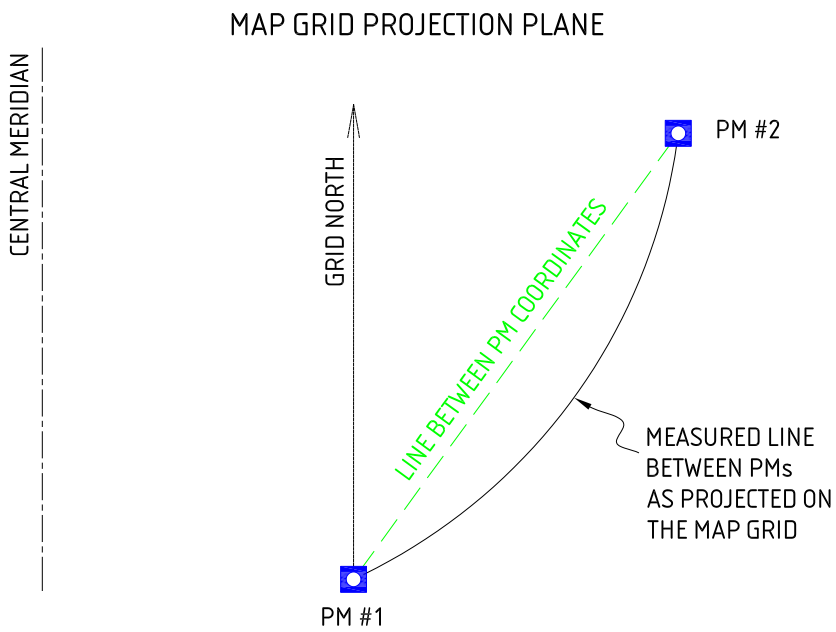

Figure 1: Measured line as projected.

As well as the Laplace correction, used for converting observed astronomical and gyro azimuths to geodetic azimuths (Featherstone and Rüeger, 2000), there are small corrections that apply to a direction measured by total station or theodolite when expressing the measured line as a geodesic on the reference ellipsoid. These corrections are the deflection correction, the skew normal correction and the correction from the normal section direction to the geodesic direction.

The deflection correction accounts for the deflection of the vertical due to the difference between the plumbline (the normal to the geoid) and the normal to the ellipsoid (ICSM, 2014). This gravimetric correction applies only to theodolite or total station direction observations as they use the plumbline as their measurement reference. The skew normal correction accounts for the fact that the ellipsoidal normals at each end of the line are not parallel (ICSM, 2014). The correction from a normal section direction to a geodesic direction accounts for the geodesic, in general, lying between the reciprocal normal section curves (Deakin, 2010).

Referring to the work of Deakin (2010), an example of an observed line from Buninyong to Smeaton, a geodesic distance of approximately 39.8 km, shows the deflection correction to be -0.020 seconds of arc, the skew normal correction to be +0.012 seconds of arc and the correction from the normal section direction to the geodesic direction to be -0.001 seconds of arc.

Within Australia, the GDA2020 technical manual reports that the maximum deflection of the vertical in terms of GDA94 and GDA2020 is of the order of 20 seconds of arc, which might result in a correction to an observed direction approaching half a second of arc (ICSM, 2018a). Featherstone and Rüeger (2000) reported a correction to a direction of 7.25 seconds of arc when reducing a line of geodetic zenith angle 45° (i.e. very large height difference) to the GRS80 ellipsoid using GDA94 position and AUSGeoid98 deflections of the vertical.

For the vast majority of cadastral surveys (i.e. traverse lines less than 10 km), the deflection correction, skew normal correction and the correction from a normal section direction to a geodesic direction are negligible and can be ignored (Deakin, 2010), though very steep lines might require application of the deflection correction.

If the above corrections are considered negligible, the direction as observed in the field for the line PM#1 to PM#2 is the tangent to the arc (the measured line as projected) at PM#1. Similarly, for PM#2 to PM#1 the observed direction is the tangent to the arc at PM#2 (Figure 2).

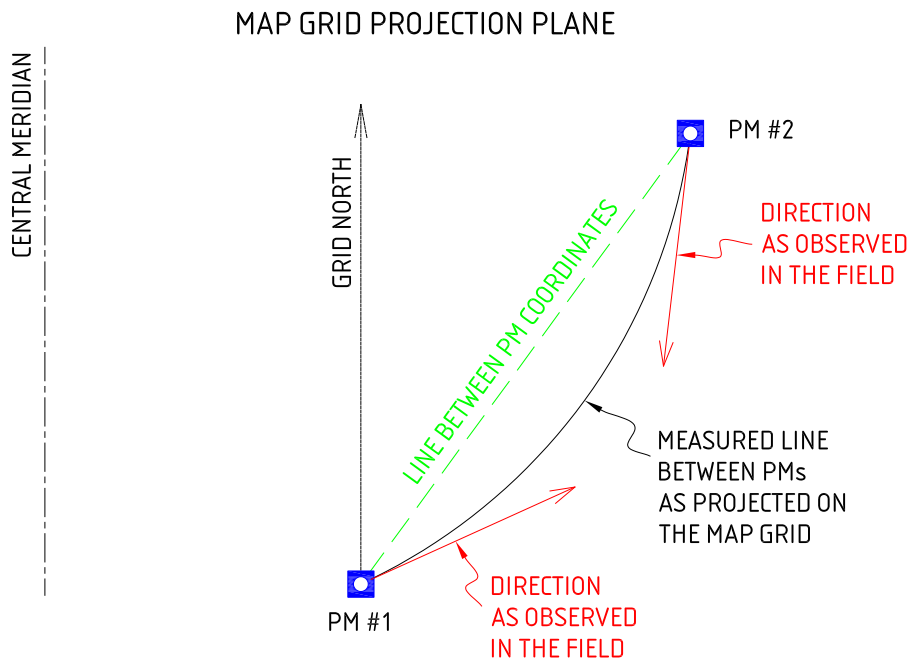

Figure 2: Observed directions on the projection plane.

The grid bearing of a measured line is the clockwise angle between grid north and the tangent to the arc (the measured line as projected) at either terminal of the arc (Figure 3).

The clockwise angle, on the projection plane, between grid north and the straight line between the projected coordinates for PM#1 and PM#2 is called the plane bearing (Figure 4).

The difference between the plane bearing and the grid bearing is known as the arc-to-chord correction (Figure 5).

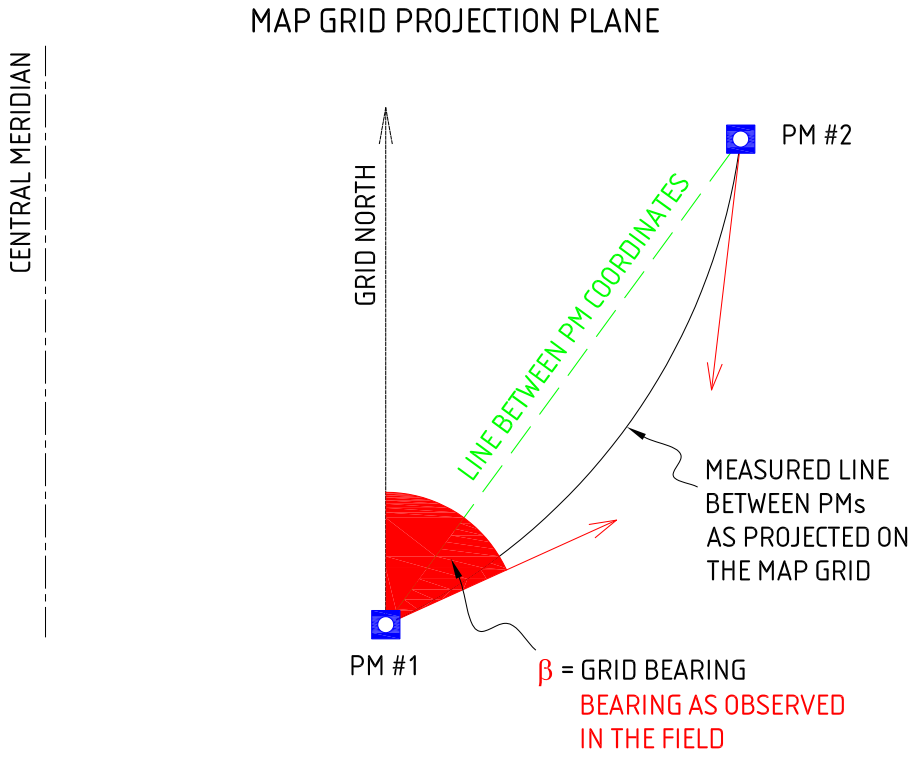

Figure 3: Grid bearing.

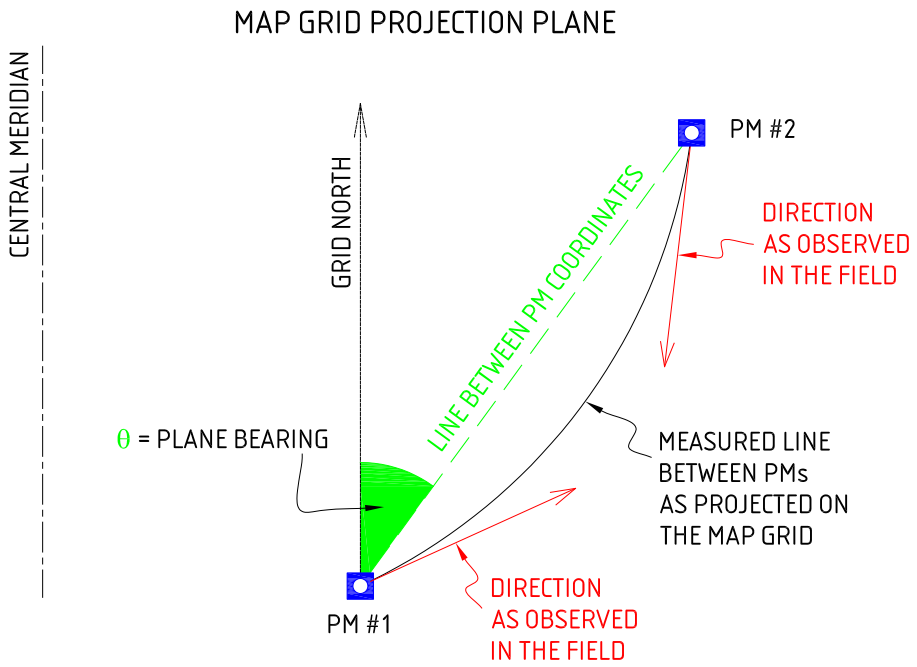

Figure 4: Plane bearing.

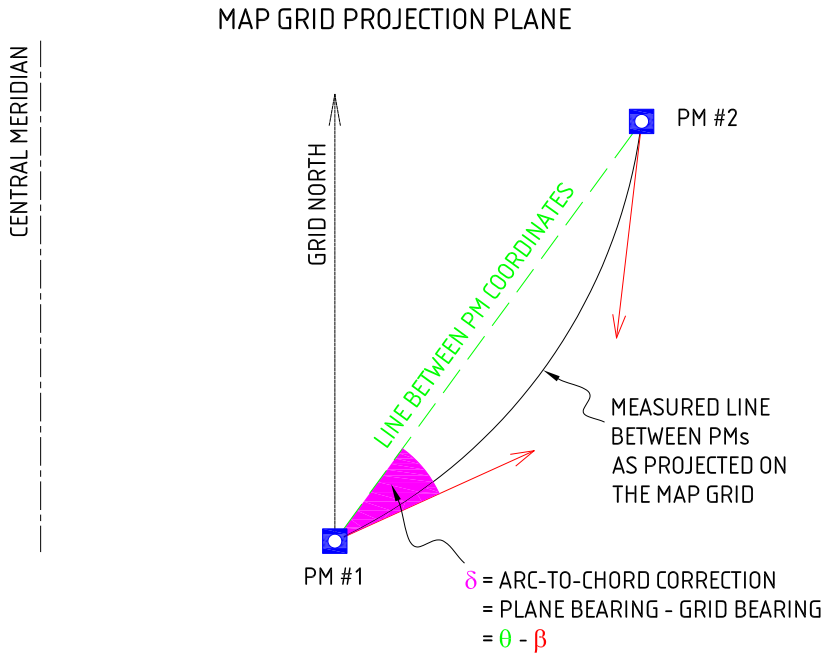

Figure 5: Arc-to-chord correction.

As a 'rule of thumb', when determining visually what direction and extent to which an arc, representing a measured line as projected on MGA, will 'bow out' on the projection plane (i.e. the direction and extent of the concavity of the arc), it is useful to consider a fictitious wind that blows from the central meridian of the projection zone towards the straight line between the projected coordinates of the line's terminals. If that straight line is thought of as a sail, then it will always bow out away from the central meridian (Figure 6). Also, the closer that straight line is aligned to the north-south direction and the longer it is, the greater the line will bow out. Lines that are aligned perfectly east-west on the projection plane and those lines perfectly coincident with the central meridian will have an arc-to-chord correction of zero. The magnitude of the arc-to-chord correction is also dependent on where in the projection zone the line is situated. For example, close to the edges of the projection zone, the arc-to-chord correction will be larger.

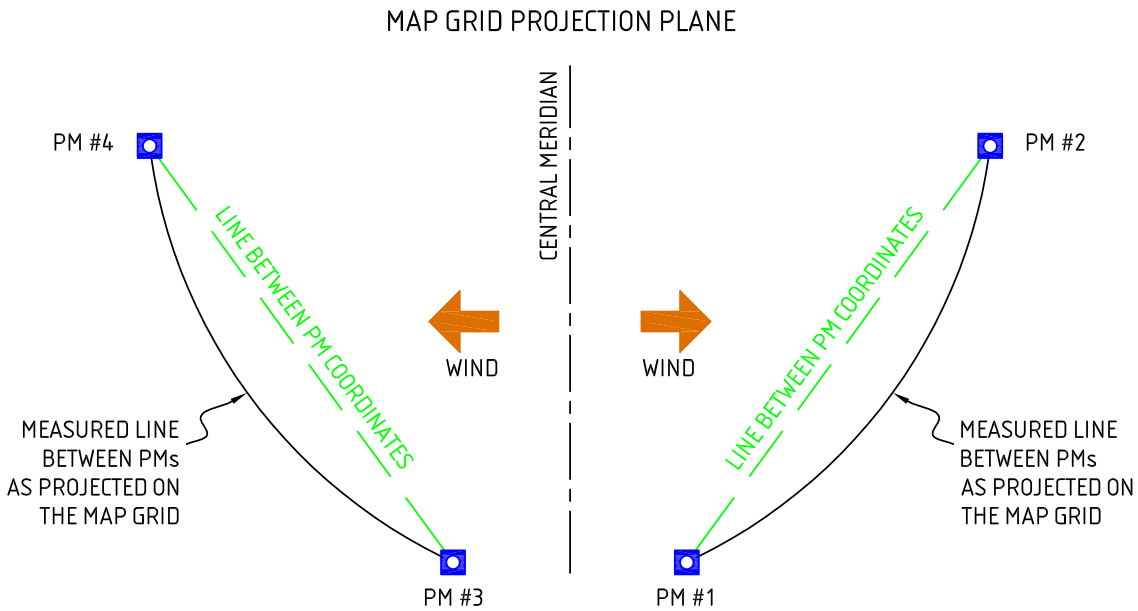

Figure 6: Visualising a measured line as projected.

Essentially, a geodesic joining two points will almost always project as a curved line lying on the side of the straight line joining the two projected terminals where the projection scale factor is greater (NMC, 1986). However, there is an exception to the rule of thumb as described above. In the case where the central meridian divides a line such that one part of the line is less than one-third of the total line length, the visualisation approach for determination of the sign of the arc-to-chord correction will fail. The sign of the arc-to-chord correction is then determined by the concavity of the longer part of the line (NMC, 1986) (Figure 7).

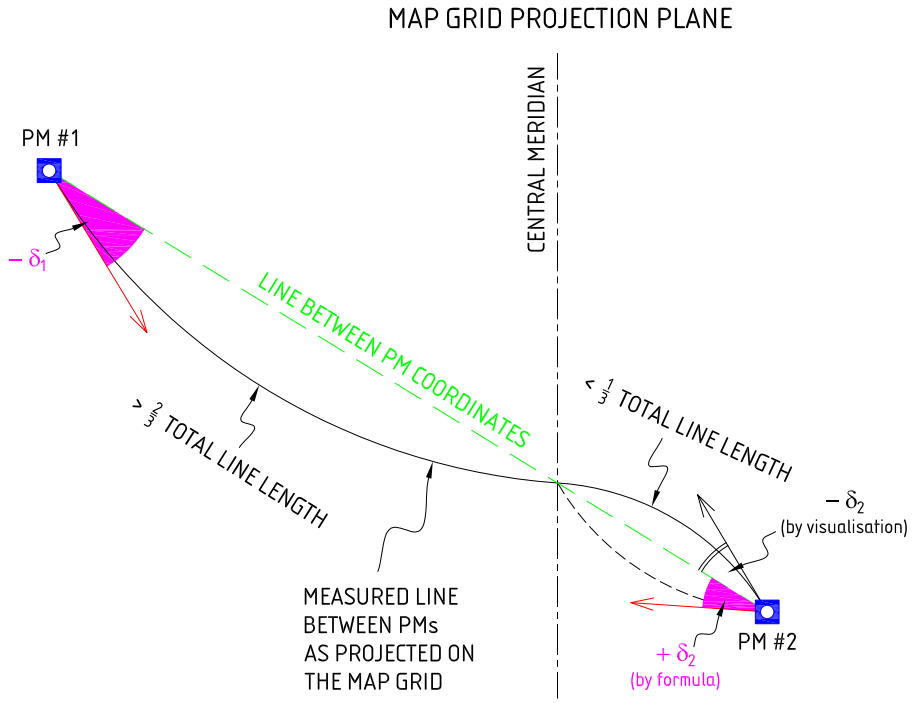

Figure 7: Exception to visualising the arc-to-chord correction.

Summarising the concept of a grid bearing:

- A line measured on the earth's surface will be projected on the MGA projection as an arc.
- The grid bearing is the bearing of the tangent to that arc at a terminal of the arc.

2.1.2 Adoption of a Grid Bearing by a Survey Plan

It can be noted from Figures 4 &5 that the forward grid bearing and reverse grid bearing for a measured line as projected will not, in most cases, differ by exactly 180°. Survey plans under the Regulation show bearings in a local plane projection where the forward and reverse bearings will differ by exactly 180°. Therefore, the requirement of the Regulation, in specific cases, for the datum line of a survey plan to adopt a grid bearing derived from the MGA coordinates of two marks will align the survey plan exactly with MGA for one terminal of the datum line only (the 'occupied' datum line terminal for the calculated grid bearing). This outcome is due to the distortions that exist between the MGA projection surface, being a UTM projection, and the local horizontal plane projection on which survey plans under the Regulation are placed. For the vast majority of cadastral surveys, being surveys of limited extent, any differences in alignment with MGA over the survey plan extent are very small and can be considered negligible in a cadastral context.

2.1.3 Calculation of a Grid Bearing

The currently available Excel spreadsheet GRIDCALC.XLS, provided by the Intergovernmental Committee on Surveying and Mapping (ICSM) enables the easy calculation of grid bearings from projected coordinates. GRIDCALC.XLS can be accessed as follows:

1. Download a copy of the GDA94 technical manual (ICSM, 2014).
2. Chapter 6 on page 23 displays a link "Excel spreadsheet – Grid calculations" by which a user can download GRIDCALC.XLS.

It is recommended that users familiarise themselves with the 'Parameters' tab to ensure that the correct parameters for the required ellipsoid and map projection are set. It should be set to MGA by default. The user should then navigate to the 'Grid coord > Bearing & Ell Dist' tab.

The user is required to input the Easting, Northing and projection zone of two points on the projection plane, and receives as output an ellipsoidal distance, a plane distance (the distance of the straight line between the projected coordinates on the map grid projection plane), grid bearings, arc-to-chord corrections and the line scale factor (Figures 8 & 9). Note that the line scale factor is *not* the Combined Scale Factor, which is discussed in section 2.2. The line scale factor is the ratio of a plane distance to the corresponding ellipsoidal distance (NMC, 1986; ICSM, 2014, 2018a).

Grid Bearing and Ellipsoidal Distance from Grid Coordinates **MGA**

	Name	East (E)	North (N)	Zone
From (1)	PM #1	737,283.595	6,291,260.090	55
To (2)	PM #2	737,694.224	6,291,635.411	55
Ellipsoidal Distance (s)	556.147			
Plane Distance (L)	556.311			
Grid Bearing (β_1)	47°	34'	20.24"	
Grid Bearing (β_2)	227°	34'	19.78"	
Arc to Chord correction (δ_1)	-0.23"			
Arc to Chord correction (δ_2)	0.23"			
Line scale factor (K)	1.000 295 40			

KEY
User input
Result

Figure 8: GRIDCALC.XLS output – standard example.

Grid Bearing and Ellipsoidal Distance from Grid Coordinates **MGA**

	Name	East (E)	North (N)	Zone
From (1)	PM 55644	222,007.144	6,287,455.333	56
To (2)	PM 79821	221,391.685	6,303,291.852	56
Ellipsoidal Distance (s)	15839.683			
Plane Distance (L)	15848.474			
Grid Bearing (β_1)	357°	46'	16.71"	
Grid Bearing (β_2)	177°	46'	39.11"	
Arc to Chord correction (δ_1)	11.20"			
Arc to Chord correction (δ_2)	-11.21"			
Line scale factor (K)	1.000 554 99			

KEY
User input
Result

Figure 9: GRIDCALC.XLS output – edge of zone example.

Figure 8 shows a standard example of a line that might well be adopted as the orientation of the datum line for a cadastral survey within NSW. Note that the arc-to-chord correction for this case would be considered negligible in the context of a cadastral survey. However, other arc-to-chord corrections for lines of differing length, orientation and position within a projection zone might well be significant in the context of a cadastral survey. Such an example on the edge of the projection zone is given in Figure 9.

2.2 Combined Scale Factor

Clause 70 of the Regulation is the clause that regulates the particulars of the coordinate schedule that must be shown on the survey plan. It is the coordinate schedule that is fundamental to the autonomous spatial enablement of the plan discussed in section 1. Clause 70(2)(h) of the Regulation requires the Combined Scale Factor to be shown

2.2.1 Combined Scale Factor Concept

Clause 59(2) of the Regulation requires a survey plan to state distances as "horizontal plane distances at ground level" (NSW Legislation, 2017), otherwise known as level terrain distances (ICSM, 2018a) or, simply, ground distances.

For other purposes, a reduced slope distance can also be expressed as a ground distance, an ellipsoidal distance, a grid distance or a plane distance (Figures 10 & 11):

- A ground distance is a reduced slope distance projected onto a local horizontal plane at mean ground level.
- An ellipsoidal distance is the distance on the ellipsoid along either a normal section or a geodesic. The difference between the normal section and geodesic distances is considered negligible, and amounts to less than 20 mm in 3,000 km (NMC, 1986; ICSM, 2014).

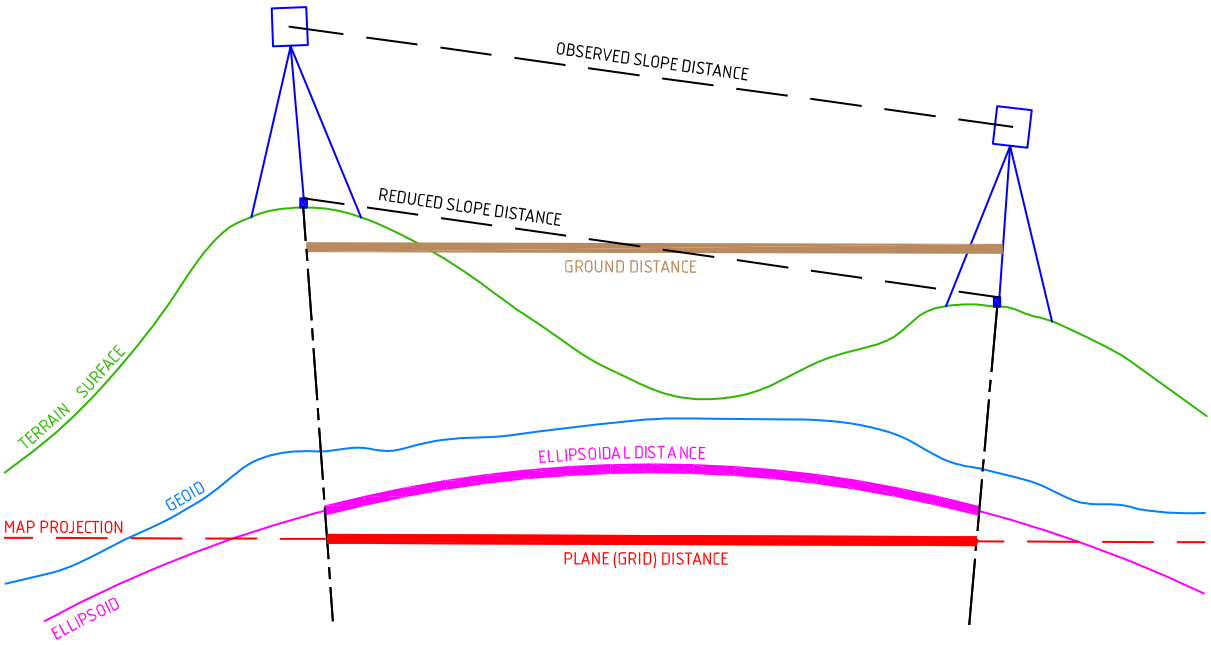

Figure 10: Distance types.

- A grid distance is the length measured on the map grid projection along the arc of a projected geodesic.

- A plane distance is the length of the straight line on the projection between the terminals of the arc of a projected geodesic. The difference in length between the plane distance and grid distance is nearly always negligible (NMC, 1986; ICSM, 2014, 2018a). Mahdi (2006) reported a line where a difference of approximately 1 mm was calculated between a 105 km projected geodesic length and its chord on a UTM projection.

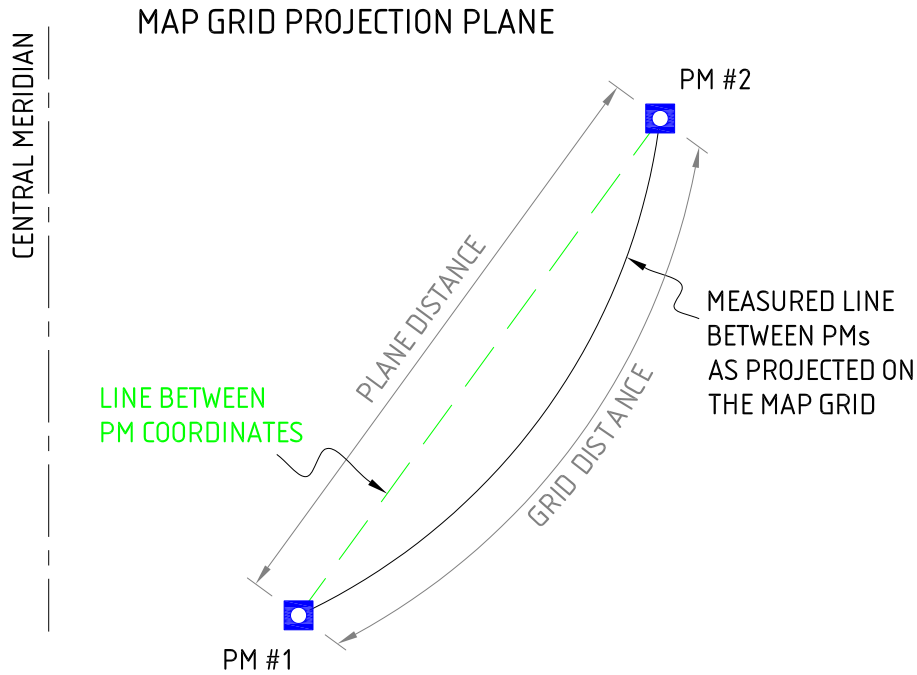

Figure 11: Plane distance and grid distance.

The Combined Scale Factor (CSF) is, as the name suggests, a combination of scale factors that describes the ratio of the plane (grid) distance to the ground distance. The CSF can be calculated for either a line or a point. The basic equation for the CSF (line) is:

$$Combined\ Scale\ Factor\ (line) = Height\ Factor\ (line) \times line\ scale\ factor \qquad (1)$$

In Equation 1, the height factor, for surveys of limited extent, is used to reduce the ground distance to the ellipsoidal distance. The line scale factor is used to reduce the ellipsoidal distance to the plane (grid) distance.

Strictly speaking, the height factor describes the reduction of a ground distance to an ellipsoidal chord distance (NMC, 1986; Deakin, 2006). However, for surveys of limited extent (i.e. the majority of cadastral surveys), the ellipsoidal chord-to-arc correction is considered negligible and thus the height factor is then considered to be the reduction from the ground distance to the ellipsoidal distance. The CSF for a line in a survey of limited extent is described diagrammatically in Figure 12.

For an ellipsoidal chord distance of 5 km, the ellipsoidal chord-to-arc correction is of the order of +0.1 mm (Deakin, 2006), and for an ellipsoidal chord distance of 15 km, it is of the order of +3 mm. Surveyors wanting to derive an accurate CSF (line) for long lines and surveys of large extent might need to consider the inclusion of an ellipsoidal chord-to-arc correction.

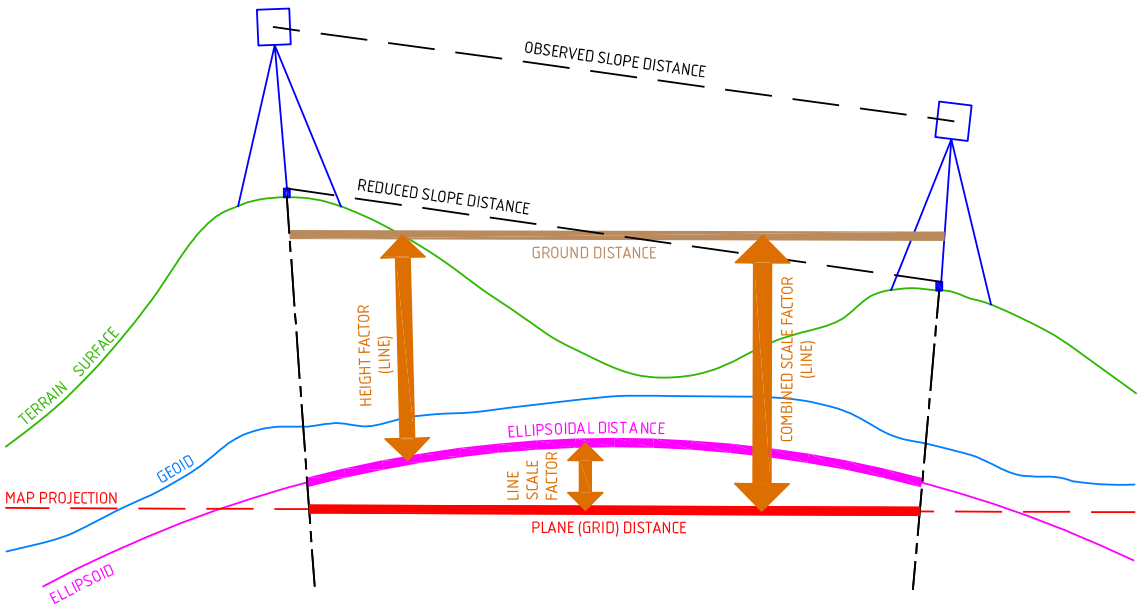

Figure 12: Combined Scale Factor (line) for surveys of limited extent.

The CSF can also be calculated for a point. The CSF for a point describes the ratio of an infinitesimal plane (grid) distance to an infinitesimal ground distance (Figures 13 & 14). The basic equation for the CSF (point) is:

$$Combined\ Scale\ Factor\ (point) = Height\ Factor(point) \times point\ scale\ factor \qquad (2)$$

In Equation 2, the height factor for the CSF (point) is used to reduce the infinitesimal ground distance to an infinitesimal ellipsoidal distance. The point scale factor is used to reduce the infinitesimal ellipsoidal distance to the infinitesimal plane (grid) distance.

Strictly speaking, the height factor in Equation 2 describes the reduction of a ground distance to an ellipsoidal chord distance. However, for a point, as the infinitesimal ellipsoidal chord approaches a length of zero, it will be of the same length as the infinitesimal ellipsoidal arc distance. Thus, for a point, the ellipsoidal chord-to-arc correction will be zero.

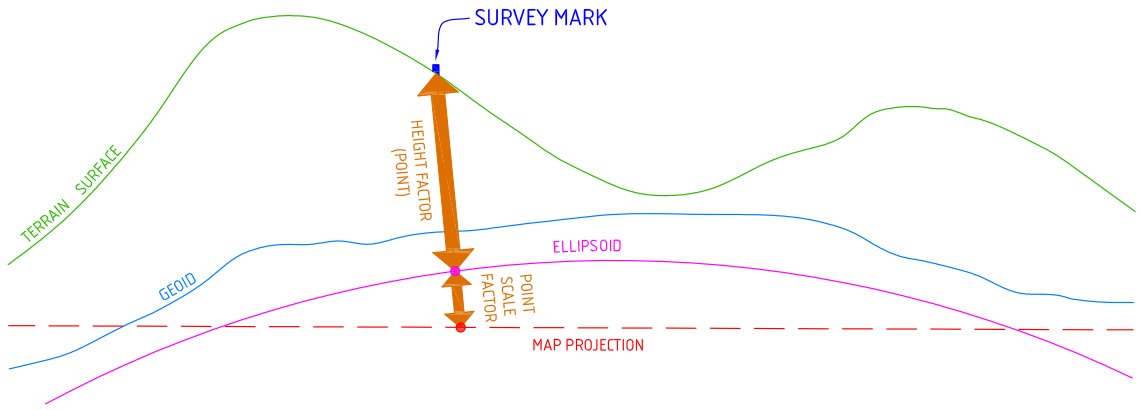

Figure 13: Components of the Combined Scale Factor (point).

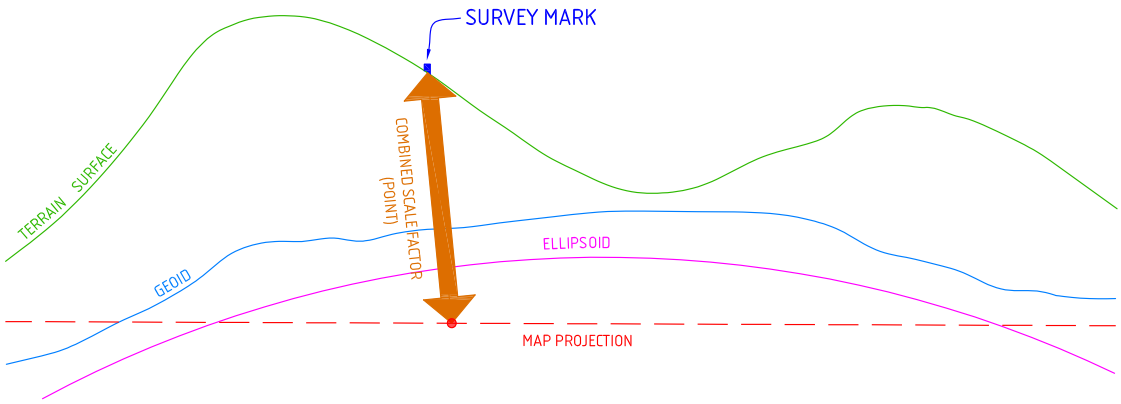

Figure 14: Combined Scale Factor (point).

2.2.2 Calculation of the Combined Scale Factor

Calculation of the Combined Scale Factor (Point)

To calculate an individual CSF (point) for MGA, an Excel spreadsheet CSF.XLS is provided by DFSI Spatial Services that enables easy calculation of the CSF (point) for MGA. It can be accessed as follows:

1. Navigate to the 'Conversion Software' section of DFSI Spatial Services' webpage (DFSI Spatial Services, 2018).
2. Under 'MGA Combined Scale Factor', use the 'Download a spreadsheet' link to download CSF.XLS.

The user is required to input the Easting, Australian Height Datum (AHD) value and geoid-ellipsoid separation (N-value) for the point (Figure 15). Users should be aware that any error in either the AHD value or the N-value will lead to an error in the CSF (point). If the combined error of the AHD value and the N-value is 6 m, the error in the CSF (point) will be approximately 1 ppm.

COMBINED SCALE FACTOR for MGA (GDA 94)

Easting (m)	Height(m)	N	CSF
222007.144	887.296	25.798	1.000409

Figure 15: CSF.XLS – Combined Scale Factor (point).

CSF.XLS uses the same equations for the CSF (point) as the Survey Control Information Management System (SCIMS), the coordinate database for the NSW survey control survey network, and will therefore give the same result as that reported by SCIMS (Figures 15 & 16).

MARK NAME STATUS	COORDINATES AND HEIGHTS				CLASS	ORDER	PU	SOURCE	CSF CONVERGENCE AUSGEOID09
PM 55644	MGA	222007.144	6287455.333	56	A	2	n/a	230288	1.000409
	GDA94	-33° 30' 58.90620"	150° 00' 25.60563"						-1° 39' 13.17"
	AHD71	887.296			LB	L2	n/a	209733	25.798

Figure 16: Part of the SCIMS report for PM55644.

The height factor and point scale factor equations used by CSF.XLS and SCIMS are shown in Equation 3 and are derived from Bomford (1980) and the Australian Geodetic Datum technical manual (NMC, 1986).

Using Equation 2 for MGA:

$$Combined\ Scale\ Factor\ (point) = \left(1 - \frac{h}{R+h}\right) \times \left(0.9996 + 1.2323\ E'^{2} 10^{-14}\right) \qquad (3)$$

Also:

$$h = H + N \qquad (4)$$

and:

$$E' = E - 500{,}000 \qquad (5)$$

where:
E' = Easting measured from a central meridian, positive eastwards
E = False Easting (as reported by SCIMS)
h = ellipsoidal height
H = orthometric (AHD71) height
N = geoid-ellipsoid separation
R = radius of curvature

In the above terms, E is the Easting as reported by SCIMS and is the Easting measured from the false origin. A suggested value for R in NSW is 6,370,100 m (NMC, 1986). The mid-latitude value of the geometric mean radius for NSW on the GRS80 ellipsoid is approximately 6,369,800 m.

The accuracy of the CSF (point) calculation relies upon the accuracy of the Easting, AHD value and N-value of the point. Generally, an accurate N-value has been the more difficult value for cadastral surveyors to determine. Cadastral surveyors in NSW have several sources by which an accurate N-value can be determined:

- SCIMS report.
- AUSPOS report.
- Geoscience Australia website.
- ICSM website.

As can be seen in Figure 16, a SCIMS report for a mark will list the N-value with respect to the geoid model applicable to the datum (GDA). Figure 16 shows the AUSGeoid09 N-value for PM55644 as 25.798 m. Note, however, that the SCIMS report also lists the CSF (point), being 1.000409 for PM55644.

AUSPOS is a free online GPS processing facility provided by Geoscience Australia, available for static GPS observations (GA, 2018b). Figure 17 shows an extract of an AUSPOS report, which may have been used as a terminal of a datum line, giving sufficient information by which an N-value can be calculated. The use of AUSPOS for datum line orientation is further discussed in Surveyor-General's Direction No. 7 (DFSI Spatial Services, 2017).

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
0402	556935.957	6728431.135	55	156.924	128.106

Figure 17: Extract of an AUSPOS report.

Referring to Figure 17, the N-value for the point observed in the AUSPOS report is calculated as the (Ellipsoidal Height) – (Derived AHD). Note that the 'Derived AHD' height is not, in a strict legal sense, the height of the point relative to the AHD71 datum as is reported by SCIMS. It is an orthometric height derived from the ellipsoidal height using the appropriate AUSGeoid model and can be considered to represent AHD71, for AUSGeoid09 in conjunction with GDA94, to an accuracy of approximately 0.1 m or better throughout NSW (Janssen and Watson, 2011) and for AUSGeoid2020 in conjunction with GDA2020 to an accuracy of approximately 0.05 m or better throughout NSW (Janssen and Watson, 2018).

Geoscience Australia provides an online calculation tool for determining the N-values of various AUSGeoid models (GA, 2018a) (Figures 18 & 19). The geoid model required is specified, the latitude and longitude of the point, referred to the appropriate datum (GDA94, GDA2020) is entered, a height (ellipsoidal or AHD) is entered and the result computed. The example shown in Figure 19 returns an AUSGeoid09 N-value of 25.799 m for the latitude and longitude entered.

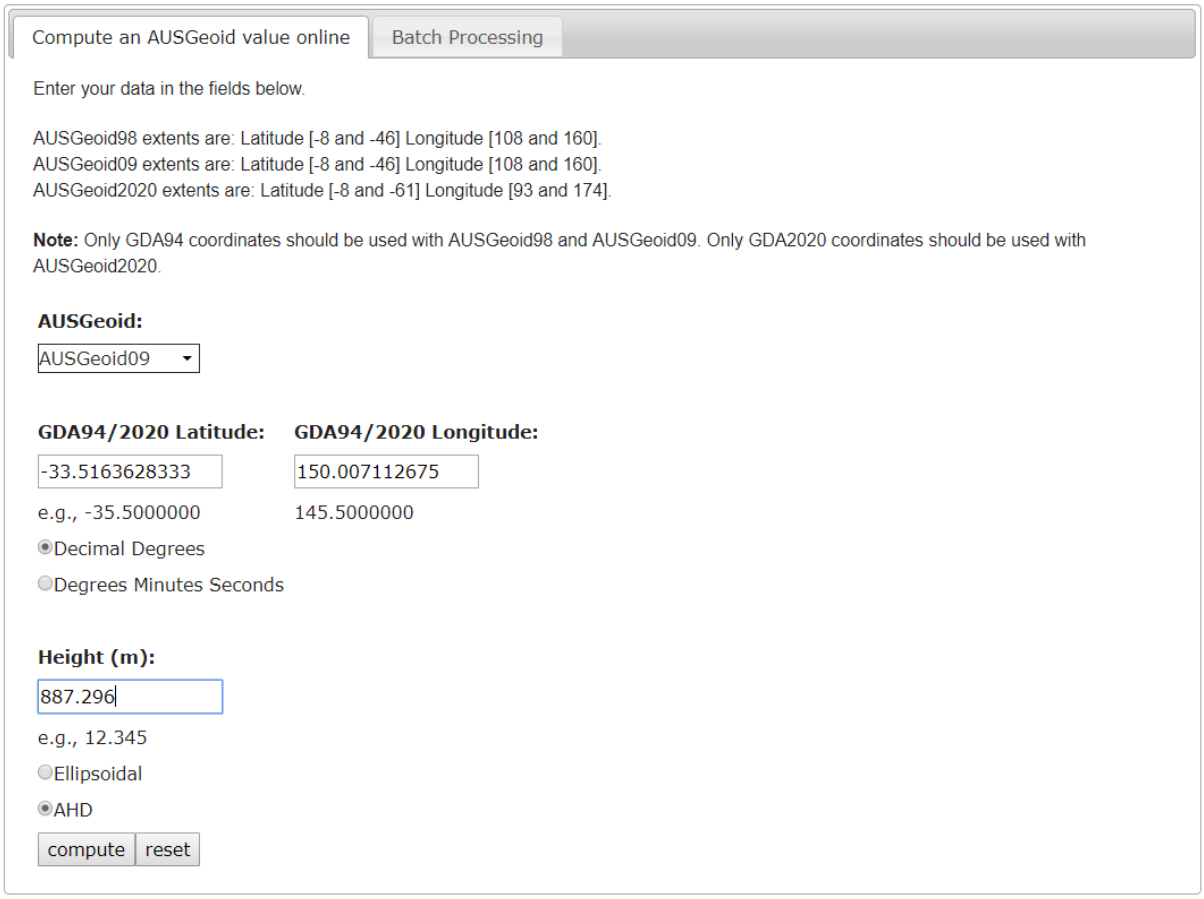

Figure 18: Geoscience Australia's online AUSGeoid calculation tool – input form.

Calculation Results

AUSGeoid file used:	AUSGeoid09
Latitude (decimal degrees):	-33.5163628333
Longitude (decimal degrees):	150.007112675
AHD height (m):	887.296
Ellipsoidal height (m):	913.095
AUSGeoid value (m):	25.799
AUSGeoid uncertainty (m):	-
Deflection prime meridian (seconds):	-5.00
Deflection prime vertical (seconds):	0.14

Figure 19: Geoscience Australia's online AUSGeoid calculation tool – results.

As an alternative, ICSM provides geoid interpolation software 'GeodInt' (ICSM, 2018b) (Figures 20 & 21). GeodInt requires a WINTER DAT format or NTv2 GSB format geoid grid file. Instructions on how to download an NTv2 GSB format geoid grid file can be found on Geoscience Australia's AUSGeoid webpage (GA, 2018a) (Figure 22).

- GeoidInterpolation.zip V1.03 December 2011 (0.6 MB)

Latest version of geoid interpolation program. Requires geoid grid file in either WINTER DAT format or NTv2 gsb format. Offers interactive and file interpolation modes and the ability to create a single NTv2 file from a grid file in the legacy AUSGeoid DAT file format. Software documentation is provided.

(Users who experience problems running this software for the first time should install the Microsoft Visual C++ 2008 Libraries.)

Figure 20: GeodInt download (ICSM, 2018b).

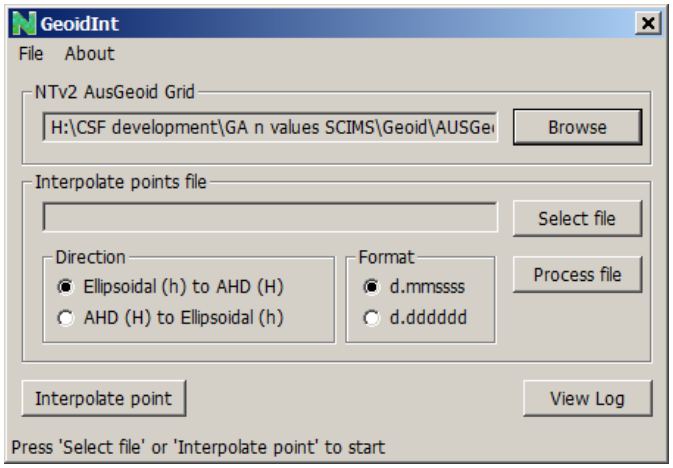

Figure 21: GeodInt user interface.

Download AUSGeoid files

The AUSGeoid files in text file format and binary format (NTv2) can be downloaded from AWS S3. To download a file, cut and paste the bucket path (https://s3-ap-southeast-2.amazonaws.com/geoid/) into a browser and append the file name you would like to download (e.g. AUSGeoid2020_20170908.gsb) and tap Enter.

Figure 22: GSB file download (GA, 2018a).

Using the CSF (Point) to Calculate the CSF (Line)

For lines measured in surveys of limited extent, i.e. the majority of cadastral surveys, the CSF (point) can, depending on the length of the line and the terrain over which the line is measured, be used to calculate the CSF (line) with adequate results within the context of the Regulation.

Methods of calculating the CSF (line) using the CSF (point) in a cadastral survey vary. Some methods are summarised here:

(a) Mean of the CSF (point) of each terminal. The mean of the point scale factors for the terminals of a line is accurate to 1 ppm in a line extending 16 km in Easting (NMC, 1986):

$$CSF_{line} = \frac{(CSF_{P1} + CSF_{P2})}{2} \tag{6}$$

(b) The CSF (point) for the mean Easting of the line. The point scale factor for the mean Easting of a line is accurate to 1 ppm in a line extending 33 km in Easting (NMC, 1986):

$$CSF_{line} = CSF_{mean\ E} \tag{7}$$

(c) Use of Simpson's Rule:

$$CSF_{line} = \frac{(CSF_{P1} + 4(CSF_{mean\ E}) + CSF_{P2})}{6} \tag{8}$$

where:
CSF_{line} = CSF for a line between point 1 (P1) and point 2 (P2)
CSF_{P1} = CSF for point 1 (P1)
CSF_{P2} = CSF for point 2 (P2)
$CSF_{mean\ E}$ = CSF for the mean easting between point 1 (P1) and point 2 (P2)

Method (c) (i.e. Equation 8) is considered to have greater accuracy than either of methods (a) or (b) (Stern, 1995).

Calculating the Combined Scale Factor (Line)

A surveyor can calculate a more rigorous CSF (line) than the procedures shown in Equations 6-8 by calculating the height factor for the line then substituting that height factor along with the line scale factor as calculated by GRIDCALC.XLS (see section 2.1.3) into Equation 1. The height factor for a line from point 1 to point 2 can be calculated using Equation 9 (section 2.3.5 of the Australian Geodetic Datum technical manual – NMC, 1986) and Equation 10:

$$Height\ factor\ (line) = \left(1 - \frac{h_m}{R_\alpha + h_m}\right) \tag{9}$$

Also:

$$h_m = \frac{h_1 + h_2}{2} \tag{10}$$

where:
h_m = mean ellipsoidal height
h_1 = ellipsoidal height of point 1
h_2 = ellipsoidal height of point 2
R_α = radius of curvature in the azimuth of the line

An ellipsoidal height for points 1 and 2 can be calculated using Equation 4. As above, an error in the ellipsoidal height of 6 m will result in an error of approximately 1 ppm in the CSF (line) (Deakin, 2006).

The radius of curvature in the azimuth, R_α, can be calculated using either the Australian Geodetic Datum technical manual (NMC, 1986), the GDA94 technical manual (ICSM, 2014) or the GDA2020 technical manual (ICSM, 2018a). For the majority of cadastral surveys, a value of 6,370,100 m can be substituted as an approximation for R_α in Equation 9 (NMC, 1986). Also, an approximate mid-latitude value of the geometric mean radius for NSW on the GRS80 ellipsoid of 6,369,800 m can be used. Deakin (2006) reports that an error in R_α of 20,000 m (20 km) will result in an error of approximately 0.2 mm in the plane distance for a line with a local plane (ground) distance of 1,000 m, mean ellipsoidal height of 500 m and value of R_α of 6,370,000 m. Therefore, use of either 6,370,100 m or 6,369,800 m for R_α for cadastral surveys in NSW is adequate within the context of the Regulation. For higher accuracy applications, R_α should be calculated for individual lines.

For surveyors requiring calculation of the CSF (line) without use of GRIDCALC.XLS, the expanded equation for a line from point 1 to point 2 is given in Equation 11, with the first term being the height factor as per Equations 9 & 10. The second term is the line scale factor as per section 5.6.2 of the Australian Geodetic Datum technical manual (NMC, 1986). Equations 12-18 will also be required.

Using Equation 1:

$$CSF_{line} = \left(1 - \frac{h_m}{R_\alpha + h_m}\right) \times k_0 \left\{1 + \left[\frac{\left(E_1'^2 + E_1'E_2' + E_2'^2\right)}{6r_m^2}\right]\left[1 + \frac{\left(E_1'^2 + E_1'E_2' + E_2'^2\right)}{36r_m^2}\right]\right\} \quad (11)$$

Also:

$$r_m^2 = \rho_m \nu_m k_0^2 \quad (12)$$

$$\nu_m = \frac{a}{\sqrt{(1 - e^2 \sin^2 \varphi_m)}} \quad (13)$$

$$\rho_m = \frac{a(1 - e^2)}{(1 - e^2 \sin^2 \varphi_m)^{\frac{3}{2}}} \quad (14)$$

$$e^2 = \frac{(a^2 - b^2)}{a^2} \quad (15)$$

$$\varphi_m = \frac{\varphi_1 + \varphi_2}{2} \tag{16}$$

$$E_1' = E_1 - 500{,}000 \tag{17}$$

$$E_2' = E_2 - 500{,}000 \tag{18}$$

where:
a = length of the reference ellipsoid semi-major axis
b = length of the reference ellipsoid semi-minor axis
CSF_{line} = CSF for a line between point 1 and point 2
e = eccentricity of the reference ellipsoid
E_1 = false Easting of point 1 (Easting as reported by SCIMS)
E_2 = false Easting of point 2 (Easting as reported by SCIMS)
E_1'= Easting of point 1 measured from a central meridian, positive eastwards
E_2'= Easting of point 2 measured from a central meridian, positive eastwards
h_m = mean ellipsoidal height
k_0 = central scale factor = 0.9996 for MGA
R_α = radius of curvature in the azimuth of the line
φ_1= latitude of point 1
φ_2= latitude of point 2
φ_m= mean latitude
ν_m = radius of curvature in the prime vertical at the mean latitude
ρ_m = radius of curvature in the meridian at the mean latitude

Term 2 of Equation 11, the line scale factor, is accurate to 0.1 ppm for lines of plane distance less than 100 km (Bomford, 1980). If further rigour is required for the CSF (line), the ellipsoidal chord-to-arc correction should be included (see section 2.2.1).

2.2.3 Use of the Combined Scale Factor

Clause 70(2)(h) of the Regulation requires the CSF for the survey to be shown. This is a single value that best represents the extent of the survey shown in the survey plan. It is not necessarily the single value used for all lines in the survey. The surveyor may choose to use separately calculated CSFs for each line requiring a CSF to be applied, or separate CSFs for various areas of the survey – anisotropic (non-uniform) scaling methods might even be considered. Surveyors are no longer required to show differing CSFs for individual permanent survey marks for cadastral surveys of large extent.

It is left to the professional judgement of the surveyor as to how best to apply one or several CSFs to a survey – each survey will be different in extent and shape, with differing terrain profiles. An approach that might be appropriate for one survey may not be appropriate for another – large changes in height within a survey will need careful scrutiny. Due to the large number of variations that might be encountered, a generic approach to application of CSF(s) for a survey cannot be specified here.

The basic formulae for applying the CSF are shown in Equations 19 & 20, again assuming a negligible difference between the plane distance and grid distance:

$$Plane\ (\text{Grid})\ distance = Ground\ distance \times Combined\ Scale\ Factor \tag{19}$$

$$Ground\ distance = \frac{Plane\ (\text{Grid})distance}{Combined\ Scale\ Factor} \tag{20}$$

3 APPROVED GNSS METHODS AND THE DATUM LINE

Clause 12 of the Regulation requires, in certain circumstances, the use of approved GNSS methods to determine the MGA position and MGA orientation of the datum line for a survey. The cases where such a requirement is applicable can be easily determined by reference to the datum line flowchart available as Diagram 3.18 in Surveyor-General's Direction No. 7 (DFSI Spatial Services, 2017).

Using an approved GNSS method to determine the MGA position and MGA orientation of the datum line for a survey requires compliance with three basic outcomes:

- An MGA coordinate *must* be determined for *each* terminal of the datum line.
- The MGA coordinate for each terminal *must* have been determined using an approved GNSS method.
- The MGA coordinate for each terminal of the datum line *must* have been determined to an accuracy of Class D or better.

In concept, using an approved GNSS method to determine the MGA position and MGA orientation of the datum line for a survey can be thought of as the surveyor bringing their own MGA coordinates to the datum line of their survey, i.e. the surveyor is operating outside the SCIMS 'ecosystem' and its inherent rigour. This means that some of the elements required by the Regulation, for example the CSF, have to be calculated by the surveyor instead of being readily provided by a SCIMS report. The means by which a surveyor can calculate these elements have been provided in section 2.

3.1 Datum Line Terminals

When determining Class D MGA coordinates for each terminal of the datum line using an approved GNSS method, there are two requirements that must be complied with:

1. Each terminal must be marked with either a permanent survey mark or a reference mark.
2. The Class D MGA coordinates of the terminal mark must be determined by direct occupation of the mark using an approved GNSS method. That is, a surveyor cannot determine Class D MGA coordinates of an eccentric station by an approved GNSS method and then determine the MGA coordinates of the datum line terminal by traverse.

The mark types comprising the terminals of the datum line do not have to be of the same form and style, i.e. a reference mark at one terminal and a permanent survey mark at the other terminal is acceptable. If a mark of the form and style of a reference mark is being used exclusively to define a terminal of the datum line, i.e. if the mark has not been referenced to a boundary corner, then that mark does not need to be within 30 metres of a boundary corner. In

such a case, the mark should be shown by the appropriate symbol (the 'double circle') as described in Schedule 5 of the Regulation and have a closed connection to the land surveyed (Figures 23-27). Note that in Figures 23-27, 'PSM' is an abbreviation for permanent survey mark and 'RM' is an abbreviation for reference mark.

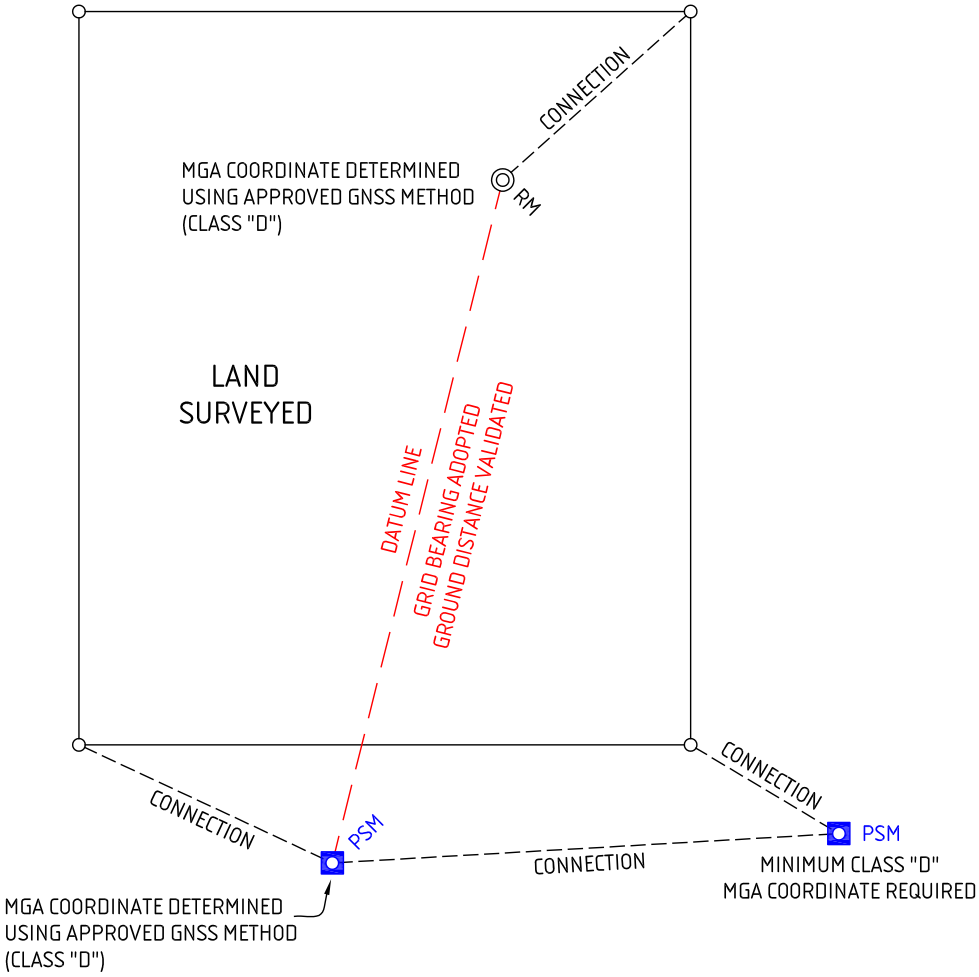

Figure 23: Datum line – permanent survey mark and connected reference mark.

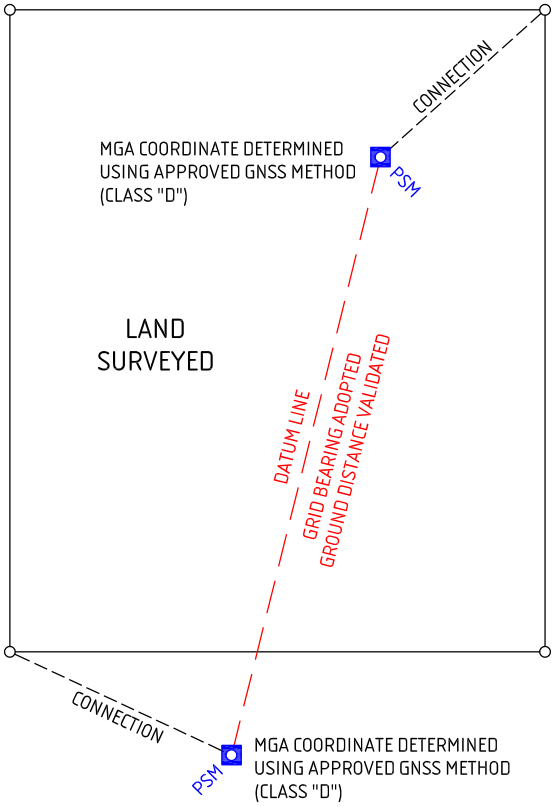

Figure 24: Datum line – permanent survey marks.

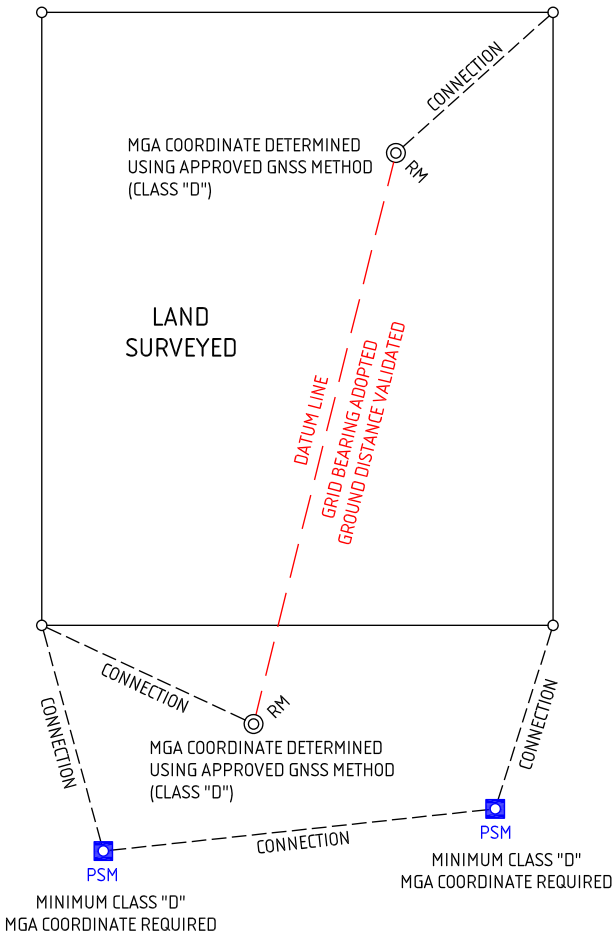

Figure 25: Datum line – connected reference marks.

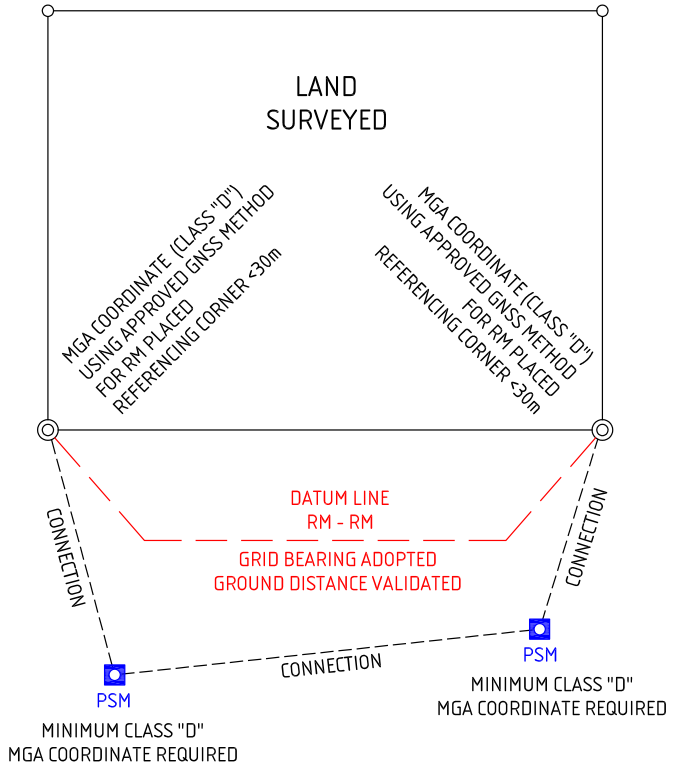

Figure 26: Datum line – reference marks referenced to a corner.

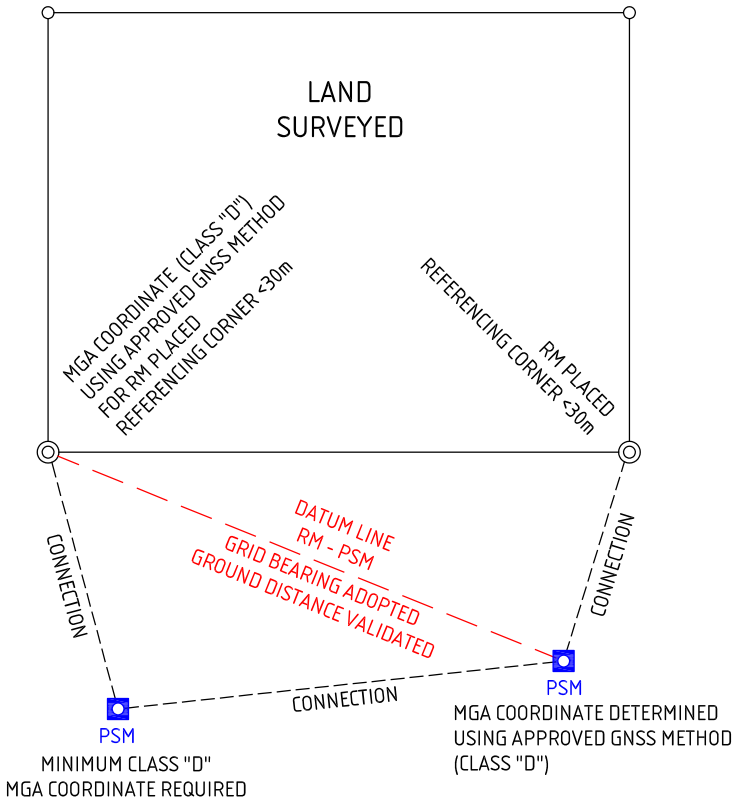

Figure 27: Datum line – reference mark referenced to a corner and a permanent survey mark.

It should be noted that when using a reference mark for a terminal or both terminals of the datum line, the surveyor must also connect the survey to the appropriate number of permanent survey marks as required by the Regulation. This means that, as an "accurate MGA

orientation" as per Clause 5 of the Regulation has been adopted, the surveyor is required, under Clause 70, to determine MGA coordinates of the unestablished permanent survey marks not used as datum line terminals to an accuracy equal to or better than Class D.

3.2 Approved GNSS Methods for Datum Line Position and Orientation

The approved GNSS methods that can be used to determine Class D MGA coordinates from which a grid bearing is derived and adopted for datum line orientation are:

- AUSPOS.
- CORS Network Real-Time Kinematic (NRTK).
- CORS single-base Real-Time Kinematic (RTK).
- CORS static.

The most commonly used methods are AUSPOS (GA, 2018b) and CORS NRTK. Each of the above methods is described in detail in both Surveyor-General's Direction No. 7 (DFSI Spatial Services, 2017) and Surveyor-General's Direction No. 9 (DFSI Spatial Services, 2014). For users of the AUSPOS GNSS method, the AUSPOS report is required to be lodged along with the survey plan when lodging the survey plan with the Registrar-General or a public authority.

There are also several commonly used GNSS methods which are *not* acceptable to determine the MGA coordinates adopted for datum line position and orientation. These include:

- Autonomous GNSS positions.
- Local single-base RTK based on a solitary mark with Class D (or better) MGA coordinates or a solitary mark with autonomous MGA coordinates.
- Static post-processed GNSS (without reference to CORS station/s) based on a solitary mark with Class D (or better) MGA coordinates or a solitary mark with autonomous MGA coordinates.

Users of geodetic GNSS equipment usually have the option to generate MGA coordinates using an 'autonomous' GNSS position. An autonomous GNSS position is considered to be a position determined by a single, standalone GNSS receiver relative to a datum as realised by the satellite control segment only, with no error modelling other than broadcast models. It is sometimes also called a 'navigated' position. Accuracy of an autonomous GNSS position is generally better than 10 m and can, in many instances, have an accuracy of better than 3 m. An example of a commonly used autonomous GNSS position is a GNSS position obtained using a mobile phone.

Use of autonomous GNSS positions to determine datum line position and orientation is not acceptable for the following reasons:

- MGA coordinates determined using an autonomous GNSS position do not achieve the required accuracy of Class D.
- MGA coordinates determined using an autonomous GNSS position have no traceability to a national standard.

Local single-base RTK and static post-processed GNSS (without reference to CORS station/s) are common methods used for carrying out a survey and are approved GNSS methods, which are acceptable to measure the relative position of marks and monuments within a survey. They are *not* acceptable methods to determine datum line position and orientation based on a

solitary mark with Class D (or better) MGA coordinates or a solitary mark with autonomous MGA coordinates.

For example, in the case of local single-base RTK, the local base station might occupy a datum line terminal having MGA coordinates of Class D or better, either a SCIMS established survey mark or a mark with the MGA coordinates determined by an approved GNSS method listed above. Coordination of the second datum line terminal solely by coordinate propagation using a measured baseline from the local base station's Class D MGA position is not acceptable. The second datum line terminal coordinates would then have no direct traceability to a national standard and would be solely reliant upon the projection parameters within the GNSS instrument or adjustment having been set correctly. That is, there would be no validation of the orientation against a national standard – it could be considered analogous to an unchecked radiation. The same principle applies to using a static post-processed GNSS baseline (without reference to CORS station/s) in the above situation as the sole measurement to coordinate the second datum line terminal.

In the case where a survey using either the local single-base RTK method or the static post-processed GNSS baseline method (without reference to CORS station/s) connects to two established survey marks within the distance restrictions specified by Clause 12 of the Regulation, then the survey is required to adopt a SCIMS MGA orientation and verify that orientation to a third established survey mark.

3.3 Selection of the Datum Line

When selecting the datum line for a survey where the datum line will adopt, as orientation, the grid bearing derived from Class D MGA coordinates as determined by the surveyor using an approved GNSS method, the surveyor should select the datum line with reference to the following matters:

- The site of either terminal of the datum line needs to be selected to minimise unwanted influences on the accuracy obtained by use of an approved GNSS method. Some of the elements that may influence the accuracy obtained using an approved GNSS method include the satellites in view, site stability, site obstructions and multipath sources.
- The length of the datum line must be commensurate with the size of the survey. As a general rule, the length of the datum line should not be less than 300 m. However, the surveyor must determine what length is appropriate for the survey. Generally, the longest length of the datum line practically feasible is desirable while having regard to the size of the survey. Note that Surveyor-General's Direction No. 9 (DFSI Spatial Services, 2014) specifies 100 m to be the minimum length of a line derived by GNSS methods.
- The position of the datum line with respect to the land surveyed has certain restrictions. The datum line must be within 300 m of the land surveyed for an urban survey and 1,000 m for a rural survey. The datum line should, if practically feasible, be integral or immediately adjacent to the land.

3.4 GNSS Validation

All GNSS constellations are operated by international parties. Most available GNSS networks are operated by Government (e.g. CORSnet-NSW, GPSnet) or commercial third parties and are not under the surveyor's direct control. As such, any GNSS equipment and methods used must be confirmed ("validated") against an independent external source of known accuracy for each survey where an approved GNSS technique is used. GNSS equipment is not a tool

which can be “calibrated” in the strict sense of the word and therefore the proper use of the equipment in accordance with Surveyor-General’s Direction No. 7 (DFSI Spatial Services, 2017) is important.

Clause 66 of the Regulation requires details of GNSS validation to be shown in an approved schedule. The approved schedule is shown in Diagram 3.32 of Surveyor-General’s Direction No. 7 (DFSI Spatial Services, 2017) (Figure 28).

GNSS VALIDATION SCHEDULE				
FROM	TO	GRID BEARING	DISTANCE	METHOD
SSM 66367	SSM 19764	289°09'34"	1092.340	EDM TRAVERSE
		289°09'34"	1092.332	CORS NRTK
SSM 172630	SSM 19087	12°44'44"	453.283	EDM TRAVERSE
		12°44'44"	453.290	AUSPOS
PM 169843	PM 169844	161°01'05"	1783.171	AUSPOS
		161°01'05"	1783.182	GNSS STATIC

Figure 28: Approved GNSS validation schedule (DFSI Spatial Services, 2017).

Where the datum line will adopt, as orientation, the grid bearing derived from Class D MGA coordinates as determined by the surveyor using an approved GNSS method, validation is required by Clause 66 of the Regulation to be performed and shown for the datum line of orientation. Validation can be thought of as being analogous to showing comparisons, for a line between two established survey marks, of the grid bearing and ground distance as measured against those derived from the SCIMS MGA coordinates. It is the same process, the only difference being that the MGA coordinates have been determined by the surveyor instead of being retrieved from SCIMS.

4 CASE STUDIES

To illustrate the application, within the context of the Regulation, of the geodetic concepts and available resources described above, two case studies where the datum line of the survey has adopted, as orientation, the grid bearing derived from Class D MGA coordinates as determined by the surveyor using an approved GNSS method. Each case study is based on a real-world survey, however the information has been modified for the purposes of illustration in this paper.

4.1 Case Study 1

The first case study is that of a survey that has determined the MGA position and orientation of the datum line via the use of the AUSPOS approved GNSS method (Figure 29). Both terminals of the datum line, i.e. PM#1 and PM#2, were directly occupied by GNSS receivers and static data logged for a minimum of 2 hours on each terminal. The static data was uploaded to Geoscience Australia’s AUSPOS processing facility, and AUSPOS reports were received. Extracts from the AUSPOS reports for PM#1 and PM#2 are shown in Figures 30 & 31 respectively. PM#3 was found and connected to the survey.

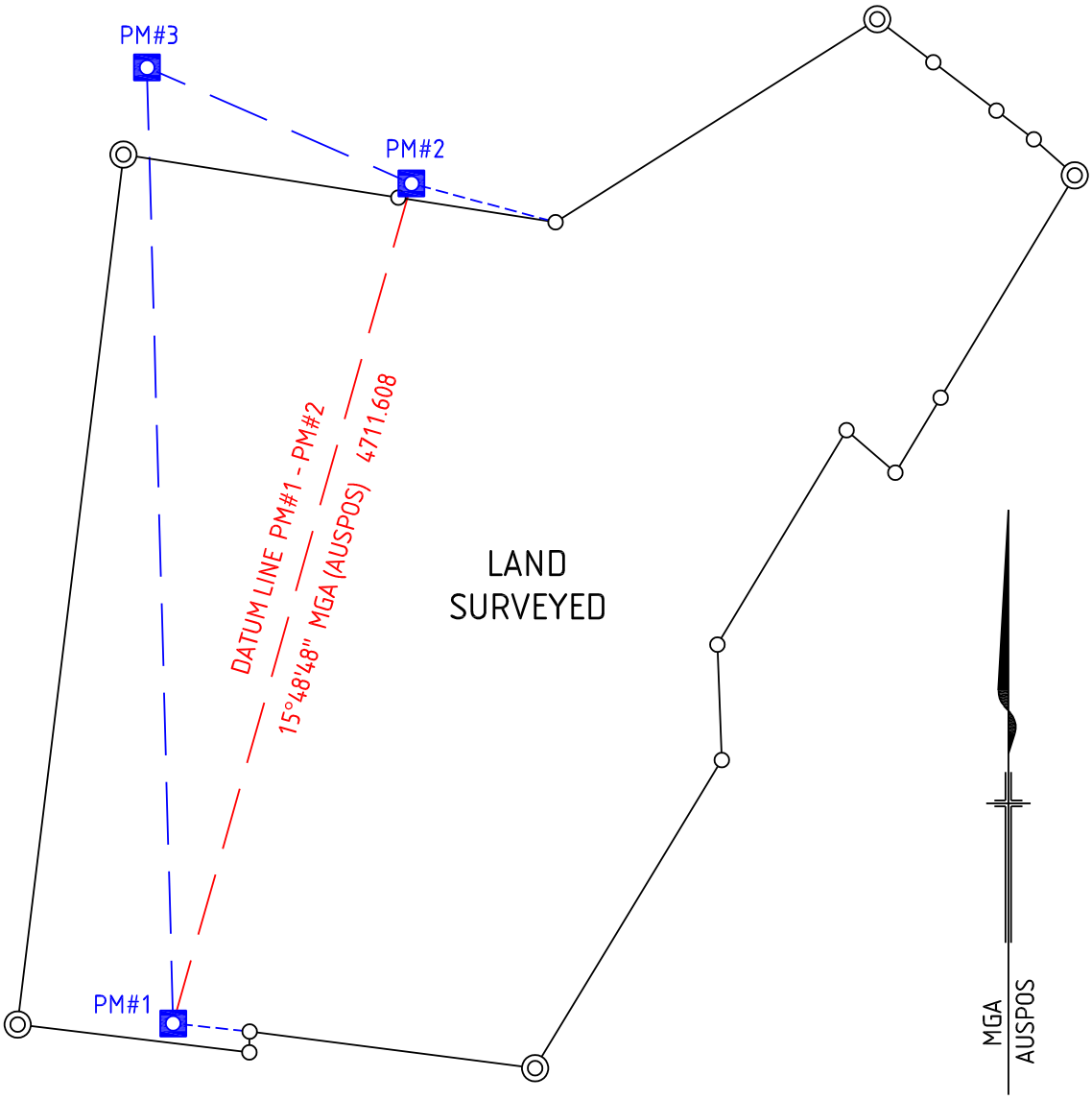

Figure 29: Case study 1.

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
0402	556935.957	6728431.135	55	156.924	128.106

Figure 30: Case study 1 – extract of AUSPOS report for PM#1.

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
5000	558219.393	6732962.691	55	157.495	128.581

Figure 31: Case study 1 – extract of AUSPOS report for PM#2.

To derive from the AUSPOS reports the grid bearing adopted and plane (grid) distance for the datum line, the coordinates from the AUSPOS reports (Figures 30 & 31) were entered into the spreadsheet GRIDCALC.XLS (see section 2.1.3) (Figure 32).

Grid Bearing and Ellipsoidal Distance from Grid Coordinates **MGA**

	Name	East (E)	North (N)	Zone
From (1)	PM#1	556,935.957	6,728,431.135	55
To (2)	PM#2	558,219.393	6,732,962.691	55
Ellipsoidal Distance (s)	4711.491			
Plane Distance (L)	4709.799			
Grid Bearing (β_1)	15°	48'	48.49"	
Grid Bearing (β_2)	195°	48'	47.16"	
Arc to Chord correction (δ_1)	-0.66"			
Arc to Chord correction (δ_2)	0.67"			
Line scale factor (K)	0.999 640 91			

KEY
User input
Result

Figure 32: Case study 1 – GRIDCALC.XLS for the datum line.

The CSF for PM#1 and PM#2 were determined by entering the Easting, derived AHD value and the N-value calculated from the AUSPOS reports (Figures 30 & 31) into the spreadsheet CSF.XLS (see section 2.2.2) (Figures 33 & 34).

The N-value of PM#1 was calculated from the AUSPOS report for PM#1 (Figure 30) as:

$$156.924 - 128.106 = 28.818$$

The N-value of PM#2 was calculated from the AUSPOS report for PM#2 (Figure 31) as:

$$157.495 - 128.581 = 28.914$$

Easting (m)	Height(m)	N	CSF
556935.957	128.106	28.818	0.99961532

Figure 33: Case study 1 – CSF.XLS for PM#1.

Easting (m)	Height(m)	N	CSF
558219.393	128.581	28.914	0.99961705

Figure 34: Case study 1 – CSF.XLS for PM#2.

The CSF for the datum line between PM#1 and PM#2 was calculated using Equation 6, the mean of the CSFs of the datum line terminals:

$$\begin{aligned} CSF_{line} &= \frac{(CSF_{P1} + CSF_{P2})}{2} \\ &= \frac{(0.99961532 + 0.99961705)}{2} \\ &= 0.99961619 \end{aligned}$$

For the datum line of this case, using Equation 7, the CSF of the mean Easting, and Equation 8, Simpson's rule, show differences to the above method of significantly less than 1 ppm. Other lines, especially those with a large difference in Easting and/or height, might require the more accurate methods of Equations 7, 8 or 11.

The ground distance between the datum line terminals from the AUSPOS coordinates was then calculated using Equation 20 with the plane (grid) distance taken from the GRIDCALC.XLS output shown in Figure 32:

$$Ground\ distance = \frac{Plane\ (\text{Grid})\ distance}{Combined\ Scale\ Factor}$$
$$= \frac{4709.799}{0.99961619}$$
$$= 4711.607$$

Having calculated, from the AUSPOS coordinates for each datum line terminal, the grid bearing to be adopted by the datum line and the ground distance between the AUSPOS coordinates, the datum line then had to be validated as per Clause 66 of the Regulation. The method used for validation was an Electronic Distance Measurement (EDM) traverse by total station. The results were then required by Clause 66 of the Regulation to be shown on the survey plan in an approved GNSS validation schedule (Figure 35).

GNSS VALIDATION SCHEDULE				
FROM	TO	GRID BEARING	DISTANCE	METHOD
PM#1	PM#2	15°48'48"	4711.608	EDM TRAVERSE
		15°48'48"	4711.607	AUSPOS

Figure 35: Case study 1 – GNSS validation schedule.

As per Clause 70 of the Regulation, an approved coordinate schedule was also required on the survey plan (Figure 36). Note that PM#3 (an unestablished survey mark) was found and connected to. Therefore, as the survey plan had adopted an “accurate MGA orientation” under the definition in Clause 5 of the Regulation, then, as per Clause 70, the MGA coordinates of PM#3 had to be determined to an accuracy of Class D or better. In this case study, the CSF shown in the coordinate schedule (Figure 36) is that of the datum line. The surveyor must place the single CSF that best represents the extent of the survey in the coordinate schedule (see section 2.2.3).

COORDINATE SCHEDULE						
MARK	MGA COORDINATES		CLASS	ORDER	METHOD	STATE
	EASTING	NORTHING				
PM#1	556 935.957	6 728 431.135	D	N/A	AUSPOS	PLACED
PM#2	558 219.393	6 732 962.691	D	N/A	AUSPOS	PLACED
PM#3	556 764.897	6 733 601.494	D	N/A	CADASTRAL TRAVERSE	FOUND
DATE OF GNSS COORDINATES: 17-10-2017			MGA ZONE: 55		MGA DATUM: GDA94	
COMBINED SCALE FACTOR: 0.999616						

Figure 36: Case study No. 1 – coordinate schedule

4.2 Case Study 2

The second case study is that of a survey that has determined the MGA position and orientation of the datum line via the use of the CORS NRTK approved GNSS method (Figure 37). Both terminals of the datum line, i.e. RMGIP "A" and RMGIP "B" were directly occupied by GNSS receivers and CORS NRTK MGA coordinates measured – each datum line terminal was occupied twice for 2 minutes per occupation (using the averaging technique) with a minimum of 30 minutes between each occupation. PM#1 and PM#2 were placed and connected to the survey as required by the Regulation.

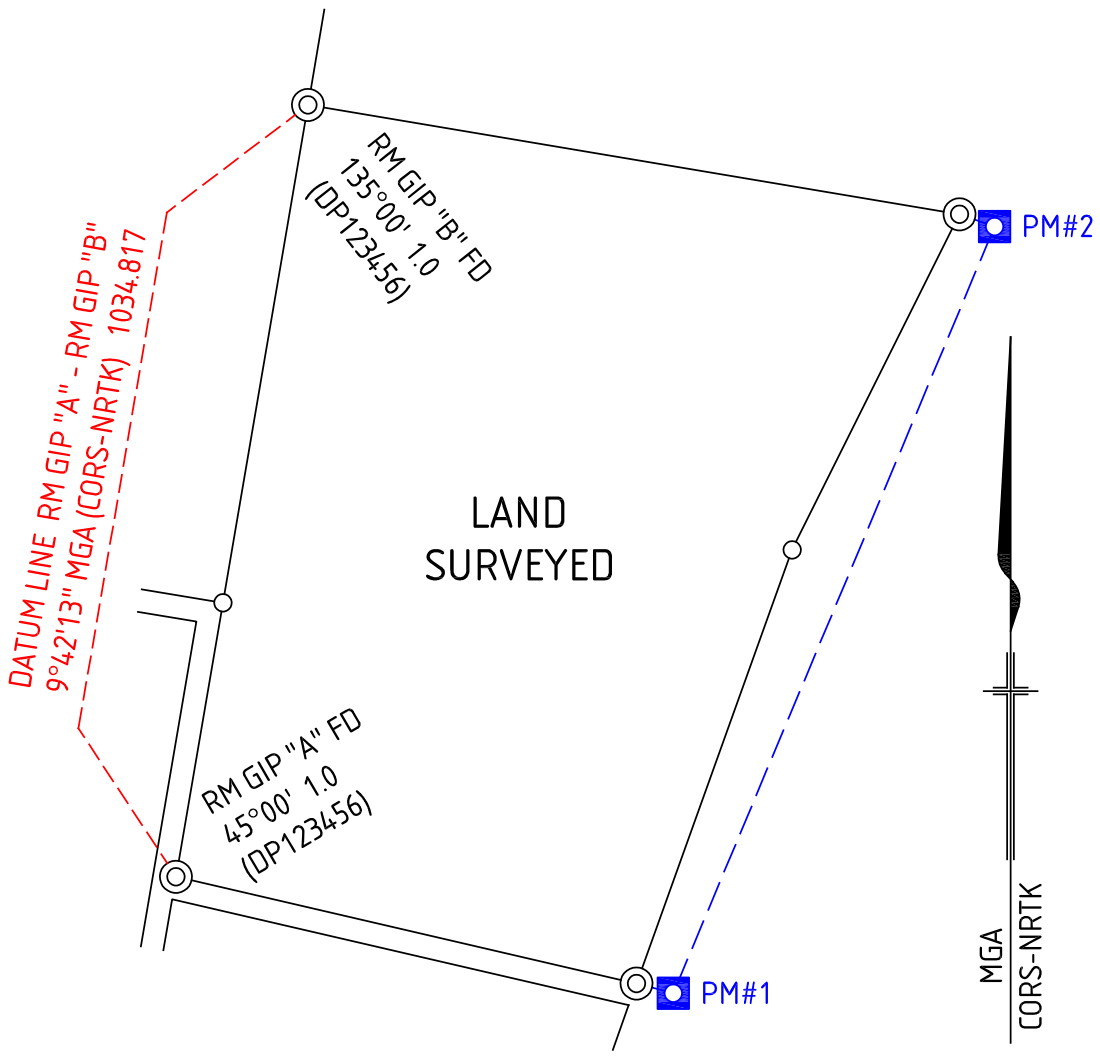

Figure 37: Case study 2.

Note that in this case, each datum line terminal is a reference mark that is within 30 m of a corner and has been referenced to that corner. Reference marks used for terminals of the datum line do not have to be *referenced* to a corner (within 30 metres) as per Clause 62 of the Regulation. However, if not referenced to a corner, then as per Clause 61(3) of the Regulation, they must be *connected* by closed connection to the survey (Figures 23 & 25).

To derive from the CORS NRTK coordinates the grid bearing adopted and plane (grid) distance for the datum line, the CORS NRTK coordinates were entered into the spreadsheet GRIDCALC.XLS (see section 2.1.3) (Figure 38).

Grid Bearing and Ellipsoidal Distance from Grid Coordinates **MGA**

	Name	East (E)	North (N)	Zone
From (1)	RM GIP "A"	625,526.045	6,232,157.627	55
To (2)	RM GIP "B"	625,700.414	6,233,177.358	55
Ellipsoidal Distance (s)	1034.744			
Plane Distance (L)	1034.532			
Grid Bearing (β_1)	9°	42'	12.74"	
Grid Bearing (β_2)	189°	42'	12.09"	
Arc to Chord correction (δ_1)	-0.33"			
Arc to Chord correction (δ_2)	0.33"			
Line scale factor (K)	0.999 794 51			

KEY
User input
Result

Figure 38: Case study 2 –GRIDCALC.XLS for the datum line.

The CSF for RMGIP "A" and RMGIP "B" were determined by entering the Easting, derived AHD value and the N-value into the spreadsheet CSF.XLS (see section 2.2.2) (Figures 39 & 40). The derived AHD value is from the observed CORS NRTK data and the N-value was calculated using Geoscience Australia's online N-value calculator (Figure 18). The latitude and longitude were taken from the CORS NRTK observed data.

Easting (m)	Height(m)	N	CSF
625526.045	401.970	20.239	0.99972790

Figure 39: Case study 2 –CSF.XLS for RMGIP "A".

Easting (m)	Height(m)	N	CSF
625700.414	390.813	20.263	0.99973019

Figure 40: Case study 2 – CSF.XLS for RMGIP "B".

The CSF for the datum line between RMGIP "A" and RMGIP "B" was calculated using Equation 6, the mean of the CSFs of the datum line terminals:

$$CSF_{line} = \frac{(CSF_{P1} + CSF_{P2})}{2}$$

$$= \frac{(0.99972790 + 0.99973019)}{2}$$

$$= 0.99972905$$

For the datum line of this case, using Equation 7, the CSF of the mean Easting, and Equation 8, Simpson's rule, show differences to the above method of significantly less than 1 ppm. Other lines, especially those with a large difference in Easting and/or height, might require the more accurate methods of Equations 7, 8 or 11.

The ground distance between the datum line terminals from the CORS NRTK coordinates was then calculated using Equation 20 with the plane (grid) distance taken from the GRIDCALC.XLS output shown in Figure 38:

$$Ground\ distance = \frac{Plane\ (\text{Grid})distance}{Combined\ Scale\ Factor}$$
$$= \frac{1034.532}{0.99972905}$$
$$= 1034.812$$

Having calculated, from the CORS NRTK coordinates for each datum line terminal, the grid bearing to be adopted by the datum line and the ground distance between the CORS NRTK coordinates, the datum line then had to be validated as per Clause 66 of the Regulation. The method used for validation was an EDM traverse by total station. The results were then required by Clause 66 of the Regulation to be shown on the survey plan in an approved GNSS validation schedule (Figure 41).

GNSS VALIDATION SCHEDULE				
FROM	TO	GRID BEARING	DISTANCE	METHOD
RM GIP "A"	RM GIP "B"	9°42'13"	1034.817	EDM TRAVERSE
		9°42'13"	1034.812	CORS-NRTK

Figure 41: Case study 2 – GNSS validation schedule.

As per Clause 70 of the Regulation, an approved coordinate schedule was also required on the survey plan (Figure 42). Note that PM#1 and PM#2 were placed and connected to. Therefore, as the survey plan had adopted an “accurate MGA orientation” under the definition in Clause 5 of the Regulation, then, as per Clause 70, the MGA coordinates of PM#1 and PM#2 had to be determined to an accuracy of Class D or better. In this case study, the CSF shown in the coordinate schedule (Figure 42) is that of the datum line. The surveyor must place the single CSF that best represents the extent of the survey in the coordinate schedule (see section 2.2.3).

COORDINATE SCHEDULE						
MARK	MGA COORDINATES		CLASS	ORDER	METHOD	STATE
	EASTING	NORTHING				
RM GIP "A"	625 526.045	6 232 157.627	D	N/A	CORS-NRTK	FOUND
RM GIP "B"	625 700.414	6 233 177.358	D	N/A	CORS-NRTK	FOUND
PM#1	626 134.283	6 232 015.877	D	N/A	CORS-NRTK	PLACED
PM#2	626 558.713	6 233 027.473	D	N/A	CORS-NRTK	PLACED
DATE OF GNSS COORDINATES: 18-12-2017			MGA ZONE: 55		MGA DATUM: GDA94	
COMBINED SCALE FACTOR: 0.999729						

Figure 42: Case study 2 – coordinate schedule.

4 CONCLUDING REMARKS

GNSS equipment and devices are tools that have come from a geodetic origin and operate in geodetic reference frames and coordinate systems, yet are becoming integral parts of a widening, disparate set of applications where the operators of such equipment are not necessarily aware of the geodetic concepts involved. For many applications, geodetic knowledge is either necessary or advisable. Cadastral surveyors carrying out surveys under the Regulation using GNSS are an example where some geodetic knowledge is necessary for correct application of GNSS methods under the Regulation.

This paper has described certain geodetic concepts, tools available to cadastral surveyors for calculation of geodetic elements, the cases when approved GNSS methods for datum line purposes are to be used, use of approved GNSS methods for datum line purposes and their application to survey plan requirements under the Regulation with reference to case studies.

As GNSS equipment becomes more affordable and GNSS techniques become more widely used for cadastral surveying, more cadastral surveyors will be required to become familiar with the required geodetic concepts described in this paper and their application under the Regulation.

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Discussion Forum: Review of the Surveying and Spatial Information Act

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ABSTRACT

The Surveying and Spatial Information Act (formerly known as the Surveying Act) commenced in 2002 and was reviewed in 2007. It makes provision with respect to the functions of the Surveyor-General, the registration of surveyors, the control of surveys and the constitution and functions of the Board of Surveying and Spatial Information (BOSSI). There has been significant change in the industry during this time and while there is a requirement to review the Surveying and Spatial Information Regulation every 5 years, there is no statutory requirement to review the Act. During 2017, BOSSI undertook an internal review of its structure and functions. As a result, BOSSI has decided to initiate a review of the Act. This discussion forum provides delegates with a summary of the BOSSI review and the opportunity to provide their thoughts on the following:

- *Objectives of the Act.*
- *Definition of a land survey.*
- *Functions of BOSSI.*
- *Registration of surveyors.*
- *Supervision, investigation and discipline.*

KEYWORDS: *Surveying legislation, Surveying and Spatial Information Act, review, industry consultation.*

Hadrian's Wall: Boundary Monument for the Northern Frontier of Roman Britannia

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ABSTRACT

Much hypotheses and over-thinking has taken place over hundreds of years in an effort to attribute purposes for the raison d'etre of the wall across northern Britain erected at the behest of the formidable Roman Emperor whose name has been ultimately used to describe this intriguing edifice. Was it built for defence, border control, a demonstration of power or any number of associated intentions as a strategic military device at the extremity of the territorial outskirts of the Great Empire? Many postulations have been advanced by engineers, stone masons, clerks of works, military experts, academics, archaeologists, historians, paleontologists and all the usual suspects. However, I have only sourced one other opinion for its creation put forward by another land surveyor like myself having been offered by my very good friend from the U.S., Mary Root (please note that U.S. Presidents Washington, Jefferson and Lincoln were all land surveyors). Well, it just so happens that I am not just a practising "historical detective" (as I label those in my profession) but I am an active field historian with a Masters in Egyptology from Macquarie University in Sydney. In addition to this area of personal and professional interest, I have done considerable research on ancient Greek and Roman surveying together with a diversion into China's surveyors of antiquity as a background to my paper "The Great Wall of China: The World's Greatest Boundary Monument!" In the present paper, I will be putting forward my offering to the discussion table about the main reasons for the erection of such a notable memorial to the time in the renowned civilisation during the second century. After elaborating further on the wall's design with specific attention drawn to certain features not before grouped together along with a focus on the desires and intentions of Emperor Hadrian himself, there may be some agreement that this iconic line across the topography is a true boundary monument in the ancient Roman traditions as a demarcation line of the northern limit of the Empire's frontier in the north-western territory of its second century enforced tenure.

KEYWORDS: *Emperor Hadrian, Roman Britannia, The Vallum, Corpus Agrimensorum Romanum, Vallum Hadriani, international borders.*

1 INTRODUCTION

"A man's worth is no greater than his ambitions." – Marcus Aurelius.
"It is not what you look at that counts; it is what you see!" – Henry David Thoreau, Philosopher/Surveyor.

On the five occasions that I have travelled to the United Kingdom on only one instance have I gone by road northwards to Scotland during which I only caught a fleeting glimpse of Hadrian's Wall (Figure 1) in 1998. After nearly 19 years I will actually be staying at the town

of Wall in accommodation adjacent to this legendary symbol of Roman times within the area such premises having been constructed with stones from the original structure itself. My subsequent curiosity with this ancient Roman masterpiece was propagated by initial readings of various texts and web articles most of which I procured from the UK itself. Most authors have proposed that the Wall had multiple purposes for its installation dismissive of a principal motive for placement as a defensive barrier or fortification suitable for the Roman forces from which to mount an armed resistance. Through my interpretations of the features of the Wall's design, combined with an instinctive feeling for the mood of the Roman Ruler himself, I will mount a convincing proposition that the main purpose of Hadrian's Wall was as a boundary monument placed to delineate the dividing territorial line for the northern limit of Roman Britannia while also serving notice to would-be interlopers that any transgressions past that line would bring great trauma.

Figure 1: A section of Hadrian's Wall in northern England showing material and construction type.

It needs to be emphasised that my research is not totally exhaustive but I have obtained many excellent publications issued over many hundreds of years, which have provided me with a broad understanding of how many surveyors were employed by the great Empire to maintain and supervise all matters pertaining to the facilitation of civic jurisdiction and orderly inhabitation of the lands over which claims had been established. Roman Surveying Law and Doctrines were well versed and enforced by a surveying profession which bore great esteem and respect along with a dependency on such experts to solve boundary disputes and supervise the creation and operation of new towns, roads and aqueducts considered vital for the convenience and livelihood of its citizens and vast military regiments.

2 JULIUS CAESAR INVADES BRITANNIA

"Veni, vidi, vici." ("I came, I saw, I conquered.") – Julius Caesar (47 BC).

The first incursions by Rome across the sea into Britannia were made by Julius Caesar in 55 and 53 BC with continuing intensity over the years under the reigns of subsequent emperors Augustus, Tiberius and Caligula. It would not be until almost another 100 years before the Romans finally conquered Britain in 43 AD when Claudius dispatched four legions to finalise the job, and even from then on there was still formidable opposition to keep the usurping

legions south of what is considered Caledonia (visa vie later most of Scotland) (Shotter, 1996, p. 15). There was the perception that there was little wealth or suitably arable lands upon which income could be generated added to the tenacity of the battle-hardened highlanders whose fight-to-the-death toughness would make many a seasoned soldier reluctant to take them on in their own surroundings. These eras in Rome's expansive ambitions are not the basis for this paper but they do serve as a salutary source as to what drove Hadrian to bring about the laying of what has become a renowned landmark of the Roman Empire at its mightiest during the second to the fourth centuries after Christ. What has been labelled "the fall" of the Roman Empire was already well into its death rolls by the time the Romans ultimately evacuated their Britannic stronghold in 411 during the rule of Emperor Jovinus and his Consul Honorius et Theodosio.

3 HADRIAN BECOMES ROME'S EMPEROR

"Better than a thousand hollow words is one word that brings peace." – Buddha.

If "word" was replaced with "wall" in this quote, it may go some way to explain Hadrian's strategy to put up his wall in northern Britannia on his 122 tour of his western colony.

In 117 AD, Rome's second "friendly" regent Trajan passed away, leaving control of Rome's extensive holdings to his successor Hadrian who was 41 (born Publius Aelius Hadrianus in 76, possibly in Itallica which is now part of Spain – but it has been suggested that in fact he was born in Rome itself?) when taking over control. Rebadging himself as Caesar Traianus Hadrianus Augustus, the new ruler clearly portrayed his traditionalist attitude with a distinct bias towards the classical culture of the ancient Greeks along with archaic literature and writings of folklore as well as displaying his veneration for his First Emperor Augustus through the inclusion of his name in that which he had adopted. The biographer of Augustus Suetonius (Graves, 1965) says that he was a "dedicated devotee of Octavian-Augustus, and had a bronze statuette of Octavian in his bedroom." I am sure that his wife was delighted! Shelving the expansionist policies of some of his predecessors, which had stretched the capacity of the governing regime to maintain control and order at the extreme edges of those regions far removed from the Rome-based Senate responsible for its existence, Hadrian saw the need for more passive measures to be employed.

The new ruler embarked on a program to consolidate the current holdings of the dominion in order to minimise the exposure of invasions and raids against the thinly spread legions guarding the vulnerable outer limits of the Empire's furthest perimeters. Hadrian had a resolute character as well as having been remembered as a leader with moderation along with Nerva (96-98), Trajan (98-117) and his successors Antoninus Pius (138-161) and Marcus Aurelius (161-180), collectively referred to as "The Five Good Emperors" (see Appendix D). In a paradox of his personality, his moderation in areas of governance was matched by his extravagance in public works such as the enlargement of The Pantheon and, of course, the placement of the Britannic Wall. The concept of territorial limits had more to do with the identification of lands currently under Roman control and *those destined to be*, rather than a declaration that the lines identified would remain at the outermost edges of the Empire. There was also a paranoic perception, sometimes justified, that the far removed generals at a tyranny of distance would be driven to forge alliances with those nearby chieftains outside the designated lines and cut ties with the Empire. Emperor Domitian (81-96) introduced frontier works in Germany with timber towers linking forts, while Trajan added fortlets prior to

Hadrian erecting a timber palisade. Where naturally occurring major landscape features such as rivers, cliffs or water table crest lines existed, they were charted as the boundary of the Empire lands for the outside regions.

In legalistic parlance, rightful ownership of property is demonstrated by what are referred to as “Acts of Dominion” such as maintaining an estate in good order, paying the required Council rates and land taxes (if applicable), plus various other actions but with one very specific action being tantamount to secure a right of ownership which is the construction of a dividing barrier between one claimant and his neighbour usually being a fence or wall along the property line of subdivision. Hence Hadrian saw an urgent need to clearly demarcate his line of dominion along the northern frontier of his western colony of Britannia. Done without mutual consent, clearly the non-consensual parties could only regard the placement of this Wall as an act of aggression or at the very least a provocatory signal to future confrontations by the angry rebels.

Through his extensive tour de force inspecting his absolute realm to its entirety, Hadrian formulated a capital works program to clearly designate the limits of his power through the placement of artificial lines of demarcation where no natural geography presented itself to adopt as suitable frontier perimeters known as “limes” which were those external boundaries as compared with “limites” being dividing lines between provinces within the overall total regime. During his visit of 122 AD to Britannia, he oversaw the erection of the great construction dividing wall 80 Roman miles (a Roman mile was 5,000 Roman feet being equivalent to 4,854 Imperial feet – a pace was equal to 5 Roman feet) from Wallsend-on-Tyne to Bowness-on-Solway along the northern territorial rim of his western colony (a distance of about 120 km – see Figure 2).

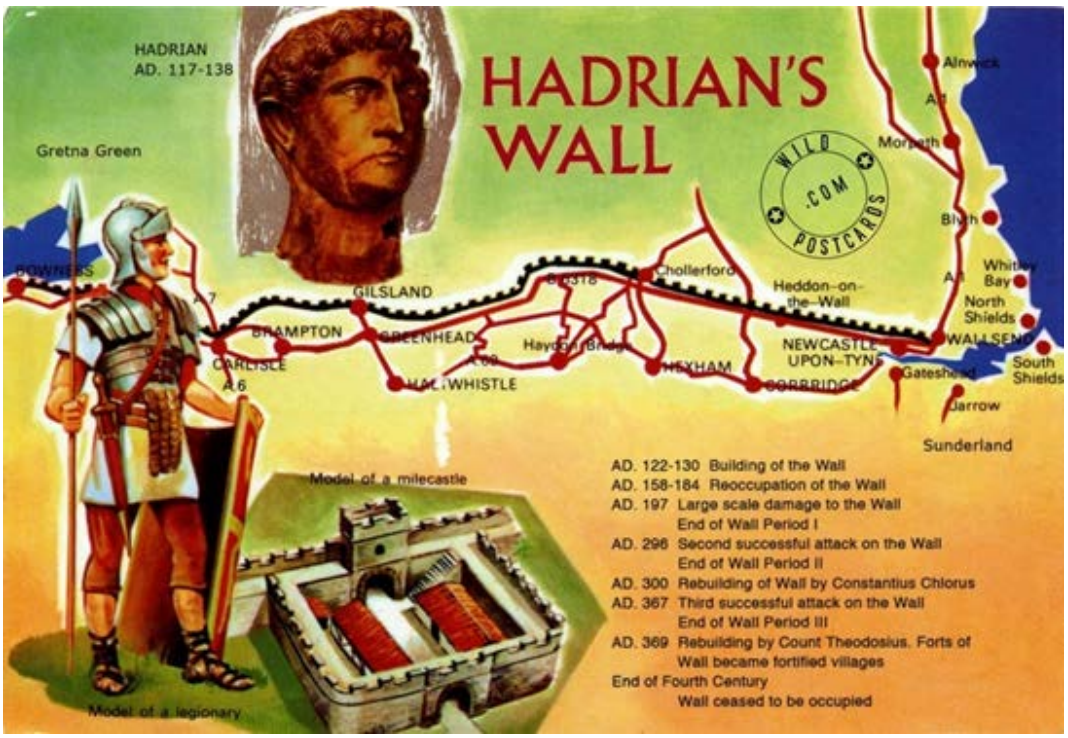

Figure 2: A postcard showing Emperor Hadrian’s bust looking over his impressive wall.

The new leader was determined to enforce “peace through strength” thus devoting his efforts to erect clear symbols of might, enclosing all that was his. In so doing, he was giving defiant

notice to any tribes outside those fortifications who contemplated crossing these barriers with ill intent that they most certainly would attract the full retribution of the Roman legions in response. Clearly the Wall was solidly and substantially built but with the relatively sparse positioning of fortlets (with gates) between quite extended stretches of narrow stone walls it was far from impregnable. The gates placed were to allow passage to and from the adjoining lands with a tacit intent of frontier control for selective admissions and exclusions as decreed.

For many years after the refocus directed towards the royal edifice since the 17th century "rediscovery" of the Wall, there was much dispute about who actually issued the decree to bring about its construction but subsequently two powerful items have emerged to prove conclusively that its paternity belongs to Hadrian himself. Hadrian's alleged biographer Aelius Spartianus from the Scriptores Historiae Augustae (translated as Augustan History), estimated to have been compiled sometime between AD 285 and 335, declares in Hadrian XI, 2-6: "And so, having reformed the army quite in the manner of a monarch, he set out for Britain, in 122. There he corrected many abuses and was the first to construct a wall, eighty miles in length, which was to separate the barbarians from the Romans." Then, as though the ancient emperor was watching over the modern proceedings and discussions concerning the archaeological investigations and restorations of his paean glorious in 1715 at Hotbank Milecastle No. 38, an inscribed slab of stone (now held in the Great North Museum, Newcastle – see Figure 3) was discovered dated to the time of Britannic Governor Nepos from 122-126 AD which in Latin states: "Imp(eratoris) Caes(aris) Traiani / Hadriani Aug(usti)/ Leg(ion) II Aug(usti)/ A(ulo) Platorio Nepote leg(ato) pr(o) pr(aetore)", translated into English saying "Of the emperor Caesar Traianus Hadrianus Augustus, the Legion II Augusta (built this), while Aulus Platorius Nepos was legate with powers of a *praetor*" (Fields, 2010, pp. 26-27).

Figure 3: Stone inscribed c. 122-124 to verify that Hadrian's Wall had been authorised by the Emperor personally around 122, that section having been built by Legion II Augusta.

Indeed another monumental artefact bore witness to the approximate completion date of the Wall around 136, adding testimony to one of the other total of three legions which carried out the massive project found near the east gate of Moresby fort translated to read: "(This work) of the Emperor Caesar Trajan Hadrian Augustus, father of his country, the XX Legion Valeria Victrix (built)" (stone dated 128-138). This was one of the most sensational finds in the history of the archaeological investigations of Hadrian's Wall, proving beyond any other speculation about someone else ordering its construction that Emperor Hadrian was its patron.

Another parallel for a stone wall erected as a solid symbol of ownership to those outside hordes are the early stages of China's Great Wall initiated by the first Emperor around 200 BC. The wall's height and breadth could not prevent them crossing it, but any such breach of the stone ramparts was a sure passport to big trouble for those warlike groups not remaining on their side of it. The more well-known Great Wall of China with high walls lined with castellations along wide interconnecting fortifications was modified and amplified to this impressive megastructure during the Ming Dynasty (1368-1644) but this battle-ready bastion saw very little wartime activity during the tenure of this legendary ruling clan famous for their ornate blue pottery (Figure 4) (Brock, 2014).

Figure 4: A section of the Great Wall of China showing some fortlets.

4 THE APPARENT ENIGMA OF THE VALLUM: IT'S REAL FUNCTION

"Once we accept our limits, we go beyond them." – Albert Einstein.

Many writers have dismissed the inclusion of the Vallum as inexplicable in its function. The Vallum is a trench dug inside the south side of the Wall with earth mounds lining the top edges on both sides, running for its entire length apart from where natural features like rocky outcrops or river banks interrupt its progress (Figure 5). One author (Carter, 2014) states that it has been surveyed like a road but is unlikely to have been used for this reason, while another (Fields, 2010, p. 15) pronounces it may have been included as an additional defensive mechanism as an obstruction to invading armies. At its depth and location in addition to the many lengths of narrow wall too thin to wage even defence by a single line of archers, let alone catapults or pots of boiling oil, it would appear less likely that the Vallum could serve any credible second line of resistance after this first ineffective barrier had been breached by any sizeable swarms of invading marauders.

Figure 5: Cross sectional diagram of the Wall construction.

If I may digress now to a much earlier archaic period in pre-Roman history in support of my suggestion that the Vallum in fact formed part of the traditional techniques of construction adopted for the creation of boundaries first attributed to Aeneas who is said by mythology to be the direct ancestor of Romulus and Remus, the mythical wolf-suckling twins who founded Rome.

As an illustration of the extent to which the Romans incorporated the establishment of new towns into their folkloric sagas, the writer Virgil describes how Aeneas founded a city in Sicily: “Meanwhile Aeneas marks the city out by ploughing; then he draws the homes by lot.” All Roman surveyors were aware through their training of the old custom whereby the limits of a new town were marked out by the consul by ploughing a furrow around it. Another author Ovid, a studier of the law including that pertaining to surveying, said that the dividing up of land with balks (*limites*) by a “careful measurer” (*cautus mensor*) emphasised the importance attached to the art of surveying.

The line drawn around a town was referred to by Virgil as *sulcus primigenius* (“the original furrow”) and was monumented with boundary stones according to Tacitus and Plutarch. Actual boundary stones have been discovered at Capua, placed during the Second Triumvirate and bearing inscriptions “By order of Caesar (Octavian), on the line ploughed”. When the Emperor wanted to extend the limits of Rome, he maintained the traditional inclusion of the “original furrow” placing inscriptional carved boundary stones which are still present today in evidence to his realignment of the boundaries of the eternal city.

Revered first Emperor Caesar Augustus so much cherished the ancient folklore of Rome that he had a Denarius coin struck dated c. 29-27 BC with his bust on the obverse and the ploughing of Rome’s first boundary furrow on the reverse during his reign for the citizens to bear recognition of their hallowed traditions (Figure 6). Emulating his legendary idol Caesar Augustus, Hadrian was not going to miss a chance to present himself in a similar portrayal of himself as the City Founder ploughing the new boundaries with a team of oxen on a coin from Aelia Capitolina (Jerusalem) in about 131-136 AD in a very clear demonstration of his admiration for his predecessor together with the folkloric divine creation of a *limes* in the form of a Vallum or Pomerium (Figure 7).

Figure 6: Caesar Augustus coin (29-27 BC) with the ploughing of Rome’s first boundary furrow.

Figure 7: Hadrian coin (c.131-136 AD) with the symbolic ploughing of a new first boundary furrow.

Indeed the folklore of the birth of Rome itself said to be in 753 BC has Romulus and Remus as direct descendants of the Trojan Prince Aeneas founding the new city. One version of the myth has Romulus cutting a *sulcus primigenius* (first furrow) around the perimeter of where he decreed the city limits to be incorporating the Palatine and Capitoline Hills, just as his ancestor Aeneas had done in other towns before him in what is believed to be an Etruscan ritual which was inclusive of the proposed line undergoing selection and final placement by auguries exercising divine control. In this recital of the folkloric epic, when Remus ridicules this action by his brother by jumping back and forth over the sacred furrow Romulus kills him in what must be regarded as an extreme act in border control indeed. Subsequently a substantial wall was erected outside this trench with the area between the inside of the wall up to and including the ditch termed "The Pomerium" within which building construction was forbidden together with other bans prohibiting any legal actions otherwise enforceable within the inner property zone by duly empowered judicial appointees. Entry from outside this line of strong delineation could take place only with permission granted by those authorities entrusted with the protection of the livelihoods of the citizens of Rome. In fact, the dictator Lucius Cornelius Sulla expanded the limits of the City of Rome in 80 BC in an act of absolute power with his new town limits further marked out by white marker stones called *cippi* which were commissioned by Claudius to delineate his extension of The Pomerium, some of which survey monuments are still in situ today as recorded by Tacitus and outlined by Aulus Gellius.

The Romans even had a god called Terminus, the God of the Boundary Stones closely affiliated with the principal deity Jupiter. Indeed it is the Romans who introduced the Feast of Terminalia which is an annual ceremony with pomp, pageantry and identification of the boundary stone monuments designating the area within which protection is guaranteed and order maintained. Boundary stones took many different forms with particular types of monuments being set to indicate the nature of the tenure under which the enclosed properties were held (Figure 8).

Figure 8: Terminus as a boundary stone.

Another absolutely splendid effort in scholarly publishing is Campbell's (2000) handsome volume on "The Writings of the Roman Land Surveyors" (in Latin *Corpus Agrimensorum Romanum*), which most astutely translates the Latin texts of the Roman authors who compiled a veritable instructional handbook on how surveying was to be conducted within the Roman Empire. This work is extraordinary and has given me a detailed appreciation for the technical and judicial expertise which was vested in the surveyors privileged to undertake such activities for the administratively thorough control imposed upon its charges. I need to clarify the interpretation of the word *Vallum* as literally it means a "mound of earth" but in the context of Hadrian's Wall it more specifically describes the trench following the line of the *limes* or boundary line which has mounds of earth along its top edges just as the *sulcus primigenius* ("first furrow") had placed along its upper edges formed from the earth excavated from the trench itself. To my amazement and delight on page 273 of Brian's superb book, he deciphers the original Latin text in the Section "…Discussion About Lands" to say "*Villa* comes from *vallum*, that is, a heap of earth, which is normally established in front of a *limes*" which is actually the borderline of the outside extremity of a Roman frontier, dividing it from international lands held by neighbouring nations or peoples. Furthermore on page 263 under the title "Here Begins a Discussion of Boundary Markers Set Up in Various Provinces" is stated:

"I have established a small ditch, which was dug out, on a boundary as a marker. Bigger ditches you will also certainly find as boundary markers. You will undoubtedly discover a raised *limes*, that is, a balk. I have built walls from limestone to mark boundaries. I have established banks that have been dug out to mark boundaries. You will find piles of earth marking boundaries."

These incredible discoveries add firm weight that the *Vallum* incorporated within the design specifications for Hadrian's Wall was following those strict instructions laid down in the Roman Surveyors Instruction Manual (Campbell, 2000) for the presentation of an international border line. This invaluable nexus to the times of the Roman surveyors translates a voluminous corpus of texts providing all historians but more especially surveyors with a detailed overview of what types of boundary marking were carried out, classifications of land types, as well as all manner of natural feature which could be adopted as boundary lines where suitable. There are even descriptions and diagrams of what style boundary markers and boundary stones were to take in given circumstances. For any interested surveyor historian, this publication is a must-have.

In an historical essay in what has been termed by its composer as "the puzzle of the Vallum", this scholar went one giant step towards explaining "the inexplicable!" Published in a 1921 issue of a journal called "The Vasculum", R.G. Collingwood (1921) titled his work "The Purpose of the Roman Wall" in which he says "…the continuous line was at first designed to serve simply as a mark to show where the Roman territory ended." Precisely Mr. Campbell, as any suggestion that the Vallum was a defensive earthwork is itself indefensible. For rampaging bands of villains it was merely a ditch with a speed hump. He goes on to reinforce: "The puzzle of the Vallum simply disappears when it is suggested that it was not a defensive work but a frontier-mark, a line indelibly impressed upon the earth to show the wandering native where he might not go without accounting for his movements." I could not have said it better myself.

Following this historic study came "The Turf Wall of Hadrian 1895-1935" where Simpson and Richmond (2011) carved cross sections through areas in the western section of the Wall

where there was a suspected earthen rise. They ascertained conclusively that there was a turf wall built before any stone wall emplacements or forts so it can be stated that the zone west of the whinsills had an earthen wall first, well before any stone structure had been laid down. Now with the timing right for the construction stages of Hadrian's Wall, I will give my pronouncement of the dating and purpose of the Vallum.

I am now going to propose a more definitive reason and origin for the placement of the Vallum combined with its true purpose. It surprises me that none of these astute writers who are perplexed by the Vallum have seized upon the very first indicator of why this structure was an essential element of this territorial border line – the Roman names first applied to it were the Vallum Hadriani or the Vallum Aeliani or Aelium (Hadrian's family name was Aelius). With strict adherence to the instructions issued to the Roman land surveyors to delineate a *limes* (international line of demarcation), it was an explicit directive to make a Vallum (literally "earth mound") (Campbell, 2000, p. 273). Naturally, to form the earth mound required to construct this visible line of subdivision the quickest way available, the legionary project supervisors devised the earthwork technique of digging the required quantity of material from the ground, leaving a trench alongside, and then stacking the spoil solidly along the edge of this continuous excavation. Hence, once again illustrating the interpretation of the meaning of a Vallum evolved to include the trench and the mound in its description.

With the benefit of the aforementioned facts to corroborate my following pronouncement, I propose that the Vallum was the first inclusion in the design for the *limes* (boundary line) to demarcate the northern limit of Rome's Empire with the famous Wall an additional barrier added to provide a show of power. The western part of this *limes* was initially placed consisting of a Vallum only until the stone creation was extended sometime later to complete the imagery of dominance. Thus the creation of the Vallum was the first step in the establishment of this northern borderline, once again with the sturdier stone divider being set at some time well after the first delineator had been laid down.

5 WALL DESIGN AND CHARACTERISTICS

"Make the workmanship surpass the materials." – Ovid (43 BC - 17 AD).

A burning question that has divided all scholars on the planning, design and project management of this major construction in the Roman capital works program has been just how much direct personal association the Emperor Hadrian himself had in its detail and execution. Another author with whom I forthrightly concur is Paul Frodsham (2013) who mounts a compelling argument in his book "Hadrian and His Wall" that the architecturally inclined Ruler not only had input into the pre-planning of the Wall's design but also personally directed some aspects of the building work while on his site inspection during the Britannic leg of his Royal Tour. With such a notion in mind, it is not hard for me to further incorporate Hadrian's penchant for history and tradition as alluded to previously in hypothesising that the Vallum was added during the erection of the Wall at its earliest incarnation to create the true legendary image of a boundary line as had been initiated by Aeneas, Romulus and a host of his predecessors in very much a recreation of The Pomerium originally enclosing the Eternal City of Rome itself. Such a final masterpiece with historic overtures would most certainly have pleased the man mostly honoured with the exceptional monument bearing his name for posterity to admire and marvel upon.

Within the wall were incorporated what have been called milecastles due to their occurrence at every Roman mile thus totalling 80, with two turrets in between each of these structures to provide look-out posts at each intervening 1/3 Roman mile thus adding up to be about 160 thereto. Apart from offering a view to the north to detect foreign troop movements, all of the manned stations looked more clearly towards the south to allow for a continuous ability to forewarn regiments of soldiers camped within the forts and villages of impending assault (see Appendix A for lineal conversions to imperial and metric units).

As has been irrefutably established by many more learned of the Wall than I, for a considerable percentage of its length it was not a fortified bastion or even bore formidable dimensions to singularly deflect any major incursions. The size of the Wall varied from a nominal height of 10 feet (3 metres) with an equivalent width up to 20 feet (6 metres) high, also with a matching girth, so for much of its coverage the sections with the lesser height presented no significant restriction to those warring groups who wished to create conflict on their foreign oppressors.

A modern example of a trench being placed to demonstrate the division between two countries can be found even today on the U.S./Canadian borderline at the north-western U.S. town of Blaine. Even though the depth and width of the sunken barrier does not preclude access, there will be a very interested U.S. border patrolman always staking out a continuous vigil on the southern side of the border, keeping a very concerned eye over anyone making an unauthorised or uninvited crossing of this line of division with a similar intent as those Roman sentries who manned the turrets along the lengths of Hadrian's Wall (Figure 9).

Figure 9: U.S./Canada borderline which is the unfenced trench at Blaine in Washington State.

6 SURVEYING AND BUILDING THE WALL

"Every wall is a door" – Ralph Waldo Emerson.

I am sure that Hadrian had no desire to make his Wall anything like a door to encourage hostile northern tribes to cross into the Roman domain, but the deterrent qualities of his Wall were not so physical rather than more indicative, for in some ways his Wall was very passable not representing a true decisive barrier to opposing camps. The three legions assigned to erect this symbol of territorial division were II Augustus, VI Victrix and XX Valeria Victrix, but upon its completion it was manned by auxiliaries rather than the legions which were called to other pressing duties somewhere removed within the vast extent of the far spread Roman

Empire. There is some inscriptional evidence for a detachment of the British Fleet making some of the granaries at the forts.

All materials used on the Wall construction were quarried locally, thus giving the final product a variety of finish only possible through the utilisation of natural resources sourced from the surrounding geological deposits with their distinctive evolutionary origins and nearby timber where such wooden carpentry was included or necessary.

Hill (2006) estimated just how many legionary surveyors were available to do the task of surveying the long straight sections of the wall construction as well as the likely work schedule, providing an estimated time for completion of the survey work required. For the reconnaissance and surveying required to facilitate site selection and final positioning of the Wall, I have formulated the Survey Work Statement for the activities necessary for a project of this proportion. Departing from any possible ritual selection of the Wall's location by the Consul or auguries, the ultimate function of this divisional barrier was to signify the limit of territorial governance while also setting an adequate line of sight both northerly and southerly for the sentries on watch to detect any likely trouble which may have been brewing along with the dual capacity to sound the alert of any likely attack.

Later in this section I will inform you of how many surveyors were available to each Roman legion as indicative of how much manpower was devoted to the vital capacity of carrying out survey requirements for the Roman nation throughout its widely distributed colonies.

The first duty was to survey and fix the exact line of the Wall, such location governed by the preceding parameters of sight lines and prevailing topography taking into account interceding natural features which themselves could serve as obstructions to foreign access such as cliffs, riverbanks and whinsills. Due to the extensive period of time during which the nearby land had already been under occupation, it is quite likely that the preliminary scouting party had a fairly definitive idea of where the Wall would be best placed with the crags of the whinsills dividing the future work into western and eastern sectors, punctuated by this extant natural barrier building westerly towards the Solway Firth and in the opposite direction to the Tyne River.

During this reconnaissance the surveyors would have left small rock cairns, possibly with a small line of stones in the direction towards the next visible marker or landmark, as well as stakes between which the later construction survey parties could align straight sections of wall and make realignments for angles where necessary. As these probably wooden stakes may not have been painted, one contemporary Republican author named Polybius (200-118 BC) on the Roman surveyors observed these men placing stakes with flags on them for easier sighting against a camouflaged backdrop of similarly textured vegetation. The ultimate route chosen ran between the banks of the River Tyne near Wallsend on the eastern seaboard and the shores of Solway Firth at the western end. Hill (2006) estimates that there were about 10 *mensores* (surveyors) present in each legion, forming part of a group known as the *immunes* as with their fellow professional compatriots such as architects, engineers and builders they were immuned from carrying out other military work due to the requirements of their designated speciality. The surveyors were called *mensori* (singular *mensore*) with a team of them referred to as a *metatore* (h2g2, 2016). This meant that there was a surveying pool of around 30 surveyors to lay out the straight lines where they could fit the landscape as well as indicating the spots for the erections of milecastles (every Roman mile) with two intermediate

turrets (or look-out towers) at around 1/3 mile separation in addition to selecting sites for troop encampments for the total workforce.

Without reiterating the specifics of Hill's (2006) calculations, I will summarise the final approximations of the various sections into which the legionary surveyors may have split their overall task. In Wall miles, the likely sections surveyed were Wallsend to Ouseburn (3 miles), Ouseburn to Dere Street (18 miles), Dere Street to North Tyne (5 miles), North Tyne to the eastern end of Whin Sill (MC34) (7 miles), Whin Sill (13 miles), Western end of Whin Sill (say MC46) to Irthing (3 miles), Irthing to the Eden (17 miles), and Eden to Bowness (14 miles). Hill's (2006) predicted time to complete the initial survey, setting out the milecastles and turrets most probably from one end together with straight alignments and angles when required could have been done in about a month. Subsequent construction of the Wall itself is believed to have taken at least eight (8) and up to fourteen (14) years with some later modifications being added after this time where such additions were regarded necessary. Thus the anticipated completion date for the Wall came only two years before Hadrian's passing, which meant that he never got to finally witness his testimonial before his death.

7 HOW LONG DID HADRIAN'S WALL LAST?

"The reward of a thing well done is having done it." – Ralph Waldo Emerson.

Between 139 and 140 (or some say 142) Hadrian's successor Antoninus Pius had what is now known as The Antonine Wall built of earth and timber substantially further north at about 140 miles (224 km) by road than the Wall we are more concerned with, connecting a shorter overall distance of 37 miles (59 km) from the Firth of Forth to the Firth of Clyde (Figure 10).

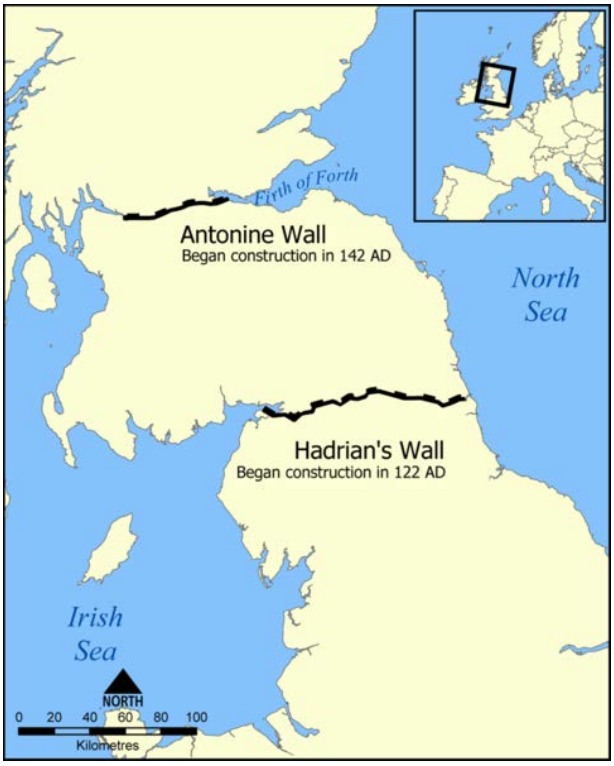

Figure 10: Map showing the location of Hadrian's Wall and the later Antonine Wall.

Once again the antiquarian Roman name given for this newly positioned *limes* was the Vallum Antonini, and this new construction conformed rigidly to the written regulation to make it a Vallum with the compacted earth mound along the rim of the dug-out channel. This earth wall standing at approximately 10 feet (3 metres) tall with an average width of 16 feet (5 metres) made this structure an even less imposing deterrent to likely invasion than Hadrian's Wall ever did. As monitoring and observation of foreign troop movements was vital, watch towers and fortlets made of timber were inserted along this shorter territorial limit around 100 miles (160 km) directly north of its more impressive southern counterpart. Even though it had been further strengthened with the insertion of more forts along its length, the order to abandon this later less substantial barrier was given in 163 with a troop withdrawal back to the more substantial wall. With uncertainty there are some who attribute this retreat to an uprising by the Brigantes with 15 years of revolts ensuing with other tribes joining the feisty Caledonians.

Periods of rebuilding Hadrian's Wall due to damage incurred during this resistance reinforced the importance of this northern bastion in Rome's colonies along with providing it with greater longevity, which allows us to enjoy and study it in the 21st Century. Along with a letter sent in 410 from Roman Emperor Honorius to the Roman Britannic forces (Hodgkin, 1886) "to look to their own defences" against the accelerating hostility from the Saxons, Scots, Picts and Angles came a refusal by Rome to send any reinforcements thus sounding the death knell for Roman Britain. However, Hadrian's Wall had represented the symbol of the northern frontier of the Roman Empire in the West for nearly 300 years, being now a celebrated treasure for archaeologists, historians and land surveyors to swoon and walk over instead of the hordes of angry tribesmen intent on vengeance during its time as a boundary divider (see Appendix C for a medieval map showing where the antiquarian map maker believed the two Roman Vallums to be found).

8 SURVEYORS: ROME'S ULTIMATE LAND EXPERTS – LET'S MEET ONE!

"Waste no more time arguing what a good man should be. Be one!" – Marcus Aurelius.

We know that surveyors were on the list of *immunes* because a list of specialists for the legions was compiled in the sixth century in a law code copied from an earlier register put together by a man known under many similar aliases as Taruttiensus Paternus, Tarruntiensis or Tarrutenius who was possibly the same individual mentioned by writer Dio as *ab epistulis Latinis* (secretary for Latin correspondence) to Marcus Aurelius, then acting as independent military commander in 179 AD. The military manual written by this man titled *De Re Militare or Militiarium* listed the special taskers to be stone cutters, carpenters, glass workers, plumbers, cartwrights, blacksmiths, coppersmiths, lime-burners and charcoal-burners, surveyors and ditchers as well as several clerical *immunes* keeping legionary records of strength, enlistments, discharges, transfers, expenses and pay records. *Architecti* were included as essential with two named as Amandus at Birrens and Aelius Verines at Mainz.

A most exciting discovery was a record of the discovery of a stone altar in 1709 at a place called Coniscliffe near Piercebridge where there was a Roman fort (now ruins remain) which unfortunately is now lost. From Figure 11, the inscription is interpreted to say:
D(eo) M(aris)
Condati
Attonius

Quintianus
Men(sor) evoc(atus) imp(eratum)
Exius(su) sol(vit) l(ibens) a(nimo)

This inscription translates to be: “To the god Mars Condates, Attonius Quintianus, **Surveyor Evocatus**, gladly fulfilled the command by order.” What a brilliant find decoded by Gale, Thoresby and Horsley said to be placed between 43 and 410 AD, so most probably during the time frame associated with Hadrian’s Wall (Vanderbilt, 1995).

Figure 11: Stone altar of Attonius Quintianus.

More thrillingly, it was funded by a surveyor who is purported to be at the time a *Mensor Evocatus* (which is a military specialist having completed in excess of 16 years’ service purported to be receiving a most impressive salary of 200,000 sesterces per annum) and may even have attained the rank of chief centurion or *praefect* (which is of great eminence within the realms of the Roman legions). You may be curious to know just how it is known that his salary was this high. The inscription shows “EXCC” after “MEN”, which is translated/deciphered to be *ex ducenario* which is in fact an officer earning this sum of remuneration, but there is alternative conjecture to suggest that it may also refer to *evocatus* as before described. To understand the value of the Roman currency at the time that this surveyor lived, the reader is referred to Appendix B. However, I will quantify our man’s salary through comparisons with other amounts paid to differing levels of officials and legionaries. From the time of Domitian (81-96 AD) a legionary was paid 1,200 sesterces per annum, a Centurion 20,000, a Chief Centurion 100,000, a Procurator 60,000-100,000 while a Senior Proconsul, the Prefect of Egypt and a senior Legate were on a hefty 400,000 per annum. A small farm was valued around 100,000 while an upmarket seaside villa in Italy or large estate in the same country would set you back 3 million sesterces. Thus our man Attonius was doing very well indeed, so it is not unexpected that another erudite Roman official would portray the land surveyor in the image of some sort of wizard or great mediator in his illustrious 6th century dissertation. It is heartening to note that a Councillor in some Italian towns was paid 100,000 per annum being half of what our surveyor Attonius was believed to be worth.

Without having to explain the indispensable work done by all of our illustrious colleagues, it is time for me to once again cite the description of a Roman official from a time late in the civilisation’s existence even after the crushing defeats at the hands of Vandals and Visigoths, a time when it could be contemplated that all authority had been usurped from those legionary surveyors who were part of an elite squad of professionals known as “the immunes”. Enriching the status already attained by the land surveyors of Rome during the mightiest era

of the imperious nation, it is not surprising that erudite and astute Roman officials such as Cassiodorus when referring to the *agrimensore* (land surveyor) could proclaim: "He walks not as other men walk!" The entire quotation of this very wise and astute man can be found in Brock (2012) in order to gain a full appreciation for just how well regarded Roman surveyors were combined with the awe with which their activities were held in Roman society.

9 CONCLUDING REMARKS

To summarise my analysis of Hadrian's Wall, I now pronounce that the Wall had a principal function as a boundary demarcation monument, which designated the limit of the territory for which Rome claimed jurisdiction and control over while being built with symbolic recognition for the traditional formation adopted by the mighty Empire for the limits of its cities and lands from the very first *sulcus primigenius* marked out by the Founder of Rome which included such a first furrow or trench adjoining the earthen mound known as the Vallum which was the actual boundary of the *limes* or international boundary line for the Roman Colony of Britannia.

For such an idyllic model of Roman greatness in engineering and surveying to be so widely recognised by anyone anywhere in the world, truly links our profession with another legendary landmark that serves as testimony to all who hear about or study this ancient edifice to the skills that surveyors have demonstrated from the earliest times of history, even before such feats were recorded by the first historians (Figures 12 & 13).

Figure 12: Hadrian's mausoleum in Rome at the Castel Sant'Angelo.

Figure 13: Hadrian, the Great Emperor.

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APPENDIX A

Table of Roman Standards of Distance Measurement:
1 Roman inch = *uncia* = 0.97 Imperial inch = 24.6 mm.
1 Roman foot = *pes* = 0.97 Imperial foot = 0.296 m.
1 pace (*passus*) = 5 Roman feet = 4.854 Imperial feet = 1.48 m.
1/8 Roman mile = 125 paces = 1 *stadium* = 625 Roman feet = 607 Imperial feet = 185 m.
1 Roman mile = 1000 paces = 1 *miliarium* = 5000 Roman feet = 4854 Imperial feet = 1479.5 m.
1500 paces = 1 *lewa* = 7500 Roman feet = 7281 Imperial feet = 2219 m.

APPENDIX B

Table of Roman monetary values:
1 gold aureus = 25 silver denarii = 100 bronze sestertii = 400 asses.
1 silver denarius = 4 bronze sestertii = 16 asses.
1 bronze sestertius = 2 dupondii = 4 asses.
1 dupondius = 2 asses.
1 as.

APPENDIX C

Reproduction of a 1250s Map of Britain by Matthew Paris (who was a monk at St. Alban's Abbey) showing both Hadrian's Wall and the Antonine Wall despite being depicted incorrectly in a geographical perspective.


SCOCIA : VLTRA MARINA
WALLIA
NORTHFOLK
SUFOLK
DORSET
London
AUSTER

APPENDIX D

List of Roman Emperors during the Imperial Period from Augustus to the abandonment of Hadrian's Wall in 411 AD (from the Department of Greek and Roman Art, The Metropolitan Museum of Art, October 2004):

Julio-Claudian Dynasty	**27 BC – 69 AD**
Augustus	27 BC – 14 AD
Tiberius	14 – 37 AD
Gaius Germanicus (Caligula)	37 – 41 AD
Claudius	41 – 54 AD
Nero	54 – 68 AD
Galba	68 – 69 AD
Otho	69 AD
Vitellius	69 AD
Flavian Dynasty	**69 – 96 AD**
Vespasian	69 – 79 AD
Titus	79 – 81 AD
Domitian	81 – 96 AD
The Five Good Emperors	**96 – 180 AD**
Nerva	96 – 98 AD
Trajan	98 – 117 AD
Hadrian	117 – 138 AD
Antoninus Pius	138 – 161 AD
Marcus Aurelius	161 – 180 AD
Antonine Dynasty	**138 – 193 AD**
Antoninus Pius	138 – 161 AD
Marcus Aurelius	161 – 180 AD
with Lucius Verus	161 – 169 AD
Commodus	177 – 192 AD
with Marcus Aurelius	177 – 180 AD
Pertinax	193 AD
Didius Julianus	193 AD
Pescennius Niger	194 AD
Severan Dynasty	**193 – 235 AD**
Septimus	193 – 211 AD
Caracalla	211 – 217 AD
with Geta	211 – 121 AD
Macrinus	217 – 218 AD
Diadumenianus	218 AD
Elagabalus	218 – 222 AD
Alexander Severus	222 – 235 AD

The Soldier Emperors	**235 – 305 AD**
Maximinus I	235 – 238 AD
Gordian I and II (in Africa)	238 AD
Balbinus and Pupienus (in Italy)	238 AD
Gordian III	238 – 244 AD
Philip the Arab	244 – 249 AD
Trajan Decius	249 – 251 AD
Trebonianus Gallus (*with* Volusian)	251 – 253 AD
Aemilianus	253 AD
Gallienus (*with* Valerian)	253 – 260 AD
Gallic Empire (West)	
following the death of Valerian	
Postumus	260 – 269 AD
Laelian	268 AD
Marius	268 AD
Victorinus	268 – 270 AD
Domitianus	271 AD
Tetricus I and II	270 – 274 AD
Palmyrene Empire	
Odenathus	c. 250 – 267 AD
Valballathus (*with* Zenobia)	267 – 272 AD
The Soldier Emperors (continued)	
Claudius II Gothicus	268 – 270 AD
Quintillus	270 AD
Aurelian	270 – 275 AD
Tacitus	275 – 276 AD
Florianus	276 AD
Probus	276 – 282 AD
Carus	282 – 283 AD
Carinus	283 – 284 AD
Numerianus	283 – 284 AD
Diocletian (*and* Tetrarchy)	284 – 305 AD
Western Roman Empire	
Maximianus	287 – 305 AD
Constantinus I	305 – 306 AD
Severus II	306 – 307 AD
Constantine I (The Great)	307 – 337 AD
Eastern Roman Empire	
Diocletian	284 – 305 AD
Galerius	305 – 311 AD
Maxentius (Italy)	306 – 312 AD
Maximinus Daia	309 – 313 AD
Licinius	308 – 324 AD

Constantine Dynasty	**337 – 364 AD**
Empire reunited by Constantine's defeat of Licinius	
Constantine II	337 – 340 AD
Constans	337 – 350 AD
Constantius II	337 – 361 AD
Magnentius	350 – 353 AD
Julian	361 – 363 AD
Jovian	363 – 364 AD
Western Roman Empire (after death of Jovian)	
Valentinian	364 – 375 AD
Gratian	375 – 383 AD
Valentinian II	375 – 392 AD
Eugenius	392 – 394 AD
Honorius	395 – 423 AD
Eastern Roman Empire (after death of Jovian)	
Valens	364 – 378 AD
Theodosius I	379 – 395 AD
Arcadius	395 – 408 AD
Theodosius II	408 – 450 AD

Improving the Cadastre using Existing Information

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ABSTRACT

Many people from both within and outside of the surveying profession use the Digital Cadastral Database (DCDB) on a regular basis. The uses of the DCDB are varied and numerous, but in most cases the DCDB is overlaid with other data. The advent of Web Map Services (WMS) from DFSI Spatial Services and many other organisations allows users to overlay data from vastly different sources. The expectation from the unknowing users is that this will simply work and the maps produced will look fine. Are these expectations reasonable? Does the data available stand up to the novice scrutiny? This paper examines a number of uses of cadastral data and the possible issues that might arise. Examples have been replicated from real-life examples. Some solutions are proposed for further consideration, including some that have been used by some users in recent times. This paper identifies some data issues that led to spatial errors within the DCDB which can easily be corrected. It also examines if our survey marking can contribute to cadastral inaccuracies. The question raised is: "Can we have too many survey marks?"

KEYWORDS: *DCDB, cadastral, marking, accuracy*.

1 INTRODUCTION

The Digital Cadastral Database (DCDB) was developed, in part, to replace the charting maps used as an index to find cadastral plans for survey and land titling purposes. The primary requirement for charting maps was the relative relationship of the land parcels, and, without further business drivers, spatial accuracy was assessed to this requirement.

At the time of the DCDB inception, a number of organisations were already capturing the cadastre for their area of interest, and in most cases this was captured into a Geographical Information System (GIS). In NSW, such organisations as the Metropolitan Water and Sewerage board and a number of local councils had a high percentage of plans captured. Following agreements, these formed the early basis for the DCDB at the cadastral level.

As the dataset grew in completeness and as the take-up of GIS increased within many organisations, the DCDB became a fundamental dataset for those organisations managing land in a wide variety of ways together with many infrastructure organisations such as utilities, transport, education and federal agencies. The increased availability of aerial photography led to the DCDB being overlaid over the photography – boundaries did not appear to coincide with fencing, and buildings appeared to be built over the boundaries.

Cadastral surveys were being connected to established Permanent Marks (PMs) and State Survey Marks (SSMs), providing significant improvement to the spatial accuracy of the DCDB, but also providing difficulties to others who had used the DCDB to capture

infrastructure. There have been many papers at previous APAS conferences, describing these issues and solutions available (e.g. Merritt and Keats, 1998; Merritt and Masters, 1999; Perry, 2001; Gardner et al., 2007).

These improvements in DCDB spatial accuracy are mostly focused around developing urban areas, taking advantage of the survey work that occurs as part of this development. In many respects, this is the area where improvements in the DCDB can also assist in the ongoing land development, if the timing of the updates fits in with the development activities.

How can we provide the same improvements in other areas? DFSI Spatial Services (then Land and Property Information) implemented a project utilising Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS) technology for DCDB upgrades and checking (Haddon, 2003). This project certainly met the requirements in terms of upgrading the DCDB from a spatial accuracy, but may be considered not economically viable in areas of low-density land use.

Others that capture their own cadastral information or update a copy of the DCDB include local government authorities, large developers, public and private utility organisations, road and railway organisations at various levels and mining companies. These various organisations all have an interest in having an up-to-date cadastre, including spatial, subdivision and attribute information.

Local councils and authorities have an interest in updating the DCDB especially in areas of rapid land development where development proposals are based on more accurate survey control than the DCDB, with the subsequent subdivision plans also having good connections to established coordinates. The proposed cadastre is often used to locate new utility services, and the various authorities do not want to load GIS systems twice with different locations from different sources.

There are many other surveys that locate cadastral information for purposes other than preparing subdivision plans, easement plans and the like. There are also surveys locating infrastructure, which could be combined with other information to assist in the DCDB upgrade. Surveys required for engineering upgrades or construction often include sufficient cadastral information to ensure that engineering works do not cross existing boundaries. There have been many occasions where project managers relied on the DCDB only to find later that the boundary was not in the position indicated by the DCDB and subsequent cadastral surveys have led to engineering works just inside or sometimes outside the boundary.

Is there a way we can utilise the less complete cadastral information to improve the DCDB? Should we even try and improve the DCDB or leave it as it is until an appropriate cadastral survey is lodged for subdivision or the like? In the next section, some examples are given where surveyors have or have access to information that exists now, and at this stage this information is not normally used to improve this valuable dataset because we do not seem to be able to bring together all that is necessary to achieve these improvements.

2 EXAMPLES OF SURVEYS WHICH COULD IMPROVE THE CADASTRE

Most of the examples given in this section are from rail infrastructure and corridor areas due to the background of the author, although there could be similar examples in other areas. The

intention is to raise the opportunities and look for others to add to the list of available information and to develop ways to utilise this information for DCDB upgrade.

2.1 Wilton: Error in DP that Led to DCDB Error

In the Wilton area, there is a rail corridor, some of which has been defined and acquired for rail purposes, and the remainder covered in a government gazette but not yet visible in the DCDB. The rail corridor was partially constructed in the 1980s with the project put on hold with a change of government. Proposed boundaries were calculated with plans prepared in the areas where the land was privately held.

One such plan was deposited plan DP732649. This plan covers about 5 km of corridor and was prepared in 1985 and registered in 1986. It was utilised, together with others, in the capture of the DCDB in this mostly rural area.

Recent investigations of this corridor suggested to some that the earthworks built in the 1980s were not within the rail corridor. This conclusion was drawn by managers looking at GIS outputs including aerial photography and the DCDB. This conclusion did not 'feel' correct because it was known that the same surveyors oversaw the earthworks, established the control and prepared the cadastral plans, so a more detailed desktop examination was undertaken.

Figure 1 shows a plot of the area, with the DCDB in thin white lines, the corridor centreline in red, which coincides with the earthworks constructed in the 1980s. A search within the NSW railway plan room was undertaken, revealing a signed and registered copy of DP732649, the engineering designs and a set of field sheets. The engineering designs and the field sheets contained Integrated Survey Grid (ISG) coordinated information and the DP included links to the ISG control. The field sheets contain coordinates (in the ISG) of the proposed boundary (see Figures 2 & 3). These are plotted in light blue in Figure 1. There is a difference of up to 65 m in the position of the boundaries from the two sources.

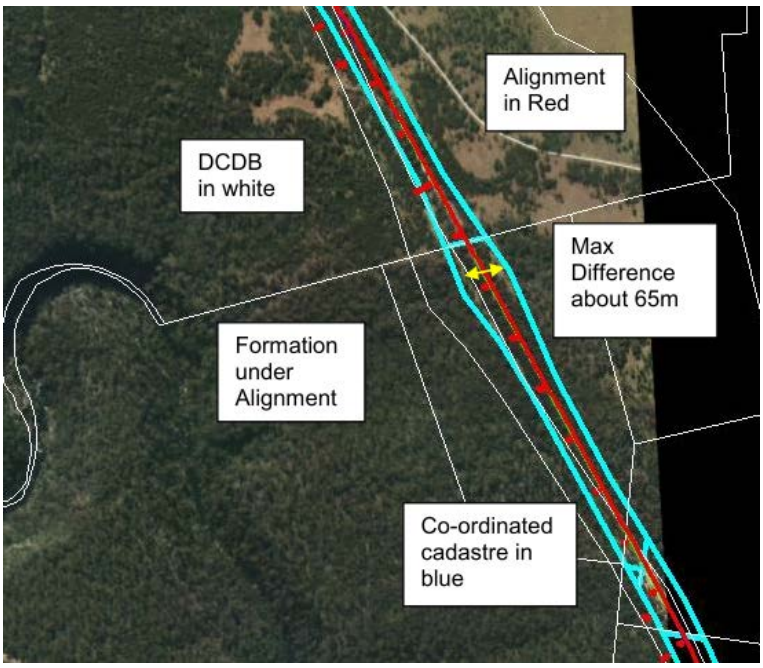

Figure 1: Wilton overlay.

STATE RAIL AUTHORITY OF NEW SOUTH WALES – WAY AND WORKS BRANCH – SURVEY SECTION

SC 6415 313

LOCALITY Avon Tunnel to Wilton | LINE DUMBARTON TO MALDON | KILOMETRAGE 98.58K TO 123.3K

SURVEY Kilometrages Offsets from ℄ and Coordinates of Corners of Railway Corridor through Water Board Crown Land | FILE No.

COORDINATES
SYSTEM I.S.G | E 272603.603
MARK (S) ADOPTED SSM 40781 | N 1192903.705
SOURCE WORKING PLAN

LEVELS
DATUM
MARK(S) ADOPTED RL
SOURCE

AZIMUTH 329° 19' 12" FROM SSM 40781 TO SSM 40774
METHOD OF DETERMINATION Calc'd from Coords.

MSL / SCALE FACTOR(S) 98.6K TO 108.5K 0.99988; 108.5K TO 117K 0.99989; 117K TO 121.5K 0.99990; 121.5K TO 123.3K 0.99991

ORIGIN OF KILOMETRAGE TP 98K 217.910. – PLAN 480-242

REFERENCES
FIELD SHEETS: SC 314
DRAWINGS: 385-650; 385-651; Working Plans

SURVEYOR BHP Engineering
SURVEY OFFICE Consultant
TELEPHONE

DATE OF SURVEY 1983-84
Surveyors Reference

I.S.G. COORDINATES – AS SUPPLIED BY PRINCIPAL SURVEYOR IN DESIGNATED ISG AREAS.
RIG COORDINATES – RAILWAY INTEGRATED GRID IS BASED ON ISG WITH COORDINATES EXPANDED BY E + 500,000 N + 2,000,000

SPARES BATCH 63
EDMS CV0364987

Figure 2: Title page for field sheets.

KILOMETRAGE	OFFSET	EASTING	NORTHING
121625.053	20.000	270308.105	1205634.029
121678.217	-25.000	270283.438	1205699.277
121678.217	20.000	270325.352	1205682.900
121731.380	-25.000	270305.072	1205749.641
121731.380	20.000	270345.806	1205730.517
121784.544	-25.000	270330.003	1205798.459
121784.544	20.000	270369.377	1205776.672
121837.708	-25.000	270358.120	1205845.513
121837.708	20.000	270395.961	1205821.160
121890.872	-25.000	270389.301	1205890.597
121890.872	20.000	270425.441	1205863.784
121944.060	-25.000	270423.422	1205933.529

Figure 3: Sample of field sheet data.

The boundary plan contained a number of references to survey control marks that were documented on the engineering designs, but these are not included on public record in the Survey Control Information Management System (SCIMS) as they were internal railway control marks. As an example, Figure 4 shows part of the plan in the subject area.

The investigation continued on two fronts, the first transcribing the field sheet information and plotting this over the aerial photography and the second to study and coordinate the DP to plot this over the aerial photography. During the second process, calculations revealed a drafting error in lot 8, where a dimension from the western boundary was put against the eastern boundary, also shown in Figure 4.

As the surveyor has since retired and could not be contacted, the Registrar General added a note to the plan, giving the calculated value. This was sent to the DCDB staff and the DCDB has been updated accordingly (Figure 5).

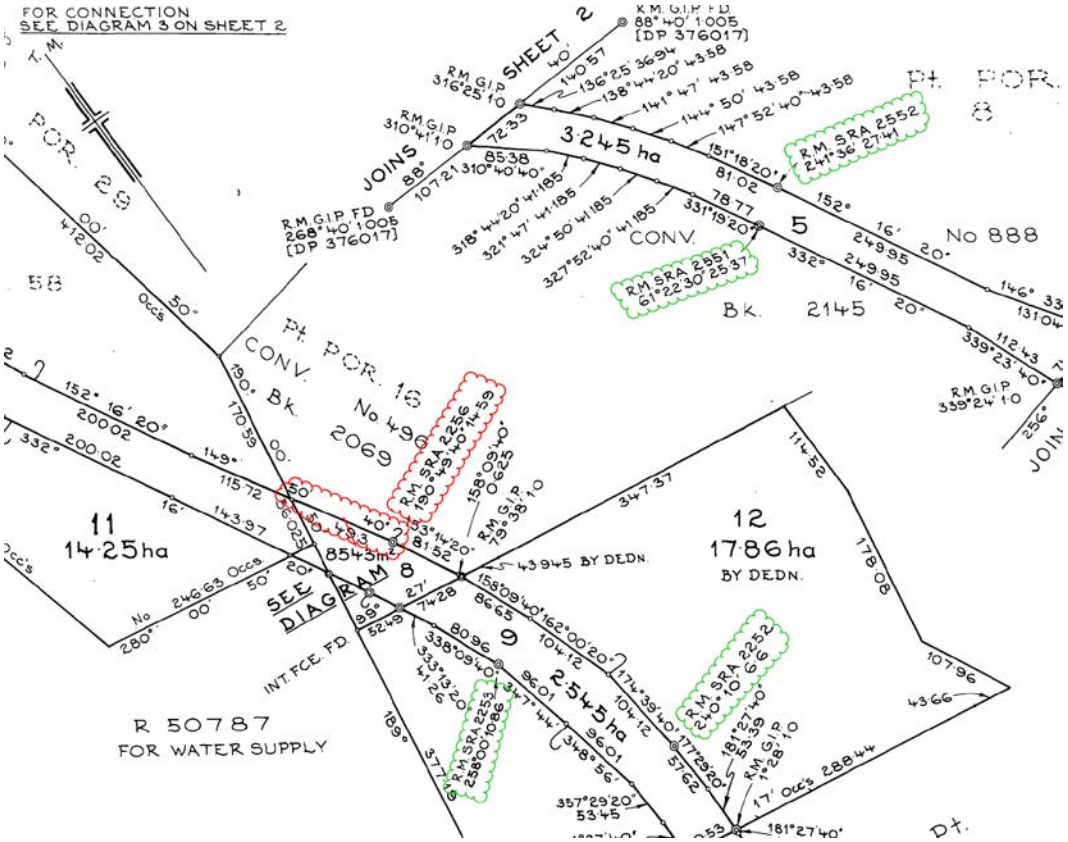

Figure 4: Part of DP732649.

Figure 5: Updated DCDB.

From this example, the following was learnt:

- Contact the Land Titles Office and report the DP error. They will endeavour to have the surveyor rectify the plan and if that is not possible, at least place a departmental note warning others of the possible error and sometimes indicate the correct information.
- Notify the DCDB update unit of the issue. This will save time when the area is readjusted.

2.2 Cobar to Elura and Parkes: SCIMS Information Showing Differences

The rail line from Cobar to Elura Mine was constructed in 1982. As part of the design and construction program, SSMs were placed along the corridor and coordinated. This control then formed the basis of subsequent aerial mapping and construction set-out.

The SSMs were placed near the corridor boundary with the offset from the rail line noted in the sketch, and the records were sent to DFSI Spatial Services to be loaded into SCIMS. Current aerial mapping has either used this control or agrees closely with the values. It is not clear how this information can be utilised, but, to the layman, the SCIMS information agrees with the aerial mapping and the DCDB must be in error. It should be noted that this information is now readily available via the SIX portal and the nswglobe.kml to any interested parties.

Figure 6 shows an extract from NSW Globe in Google Earth with the imagery, DCDB and Survey Marks layers turned on. The rail alignment was supplied to the Railways in ISG and is shown in red and is almost directly over the rail line. The cleared areas to the west are an access road and a powerline easement.

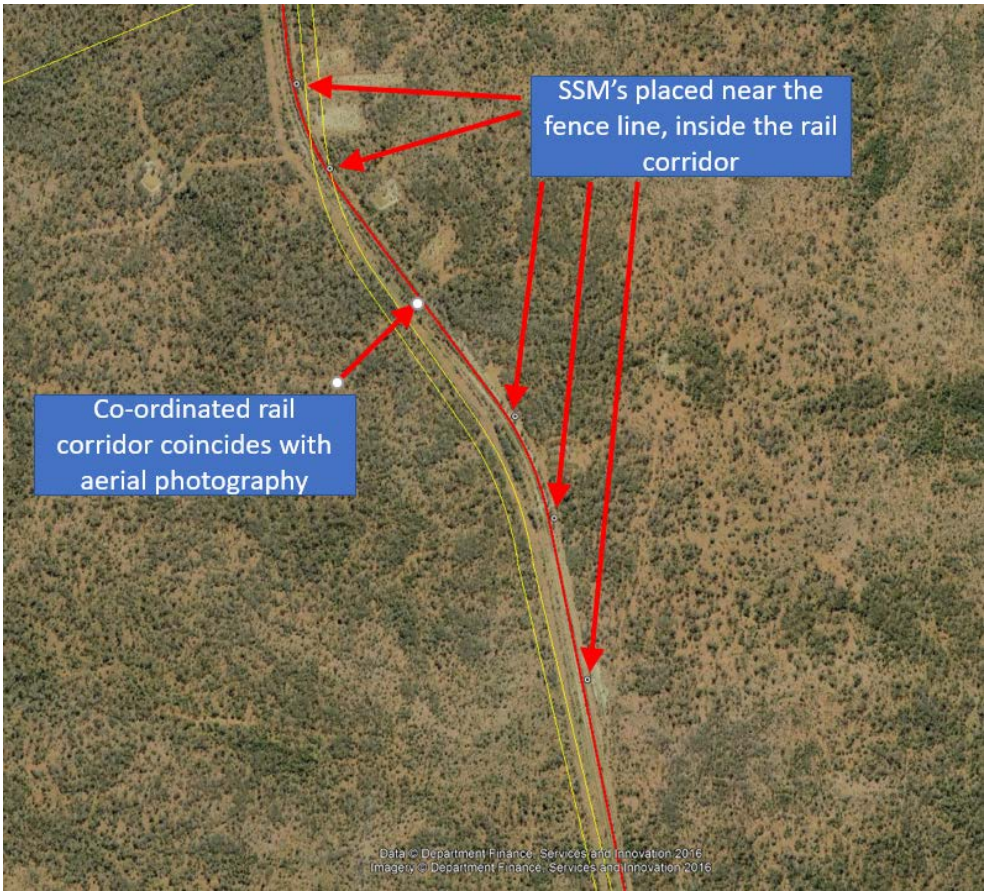

Figure 6: Cobar to Elura Mine overlay.

Further evidence of the SSM location relative to the rail line is shown in the sketch plans for each mark (Figure 7). Unfortunately the sketches are a photocopy of mapping with the rail line added. However, there is a note at the bottom of the sketch indicating the relative position of the SSM to the rail line. This again suggests that the aerial photography is being plotted in the correct position, so the question of accuracy of the DCDB is again raised.

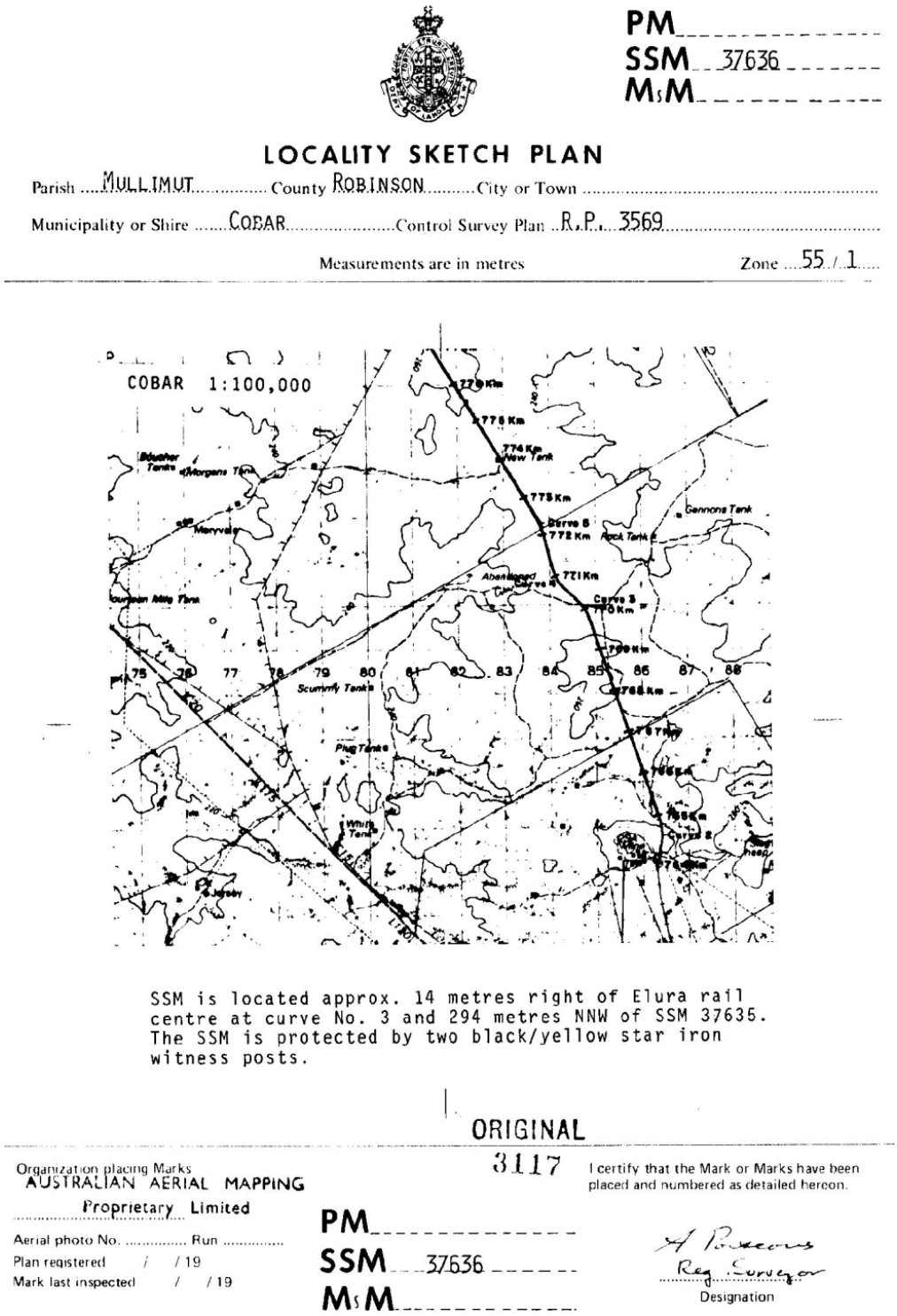

Figure 7: Locality sketch for SS37636.

2.3 Parkes

A similar situation can be seen north-west of Parkes. The sketch plan of PM82742 shows the position of the PM with respect to a fence line and a nearby fence corner (Figure 8). Additional information indicates the length of the fence line (or possibly the boundary), the position of an unformed road and the railway line. Diagrammatically a dam is also plotted. This information should meet its objective to aid others in finding the mark. Can this information also aid in the positioning of the DCDB?

Figure 8: Locality sketch for PM82742.

The current DCDB from NSW Globe (Figure 9) shows the PM to be located east of this fence corner in a possible but unlikely spot. This is due to the mark being in an adjustment and having reasonable coordinates (class B). In this area, the unformed road as shown in the DCDB appears to be a lot wider than the 20.115 m stated in the sketch. If these were adjusted the rail line in the photo would appear to be approximately in the centre of the corridor.

Figure 9: Parkes overlay.

The Australian Rail Track Corporation (ARTC) is currently undertaking rail upgrade works in this area (Oberg, 2018). It would be reasonable to assume that some sort of confirmation of the boundaries would have been undertaken, even if it is only a desktop exercise to coordinate the rail boundaries in this area to ensure works stayed within the rail corridor. If this is the case, this information could be a great aid in updating the DCDB.

2.4 Bogan Gate: Combining Mapping, SCIMS and Aerial Photography

In 1994, Freight Rail conducted a large mapping survey of rail assets across NSW (Latella, 1995). As part of this project, check points were required, and at each of these locations a pair of survey marks were utilised, and often placed. At Bogan Gate, two PMs were coordinated, with the check point on the track established. These PMs have good coordinates, and the connection to the track agrees with the aerial photography, but the DCDB appears to be too far south by 15 m or more (Figure 10).

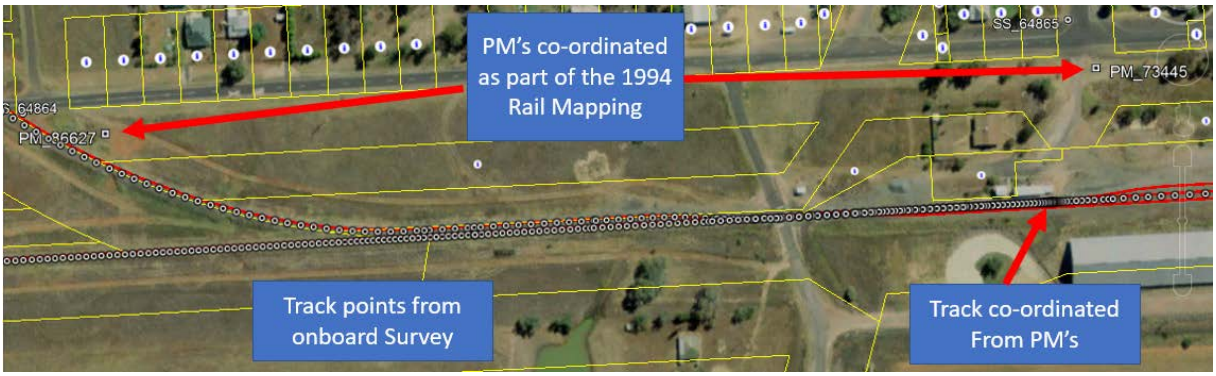

Figure 10: Bogan Gate overlay.

Again, independent data confirms the aerial photography. Can this then be utilised to improve the DCDB? To the average user of Google Earth and the NSW Globe dataset, the answer is yes and perhaps why has it not been done.

2.5 Helensburgh: Partial Boundary Survey in the Railway Plan Room

At Helensburgh, a survey was undertaken to mark the boundary of the rail corridor. This survey was documented in a set of field sheets registered in the railway plan room, which included the ISG coordinates of the corners. When an overlay is prepared with aerial imagery, the difference between the DCDB and this coordinated boundary is obvious. Figure 11 illustrates this difference, showing the DCDB in yellow, the existing track centrelines in red and the railway boundary definition in white.

Figure 11: Helensburgh to Helensburgh tunnel overlay.

Can this information be used to help improve the spatial accuracy of the DCDB? This information is easily available to the public, but it is registered in a government owned plan room.

3 TOPOGRAPHIC SURVEYS WITH BOUNDARY DEFINITION

In many engineering projects, surveys are acquired in the early stages to aid in the design. If the proposed works are to be near the cadastral boundary, a boundary definition is sometimes included so that design decisions can be made to either stay within the boundary or negotiate with the adjoining landholder.

These surveys are never seen by those who work diligently in upgrading the DCDB unless the works involve a subdivision and title transfer. The challenge is to those conducting the surveys, those having the surveys done and those managing the DCDB to consider if and how this untapped survey information can be utilised to the benefit of the wider community in order to improve the spatial accuracy of the DCDB.

The public survey system only holds information for some of the surveys undertaken, including cadastral boundaries where the plans are registered and survey control where some additional information (e.g. observations) are sometimes submitted to support the assigning of coordinates to control marks. There could be a case to have more of the underlining survey information registered and made available to other surveyors. This brings about issues around liability to third parties, but this can be managed with appropriate processes to the advantage of all involved. The survey information that is relevant to the DCDB could then be extracted and added to the inputs used to improve the DCDB.

4 CAN WE HAVE TOO MANY SURVEY MARKS?

The final area where surveys could help the DCDB is SCIMS. The intersection shown in Figure 12 includes a total of 10 marks in SCIMS, although some are replacements for others in approximately the same location. These are in a small area and fairly close to one another. Provided that these marks are in good condition, all should be fine to use. The more marks, the better? Probably not, although in this particular location many of the marks have been destroyed, and the PMs are used by Sydney City Council to aid in the fixing of the street boundaries.

The example in Figure 12 brings about the issue of safety for surveyors as many of these marks are in the carriageway of two busy city streets. This in itself may cause even more marks to be placed in the footpath, so that surveyors do not need to close off a portion of the carriageway.

In this case, each survey mark is uniquely identified by its number and therefore there is little opportunity for errors to creep into the DCDB. There are locations where survey marks that are not uniquely identified have the possibility of causing errors in cadastral surveys, which then propagate into the DCDB. This example is only small but does show how problems may arise.

Figure 12: Intersection in Sydney (Bridge and Pitt Streets).

Let us examine three plans of the same corner. In the first plan (Figure 13), the surveyor found a RM GI pipe at corner Z in 1957 – this is on the line of the side boundary.

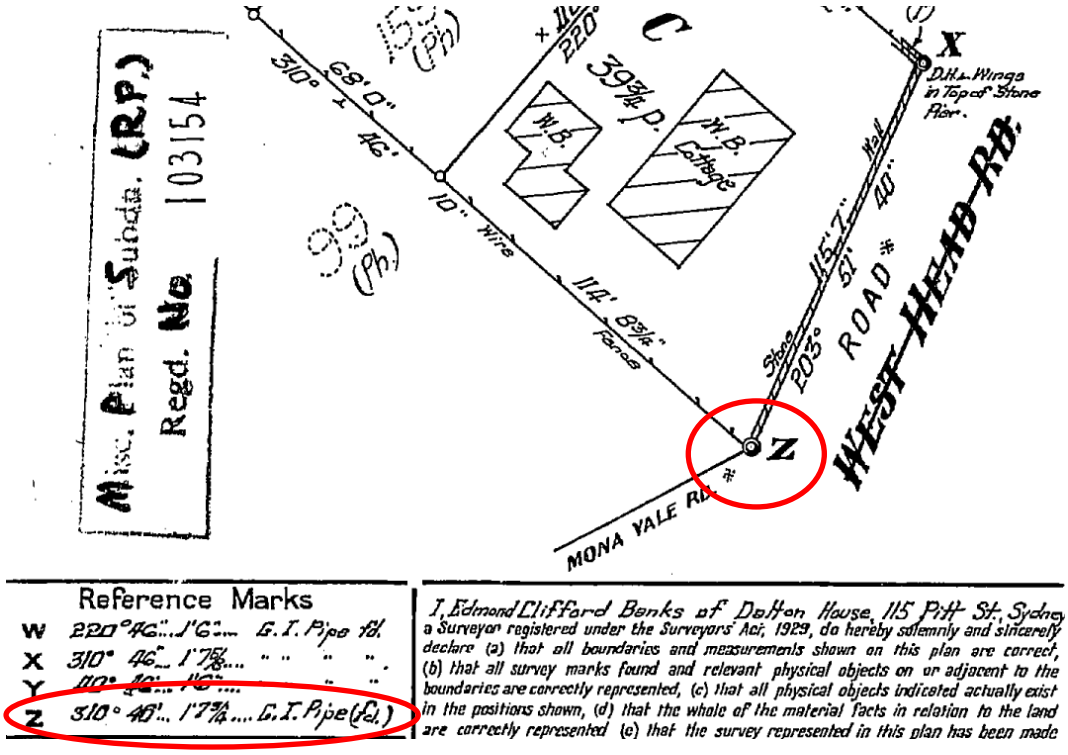

Figure 13: Part of FP403154, i.e. now DP403154 (1957).

A few years later, the road widening plan shown in Figure 14 found two RM GI pipes for the same corner – neither of these is on the line of the side boundary. The first is square to the old alignment, and the second is about 3.5º off the side boundary line and half an inch less.

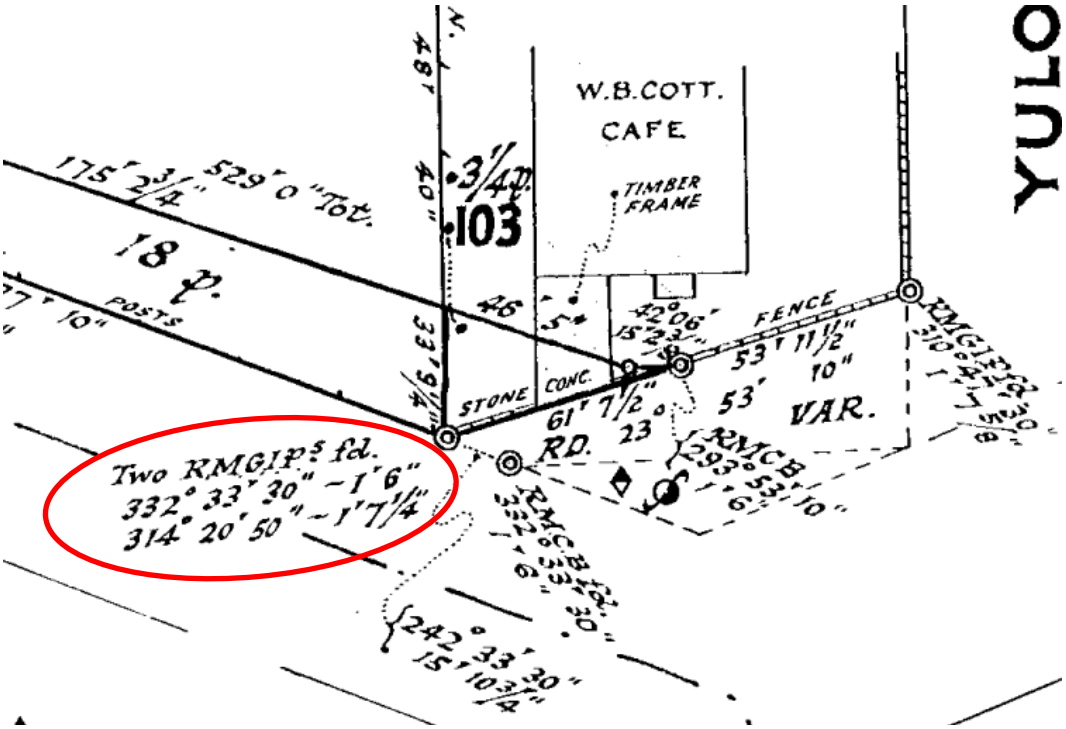

Figure 14: Part of road widening DP218268 (1963).

More recently, a community title plan found the first one of these RM GI pipes and shows a small excess (Figure 15). It must have taken some effort to confirm which GI pipe was found, and presumably the other GI pipe is either not there anymore or at least was not found.

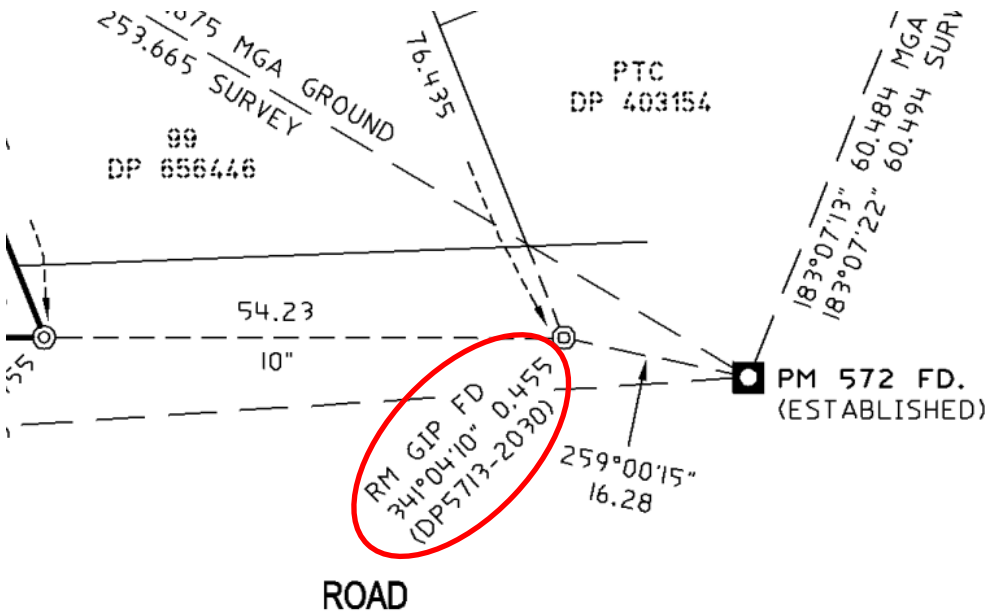

Figure 15: Part of DP270547 (2007).

It can be suggested that this is a case of too many survey marks. As these marks are not separately identifiable, and therefore the surveyor has to do more survey work to confirm

which mark is found. The same could be said for witness marks, i.e. those witness marks that are not separately identifiable could be confused for some other mark.

5 CONCLUDING REMARKS

The DCDB has become a popular tool to aid all sorts of people in all sorts of activities. Since the release of NSW Globe and the WRMS services, many people have access to the various spatial datasets available from DFSI Spatial Services. These various datasets do not always overlay correctly, and as the use of these datasets increases, the need to update the data grows.

Many of the examples outlined in this paper utilise aerial photography as a tool. In all cases where this occurs, there needs to be sufficient information to check the aerial photography geo-referencing. This checking can often be performed utilising various information available within the datasets, and sometimes information available from other datasets. Once the checking has been completed, the inferred positions of the DCDB can be extracted and compared to other information used to define the DCDB. Those updating the DCDB cannot take this or any other information on face value but once collaborated, this could be used to strengthen the overall DCDB in the area.

In addition to this check, the aerial photography can only assist in the location of fencing and other infrastructure, which in some cases may be deliberately not placed on the boundary. Furthermore, in more remote areas, the variation between fencing and boundaries may be much larger than what we see in more developed areas. In urban housing areas people might worry about 0.1 m, while in rural areas new fences are sometimes built beside (perhaps 1 m or more) the previous one to aid in the construction without letting stock escape from a paddock.

In a similar manner, PM and SSM sketches can be used to identify the relative positioning of the survey marks and fencing. However, in cases where the mark is not established, the spatial position is often determined from the DCDB and therefore cannot be utilised as evidence of the spatial position of the DCDB.

This paper has presented some ideas from one perspective. The challenge to the survey profession can be summarised as how can existing information and changes in the way surveys are completed and reported be utilised better to help the general community in their consumption of spatial data.

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DCDB Upgrade of the NSW-Queensland Watershed Border: The Tick Protocol

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ABSTRACT

The NSW Digital Cadastral Database (DCDB) is a state-wide integrated database of current land title boundaries used for administrative purposes. State boundary abuttals form part of the DCDB. DFSI Spatial Services periodically upgrades sections of the DCDB so a more accurate representation of the State cadastre is available to users. As part of this ongoing process and to maintain consistency across national cadastral databases, a desktop upgrade of the NSW-Queensland watershed border from the Dumaresq River to Bald Rock was undertaken. This paper gives a brief overview of the upgrade process, the difficulties encountered so far, and has a lighter look at some of the history behind the NSW-Queensland watershed border.

KEYWORDS: *DCDB, state cadastre, borders, watershed.*

1 INTRODUCTION

The NSW Digital Cadastral Database (DCDB) is maintained by Spatial Services, a unit of the NSW Department of Finance, Services and Innovation (DFSI). The DCDB is the digital spatial representation of land title ownerships and land administration for New South Wales. In order to provide national coverage for cadastral data for large national and international clients such as Google, Telstra and Australia Post, the NSW dataset is merged with adjoining state jurisdictions (i.e. Queensland, South Australia and Victoria). Each jurisdiction evolved and developed their own cadastre separately and that included the definition of the state border at their margins. When the respective cadastral datasets are merged to form the national dataset, there are small anomalies along the state border. These anomalies are encountered each and every time the datasets are merged. In order to streamline processes for the creation of future national datasets, NSW and Queensland have been upgrading their respective DCDBs so that they bind along a common and agreed state border. This paper gives a brief overview of the upgrade process, the difficulties encountered so far, and has a lighter look at some of the history behind the NSW-Queensland watershed border.

2 BACKGROUND

The NSW-Queensland border was originally described in the letters patent of Queen Victoria dated 6 June 1859 when Queensland was separated from New South Wales in 1865. A part of that description states:
"*…in pursuance of the powers vested in us by the said Bill and Act and of all other powers and authorities in us that behalf vested separated from Our Colony of New South Wales and erected into a separate colony so much of the said Colony of New South Wales as lies northward of a line* ***commencing*** *on the sea coast* ***at Point Danger****, in latitude about twenty-eight degrees eight minutes south and* ***following the range thence which divides the waters*** *of the Tweed, Richmond and Clarence Rivers from those of the Logan and Brisbane Rivers, westerly to the dividing range between the waters falling to the east coast and those of the River Murray following the great dividing range southerly to the range dividing the waters of Tenterfield Creek from those of the main head of the Dumaresq River following that range* ***westerly to the Dumaresq River and following that river*** *(which is locally known as the Severn) downwards to its confluence with the Macintyre; thence following the Macintyre River which lower down becomes the Barwan [sic]* ***downwards to the twenty-ninth parallel of south latitude, and following that parallel westerly to the one hundred and forty first meridian of east longitude*** *which is the easterly boundary of South Australia together with all and every the adjacent islands, their members and appurtenances in the Pacific Ocean: and do by these presents separate from our said Colony of New South Wales* ***and erect the said Territory so described into a separate Colony to be called the Colony of Queensland****.*"

In order to summarise the above description, the border has three main components:
1. The watershed – from Point Danger near the Gold Coast to the Tenterfield Creek / Dumaresq River confluence.
2. The river (including Dumaresq, Macintyre and Barwon Rivers) – from Tenterfield Creek to Mungindi.
3. The 29th parallel – from Mungindi to Cameron Corner.

The watershed was surveyed by Surveyors Isaiah Rowland (NSW surveyor) and Francis Edward Roberts (QLD surveyor) from 1863-66. Before John Cameron's survey of the 29th parallel in 1879, the 29th parallel was surveyed at the main river crossings only by QLD Surveyor-General A.C. Gregory and NSW District Surveyor W.A.B. Greaves. These plans are recorded in the 'River' series (small number 3039) of Crown Plans as plans 1-6 (Figure 1). The purpose of these surveys was to give the landholders an indication of their leases with respect to the border. The survey of the entire 29th parallel was completed by John Brewer Cameron from 1879-81. Queensland surveyor George Chale Watson was to assist Cameron, but he withdrew from the project after surveying approximately 100 miles from Barringun to Hungerford.

There have been many redeterminations of the border by surveyors since the original surveys. Probably the most significant of these (and definitely the most photographed) would be the construction and placement of the concrete pillar at the original survey mark at Cameron Corner at the 3-way intersection of the borders between New South Wales, Queensland and South Australia by Surveyor David Vincent on 14 May 1969 as recorded on registered Deposited Plan DP767473.

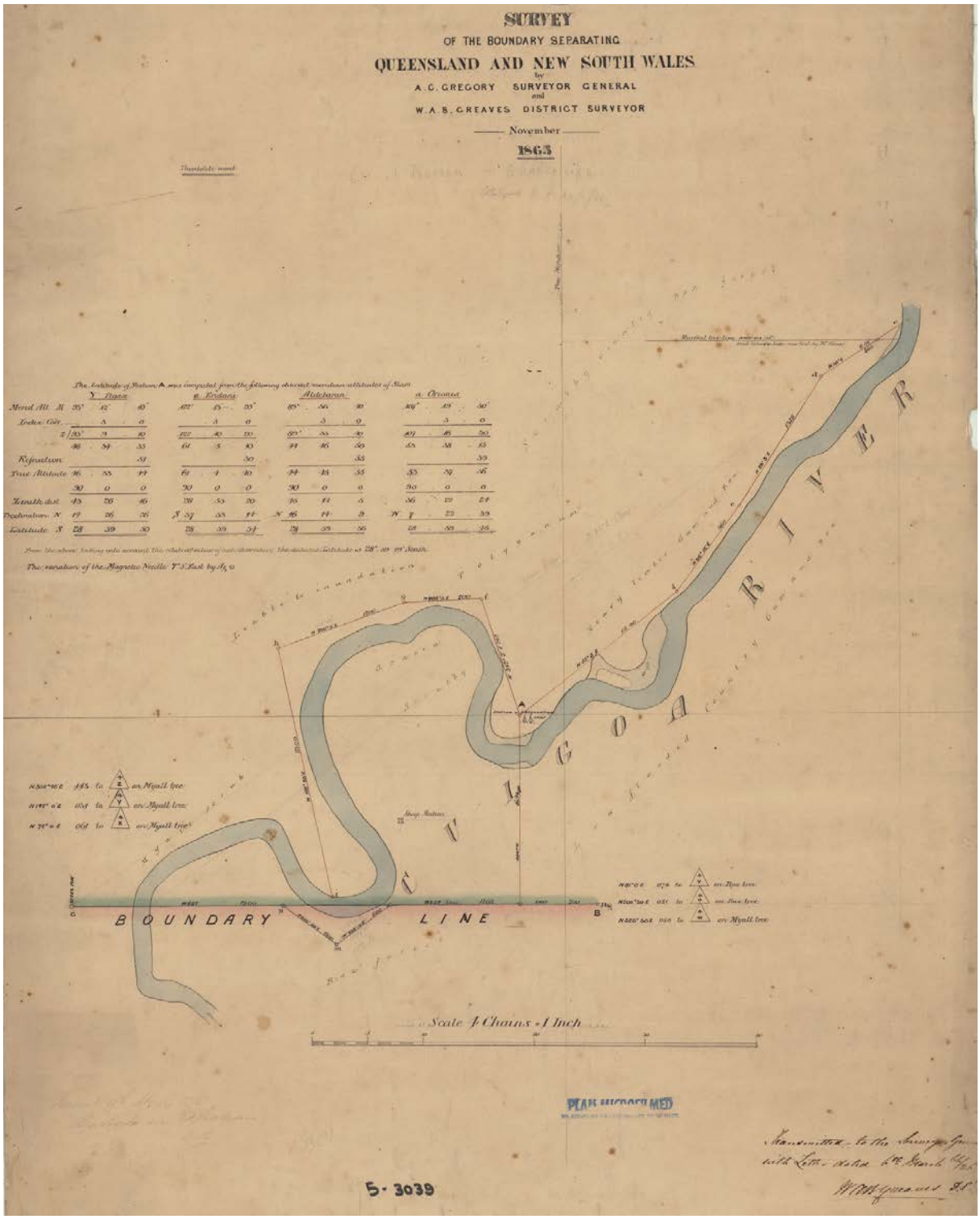

Figure 1: Survey showing the NSW-QLD border crossing the Calgoa River (plan number 5-3039).

John Cameron originally started the survey of the 29th parallel by determining the latitude and longitude of three observatories and comparing that position by using the Sydney observatory as it was linked by telegraph line from Sydney to Greenwich. The telegraph line passed through the small village of Barringun, and the survey could provide a check on distances to the South Australian border. The distance from Barringun to Cameron Corner is 285 miles 24.96 chains (459 km), and from Barringun to the Barwon River 199 miles 40 chains (321 km). John Cameron surveyed the border as a series of 5-mile chords to represent the curved

line on the ground. Every 5th mile is critical in the description of the border as there is a 2' 24.15" angle between each chord. The intervening mile posts and ¼-mile pegs are on a straight line (Figures 2 & 3).

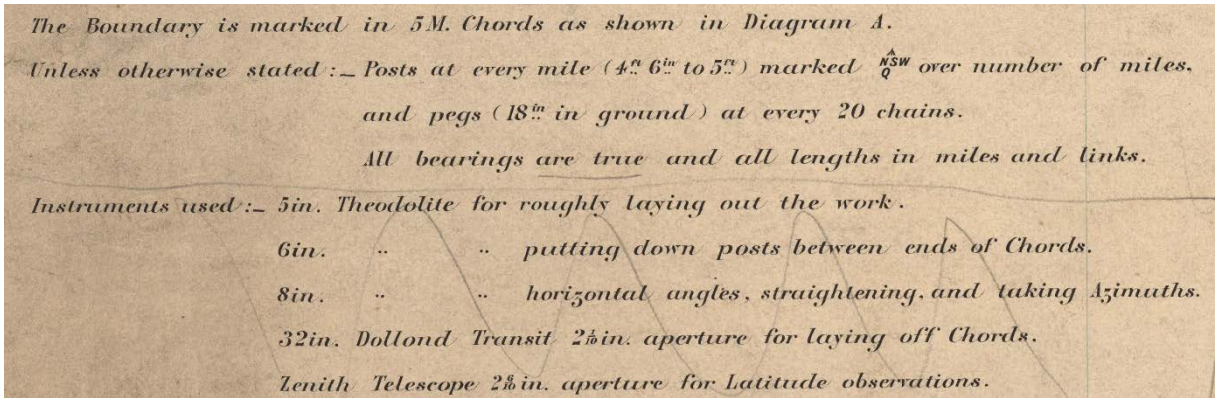
The Boundary is marked in 5M. Chords as shown in Diagram A.
Unless otherwise stated :— Posts at every mile (4ft. 6in. to 5ft.) marked NSW Q over number of miles,
and pegs (18in. in ground) at every 20 chains.
All bearings are true and all lengths in miles and links.
Instruments used :— 5in. Theodolite for roughly laying out the work.
6in. " " putting down posts between ends of Chords.
8in. " " horizontal angles, straightening, and taking Azimuths.
32in. Dollond Transit 2 1/10 in. aperture for laying off Chords.
Zenith Telescope 2 6/10 in. aperture for Latitude observations.

Figure 2: Part of Cameron's survey, showing explanation of marking and equipment used (plan number 115-3014).

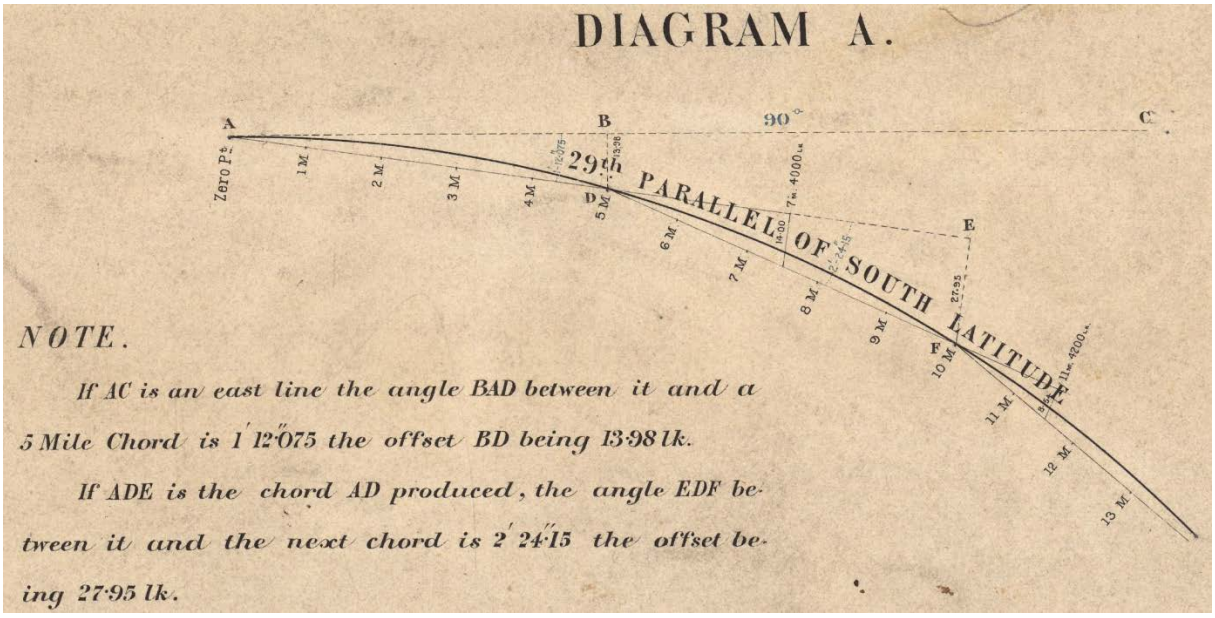

Figure 3: Part of Cameron's survey, showing explanation of marking (plan number 115-3014).

Generally speaking, the border has not been re-surveyed or re-determined since the original surveys. Only occasionally has there been a need to re-determine the border since the 1880s, and as a consequence of the lack of modern surveys, an accurate determination of the border is very difficult.

3 MODERN DETERMINATIONS

3.1 Reconnaissance Surveys

QLD Surveyor R.R. Spurdle undertook a 'speedo traverse of the NSW-Queensland border' in August 1969 from Hungerford to Barringun (plan number KU73) (Figure 4). This survey covered 75 miles of the border and found 22 (29%) of the original mile posts. No survey measurements are recorded on the plan.

Figure 4: Part of the speedo traverse by Spurdle (plan number KU73 (Qld)).

QLD Surveyor Bill Kitson drove around the Queensland borders during 1985 (plan numbers KU79 & KU80) (Figure 5) to find and recover as many of the original survey marks (i.e. mile posts) placed by the original surveyors (including John Cameron) on the NSW-QLD border. Only 68 (34%) out of a possible 199 mile posts were found on the eastern section from Barringun to Mungindi. On the western section from Barringun to Cameron Corner, only 33 (11%) out of a possible 282 were found. As the miles posts were found, identified and recovered with witness marks by Kitson, they were later accurately surveyed by Global Navigation Satellite System (GNSS) static survey campaigns to derive accurate Geocentric Datum of Australia 1994 (GDA94) coordinates for each mile post from Cameron Corner to the 'One Ton Post' at Mungindi. The locations of the found mile posts were used to derive a model to predict the location for all intervening mile posts. The distance of one mile was scaled to fit between respective mile posts found.

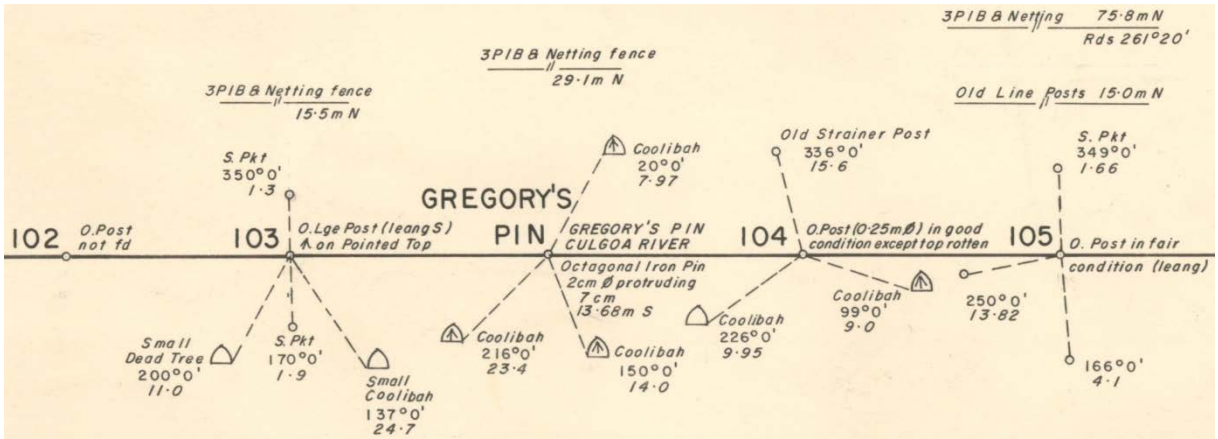

Figure 5: Part of the recovery survey by Kitson (plan numbers KU79 & KU80 (Qld)).

Only 16 (8%) of the mile posts out of a possible 199 mile posts from Barringun to Mungindi were used to compute the model to help find marks on the eastern section. 26 (9%) mile posts out of a possible 282 mile posts were used to compute the model in the western section from Barringun to Cameron Corner.

3.2 Re-Survey: Cameron Corner to Barringun

During 2015, preliminary work was undertaken on the western section from Cameron Corner to Barringun. Permanent survey marks (PMs) were placed at every 5 miles (as that is the point where the border chords form the angle) and extensive searching for each intervening mile post was undertaken using Real-Time Kinematic (RTK) GNSS techniques.

From Cameron Corner to Hungerford (approximately 200 miles), no additional mile posts were found. The section from Hungerford to Barringun has not been re-surveyed at this stage. It is hoped to re-survey this section soon.

As no additional mile posts have been found from Cameron Corner to Hungerford, the best determination of the border will be the predicted model. The model fixes the position of each mile post found and then scales the distances and angles to fit. Generally the distances are not accurate. Sections for the border have scale factors applied as shown in Table 1. As can be seen from the results, there is a large variety of scales that were applied to various segments of the border.

Table 1: Scale comparison from Cameron Corner to Barringun.

From	To	Scale Per Mile (m)
282 W (Cameron Corner)	226 W	+0.64
226 W	210 W	+1.19
210 W	144 W	-0.37
144 W	141 W	+1.59
141 W	125 W	+0.30
125 W	95 W	+0.07
95 W	60 W	+0.18
60 W	10 W	+0.02
10 W	zero	+0.09
Cameron Corner	**zero**	**+0.18 (average)**

3.3 Re-Survey: Barringun to Mungindi (Barwon River)

This section has been completely and extensively re-surveyed by surveyors G.R. Stewart (NSW) and R.A. Jenkins (QLD). Four deposited plans have been registered that define the border in 50-mile stages: DP1142937 (zero – 50 mile), DP1142938 (50 – 100 mile), DP1142939 (100 – 150 mile) and DP1142940 (150 – 199 mile). Each sheet of the DPs has 10 miles defined, i.e. two 5-mile segments. In this section, the border is defined by Map Grid of Australia 1994 (MGA94) coordinates for each mile post, and established PMs are located nearby with a distant mark to provide orientation at each mile post. The remains of 71 mile posts (35%) were found and surveyed out of a possible 199 posts. The comparison of each mile interval from Barringun to Mungindi is variable. On average, each mile is 0.63 m short.

3.4 River Section

The New South Wales – Queensland Border Rivers Act 1946 (QLD Legislation, 2002) ratifies certain agreements between the two states, and ‘border rivers’ is defined in the agreement as the median line in question for the respective Dumaresq, Macintyre and Barwon Rivers. The border along the river is a natural-feature boundary and has not been defined by survey. As there is no additional documentation or opinions regarding the description of the border, the common law presumption of *ad medium filum aquae* is to apply to this natural feature as the border. That is, the boundary line between the two states is the middle thread or

line of those rivers as they are presently constituted. The middle thread is the line that divides the bed equally.

The bed is defined in section 172 of the Crown Lands Act 1989 (NSW Legislation, 2016):
"bank" means the limit of the bed of a lake or river.
"bed" means the whole of the soil of a lake or river including that portion:

(a) which is alternately covered and left bare with an increase or diminution in the supply of water, and
(b) *which is adequate to contain the lake or river at its average or mean stage without reference to extraordinary freshets in time of flood or to extreme droughts.*

No known modern surveys have determined a recent definition of the NSW-Queensland border along the river section. On the upper reaches of the Dumaresq and Macintyre Rivers there are significant differences or changes from the original cadastral riparian boundaries as defined in the original portion surveys to that of the present river bed.

3.5 Watershed Border

This section presents significant challenges to those seeking to accurately define the NSW-Queensland border. The original survey was undertaken by surveyors Roberts and Rowland in the period from 1862 to 1865. The watershed border has been given special consideration as there is often a road or reservation that separates the adjoining cadastre from the border on both sides. Therefore, in such cases, any subsequent subdivision or development will not form and has not formed a common boundary with the state border. Often the road or reservation is of variable width.

The watershed section is approximately 450 km in length and traverses terrain that has varied land use and varied tenure, is extremely steep and broken, and covered in thick forest. Later on, the area also featured plenty of bush ticks. The challenges that faced the original surveyors Roberts and Rowland would have been significant. The watershed surveys of Roberts and Rowland were essentially two different surveys, which initially diverged significantly as agreement between the two survey parties could not be formed. That divergence continued until near Richmond Gap where, apparently, an accord was reached and the two surveys after Richmond Gap appear to (more or less) coincide. The survey of Roberts is tacitly accepted by both NSW and Queensland governments as the pre-eminent definition of the watershed border.

The document 'Redefining the Queensland – New South Wales Border: Guidelines for Surveyors' (DITM & DNRM, 2001) outlines a great deal of detail and procedures of how the surveys were undertaken. The sections near Bald Rock, Wilsons Peak and Mount Lindsay were not surveyed in the original work by Roberts or Rowland.

Not only did the two survey parties of Roberts and Rowland fail initially to form an agreement on the position of the watershed boundary, it would appear from that there was some tension between Rowland and the then NSW Surveyor-General, Walker Rannie Davidson, as indicated by the following correspondence from Davidson to Rowland (Davidson, 1864):

20th June, 1864
Sir,

1. I have to remind you that the long period of 18 months has elapsed since you received my instructions to survey the boundary between Queensland and the Colony of N.S.W. and I am not in the possession of any information as to the progress of the survey, being only reminded that an officer of my Department is so employed thereon by signing large cheques for extra wages and forage allowance, the total expenditure of such service approaching at this moment the sum of nearly £2000.
2. In the absence of monthly Journals, which should have been forwarded with all practicable regularity, I look for a particular account of how your time has been employed since commencing the survey, and which time, however intricate and difficult the country may have been through which it has been carried, has been ample for the accomplishment of a very large amount of work.
3. Indeed, as the distance from Point Danger to where your survey would probably terminate on the Dumaresq River, which cannot, I apprehend, exceed 200 miles, and as the time occupied exceeds 429 working days to be accounted for deducting the period allowed you for leave of absence, I am of the opinion that the survey ought to have been completed, unless very unusual difficulties, of which I am quite uninformed, have arisen. When, however, I consider that a second party, equally strong with your own, has been supplied by Queensland to assist in this work, I am at a loss to understand how it happens that the work has not been completed long before now.
4. It appears to me, may I add, that no excuse can exist for your not having informed me as to your progress, as you assuredly might have availed yourself of the opportunities by which you forward your accounts, to supply me with useful and important information as to your progress in the work which has been entrusted to you. The omission appears to me extremely blameable in an officer so far removed from Head Quarters and entrusted with a work of so much interest.
5. I am compelled to add that in the event of the continued absence of the information which I seek, I shall feel an almost insuperable difficulty in signing further abstracts for pay and allowance.

I have the honour etc.
Sgd. W.R. Davidson
Surveyor-General.

In addition to this candid letter, it would appear that Rowland had later requested payment of a bonus. The reply by Davidson shown below (Davidson, 1865), in addition to his (relatively) brusque assessment of Rowland's request, also shows a fascinating insight into the physical difficulties faced by surveyors of the period:

7th November, 1865
Sir,

In replying to your application of the 2nd instant wherein you seek for the payment of a bonus in consideration of extra services and certain unforeseen expenses incurred on account of the survey of the Northern boundary of the Colony, I have to acquaint you that the grounds on which the bonus in question has been sought are not sufficient to warrant me to make my recommendation in your favour.
The allowances extended to you on account of the expedition were for extra equipment, forage and men's wages and in quoting Mr. Roberts' case as a precedent you have been

unfortunate, as the Surveyor-General of Queensland states that the bonus paid to him was only in fact to cover the cost of equipment but chiefly to compensate for the loss of camp equipment and several horses carried away by floods whilst engaged in a previous survey.

Sgd. W.R. Davidson
Surveyor-General.

Surveyor William Drummond surveyed the section not surveyed by Roberts near Bald Rock as described in two Crown Plans being 109-3026 (completed 22 February 1884) (Figure 6) and 118-3026 (completed 23 April 1885). The Crown Plan small number '3026' equates to the 'Mountain Plans' (type of feature survey) series. It is interesting to note that Crown Plans 2414-3010 and 2416-3010 show land that the NSW Department of Agriculture excluded and fenced from the adjoining Queensland Portions (14 January 1957). As there are national parks on both sides of the border in this area, no further surveys have taken place since.

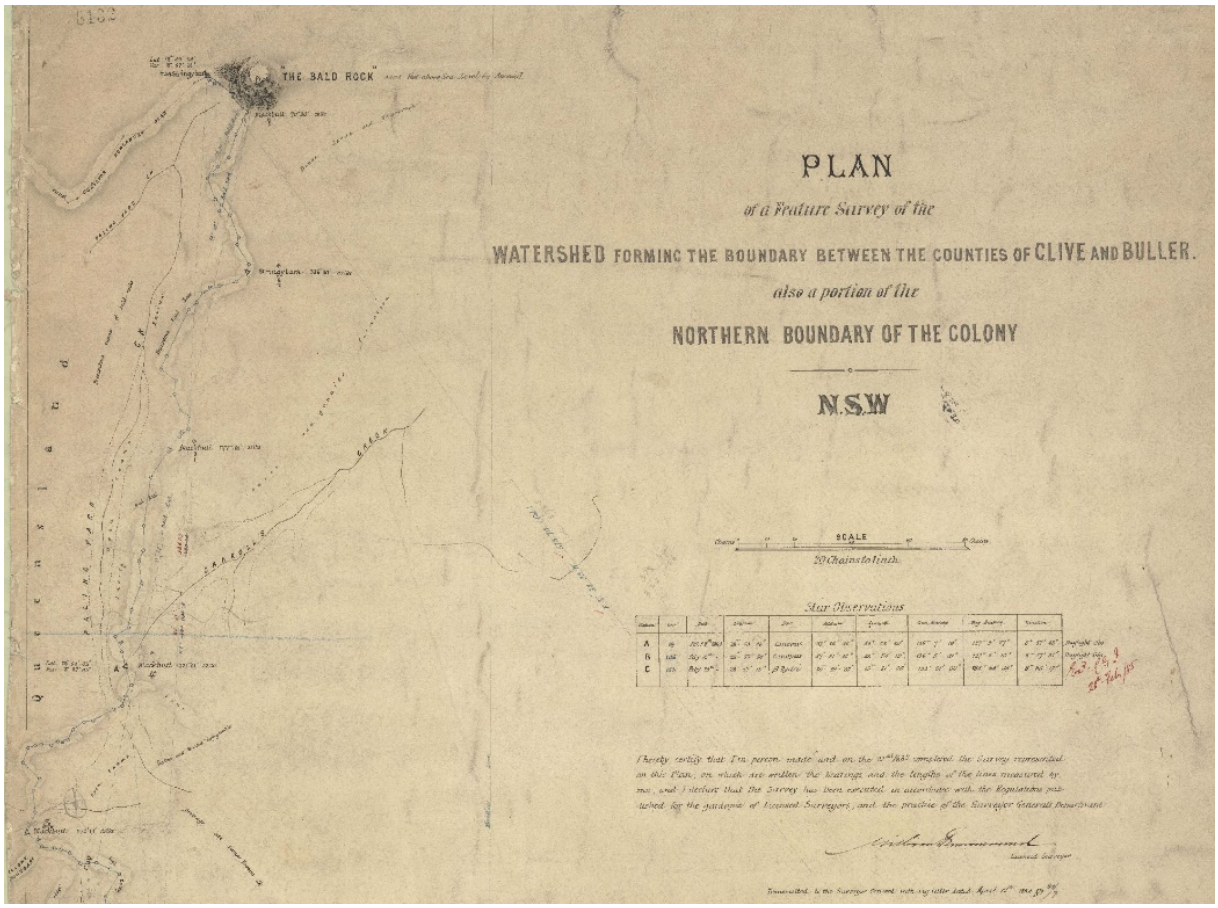

Figure 6: Part of the survey of the watershed by Drummond (Crown Plan 109-3026).

The infestation of ticks was a major issue during the 1930-50s. The NSW Department of Agriculture excluded many areas from adjoining titles in the coastal Queensland area. The Parishes of Tallebudgera and Tenterfield are the few Queensland parishes that alienated land adjacent the NSW-QLD border. Surveyor B.R. Hindmarsh surveyed the watershed and fencing along the border in the area adjoining the Parish of Terranora in 1934 (see Crown Plan 2238-3050, Figure 7), and surveyor Edmund Adrian Du Rieu Hill also surveyed an area adjacent the Parish of Berwick (see Crown Plan 2305-3050, Figure 8).

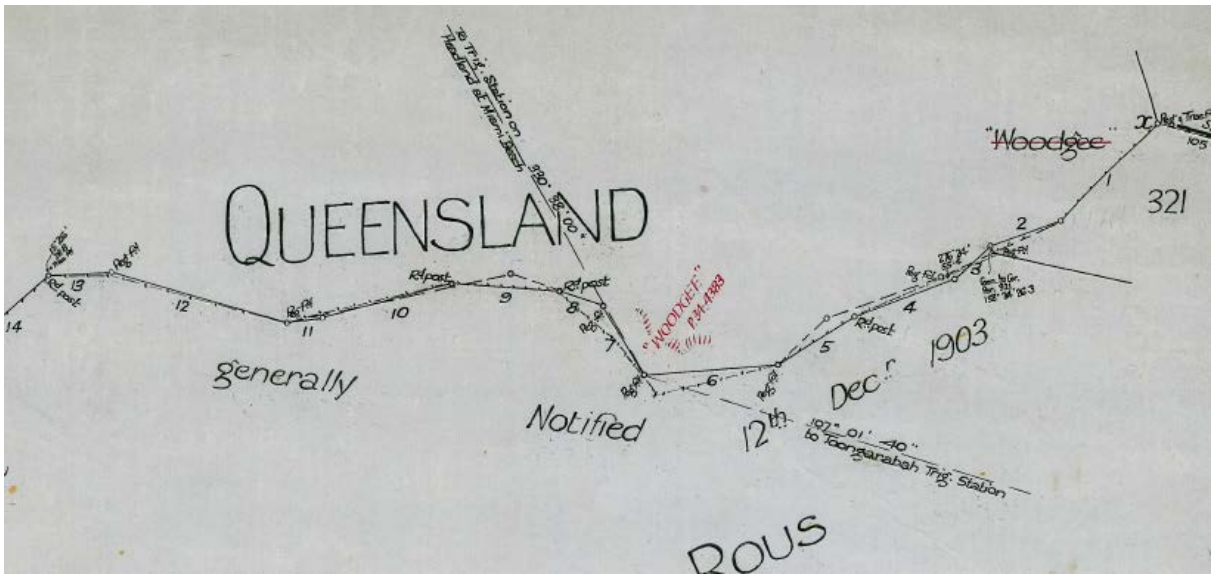

Figure 7: Part of the survey of the watershed of the McPherson Range by Hindmarsh (Crown Plan 2238-3050).

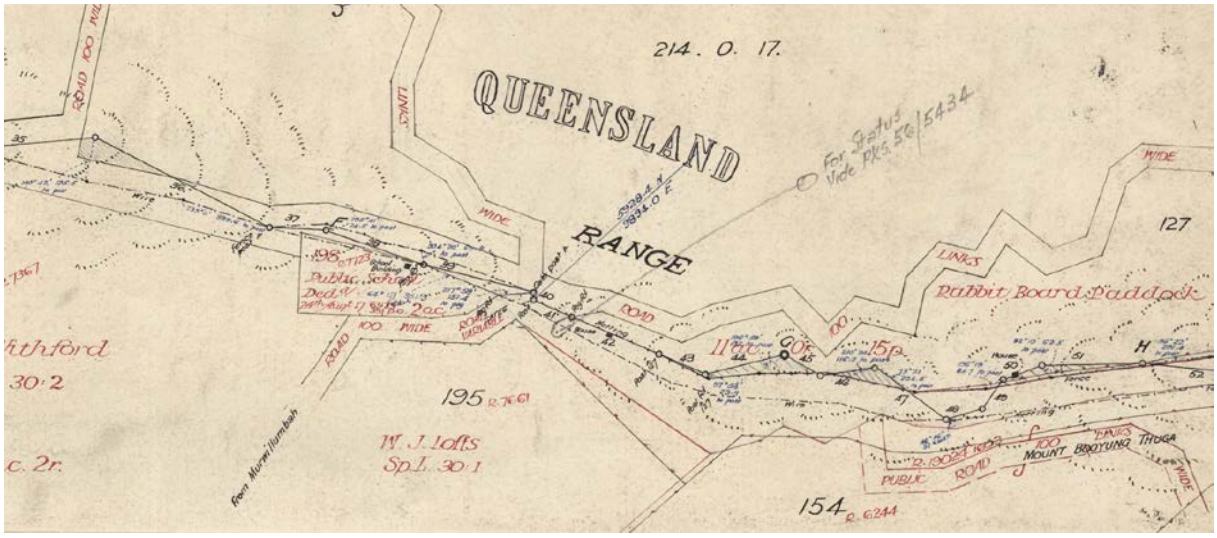

Figure 8: Part of the survey of the watershed of the McPherson Range by Du Rieu Hill (Crown Plan 2305-3050).

These surveys were later followed by land acquisition surveys for the NSW Department of Agriculture by surveyor Stan Hosie (as Hindmarsh was not registered as a surveyor in Queensland) where land was taken from the Queensland titles so that no Queensland title crept over the watershed into the NSW catchments. The theory was that ticks would wash off the cattle in Queensland and roll down the hill into New South Wales. Great attention to detail appears to have been applied to this problem.

Those modern surveys that have been undertaken along the watershed boundary have only redefined small sections relative to the total length of the watershed. The watershed remains largely unsurveyed since its original survey by surveyors Roberts and Rowland.

3.6 DCDB Desktop Upgrade of the Watershed Border

The DCDB desktop upgrade of the watershed border essentially consists of using existing deposited plans with connection to State control survey marks of adequate MGA coordinate accuracy to determine fixed control points on the watershed. The watershed dimensions given

by the existing transcriptions of surveyor Roberts' field books are then swung and proportioned between watershed control points. Unfortunately, Roberts' field books have been lost. Rowland's first field book exists, while his second field book was presumed lost in the Garden Palace fire of 22 September 1882.

The established State control survey network is normally realised within towns and villages or along infrastructure projects and corridors. Very few trigonometrical stations are located along the watershed border, nor are there any established survey marks. In addition, as the area is predominantly covered by state forest, national parks and rural farming, very few subdivisions or surveys have been undertaken since the original land grants along the area of interest. Only in the areas where a survey has been completed that connects from the established network, i.e. since 1990, is it possible to determine a position of the border to any certainty. Therefore, without extensive field work, the entire watershed border feature is very difficult to redefine and locate with any certainty from a DCDB desktop upgrade perspective.

Preliminary work has been undertaken along a 60 km section of the western end of the watershed from the Dumaresq River to Bald Rock (Roberts' watershed corners 1648-1290). There is only one fixed section of watershed control points that provide a reliable definition and position along this section. That section is from an investigation survey (DP1150605) by surveyors David Mallet and Grahame Wallis that redefined Roberts' watershed corners 1595-1608 (Figure 9).

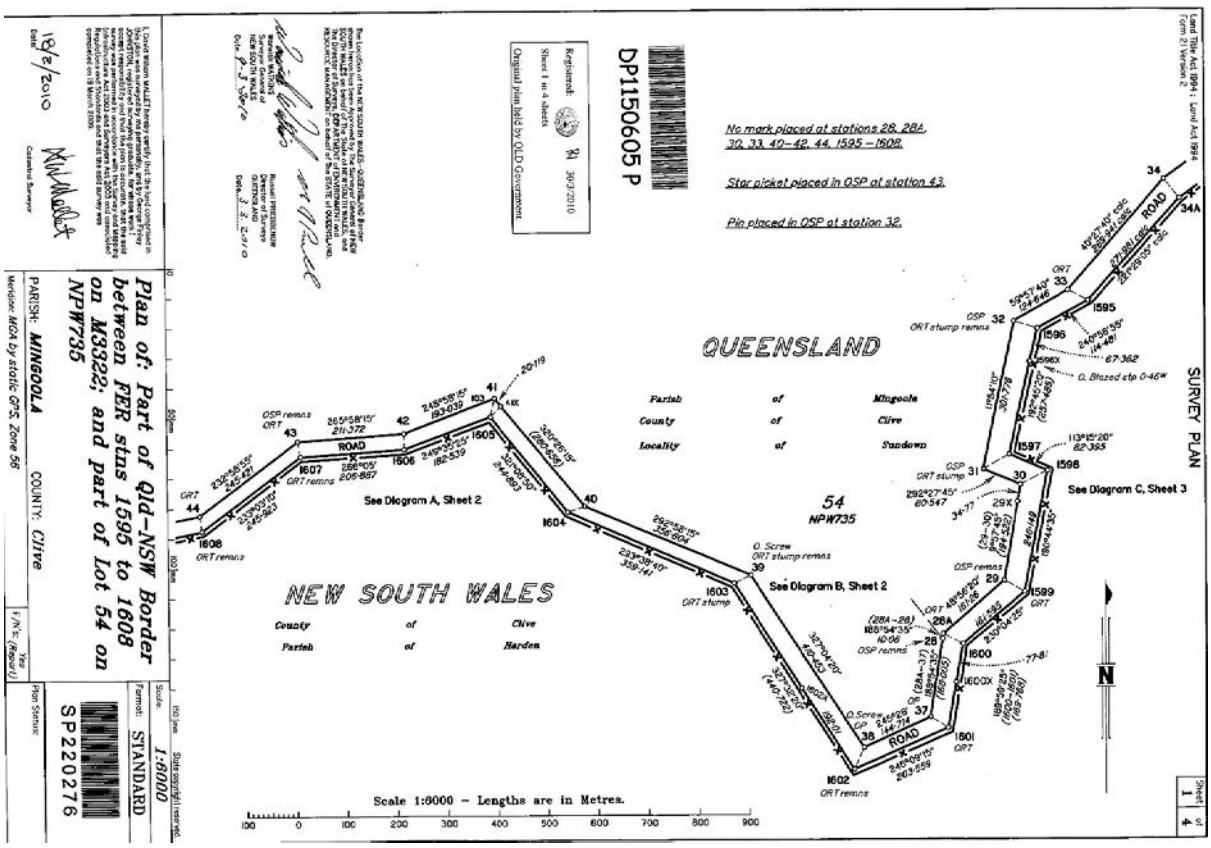

Figure 9: DP1150605 (investigation survey), defining the NSW-QLD border between stations 1595-1608.

Analysis of Table 2 shows the differences in bearings and distances between DP1150605 and surveyor Roberts. It can be seen that the differences are varied and large. The orientation of each line swings approximately ±0.5º and the length has a scale as high as 1.029 or 29 m/km.

The swings and scale factors are consistent with those found for Roberts in the DCDB desktop upgrade, as shown in Table 3 for Roberts' watershed corners 1648-1400. The results (or differences) noted in DP1150605 highlight the size and variability (i.e. 4.8 m per 170 m) of the original border surveys. Due to their varied nature without any ground control to provide constraints, it is very difficult to extrapolate any results that could be considered reliable.

Table 2: Comparisons of bearings and distances of the border between DP1150605 and Roberts.

By F.E. Roberts					By DP1150605		Differences		
From Corner	**To Corner**	**Bearing**	**Distance (links)**	**Distance (m)**	**Bearing**	**Distance (m)**	**Swing**	**Δ Dist.**	**Scale Factor**
1594	1595	213°30'	1,340	269.565	221°29'05"	271.981	+7°59'05"	2.42	1.00896
1595	1596	233°00'	564	113.459	240°58'55"	114.481	+7°58'55"	1.02	1.00901
1596	1597	185°00'	1,250	251.460	192°45'20"	257.485	+7°45'20"	6.03	1.02396
1597	1598	105°30'	400	80.467	113°15'20"	82.395	+7°45'20"	1.93	1.02396
1598	1599	183°00'	1,195	240.396	190°44'35"	246.149	+7°44'35"	5.75	1.02393
1599	1600	222°00'	800	160.934	230°04'25"	161.595	+8°04'25"	0.66	1.00411
1600	1601	182°00'	820	164.958	189°59'25"	169.768	+7°59'25"	4.81	1.02916
1601	1602	238°30'	1,000	201.168	246°09'15"	203.559	+7°39'15	2.39	1.01189
1602	1603	320°00'	2,148	432.109	327°32'20"	440.722	+7°32'20"	8.61	1.01993
1603	1604	286°00'	1,760	354.056	293°38'40"	359.141	+7°38'40"	5.09	1.01436
1604	1605	313°30'	1,200	241.402	321°08'50"	244.893	+7°38'50"	3.49	1.01446
1605	1606	242°00'	900	181.051	249°35'25"	182.539	+7°35'25"	1.49	1.00822
1606	1607	258°30'	1,020	205.191	266°05'00"	206.887	+7°35'00"	1.70	1.00827
1607	1608	225°30'	1,213	244.017	233°03'10"	245.923	+7°33'10"	1.91	1.00781
						Range	**0°32'05"**	**7.95**	**0.0251**

Table 3: DCDB desktop upgrade – swings and scale factors between corners 1648 and 1290.

From Corner	To Corner	Original Surveyor	Swing	Scale Factor
1648	1632	F.E. Roberts	+7°42'25"	1.014190
1632	1608	F.E. Roberts	+7°33'31"	1.016018
1608	1595	F.E. Roberts	+7°44'59"	1.014860
1595	1400	F.E. Roberts	+7°46'43"	1.014296
1400	1398	F.E. Roberts	+8°34'37"	1.011650
1398	1390	F.E. Roberts	+8°30'42"	1.010364
1390	1375	F.E. Roberts	+8°39'41"	1.012226
1375	WD7	W. Drummond	+8°36'42"	1.007969
WD7	WD59	W. Drummond	+8°27'05"	1.001115
WD59	WD74	W. Drummond	+8°21'35"	0.995324
WD74	WD81	W. Drummond	+8°20'28"	0.996714
WD81	WD91 (ref tree for cor. 1373)	W. Drummond	+8°20'28"	0.996714
1373	1366	F.E. Roberts	+8°40'04"	1.013134
1366	1290	F.E. Roberts	+8°21'22"	1.014972

The DCDB desktop upgrade either side of Mallet and Wallis' DP1150605 used fixed watershed control points at Roberts' corner 1632, i.e. a permanent survey mark (PM142367) placed by surveyor Les Gardner through the remains of an original border peg to the west of DP1150605, and eastwards at the town of Jennings, i.e. Roberts' corner 1400. In particular, the section from DP1150605 east to Jennings (Roberts' corners 1595-1400) highlights the essential problem of a DCDB desktop upgrade of the watershed as it is a very long section with no intervening fixed control and suspected major errors in the transcription of Roberts'

field notes. Given also the large variance in the measurement comparisons with Roberts' work (see Tables 2 & 3), the proportioning of such a long section of watershed inevitably leads to severe lack of reliability of the results. Reliability of results can only be achieved with extensive field work.

Table 3 refers to the DCDB desktop upgrade and shows the MGA swings and ground distance scale factors for the sections between the corners for which an MGA coordinate fix has been derived. The prefix 'WD' for the station numbers refers to corners surveyed by William Drummond in the hiatus section of the watershed not surveyed by Roberts between Roberts' corners 1374 and 1375.

Table 3 also reveals what appears to be a neat 1º error in the angle 1401-1400-1399. Thorough examination of old Crown Plans in the area confirms this error in Roberts' original work. This is another example of the errors that could be present in any section of the watershed border. Without sufficient density of watershed control points derived directly from original monumentation, such errors will be very difficult to identify, again reducing the reliability of the results.

The investigation of the section near Bald Rock that was re-surveyed by surveyor William Drummond revealed that the starting point used by Drummond is actually the corner denoted as no. 1373 by Roberts in his original survey, not corner no. 1374 as shown on Drummond's plan 109-3026 (Figure 10). This raises the question as to what constitutes the watershed boundary for this section. This question can only be resolved by mutual agreement between the NSW and Queensland governments.

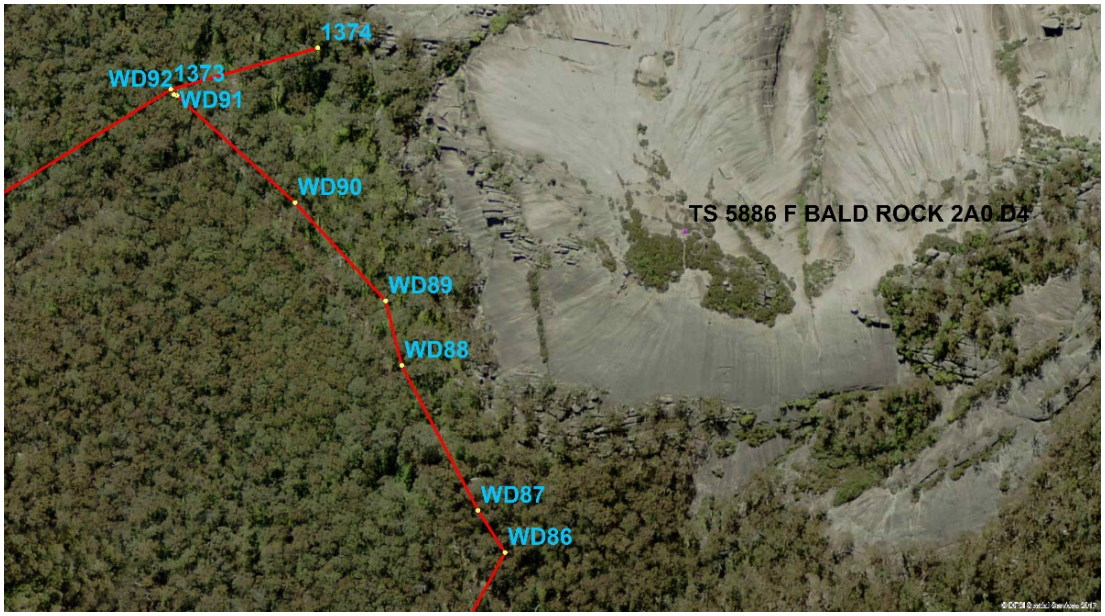

Figure 10: Part of the re-survey of the watershed by Drummond, showing starting point is actually 1373, not 1374. Note that the original border definition has not adopted the true (physical) watershed, as TS5886 is actually located at the top of Bald Rock.

A bare few preliminary GNSS positions on rare original monuments have been available so far to aid in the DCDB upgrade of the NSW-Queensland watershed border. The most notable of these is the substantial rock cairn (Figure 11) found at surveyor Roberts' station no. 1375, being the point of commencement of Roberts' watershed survey after his hiatus west from Bald Rock (the hiatus surveyed by William Drummond).

Figure 11: F.E. Roberts' original rock cairn at station 1375 (photo courtesy Neal Holmes, QLD Department of Natural Resources and Mines).

4 CONCLUDING REMARKS

This paper has outlined a brief history of the NSW-Queensland border with emphasis on the watershed border and has given a summary of the difficulties faced so far as a precursor of the difficulties likely to come in the continued DCDB desktop upgrade of the NSW-Queensland border. Given the paucity of modern border surveys defining the watershed border with reference to original border monumentation and coordinated State control survey marks, any DCDB desktop upgrade of the watershed will not have the rigour associated with a border definition by extensive field work. Such field work would require significant resources. Until a final analysis of all cadastral survey plans has been undertaken in conjunction with extensive field work, a modern and rigorous definition of the NSW-Queensland watershed border cannot be delivered. In the absence of extensive field work, only a line of agreement between the two jurisdictions that equates to a useable description of the watershed border for the purposes of DCDB integrity is possible.

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The Sydney Harbour Bridge High-Precision Terrestrial Laser Scanning Survey and 3D CADD Modelling

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ABSTRACT

Roads and Maritime Services is undertaking design and installation of new Arch Maintenance Units (AMUs) on the Sydney Harbour Bridge (SHB) structure. The key component of the project is precise design and installation of rails, on the eastern and western side of the SHB arch, for the AMUs to travel along. Terrestrial Laser Scanning (TLS) has been identified and implemented as the most suitable technique to provide the high-precision, 3-dimensional Computer-Aided Design and Drafting (CADD) model required for the AMU design, accurate manufacture and installation with minimum onsite modifications. Due to the unique location, safety aspects and high degree of relative accuracy required, this project involved developing and testing unique survey methodologies, utilising bespoke equipment and multiple laser scanners operating concurrently. Point cloud calibration and modelling took into account the continual movement of the bridge, constantly changing coordinate systems and customised modelling procedures to effectively model the iconic structure. This included precisely locating in excess of 41,000 rivets, brackets, hatches, portals, stairs, hand rails and services. To support further investigation of the structural behaviour of the SHB due to train loading, simultaneous monitoring surveys of the eastern and western arches were conducted to determine the relative horizontal and vertical movements at the top of the arch. Survey results assisted with understanding the actual movement patterns and magnitude. This paper presents an overview of the results, including aspects of the many challenges faced on the project, site constraints, safety considerations, design and selection of survey methodologies, customised survey equipment, personnel, data post-processing and modelling methodologies applied to deliver the data to Roads and Maritime G73 specification. Confidentiality and security of the information collected during this project were paramount. It is anticipated that a greater awareness and insight into the complexities of TLS and monitoring of structures will be gained from this paper.

KEYWORDS: *Terrestrial Laser Scanning, Sydney Harbour Bridge, monitoring, survey, high precision.*

1 INTRODUCTION

The Sydney Harbour Bridge (SHB) was designed in 1923 and constructed between 1923 and 1932 following decades of planning. Design and construction work were led by great visionary Civil Engineer, Dr John Job Crew Bradfield (1867-1943).

The SHB holds a significant place and value in the overall landscape of Sydney. It is one of Australia's most iconic heritage structures and a major rail and road arterial route for Sydney. The bridge now carries eight lanes of traffic, two rail lines, a dedicated cycleway and a pedestrian walkway. It supports the transit of an average of 204 heavy trains, more than 160,000 vehicles and 1,900 bikes every day. Since its introduction in 1998, the famous Bridge Climb also attracts hundreds of tourists from around the world to climb the bridge every day.

The maintenance of the SHB is an ongoing, programed task undertaken by Roads and Maritime Services (Roads and Maritime, 2007, 2017). The bridge is exposed to various atmospheric and environmental conditions that cause corrosion of the bridge steelwork and hence significant damage. Endless painting of bridge arches (and all steelwork in general) to protect the structure from corrosion presents a critical part of the maintenance work. In order to improve current maintenance processes, and painting in particular, Roads and Maritime is undertaking detail design, manufacturing and installation of a new mechanical access system to provide environmental and safety benefits. The key component of the project is the precise design and installation of rails on the eastern and western side of the SHB arch for the new Arch Maintenance Units (AMUs) to travel on. Two independent AMUs are proposed to be installed, one on the southern end and the other on the northern end of the bridge. These will travel independently over the arch. The AMUs are described in Figures 1 & 2.

A detail survey of the SHB structure to provide an accurate 3D Computer-Aided Design and Drafting (CADD) model for the AMU's design, manufacture and installation has been the main requirement of this project. The survey was divided into two parts, each with different tolerances required. Figure 3 describes the extent of each part. The relative tolerance required for area 1 (green) was ±3 mm and for area 2 (red) was ±50 mm.

The final 3D model needed to be produced in a file format compatible with Autodesk Inventor design software. Being a non-standard request and a critical point for the project realisation, this presented additional challenges for surveyors.

Terrestrial Laser Scanning (TLS) was recommended by Roads and Maritime as the most efficient methodology to capture the most detail information during field survey. However, it was uncertain if it could produce the final deliverables to the required tolerances. Roads and Maritime Surveying Section invited tenders from a select number of highly reputable Roads and Maritime Geospatial Survey Panel members to develop appropriate survey and processing methodologies to deliver the survey model to Roads and Maritime requirements. Jacobs Group (Australia) Pty Ltd was the successful tenderer and awarded the contract work in July 2017. To ensure the proposed field and processing methodologies would deliver the project requirements, Roads and Maritime required a small test area be completed and delivered first (see Figure 3).

This paper provides an overview of this unique project, including challenges faced, site constraints, safety considerations, design and selection of survey methodologies, customised survey equipment, personnel, data post-processing and modelling methodologies applied to deliver the data to a site-specific Roads and Maritime G73 Detail Survey specification. Confidentiality and security of the information collected during this project were paramount.

Figure 1: Visualisation of the Arch Maintenance Unit (AMU), rails and Bridge Maintenance Unit (BMU).

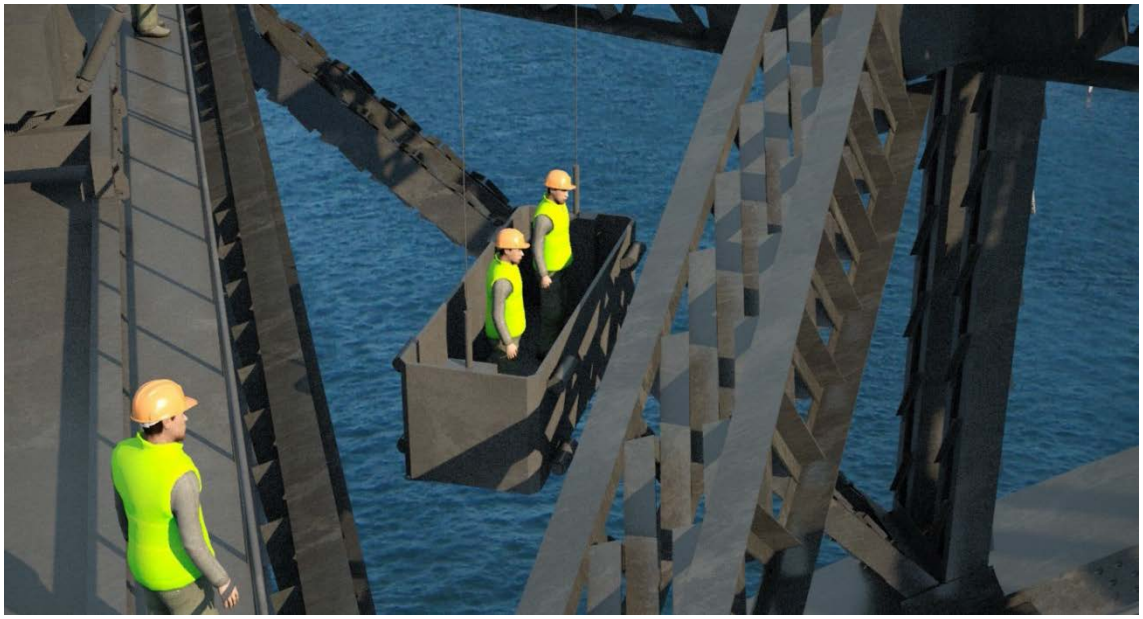


Figure 2: Visualisation of the BMU for difficult-to-access parts.

Figure 3: Areas of the bridge to be surveyed.

2 PROJECT CONSIDERATIONS AND LIMITATIONS

Technical and non-technical challenges associated with this project were overcome through innovation and sound project management involving considerable stakeholder consultation.

2.1 Information Security and Confidentiality

As the owner and operator of the SHB, Roads and Maritime has an obligation to protect the bridge from threats and restrict any information that could be used to plan or facilitate a breach or compromise of security for the bridge.

All those involved on the project were required to complete a Roads and Maritime Confidentiality Agreement that specified information that was to remain classified, including:

- Bridge plans and technical drawings that depict specific locations, measurements and materials of the bridge structures.
- Reports (including text, drawings and photographs) that identify or infer any vulnerability in the structure, bridge systems or maintenance regime.
- Photographs and video or film footage that reveal the assembly of major structural components that are otherwise hidden from public view.
- Any data relating to loading capacity or stress points on the bridge.
- Any details of bridge safety and security systems.

Guidance and assistance with this process was provided by the Critical Infrastructure and Security Resilience Branch within Roads and Maritime.

2.2 Technical Complexities

Technical complexities included:

- Developing and testing unique survey methodologies to deliver the data to the strict tolerances required.
- Programming and duration of surveys (control, detail and monitoring).
- Customised survey equipment.
- Number of highly skilled personnel.
- Survey network design.
- Calibration and control of point cloud data captured on a dynamic bridge structure.

- Customised modelling methodologies applied to deliver the data to Roads and Maritime G73 specification.
- Assurance that the final CADD model would be compatible with Autodesk Inventor design software.
- Large dataset analysis and presentation of the monitoring survey results.

2.3 Non-Technical Complexities

Non-technical complexities included:

- Project management.
- Collaboration and stakeholder consultation.
- Heritage considerations.
- Work Health and Safety (WHS).
- Bridge site access.
- Work around Bridge Climb operational hours.
- Obstructions at bridge walkways (e.g. current painting gantries, various equipment, Bridge Climb groups and temporary removal of steel mesh).
- Weather conditions.

3 ROADS AND MARITIME SURVEY REQUIREMENTS

3.1 Detail Survey and CADD Modelling: Area 1 and Area 2

An accurate 3D CADD model of the SHB arches was required to enable the design, manufacturing and installation of two AMUs and rails for AMUs to travel on. TLS was identified as the most suitable survey technique to provide the high-precision 3D CADD model required.

The survey specifications needed to comply with the Roads and Maritime Quality Assurance (QA) Specification, G73 Detail Survey. The survey area was broken into two parts, as described below.

3.1.1 Area 1

Detail survey and modelling of the inner third of the SHB top surface chord, along both the eastern and western side of the SHB, had to be performed to a relative tolerance of ±3 mm (Figure 4). This was later extended to include the inner two thirds of the chord. This was to include accurate locations of rivets, plates and changes in angle at the node points.

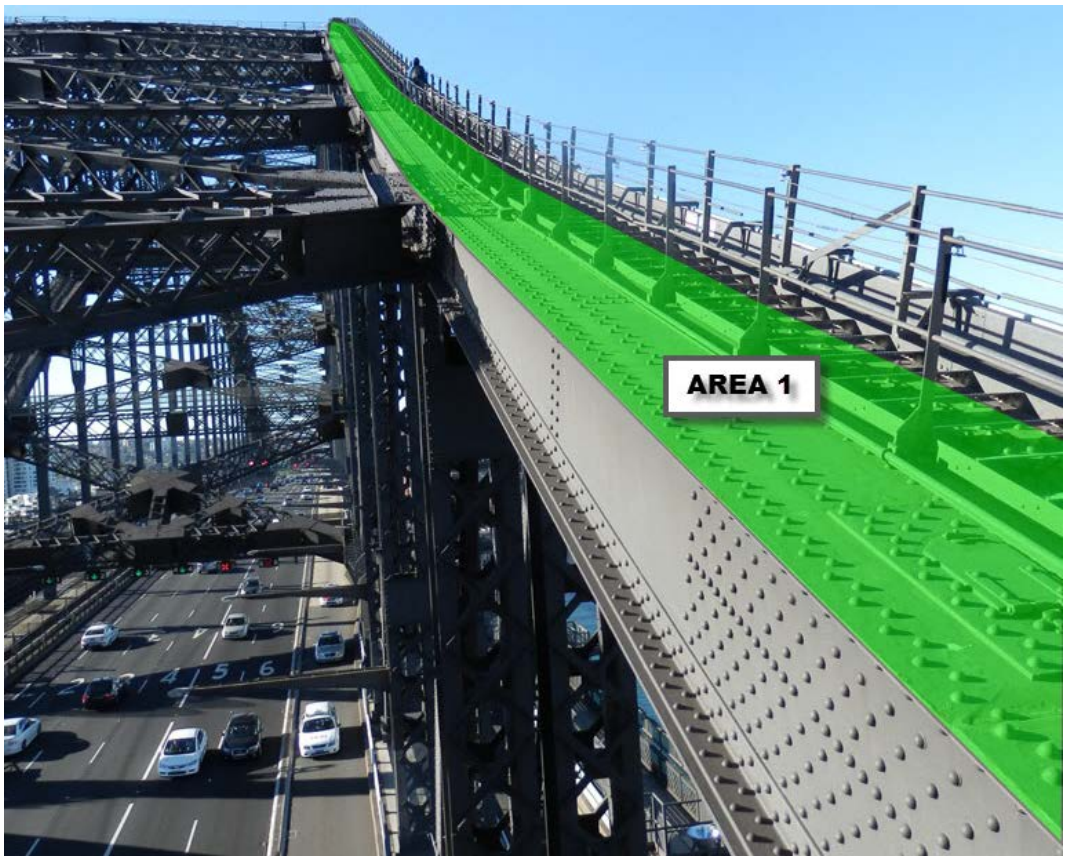


Figure 4: Nominated area 1 for detail survey and modelling (highlighted in green).

3.1.2 Area 2

Detail survey and modelling of the structure down to and including the lower chords had to be performed to a relative tolerance of ±50 mm. The level of detail was less than for area 1 and it was not required to model all the individual bridge elements in detail (Figure 5).

Figure 5: Nominated area 2 for detail survey and modelling (highlighted in red).

3.2 Detail Survey and CADD Modelling: Test Area

This project involved developing and testing unique survey and processing methodologies, utilising multiple laser scanners operating concurrently and the use of customised survey equipment. Significant investigation was required to deliver a 3D CADD model, compatible with Autodesk Inventor design software, which could be successfully used to design new AMUs and rails.

In order to ensure that field and processing survey methodologies were successful and that the deliverables complied with the specifications and tolerances required, a test area was nominated for detail survey and modelling. This test area needed to be completed and accepted in full by Roads and Maritime before proceeding with the survey of the whole project area. Combined top and lower arches, over the length of 20 m at the northern end of the SHB, were nominated as the test area (see Figure 3).

3.3 Survey Control Requirements

The project involved the establishment of suitable survey control network for all the survey activities. The control network was required to comply with class C as outlined in ICSM's Standards and Practices for Control Surveys (SP1), version1.7 (ICSM, 2007). Horizontal positions and levels of control marks were reduced to a plane coordinate system (approximating MGA56, i.e. MGA94 zone 56) and the AHD level (height) datum.

3.4 Monitoring Surveys

In 2015, Roads and Maritime investigated the structural behaviour of the western arch of the SHB due to train loading. This involved simultaneous monitoring surveys of three locations on the western arch (each end and top). Detailed analysis of the survey results determined the movement in the western arch caused by passing trains over the bridge. The largest movements were identified in the top of the arch. Details can be found in Roads and Maritime's 2016 Excellence in Surveying and Spatial Information (EISSI) Award Roads and Maritime nomination.

To better understand the relative horizontal and vertical movement of the two arches, additional simultaneous monitoring surveys of the top arches, on both the western and eastern sides, were required. Monitoring surveys were requested over 2 hours during the morning peak between 7 am and 9 am, when maximum train loading occurs, and over 2 hours well before dawn, when there were no trains on the bridge.

Continuous and simultaneous observations with two total stations of a minimum 1" angular accuracy and at 1-second time intervals were requested. Survey stations were located at ground level. Survey targets were Leica round prisms mounted to the SHB structure with custom-made steel brackets and installed by SHB riggers (Figures 6 & 7).

Monitoring survey results played a critical role in understanding the bridge dynamics and the selection of the most appropriate time window for the TLS survey. To minimise the impact of bridge movement and ensure the relative accuracy of the 3D model could be achieved, all laser scanning was undertaken at night and from approximately 12:30 am to 5 am, when there were no train movements over the bridge. The monitoring survey results also provided important information about relative movements that needed to be considered in the design of

the AMUs.

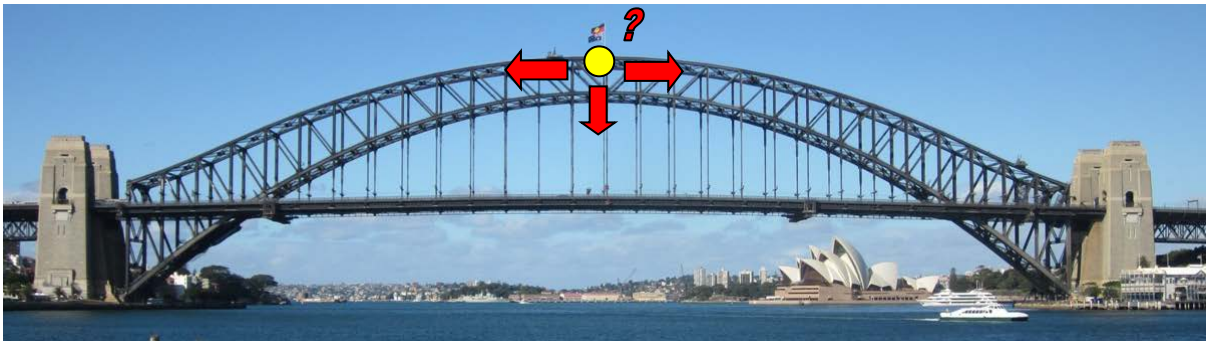


Figure 6: Prism locations on top of the bridge arch, western and eastern side.

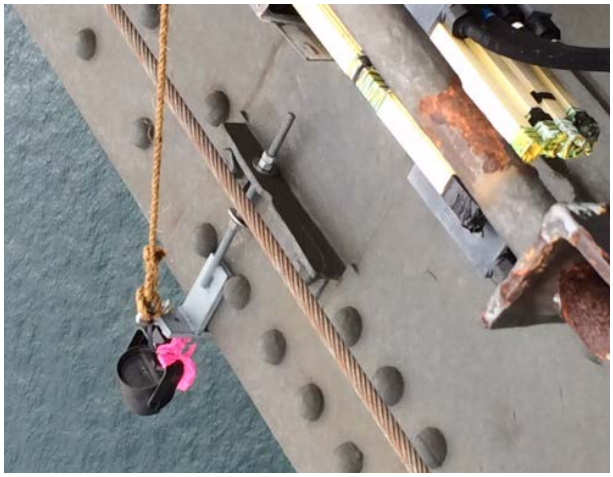


Figure 7: Typical monitoring target with custom-made mounting bracket.

3.5 Other Standard Requirements Unique to Roads and Maritime

As part of a standard Professional Services Contract (PSC) engagement process on Roads and Maritime projects and compliance with Roads and Maritime G73 Specification, Jacobs Group was required to submit evidence of the following hold-point documentation to the Roads and Maritime representative for approval:

- List of survey equipment to be used on this project and calibration records.
- List of surveyors to be working on this project and copies of their qualifications.
- Project QA plan.
- Documented methodology.
- Control survey network.
- Least squares adjustment output.
- Raw and processed survey data.
- Survey reports.
- Spreadsheets of results and graphs.

3.6 Environmental and Heritage Constrains

Compliance with environmental and heritage requirements was critical throughout this project. The SHB has outstanding national and state heritage significance. The bridge structure is protected by the Heritage Act (NSW) 1977 (2010) and its care and management

comply with specific conservation polices.

Heritage constraints for the survey work on this project required that there be no permanent marks or adverse impact on the SHB structure. Customised temporary brackets for survey equipment were designed to accommodate the heritage restrictions (Figure 8). Installation of the specially designed brackets on the steel structure required checking and approval by the SHB engineers.

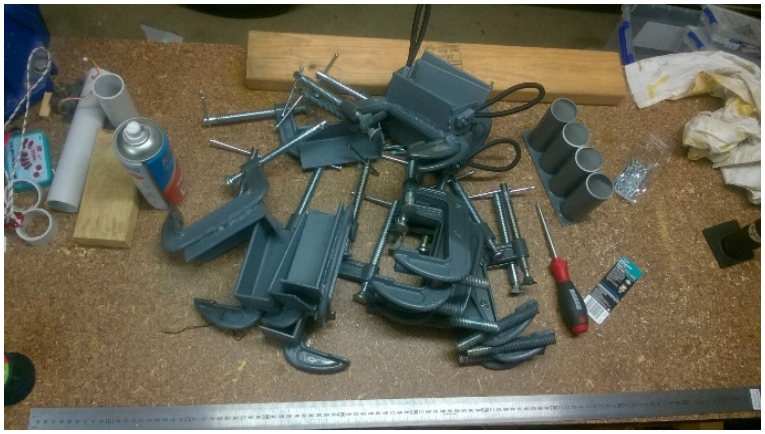


Figure 8: Array of customised mounting brackets.

3.7 WHS and Security

Compliance with Roads and Maritime SHB QA Specification G1 Job Specific Requirements was required for all workers at the site. G1 refers further to compliance with WHS documents and processes, including Roads and Maritime Specification G22 Work Health and Safety (Construction and Maintenance Work) and the SHB WHS Management Plan.

One of the main safety concerns when working on the SHB arches is objects falling from height onto the road or walkways and causing injury or damage. This issue had a significant impact on the survey activities as the team of surveyors carried a lot of survey equipment each night around the site. Each piece of equipment had to be secured by a lanyard to the structure at all times.

Jacobs was required to develop a site-specific Safe Work Method Statement (SWMS) and address all potential risks whilst on the SHB site. This document required approval by the Director Sydney Maintenance, Roads and Maritime. All nominated Jacobs field survey staff attended mandatory SHB site-specific inductions and fully complied with all Roads and Maritime requirements. Police criminal history checks for individual staff were also required to obtain SHB security clearance.

4 MEETING ROADS AND MARITIME CRITERIA AND JACOBS APPROACH

As outlined earlier, the project was broken into a series of tasks, including:

- Survey control: Primary control and scan control prisms.
- Monitoring of the top of the east and west arches (discussed above).
- A test area.
- Survey area 1: Top chord.

- Survey area 2: Mid-level laterals.
- CADD modelling: Feature extraction.

In the following sections, each of these tasks is discussed in detail.

4.1 Survey Control: Primary Control and Scan Control Prisms

A robust survey control network was crucial for undertaking the bridge monitoring portion of the project (Figure 9), and it was a fundamental requirement to achieve the high relative accuracy required for the scanning and subsequent modelling of the bridge structure.

A survey control traverse between existing Survey Control Information Management System (SCIMS) control marks, previous monitoring survey control marks and one new survey control mark was undertaken to provide a fully coordinated survey control network in a plane horizontal coordinate system (approximate MGA) and AHD datum meeting the specifications defined in the Roads and Maritime brief.

Jacobs undertook the control network observations with a 0.5” Leica TS30/60 total station and a Leica DNA03 digital level for height control. Not being feasible to undertake a reliable digital level run across the bridge, Jacobs used constrained centred bi-directional trigonometrical heighting to calculate the height differences across the harbour.

The coordination of the scanning control prisms was undertaken prior to the scanning work and consisted of firstly coordinating four high-accuracy 360 prisms, one on each of the four bridge pylons. SHB riggers installed the prisms using special mounting adapters specifically fabricated to allow attachment to the hand rails around the top of the pylons (Figure 10).

Interrogation of an existing Mobile Laser Scanning (MLS) point cloud, acquired by Jacobs from the deck of the bridge for an earlier project, showed that it would not always be possible to see the four 360 prisms installed on the pylons and that additional control prisms would be required on both the upper and lower chords of the arch (Figure 11).

All network control observations were adjusted in a minimally constrained ‘freenet’ adjustment and achieved class B for the prisms mounted on the top of each pylon. The traverse was constrained by adopting PM285 and SS175644, achieving order 2 (Figure 12). AHD values for PM285 and SS175645 were adopted for height. Trigonometrical heighting checks agreed within 0.005 m across the harbour. The survey coordinates were then converted to a plane datum (holding the MGA coordinates of PM285 fixed), providing a plane horizontal datum and AHD for height.

It was from this control network that the multiple image targets captured in each of the laser scans were coordinated. Targets were coordinated using resection techniques, taking into account atmospheric corrections throughout each night and adjusted using CompNet version 2.9 to provide the plane coordinates used for the registration of each scan.

Figure 9: Survey control network.

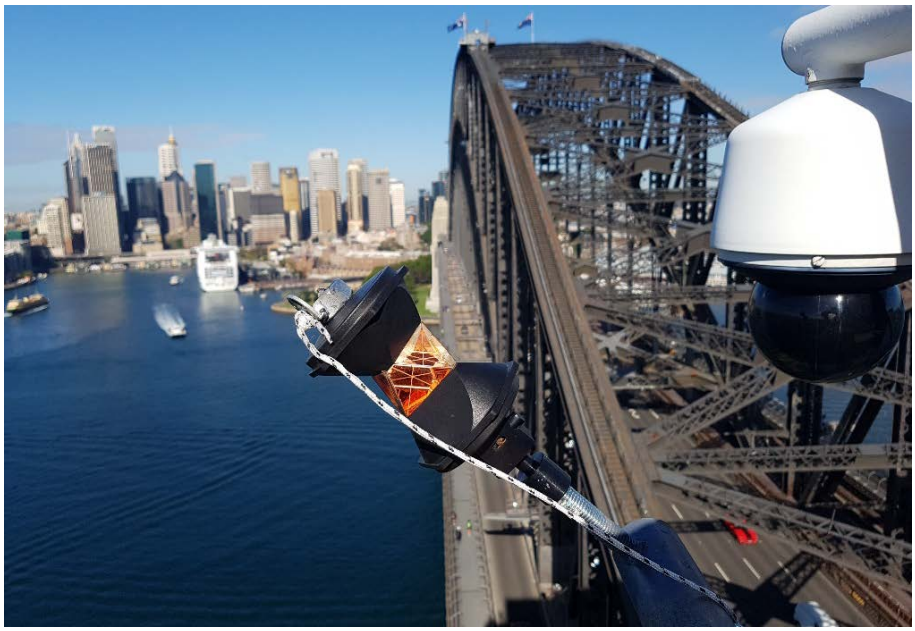


Figure 10: Typical 360 prism install at the pylons.

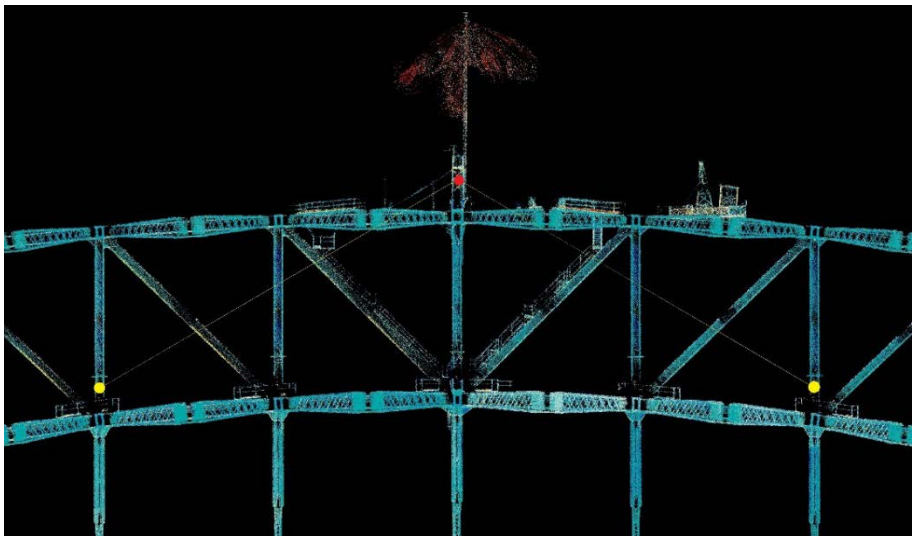


Figure 11: MLS point cloud and selection of lower chord prism locations.

Figure 12: Primary control mark.

4.2 Initial Proposed Methodology

The proposal phase of the project included extensive investigation by Jacobs into how the project could be carried out. The methodology proposed included using two Leica P40 laser scanners simultaneously, one on each side of the arch (within the walkway), with individual scans taken every 5 m over a length of 520 m. Four laser scan targets were to be placed on the outside edge of each walkway and coordinated, so that each scan registration was able to use up to eight targets (Figure 13).

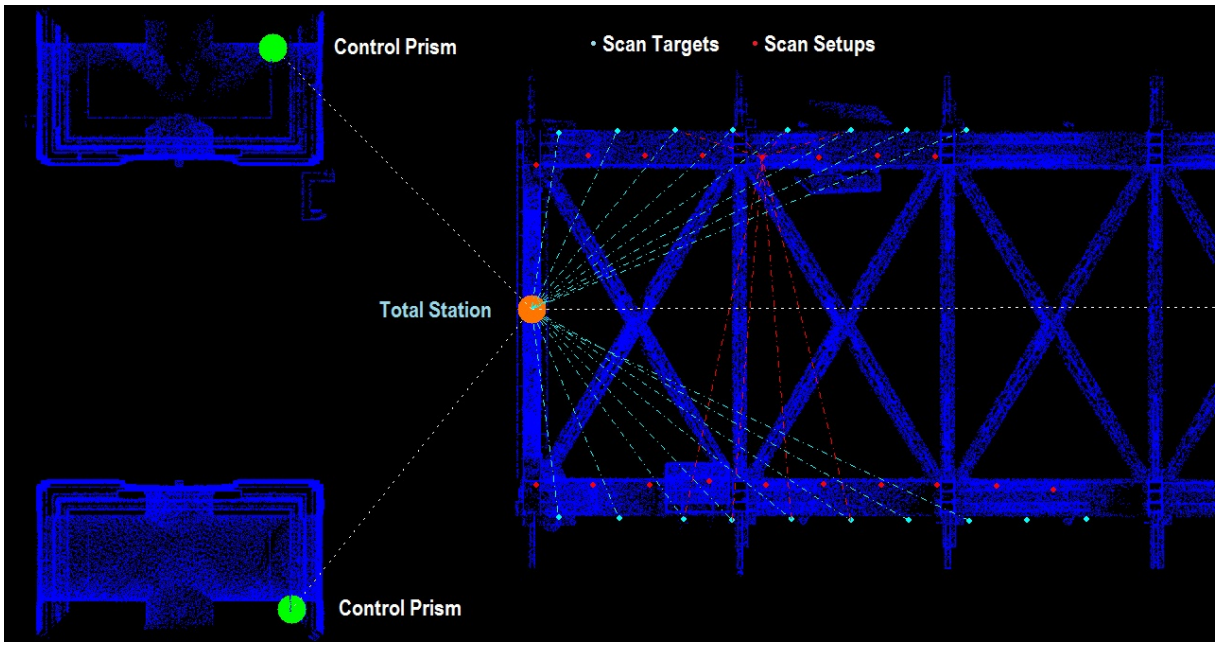


Figure 13: Indicative scan and target locations.

The initial concept involved setting the laser scanners up on custom-made scanning platforms clamped onto the steel stair stringers. The scanning platforms were to be attached near a guidepost anchor to minimise any lateral movement. The scanners were to be set up on an adjustable mount built in a 'T' format that lies across the stairs from stringer to stringer with the third arm attached to an adjustable magnet to sit on the flat of the arch between the steps. The adjustable platform could accommodate the varying incline of the bridge chord that varies from approximately 26º to zero at the top (Figure 14).

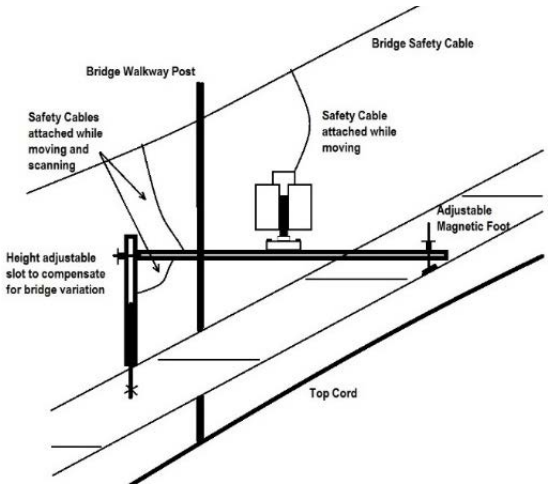


Figure 14: Proposed adjustable scan mount.

In addition to the 5 m scan locations, Jacobs had proposed to undertake a tripod-mounted scan approximately every 20 m along the walkway that would give a viewpoint from above the railing. The four laser scan targets on each side were composed of a G-clamp with welded 5/8th thread that the rotating laser scan targets screwed onto. Each target had a cable (lanyard) and carabiner that could be attached to the bridge walk safety cable while in place or attached to a carabiner on the workers belt while moving (Figure 15). The targets were attached to the upright guiderail poles running alongside the walkway, which are securely attached to the bridge chord and are the most solid structure available. The targets were to be located on the outside-edge guide posts at a distance of between 2.5 m and 5 m from each laser scanner.

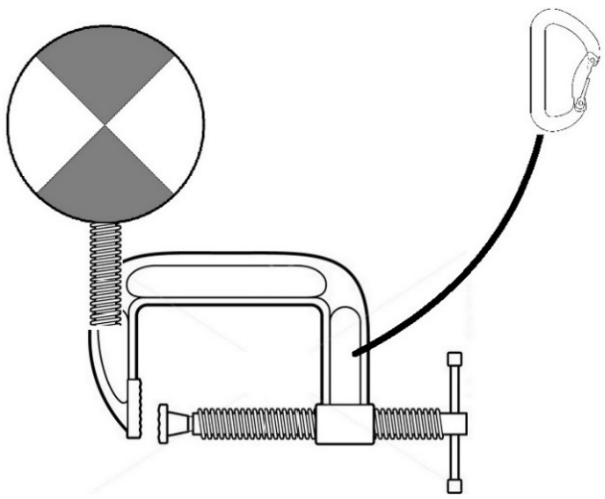


Figure 15: Proposed target attachment.

The total station setup locations were proposed to be on the cross walkways between the arches where they would have line of sight to coordinate each of the laser scan targets and be able to make check measurements between the arches from a single setup. Laser scan targets were be coordinated using a Leica TS15 1” instrument as a single set of four arcs, with the first and last observation arcs being to the control prisms. Atmospheric measurements were to be recorded and set within the instrument. Averaging limits of 5 mm would be in place within the sets of angles to alert the survey staff if any target measurements exceed these limits.

The methodology included a 5-person survey team, with one surveyor operating the total station and coordinating the laser scan targets, two surveyors to operate the two laser scanners and two surveyors moving the targets.

To assist with infilling data for both area 1 and area 2, it was proposed to undertake a series of laser scans on the lower level walkway in a similar fashion to the top level scans in order to capture additional detail not visible from the top or the road. This would equate to approximately another 20 scans on each side (Figure 16).

Figure 16: Lower chord scan positions.

4.3 Survey Area 2: Lower Arches

As discussed above, Jacobs was fortunate to have captured an MLS point cloud over the deck of the Sydney Harbour Bridge for the Roads and Maritime M1 Smart Motorway project. The existing cloud is highly detailed, with over 400 million points captured between the main bridge pylons (Figure 17). The existing point cloud had a relaxed accuracy of approximately ±100 mm, however Jacobs were able to improve this to well beyond the required ±50 mm and use this point cloud to model the additional detail required.

Figure 17: M1 Smart Motorway MLS.

4.4 Test Area

As required by Roads and Maritime, Jacobs undertook an initial pilot survey of the test area on the northern side of the bridge. The pilot survey involved a team of five surveyors, two Leica P40 scanners, one Leica TS60 total station, eight scan targets and dozens of mounting brackets and lanyards. The scanning included the first four spans of the bridge structure and was undertaken in a single night (Figure 18).

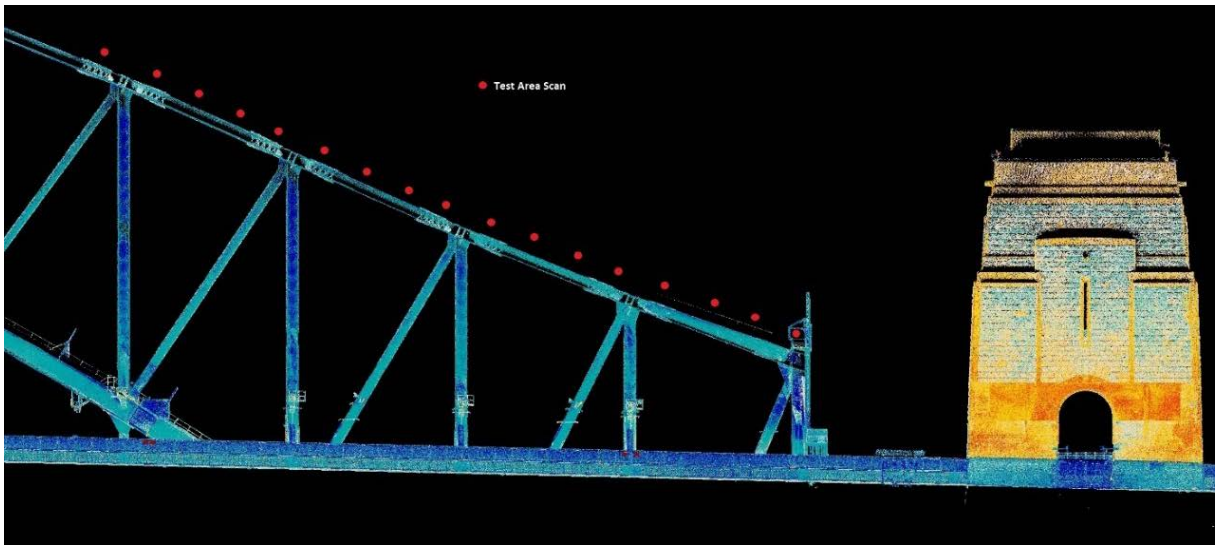


Figure 18: Test area scan locations.

4.5 Lessons Learned, Issues Encountered and Revised Scanning Methodology

After scanning the test area, there was a scope change to increase the scan coverage of the upper chord from the inner third up to the inner two thirds. This required a revised approach as it was now a requirement to survey a significant number of rivets located underneath the steps on the walkway.

The following is a summary of the revised methodology required to either meet the change in scope, or to address shortcomings of the initial proposed methodology:

- As the scope now required full survey data below the steps on the walkways, the scan distance was changed from every 5 m down to every 3.75 m or approximately every second walkway pole.
- Jacobs had developed platforms to mount the P40 scanners that securely attached to the step treads and stringers (Figure 19). However, it became apparent after the test that the platforms were cumbersome and time-intensive to set up and, more critically, there were shadow areas in the resultant cloud as the scanner was not positioned high enough to see over the stair stringers into the inner half of the chords.
- After the test, the scanning platforms were abandoned in favour of tripods. The extra height of the tripod yielded better point cloud coverage. Two feet of the tripods were held by G-clamp brackets to the base of hand rail uprights, the remaining foot was held by a magnet (Figure 20). Tripod setups were more likely to be affected by wind, so scanning was only undertaken in light winds.
- Upon processing and registering the point cloud from this first night, it became apparent that the targets furthest away from each scanner exhibited poor orientation towards the far scanner. Whilst the initial methodology was to scan concurrently to minimise any relative movement (east/west) between the chords, it was necessary to scan on one side first with all targets orientated towards the active scanner, then reorientate the targets and carry out the second scan (Figure 21). Typically there were only 20-30 seconds between the first scanner finishing and the opposite scanner starting. This resulted in a minor increase in scanning time.

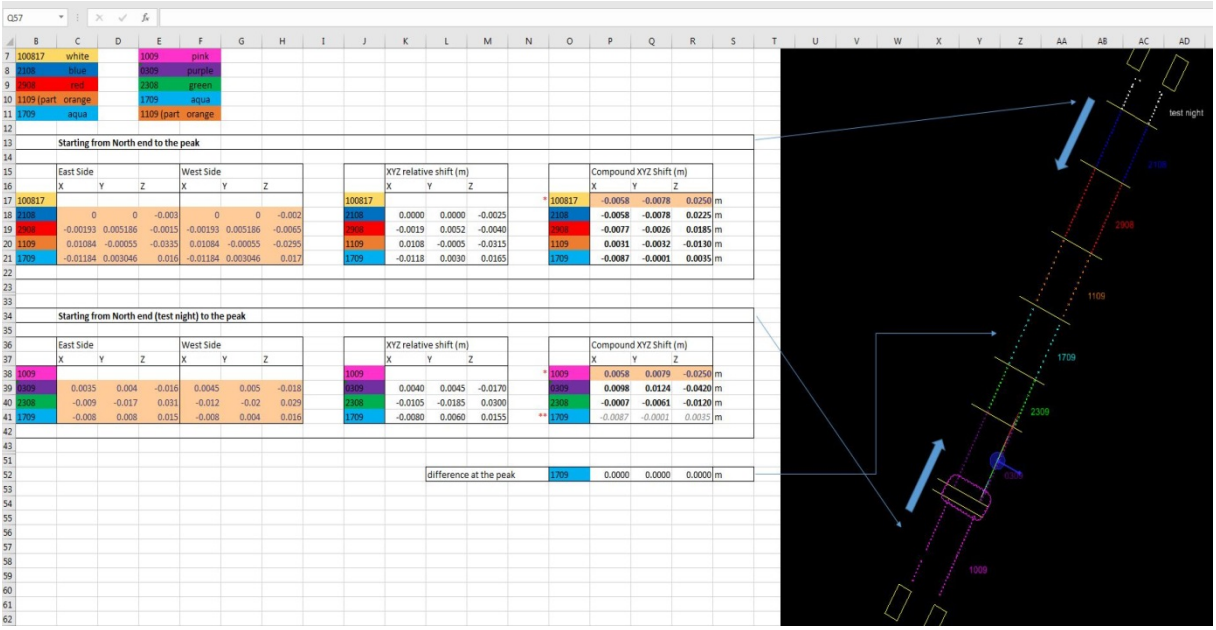
Figure 19: Trial adjustable scan platform.

Figure 20: Tripod leg attachment.

Figure 21: Scan target attachment.

- Total station location: The position of the total station used to coordinate the laser scan targets and take the QQ measurements between the chords, was initially proposed to be located centrally on the transverse walkways to allow a clear view of all scan targets. This was not possible on the north end as this position is not accessible. The other walkways were found to be unstable. To address this, the total station was positioned on the chords either uphill or downhill from the scan locations and did require several re-setups during each night. This had a small impact on the scan rates and also the capture of QQ points. As per the initial plan, the total station was coordinated by resection using visible pylon prisms, additional prisms placed on the bridge and survey control marks on the ground.
- Due to the amount of survey equipment necessary to take onto the bridge each night, all equipment (with the exception of laser scanners and total station) were stored in a locker room within the pylons overnight.
- Each night, equipment was taken onto the bridge and set up prior to the last scheduled train. Scanning was undertaken between approximately 12:30 am and 4:30 am while no trains were running.

- Walkway covering: Walkways at the top of the bridge have no steps installed and are instead covered with steel or fiberglass mesh and carpet to eliminate slips and provide safe walking of bridge climbers. These covers can only be temporarily removed overnight between Bridge Climb tours. After the initial scope was extended to cover the inner two thirds of the chord, the grated walkway covering at the top of the bridge became an issue as it significantly obstructs the rivets and structure below. Capture of these rivets will require the removal of steel or fibreglass mesh with carpet at a later stage and has been excluded from the current scanning/modelling scope until a feasible system for the capture can be developed.
- Painting equipment, scaffolding and existing AMUs: The existing AMUs and equipment related to painting caused minor obstructions to the laser scanning. This was addressed as much as possible on site. However, one of the existing AMUs was unable to be moved and has resulted in some data shadows. Some additional scanning may be required to capture the missing bridge detail – this could possibly be done when the walkway scanning is undertaken.
- Survey QQ points: Poor lighting and difficult access meant that it was not possible to accurately measure to the outside of the chord. As an alternative, check measurements were taken between the top centre of rivets on each side of the bridge and these coordinates used to evaluate the absolute and relative accuracy of the laser point cloud. Reflectorless observations proved to be problematic, due to insufficient light, so a mini-prism was used to measure to the top of the rivets.
- Bridge contraction and nightly adjustment: After several nights of laser scanning had been completed, it was discovered that there was a noticeable movement of the bridge structure over the course of each night due to the contraction of the steel. In short, this equated to a mostly vertical shift of up to 15 mm in the position of the bridge structure at the start of the night compared to the end of the night. This had some effect of the correctness of QQ shots taken if the observation time differed significantly to when the scanning was undertaken. The main impact was on the relative position of each consecutive night's scans. When fixing each end of the bridge and connecting each consecutive night's scans, it resulted in an approximately 60-70 mm height difference at the flag poles at the top of the arch. After consultation with Roads and Maritime, this was addressed by adjusting each night's absolute position slightly (Figure 22).
- During each night, there were often unscheduled train movements across the bridge. This required suspending operations until the train had passed. We understand that these movements were as a result of Sydney Trains repositioning empty trains around their network. These train movements had a small but noticeable impact on the laser scan rate.
- The southern pylon king post lift was not working for a portion of the project. This required the team to carry equipment across the bridge on some occasions. This also had an effect on the order that the scanning was undertaken in.
- Truck movements were found to have a noticeable effect on the bridge, with larger trucks causing the deck and structure to 'bounce' slightly. While these movements are unavoidable, we believe they had a small effect on the laser scan registrations, with the largest error vectors generally being in the Z direction.



100817	white		1009	pink
2108	blue		0309	purple
2908	red		2308	green
1109 (part	orange		1709	aqua
1709	aqua		1109 (part	orange

Starting from North end to the peak

	East Side X	Y	Z	West Side X	Y	Z
100817						
2108	0	0	-0.003	0	0	-0.002
2908	-0.00193	0.005186	-0.0015	-0.00193	0.005186	-0.0065
1109	0.01084	-0.00055	-0.0335	0.01084	-0.00055	-0.0295
1709	-0.01184	0.003046	0.016	-0.01184	0.003046	0.017

	XYZ relative shift (m) X	Y	Z
100817			
2108	0.0000	0.0000	-0.0025
2908	-0.0019	0.0052	-0.0040
1109	0.0108	-0.0005	-0.0315
1709	-0.0118	0.0030	0.0165

		Compound XYZ Shift (m) X	Y	Z	
*	100817	-0.0058	-0.0078	0.0250	m
	2108	-0.0058	-0.0078	0.0225	m
	2908	-0.0077	-0.0026	0.0185	m
	1109	0.0031	-0.0032	-0.0130	m
	1709	-0.0087	-0.0001	0.0035	m

Starting from North end (test night) to the peak

	East Side X	Y	Z	West Side X	Y	Z
1009						
0309	0.0035	0.004	-0.016	0.0045	0.005	-0.018
2308	-0.009	-0.017	0.031	-0.012	-0.02	0.029
1709	-0.008	0.008	0.015	-0.008	0.004	0.016

	XYZ relative shift (m) X	Y	Z
1009			
0309	0.0040	0.0045	-0.0170
2308	-0.0105	-0.0185	0.0300
1709	-0.0080	0.0060	0.0155

		Compound XYZ Shift (m) X	Y	Z	
*	1009	0.0058	0.0079	-0.0250	m
	0309	0.0098	0.0124	-0.0420	m
	2308	-0.0007	-0.0061	-0.0120	m
**	1709	-0.0087	-0.0001	0.0035	m

difference at the peak	1709	0.0000	0.0000	0.0000 m

Figure 22: Night vertical shifts.

5 DATA EXTRACTION AND MODELLING

Jacobs utilised Microstation Topodot software to undertake the 3D modelling exercise. Modelling was required of the following bridge elements:

- Arch edges.
- Changes in angle.
- Existing rail connection.
- Plate locations.
- Rivet locations.
- Hanger posts.
- Stringers.
- Hand rails.
- Cross-girders.
- Cable trays/conduits.
- Laterals.
- Other infrastructure.

The modelling involved extensive consultation with both Roads and Maritime and Design Company engaged and has gone through a significant number of modifications and variations. This section summarises the issues encountered and how they were addressed.

The initial proposal was to model the structures as a series of vectors as a wireframe. However, it became apparent that the design package Autodesk Inventor could not effectively use a wireframe and so modelling as complex 3D solids was required. Unlike a wireframe, where the edges can be vectorised relatively quickly, this significantly complicated the modelling process, effectively increasing the modelling time by approximately 25-30%.

It was requested that Jacobs model all rivets within the scope area as a 3D dome. This was a significant endeavour as there were approximately 40,000 rivets to be modelled. These were

modelled initially as a 2D circle placed perpendicular to each major bridge plate, which was then draped onto the surface of the plate to create the base of the dome and provide the axis/rotation for the dome (Figure 23).

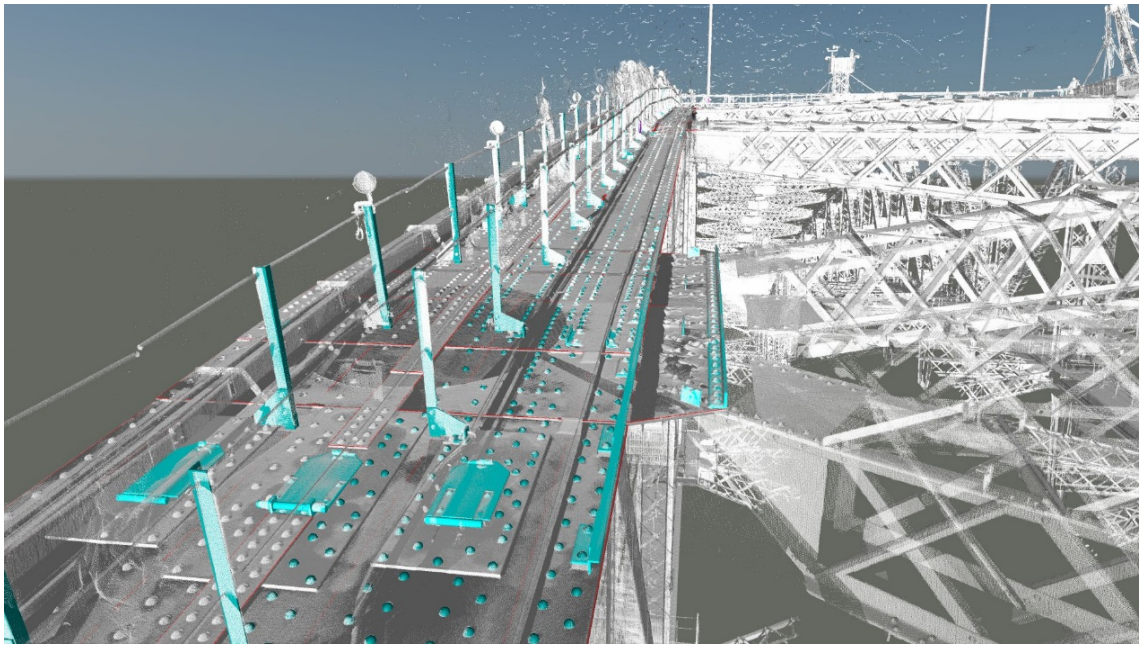


Figure 23: Solids modelling over point cloud.

There was an amount of shadowing from obstructions, particularly from the walkway step treads. If there was not enough cloud to accurately model the rivet, then an approximation was made as a best fit and moved to a secondary layer tagged with an uncertainty. The modelling and placement of rivets included development of a script to help automate the process.

Together with the additional modelling across the chord, there was a request to model one cross walkway in high detail (other elements/structures in this area were only modelled in low detail to ±50 mm), with the intention of highlighting what features and obstructions the new AMUs may have to navigate as they make their way up the bridge (Figure 24).

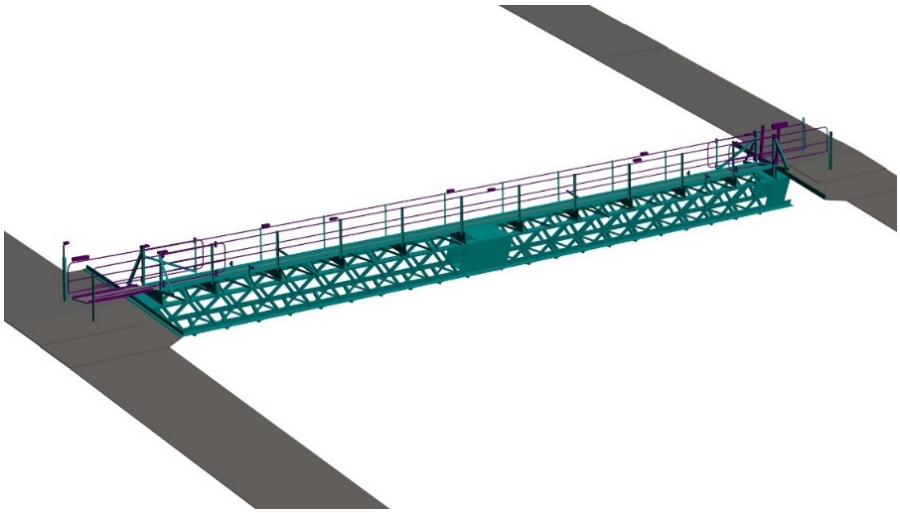


Figure 24: Detailed modelling of connecting walkway.

Element deformation: As the project progressed, it became evident that the bridge was far from uniform; in fact it showed a series of deformed and warped elements. This meant that the original methods of modelling that had a level of generalisation did not meet the accuracy requirements for the modelling, a much higher level of sampling was required than originally planned. In addition, it was requested that objects modelled be independently positioned and orientated, and a significant number of unique features were modelled. It was also noted that many of the edges in many of the plates were difficult to distinguish as their edges had been filled in, possibly to limit water pooling and further corrosion.

Coordinates: Jacobs modelled the bridge in plane (approximate MGA) coordinates as required by the project brief. The number of significant digits in the coordinates caused difficulties importing the model and displaying correctly in Inventor. It was found that Inventor could not display complex 3D surfaces in real-world coordinates. Despite spending many days trialling different formats and coordinate options for an import solution into Inventor, it was necessary to shift the model back to a 0,0,0 origin.

Data format: The original proposal intended to provide the extracted model in a DWG format. However, this did not import correctly into the design package (Inventor), despite being an Autodesk product. This required significant trial and error, and in conjunction with the coordinate issue there were issues with certain objects (e.g. complex 3D solids and extrusions) not converting with errors or not converting at all.

Additional data sources: Jacobs spent significant time investigating the existing plans to obtain a more complete understanding of the bridge elements than what was visible from the cloud only. This allowed more accurate interpretation of structure elements to be modelled than could be observed from the cloud alone and helped provide a more complete and accurate model.

Modelling of survey area 2 was simpler and required a lower accuracy, providing just the shapes of the main beams and excluding small lateral beams, with the intention of modelling to only show structures, which could potentially impede the clearance of the AMU or the painting module that will be deployed.

6 RESULTS

6.1 Monitoring Survey and Results

6.1.1 Monitoring Survey: Night

Relative horizontal and vertical movements were presented as differences from the initial observation recorded (XYZ) at time 00:35:53, along the bridge alignment and with *positive* directions for offset X-East, chainage Y-North and height Z-Up. Monitoring survey results and individual observations were presented in Excel spreadsheet tables and graphs.

The survey results indicate the magnitude of the movements is generally consistent and stable in both survey targets, at the western and eastern top arches. No significant changes in horizontal position and level were identified in both monitoring targets for the duration of the survey, except at one event at time 02:02:30. Times and descriptions of train passes were not recorded during this survey. It has been assumed that the sudden movement in both observed

targets for a short time was caused by an irregular train passing over the bridge. This event has caused a change of more than 10 mm in offset, chainage and level in the western target and a drop of more than 10 mm in offset only in the eastern target.

The survey results further indicate changes in the western and eastern top arches at the same time (Tables 1 & 2). It should be noted that the observations during the train event from 2:02:26 to 2:02:37 were excluded from the dataset.

Table 1: Western top arch movements (night).

Top Arch West	**Range**		**Average**
	From [mm]	**To [mm]**	**[mm]**
Offset X	-6	13	4
Chainage Y	-6	7	-1
Height Z	-13	10	-7

Table 2: Eastern top arch movements (night).

Top Arch East	**Range**		**Average**
	From [mm]	**To [mm]**	**[mm]**
Offset X	-6	8	0
Chainage Y	-5	5	0
Height Z	-9	8	-3

Analysis of the night-monitoring survey results indicates:

- Eastern top arch target being more stable than western top arch target. More noise was detected in the 3D position of the western top arch.
- Progressive drop in level in the *western* top arch target by the end of the survey to around 10 mm progressive increase in leaning towards the western direction to around 5 mm, and unchanged chainage.
- No significant change in the *eastern* top arch target, except a slight progressive drop in level to around 5 mm by the end of the survey.
- Maximum changes in 3D position identified in the eastern top arch have not been recorded during the train event, they have occurred at different times. These changes may have been caused by heavy trucks crossing the bridge. Details of road traffic were not recorded during survey.

6.1.2 Monitoring Survey: Day

Relative horizontal and vertical movements were presented as differences from the initial observation recorded (XYZ) at time 06:55:45, along the bridge alignment and with *positive* directions for offset X-East, chainage Y-North and height Z-Up.

Times and descriptions of train passes were not recorded during this survey. The relative movements of the two prisms correlate with the movement of trains over the bridge. The magnitude of the movements is generally consistent and repeatable.

The survey results indicate changes in western and eastern top arches at the same time (Tables 3 & 4).

Table 3: Western top arch movements (day).

Top Arch West	Range From [mm]	Range To [mm]	Average [mm]
Offset X	-31	9	1
Chainage Y	-13	13	0
Height Z	-40	6	-2

Table 4: Eastern top arch movements (day).

Top Arch East	Range From [mm]	Range To [mm]	Average [mm]
Offset X	-46	7	-6
Chainage Y	-10	15	0
Height Z	-6	24	5

Analysis of the day-monitoring survey results reveals:

- 64 'spikes' indicating change from the nominal position in both western and eastern top arch targets for the duration of the survey (over 132 minutes). These changes have been caused by single or multiple trains passing the bridge in each direction.
- There is a typical shape and magnitude of 3D movement in western and eastern top arch targets at the *same time*, as shown in Figures 25 & 26 (sample data shown are simultaneous observations taken at 1-second interval and over 70 seconds, from 6:57:58 to 6:59:08).

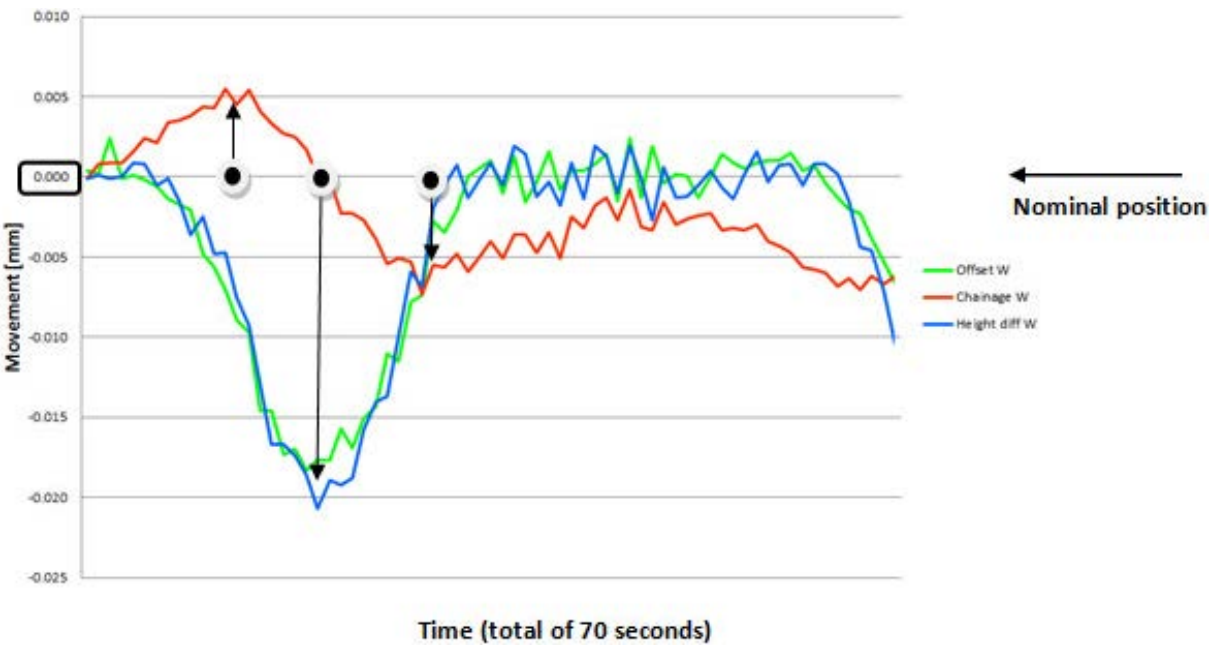


Figure 25: Typical 3D movement at SHB west top arch (observations at 1-second interval).

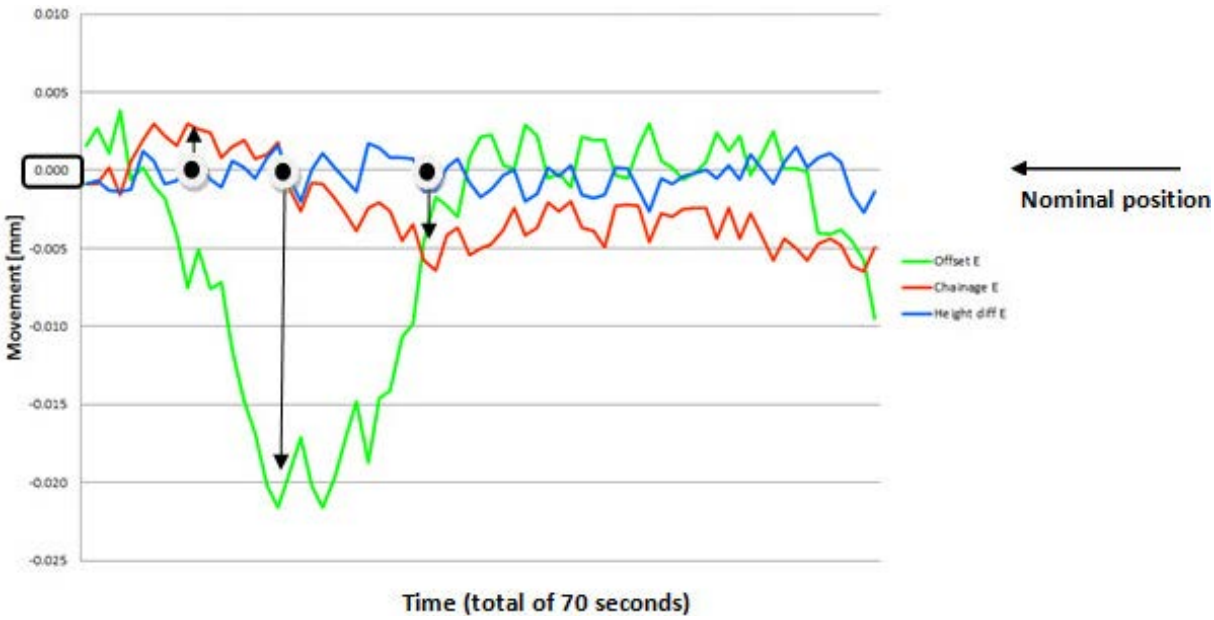


Figure 26: Typical 3D movement at SHB east top arch (observations at 1-second interval).

Generally, when trains reach the centre of the bridge, the western top arch leans towards the west and drops in level at a similar magnitude. Changes in chainage (up and then down) indicate that the western top of the arch moves in the northern direction and then the same distance in the southern direction, before it returns to its nominal position.

At the same time, the eastern top arch leans towards the west for a similar distance as the western top arch. The chainage follows the same shape of movements as the western top arch but for smaller distances. The levels are mostly unchanged.

Other general observations include:

- As of around 7:50 am, the *eastern* top arch gradually *rises in level* for up to 20 mm and stays *up* until the end of the survey, not returning to nominal zero.
- As of around 8:20 am, the *eastern* top arch moves in a *westerly* direction for up to 20 mm and stays in that position until the end of the survey.
- As of around 8:45 am, the *eastern* top arch moves in a *northerly* direction for up to 5 mm and stays in that position until the end of the survey.
- As of around 7:50 am, the *western* top arch moves slightly in an *easterly* direction but returns to its nominal position after around 25 minutes. As of 8:45 am, it moves in an *easterly* direction for up to 5 mm and stays in that position until the end of the survey.
- Chainages and levels of the *western* top arch generally return to their nominal positions after the train passes.
- An observation recorded by the Jacobs survey team is that truck movements had a noticeable effect on the bridge, with larger trucks causing the deck and structure to 'bounce' slightly. The largest impact would generally be in the Z-Up direction.

An analysis of relative differences between the eastern and western prisms are shown in Table 5, indicating the range and average values. Graphical representations can be found in Figures 27 & 28.

Table 5: Relative differences in east-west direction.

Relative Diff (east-west)	Range From [mm]	Range To [mm]	Average [mm]
Offset X	-25	7	-6
Chainage Y	-5	13	0
Height Z	-7	43	7

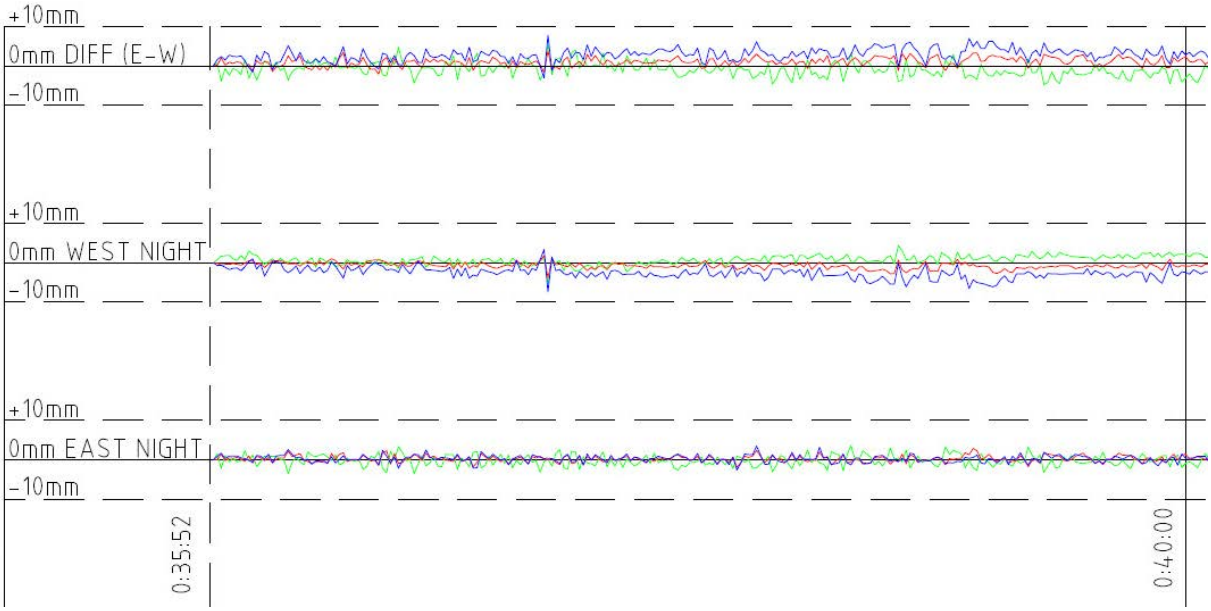


Figure 27: Sample graphical presentation of relative movements at night over an 8-minute interval, including legend.

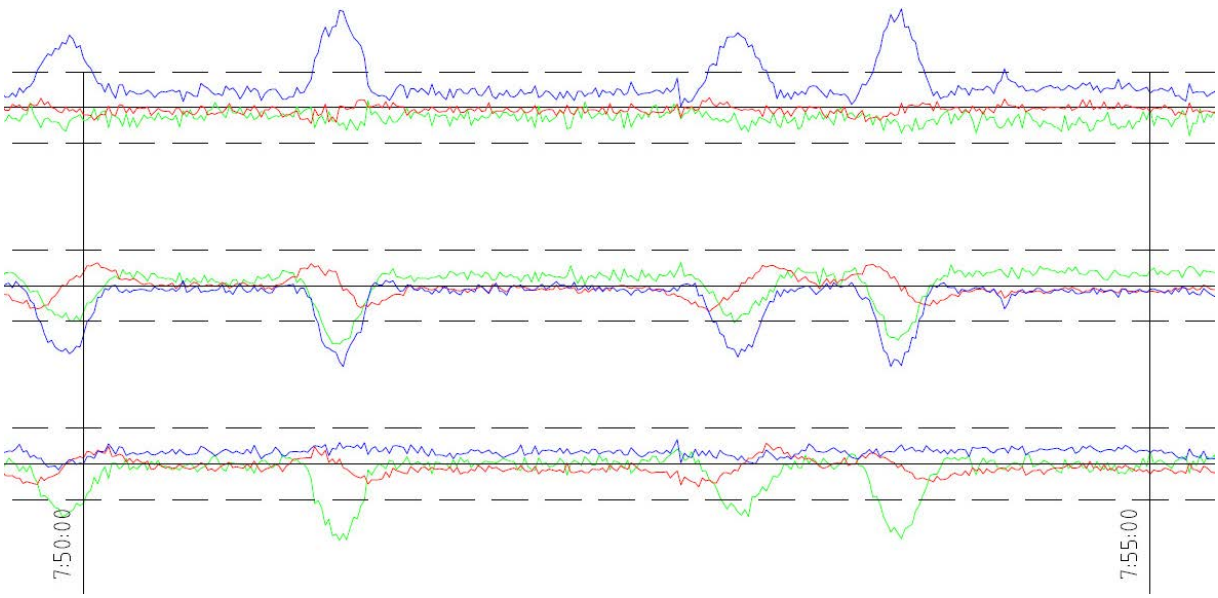


Figure 28: Sample graphical presentation of relative movements during the day survey over a 5-minutes interval.

6.2 Scan Results

Due to limitations of the total station setups and the movement of the bridge throughout the night, the most accurate and reliable source of QA for relative accuracy were the laser

scanning registration reports. These reports show the error vectors between the position calculated for each scan target in each separate scan and the target location calculated from the reflectorless total station measurements. This provided an excellent comparison to multiple targets that were taken at the same time as the laser scanning, which compensated for the bridge movement due to temperature and also localised movement from vehicles on the bridge.

Results indicate that it was more reliable to measure reflectorless to the centre of the scan target than it was to take a mini-prism shot to the rivet heads. So while the rivets are a valuable, fully independent check on the scan accuracy, the registration results themselves more correctly show the relative accuracy between scans and provide independence through redundancy. It should be noted, as mentioned earlier, that it was very difficult to see and measure to the inside chord flange. Furthermore, it was not physically possible to reach out and measure the chord-flange edge with the mini-prism as it was outside arm's reach.

With each scan having the same eight targets as the opposite scan and six overlapping targets as each adjacent scan, this provided a large number of constraints and points for comparison. The point cloud adjustment software, Cyclone, created a best-fit position using all of these constraints to give the scans an absolute position fix. The registration report compares these position coordinates for every scan.

Each registration report has hundreds of constraints, as summarised below (some targets were occasionally excluded, generally due to distance or obstruction):

- Night 1: Mean absolute error: for enabled constraints = 0.003 m (615 constraints).
- Night 2: Mean absolute error: for enabled constraints = 0.002 m (931 constraints).
- Night 4: Mean absolute error: for enabled constraints = 0.002 m (804 constraints).
- Night 5: Mean absolute error: for enabled constraints = 0.003 m (1,251 constraints).
- Night 6: Mean absolute error: for enabled constraints = 0.003 m (1,181 constraints).
- Night 7: Mean absolute error: for enabled constraints = 0.002 m (1,479 constraints).
- Night 8: Mean absolute error: for enabled constraints = 0.003 m (674 constraints).
- Night 9: Mean absolute error: for enabled constraints = 0.002 m (491 constraints).
- Night 10: Mean absolute error: for enabled constraints = 0.002 m (201 constraints) (lower chord ±50 mm requirement).
- Night 3/4: Mean absolute error for enabled constraints = 0.003 m (747 constraints), for disabled constraints = 0.010 m (80 constraints).

While the laser scan registration provides an excellent metric of the relative scan accuracy, independent total station readings were also taken to provide a check on the absolute accuracy and additional checks on the relative scan positions. Due to the low lighting, it was not feasible to take reliable reflectorless shots to the inside edge of the chord beam and it was also not generally possible to have total station setups on both sides of the bridge within a single night to capture inter-chord measurements.

Due to these factors, QA shots were taken to the top of the rivets using a mini-prism, which was then compared to the comparable point within the registered point cloud (Figure 29). For the inter-chord comparisons, the distance in the point cloud between rivets at approximately the same position on each side of the bridge was compared to the total station measurements. In order to check the height more accurately, extra shots were taken to the face of the chord.

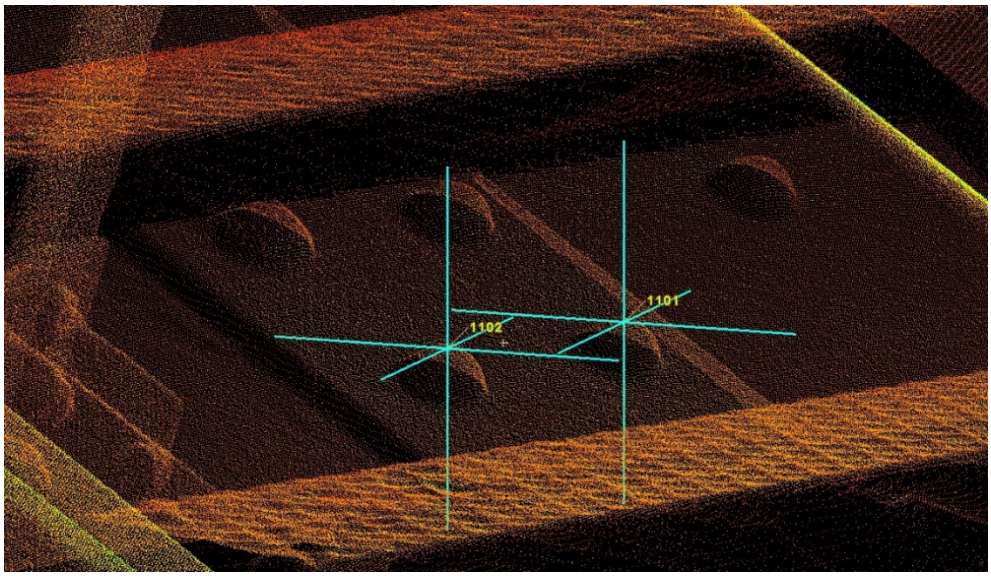


Figure 29: QA – Rivet location.

The results show that the scanning meets the 3 mm (1 sigma) relative requirements for the project (Figure 30).

		INTER-CHORD DISTANCE CHECKS - RIVET TO RIVET								
DIST CTRL					DIST CLOUD					Δ dist
334585.1	6252995	70.669			334555.2	6253002	73.214			
334555.2	6253002	73.21	30.8349		334585.1	6252995	70.6696	30.8336		-0.001
334574.7	6252974	79.668			334548	6252987	79.6716			
334548	6252987	79.669	29.877		334574.7	6252974	79.6703	29.8769		-0.001
334542.2	6252976	85.402			334542.2	6252976	85.401			
334568.2	6252961	85.861	29.676		334568.2	6252961	85.8634	29.6748		-0.001
334531.9	6252955	95.642			334531.9	6252955	95.644			
334558.9	6252943	95.096	29.624		334558.9	6252943	95.0996	29.6244		0.000
334472.8	6252835	131.043			334472.8	6252835	131.044			
334501.4	6252827	130.477	29.809		334501.4	6252827	130.4792	29.8078		-0.001
334425.3	6252742	129.702			334425.3	6252742	129.7007			
334453	6252731	129.975	29.817		334453	6252731	129.9767	29.8174		0.001
334419.8	6252731	127.836			334419.8	6252731	127.8329			
334447.4	6252718	127.909	30.290		334447.4	6252718	127.9082	30.2898		-0.001
334411.1	6252713	124.232			334411.1	6252713	124.2276			
334438.6	6252701	124.455	30.169		334438.6	6252701	124.4524	30.1680		-0.001
334343.8	6252579	70.132			334343.8	6252579	70.1335			
334369.1	6252563	69.189	29.704		334369	6252563	69.1916	29.7039		0.000

Figure 30: Inter-chord distance checks.

7 CONCLUDING REMARKS

Roads and Maritime has engaged with a private-industry specialist partner to deliver this challenging project. Working in collaboration with Roads and Maritime, a set of procedures were established fulfilling the requirements of the G73 Specification, which may be applied to future projects.

The high-precision 3D CADD model produced as part of this project will enable design, manufacture and installation of two AMUs at the Sydney Harbour Bridge. This will increase

the efficiency and provide safety benefits for Roads and Maritime when undertaking routine maintenance activities on the bridge.

The high-precision 3D CADD model may also be used for other asset maintenance activities, including development of a Building Information Model (BIM), logging completed and planned activities. The accurate and comprehensive point cloud data captured for this project may be used for further investigation of bridge attributes as required in the future.

The ability to use this dataset as a source for future 'data mining' should be emphasised, recognising that data captured now may later be used for data extraction of additional features as required by Roads and Maritime and other stakeholders, i.e. 'capture once, use many times'.

ACKNOWLEDGEMENTS

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DISCLAIMER

The views, opinions, considerations and conclusions expressed in this paper are strictly those of the authors and do not necessarily reflect the views of Roads and Maritime Services.

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Can the Spatial Industry Attract (and Keep) Gen Z Employees?

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ABSTRACT

If like me you were born between 1955 and 1964 (or thereabouts), you are a 'Baby Boomer', sometimes referred to as a 'Post-World War II Baby Boomer'. As professionals we are generally regarded as having strong work ethics, being self-assured, competitive, goal-centric, resourceful, mentally focussed, team oriented and disciplined. Following hot on our heels was 'Gen X'. Hard-working and independent, they had much the same traits as us but preferred flexibility in their work over stability. 'Gen Y' (also known as the Millennials) was born between 1980 and 2000. Typified by a strong 'look at me, look at me' focus, they seem more interested in smartphones, Facebook, texting, sexting and other technology rather than actual work (or am I just an old cynic?). And now we have 'Gen Z', the most global, social, visual and technological generation ever. Will they be attracted (and stay with) the spatial industry? What can we as an industry, employers or educators do to understand and attract Gen Z employees or has that horse already bolted? This paper discusses this issue and aims to provide answers to these questions.

KEYWORDS: *Gen Y, Gen Z, future, surveying profession, employees, attractors.*

1 INTRODUCTION

The future of our industry in part relates to the employees we attract (and keep). In that respect, an understanding of Gen Z (and in fact all of the generations) will be beneficial to us and the industry. Understanding what appeals to Gen Z and what they are looking for will inform the strategies we adopt to get the best out of them and help them grow.

1.1 Who is Gen Z?

Baby Boomers, Gen X, Gen Y, Gen Z… There is no clear-cut definition for the birth years that separate these definitions, but most researchers typically use the mid-1990s to mid-2000s as starting birth years for Gen Z. That means that the school leaver you employed for a gap year or the TAFE / university graduate you just employed is a Gen Z. So, other than how old they are, what defines a Gen Z? Probably the best stating point would be to see who came before them and what were their characteristics and traits.

1.2 The Generations by Name

Figure 1 gives us an idea about the different generations and some of their characteristics. While this is a starting point, the characteristics of Gen Z are more complex than this simplistic figure. In fact, a lot of what we perceive about Gen Z is misconception based on the press and hearsay… and the fact that we do not know what they are saying sometimes!

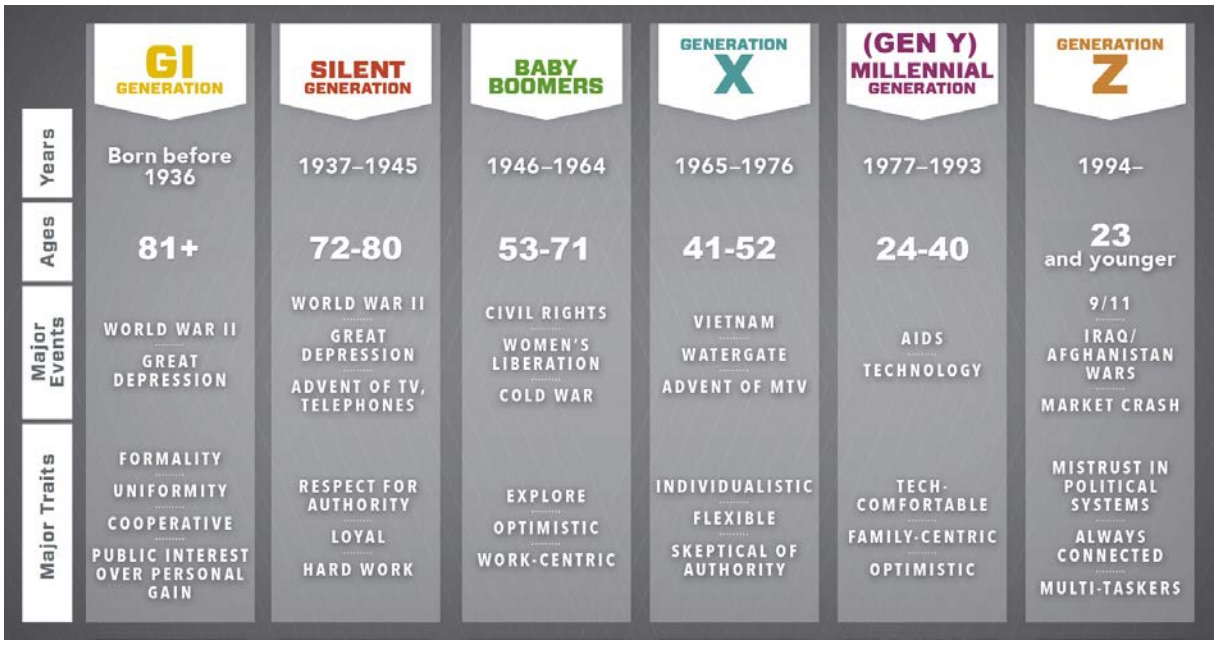


Figure 1: Generation names and their characteristics (WordPress and Maxwell, 2017).

One of the 'facts' often quoted about Gen Z is that they have an 8-second attention span (Hope, 2016). How do you employ someone with such a short retention span? This is a prime example of how we misunderstand, or are led to misunderstand, Gen Z. Finch (2015) states "Gen Z actually have what we're calling highly evolved 'eight-second filters.'" In fact, this filter allows them to decide if an event, article or activity is attention-worthy and, if so, then Gen Z can become intensely committed and focussed.

2 WHAT REALLY TYPIFIES GEN Z?

Let us wipe away the myths, the YouTube videos, the misconceptions and the downright bullshit and discover what is left.

2.1 Statistics

Firstly, here are some bare-bones statistics about Gen Z (Abramovich, 2015; Mediakix, 2017):

- 96% of Gen Z owns a smartphone.
- 85% of Gen Z uses social media to learn about new products.
- Almost half of Gen Z is connected online for 10 or more hours a day.
- One-third of Gen Z watches one hour of online video a day.
- More than 25% of Gen Z is 'constantly' checking Facebook.
- Gen Z shares the entrepreneurial spirit of millennial innovators: About 72% of current high-schoolers want to own their own businesses, and 76% hope they can turn their hobbies into full-time jobs.
- Gen Z are adept researchers. They know how to self-educate and find information. 33% watch lessons online, 20% read textbooks on tablets, and 32% work with classmates online.
- 58% of Gen Z is either somewhat or very worried about the future.

2.2 What Typifies Gen Z as an Employee?

Statistics aside, what typifies a Gen Z as an employee? Before we consider how to attract and retain Gen Z employees, we need to know what they are like in general as employees. From the statistics, we already have an idea what Gen Z is like in general but let us look further into what Gen Z is like as an employee.

Gen Z grew up in a post 9/11 era with all the associated fear, market crashes and recessions. Hence it is no surprise that they place job security as a high priority in their lives. Like the Millennials (Gen Y) before them, Gen Z have high expectations of good jobs and good salaries, but unlike the much maligned Millennials, Gen Z is prepared to work hard to get what they want (Figure 2).

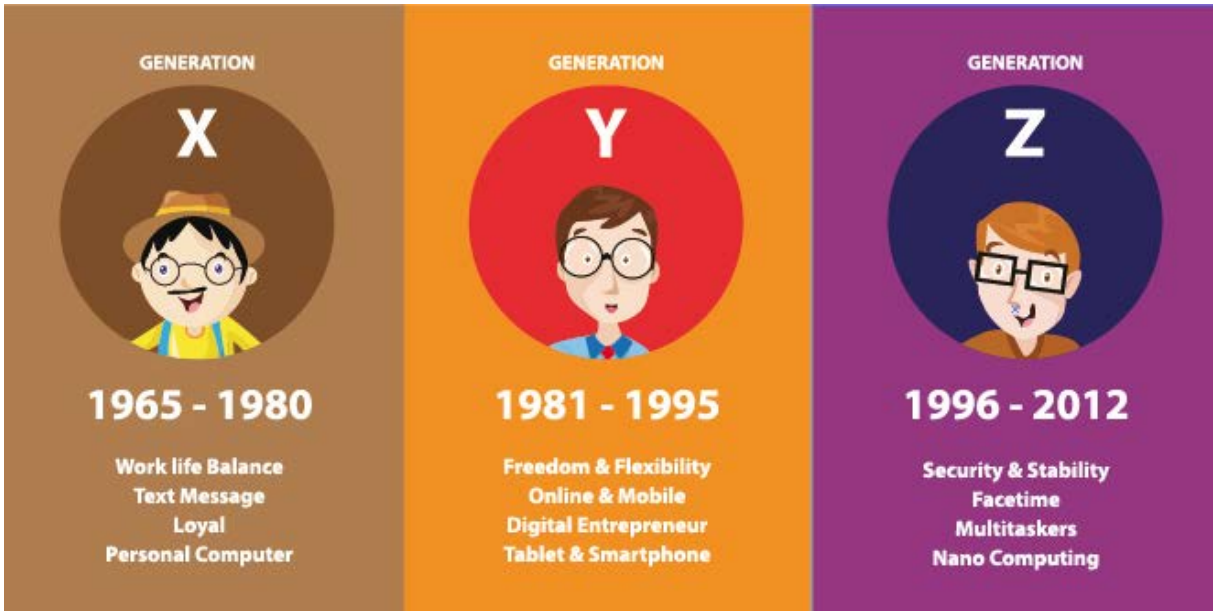


Figure 2: Characteristics of Gen X, Gen Y and Gen Z.

Boitnott (2016) states "Generation Z has a great amount of drive, talent, and ambition to bring to the table. They are loyal, and are able to innovate your company to match the changing times. They are willing to grow and progress quickly and intend on making an impact on the company they work for from the beginning."

This is quite a challenge. How do we engage Gen Z and make use of their traits and skills? The following sections looks at Gen Z from an employer's point of view but also from the an educator's point of view. Why educators? Because we need to consider Gen Z as current employees as well as the Gen Z who will be entering the workforce in the future. We need to consider Gen Z employees from the perspective of employers and educators.

3 WHAT CAN WE DO AS EMPLOYERS?

Companies must be willing to work hard for their attentions and offer adequate salaries and benefits in order to attract talented Gen Z employees. Employers have to be prepared to think differently to work with Gen Z. This section provides some thoughts and observations in this regard.

3.1 Offer Career Growth

Unlike Gen X and Gen Y and their desire for change and mobility, Gen Z has lived through recent difficult times and they are looking for stability within careers. "Gen Z have experienced perhaps the most rapid, dramatic shifts of societal standards than any other generation" (Insight.FYA, 2017). With that stability must come direction and purpose. They are looking for a career with purpose and direction and not just a 'job'.

3.2 Learn to Speak 'Z'

Actually *don't*. Nothing sounds stranger than a Baby Boomer speaking 'Z'. If you think the following makes perfect sense to you, think again: "tbh, rn you want to be lit but not salty – all g?" Gen Z is the most technologically literate generation to date. Instead of trying to speak 'Z', you should use a common language, i.e. technology. While we struggle to use a mobile phone while typing, Gen Z can (and do) use multiple devices simultaneously.

3.3 Create Ideas and Solutions with Gen Z

Independence, creativity and innovation are words often used to describe Gen Z. Their independence, creativity and innovation are perhaps their greatest strengths and simultaneously weaknesses. Build solutions with then and do not try and impose answers upon them.

3.4 Listen, Listen, Listen

Other than the language issue already mentioned, Gen Z wants to be heard. They are smart, technologically literate and know where to find answers. They may not always be right but they do have a strong and positive voice.

3.5 Change Your View of Gen Z

Although this paper has talked about statistics and characteristics of Gen Z, there is really not one single 'view' of Gen Z. Nonetheless, of all the generations, Gen Z seems to be the most flexible, tolerant and accepting (Boitnott, 2016).

3.6 Embrace Technology

We work in a paradoxical industry. While old reference trees, RM bottles and lockspits still form part of our psyche, we are also in one of the most technologically changing times (Figure 3). As Fosburgh (2012) states: "New technologies and changing demands are driving a paradigm shift in modern surveying. Rapid technological development extends beyond measurement to include computing, communications and geospatial data mapping." Who better to involve in this new world than Gen Z?

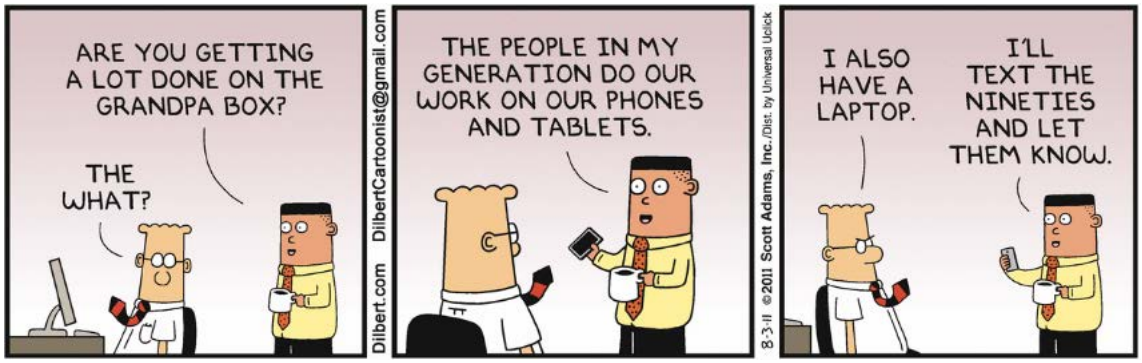


Figure 3: Changing technology (Dilbert, 2011).

4 WHAT CAN WE DO AS EDUCATORS?

As mentioned earlier, Gen Z uses an 8-second filter. How do educators deal with this when traditional subjects ran for months and courses for years? The challenges facing educators are similar (but not the same) as the challenges facing employers. For this reason, the subsections that follow parallel the subheadings in section 3.

4.1 Offer ~~Career~~ Educational Growth

There has been a strong tradition of progressing from school to university for the 'brighter' kids and to TAFE for those who did not make it to university. This archaic (and inaccurate) approach needs revisiting in light of Gen Z. It would take a whole paper in its own right to explore this further, but here is an option worth considering.

As already mentioned, Gen Z are "adept researchers. They know how to self-educate and find information. 33% watch lessons online, 20% read textbooks on tablets, and 32% work with classmates online" Mediakix (2017). Educators should be harnessing this. Students should be encouraged from early high-school years to undertake learning that informs a career in the spatial industry. They should progress through a learning path that takes them into a career, enhances their learning and supports their career. What they learn, how they learn and how they adapt the learning should be the focus. Qualifications from university or TAFE should be the by-product of learning, not the other way around.

4.2 Learn to Speak 'Z'

If 30 years in adult education has taught me anything, it is that communication is key. Unfortunately, my knowledge of the language of Gen Z is about as good as my knowledge of German: "Nicht so gut" (not too good).

The historic approach has been for educators to teach and students to learn. However, with Gen Z so much learning is done from Gen Z to Gen Z or their interaction with technology. Educators need to harness these skills and be education facilitators and not the 'teachers' of the past. Educational facilitators "who understand the connection between digital engagement and student experience will cause dynamic changes within their organisations. Student-focused efforts, led via savvy social media practitioners, will win the day" (Povah and Vaukins, 2017).

4.3 Create Ideas and Solutions with Gen Z

Here is an example: What if you could use an app to find the latest information about a topic, link yourself to the software developer/supplier/technologist, communicate with your trainer or facilitator, and then capture the learning for a submission as part of your course/learning journey? I have no idea where to begin with this, but I bet a Gen Z does.

4.4 Listen, Listen, Listen

As an educator, communication is important. It is *how* we communicative with Gen Z that counts. There is a reason Instagram is so popular. Gen Z are highly visual communicators, and educators need to consider this in the development of learning activities for Gen Z. "They say a picture's worth a 1,000 words and Gen Z takes that to a whole new level. They speak fluently in images, from emojis to photo and video based social media. Let's just say Gen Z isn't typing out their status updates" (Inflexion, 2016). As educators we cannot limit our thinking, techniques and communication skills to the past. We must embrace the future.

4.5 Change Your View of Gen Z

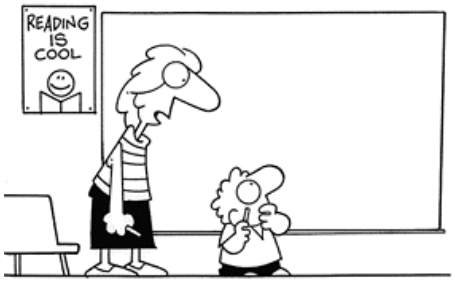
In the past, educators viewed students as 'sponges' to 'absorb' learning. Ask a teacher of even 10 years ago what they thought of students and these are *not* the words that would come to mind (McKenzie, 2016):

- Social learners.
- Mobile.
- Global.
- Digital.
- Visual.

Educators, like employers, need to change their view of Gen Z in order to realise, promote and use this generation's potential.

4.6 Embrace Technology

The journey from chalk boards to smartboards technology and beyond has always been part of education (Figure 4). With Gen Z, it is even more relevant that we use technology to engage, teach, interact and share. But it is important to also remember that "technology no longer has the buzz that it used to have. Several years ago, if you sat a student in front of a computer, you would get instant engagement. This is no longer the case. Technology is just [a] tool not [the] tool. If your use of technology is not underpinned by sound educational techniques, then it will fall short" (Using Technology Better, 2017).



"There aren't any icons to click. It's a chalk board."

Figure 4: The mysteries of the chalk board (Using Technology Better, 2017).

5 HAS THAT HORSE ALREADY BOLTED?

I would like to say a definitive "no" but that would be untrue. I cannot say a definitive "yes" either. I strongly believe that Gen Z employees have a great role to play in the spatial industry. Their strengths will contribute positively to the industry, and the industry will be better for their presence. Equally, education will play an important part in helping Gen Z be ready to find and create their place in the future. "Education is the passport to the future, for tomorrow belongs to those who prepare for it today" (Malcolm X).

Has the horse already bolted? I do not think so. But I do know we are in for one hell of a ride.

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Cornering the Cadastre

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ABSTRACT

In solving a jigsaw puzzle on the scale of a Local Government cadastre, it is easier to reconstruct by doing the edges (or straight bits) first. The original Crown Land Grants in Ryde occurred in two waves. The first was under the guidance of Arthur Phillip in 1792, when 149 Portion grants were allocated in Ryde (then known as Eastern Farms). These first grants formed the first cadastre, but contained no survey information other than area, and that area was drawn on the maps as a rectangle. The basic land grant was 30 acres, which is 30 chains by 10 chains (approximately 600 m x 200 m). The second Crown Land release occurred 90 years later, with the granting of 806 small Portions between 1882 and 1886. This second release abutted the limits of the first grants and is survey accurate (as proven by the author at APAS2017). The boundaries of the first grants became established through fencing occupation and by later survey, usually at the time of subsequent subdivision or Primary Application. Many of these later surveys referred to corners and boundaries of the original first grants, and somewhat surprisingly, nearly all of the streets and driftways formed in the first grants are still active as roads in today's cadastre. The aim of this paper is to try to re-instate boundaries of these long-standing roads, by reconstructing the cadastral pattern, with reference to the survey plans throughout Ryde's history, which found and connected to any original survey marks.

KEYWORDS: *Corner, cadastre, original marks, re-instate.*

1 INTRODUCTION

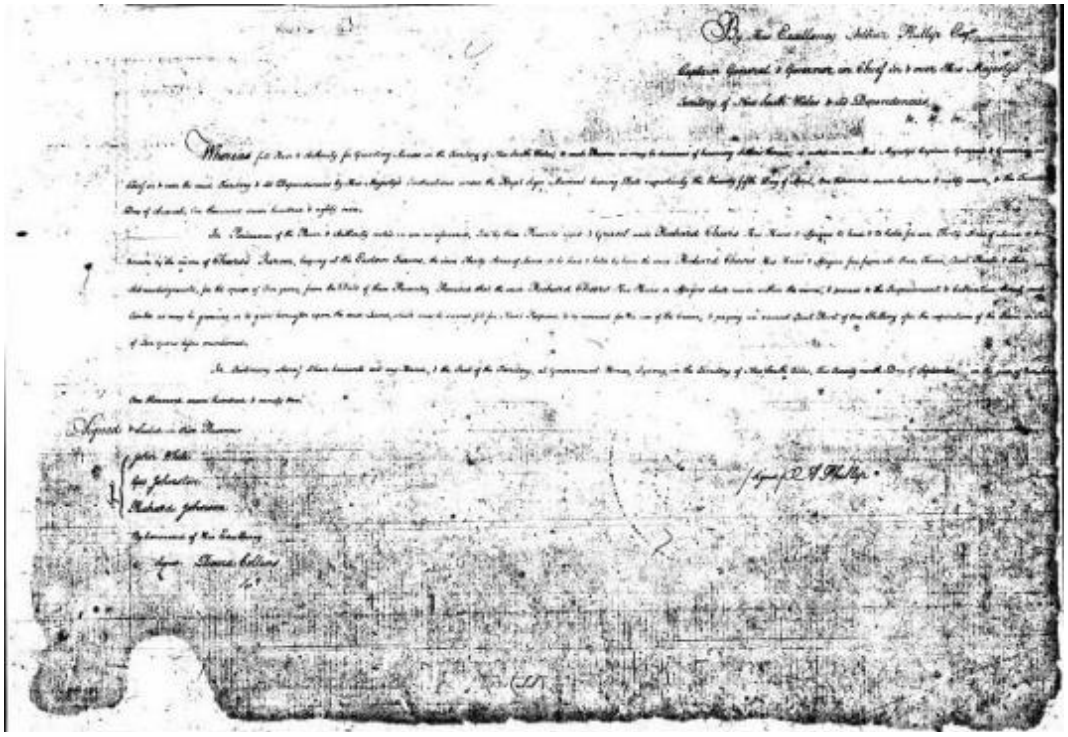
Some of the first land grants in the Territory of New South Wales were in Ryde, from 1792, with each land grant being duly signed by Captain General and Governor in Chief, Arthur Phillip. A total of 149 Portions were created, along the shore of the Parramatta River and heading north (Figure 1), one example being Richard Cheers' Portion 15 (Figures 2-4).

Free settlers and ex-convicts, who were "of good conduct and disposition to industry" (i.e. hard work) were entitled to a free land grant. Each single male was given 30 acres, an additional 20 acres, if married, with a further 10 acres for each child. 30 acres is a rectangle 30 chains by 10 chains (which is approximately 603 m by 201 m). However, these first maps showed no dimensions (Figure 5). The first cadastre (Figure 6) only showed portion numbers, grant areas and names of the grantees.

The boundaries of these grants became established through fencing occupation and by later survey, usually at a time of subdivision or primary application. The cadastre was now being determined by dimension and marking, however, modern survey accuracy was not attained until 1881-82 (Figure 7). Only then could the cadastre be considered more stable and reliable.

Figure 1: Crown Plan F145, showing the original grants.

Figure 2: Detail showing Portion 15, Richard Cheers' 30 acre grant.



"… Authority for Granting Lands in the Territory of New South Wales; to such Persons as may be desirous of becoming Settlers therein …
In pursuance of the Power and Authority vested in me … I do by these presents Give and Grant unto Richard Cheers His Heirs and Assigns to have and to hold for ever Thirty Acres of Land to be known by the name of Cheers's Farm, laying at the Eastern Farms, …
in the year of Our Lord, one thousand seven hundred and ninety two." signed A Phillip

Figure 3: Richard Cheers' 30 acre grant, dated 29 September 1792.

Figure 4: Plan 231 – First edition of Hunters Hill Parish Map.

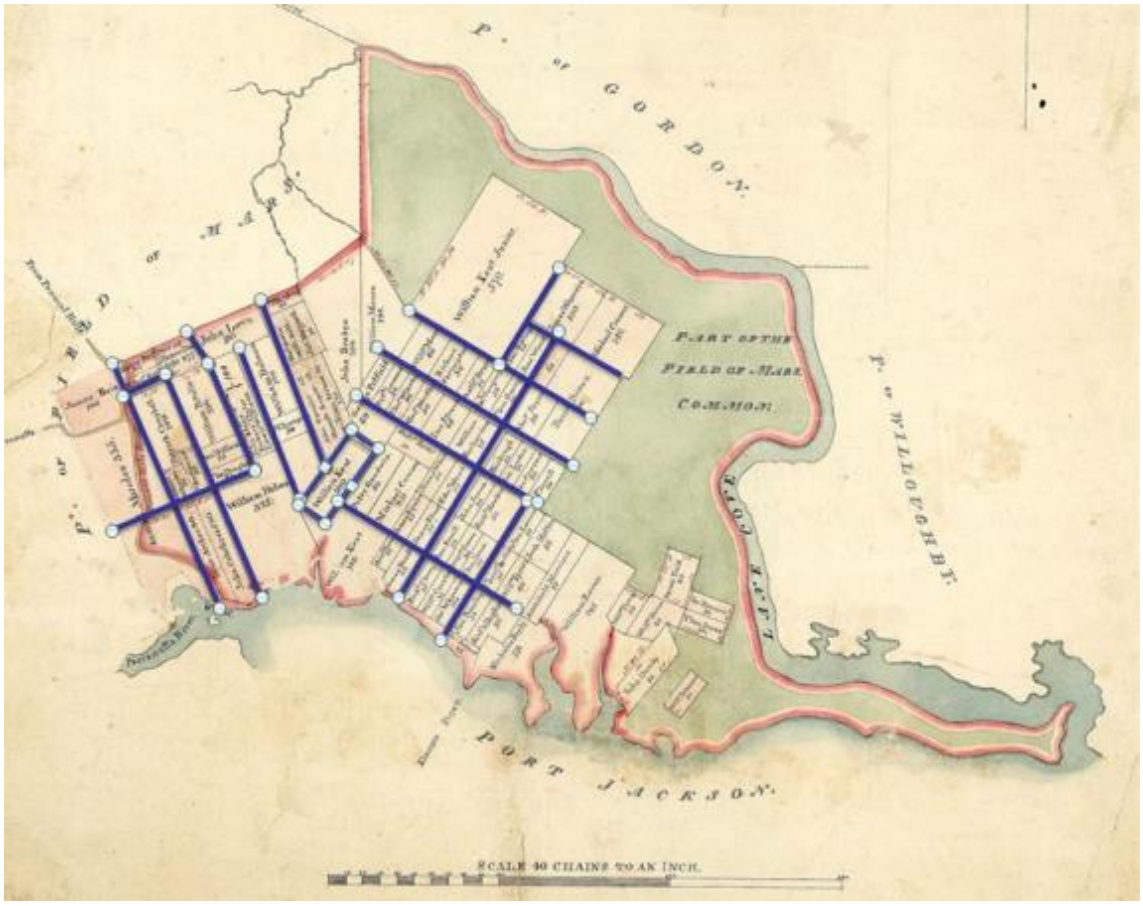


Figure 5: Ryde's original road/driftway pattern.

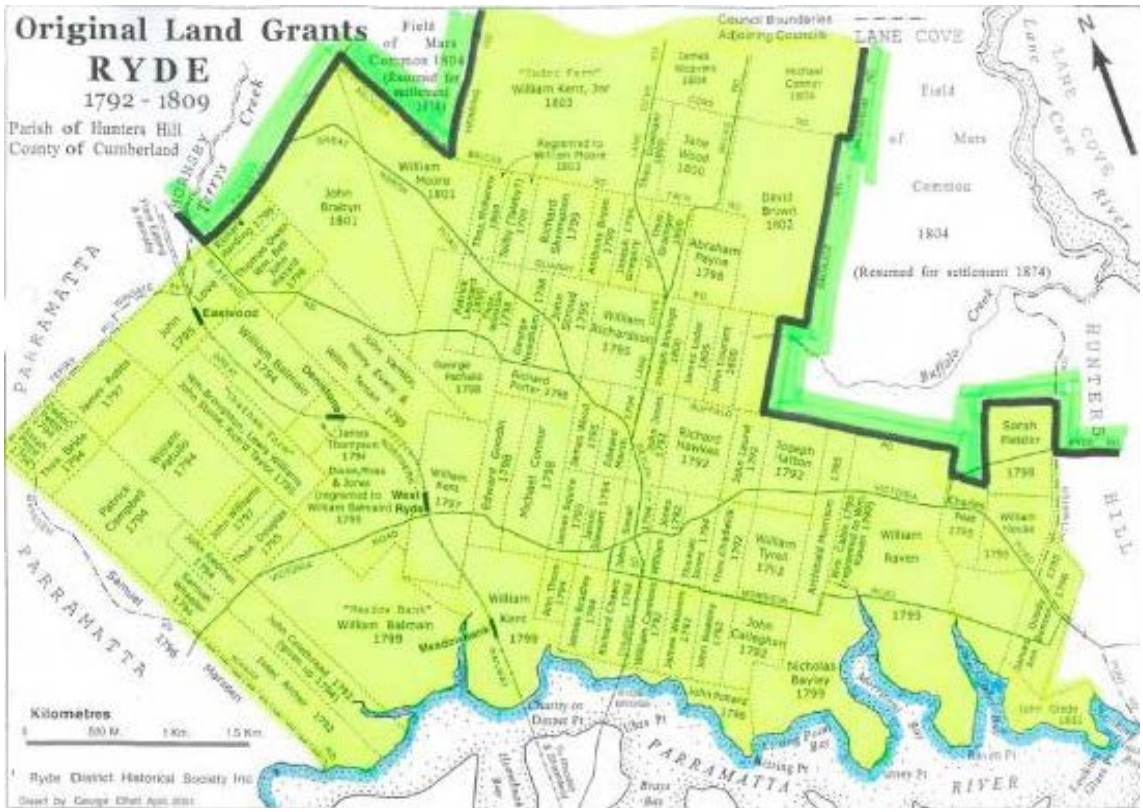


Figure 6: This map of Ryde is, effectively, its first cadastre.

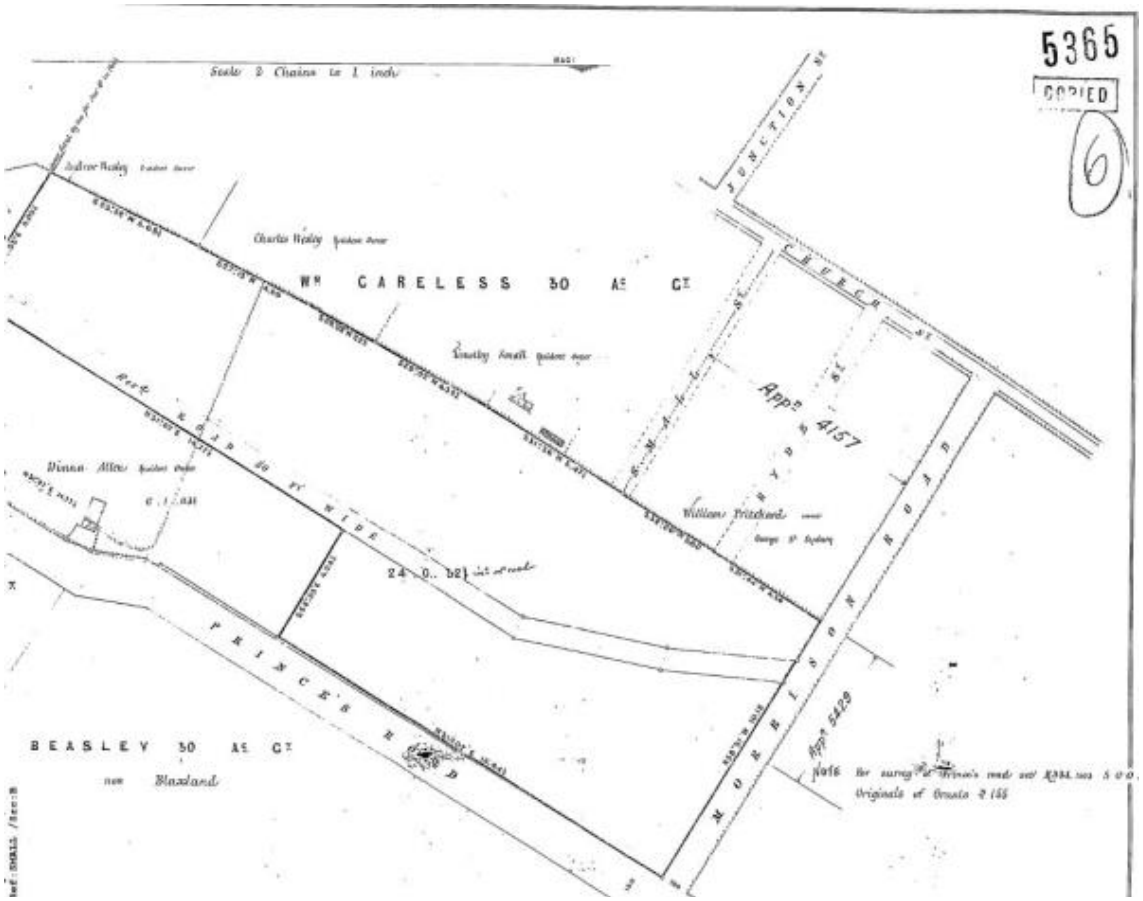


Figure 7: 1881 survey of part of James Weavers' 30 acres.

2 A MODERN CADASTRE TAKES SHAPE

At North Ryde in 1881-82, Lands Department Staff Surveyor Charles Robert Scrivener undertook a subdivision of Crown Land, being part of Field of Mars Common. This survey abutted the limits of those first Land Grants. He created 125 Portions (generally 4, 5 or 6 acres each) (Figure 8). This was the first new Crown Land release at Ryde since the original land grants, 90 years earlier. The overall area of this new release was equivalent to one tenth of the current Ryde Local Government Area.

Figure 9 shows detail of two parts of Crown Plan 386, where one is decidedly less clear and less legible, looking disconcertingly very like the First Grants plan (Figure 1). Scrivener's survey was undertaken using accurate measuring tools (theodolite and steel riband) and incorporated direct observations from an area-wide network of trigonometrical stations. This survey should form the basis of the modern cadastre in the City of Ryde. De Belin (2017) outlines how Crown Plan 386.2030 was re-stored and re-established into a condition fit to be used. Subsequent field results show Crown Plan 386.2030 is completely accurate to today's standard, and, moreover, is able to be fully replicated. Its importance to the modern cadastre is assured!

Figure 8: Crown Plan 386.2030, date of survey from September 1881 to May 1882.

Figure 9: Detail of parts of Crown Plan 286.2030.

3 A CADASTRE GETS SET

There are now 2,243 lots descendant from the 125 Portions as surveyed by Scrivener in 1881-82, so there are many ongoing benefits in having and maintaining a sound cadastre. Crown Plan 386.2030 was the first new Crown Land release since the original grants. Crown Plan 1137.2030 (Figure 10) followed four years later in September 1886, and was part of the second new land release, extending from Marsfield to Eastwood. It was four times as extensive, creating 454 Portions.

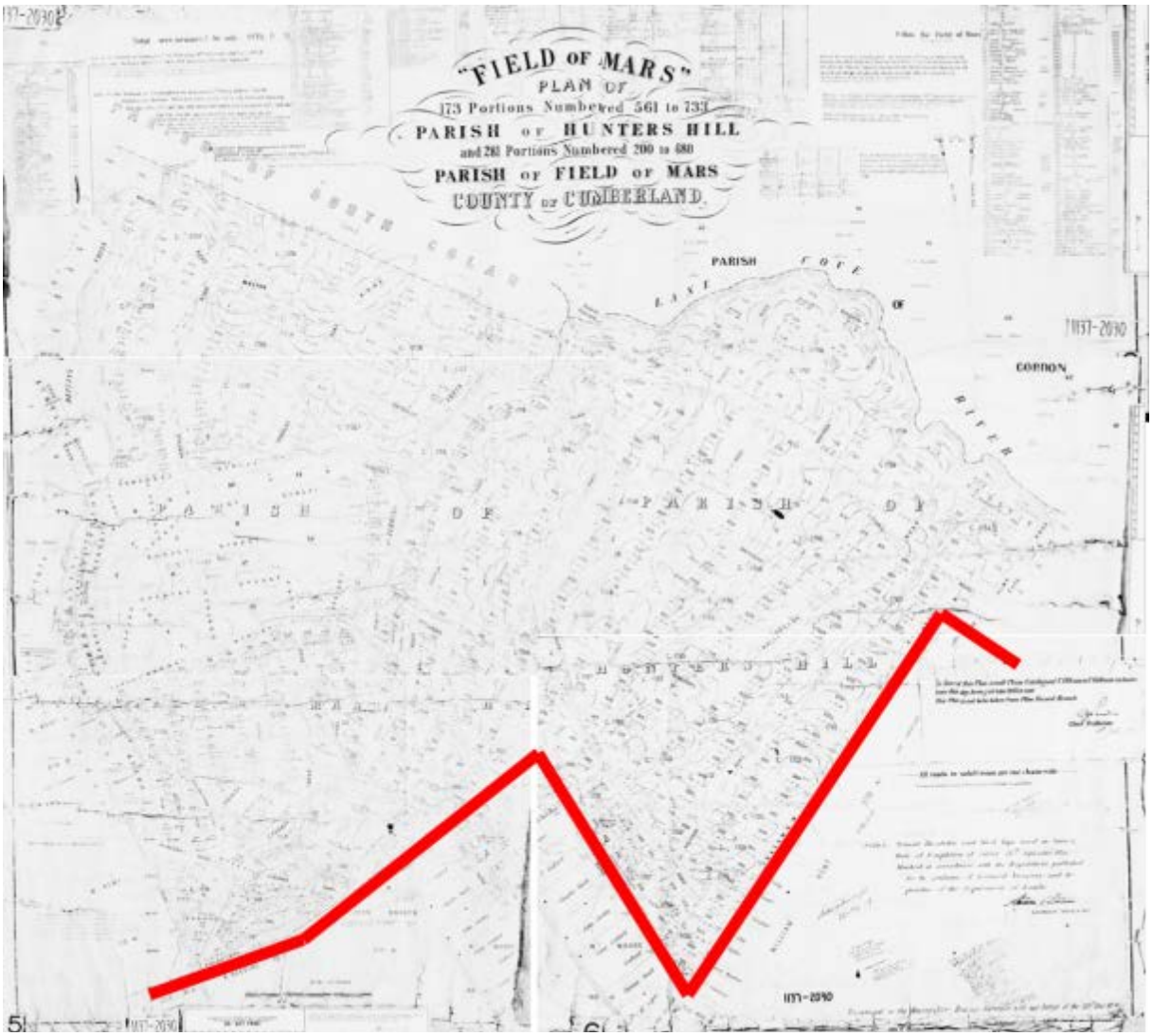


Figure 10: Crown Plan 1137.2030 of 1886, showing the limit of first grants in red.

A further crown subdivision followed in February 1887 (Figure 11), creating 227 more Portions. These two Crown plans were also in such a parlous state that within only 10 years (Figure 12), they had to be completely redrawn, this time onto smaller plans (Figure 13), showing releases of between 10 and 20 Portions each. Notwithstanding the wonderful foresight and skill of the Chief Draftsman in 1896, much survey information was not transferred to the copies, especially the type of marking.

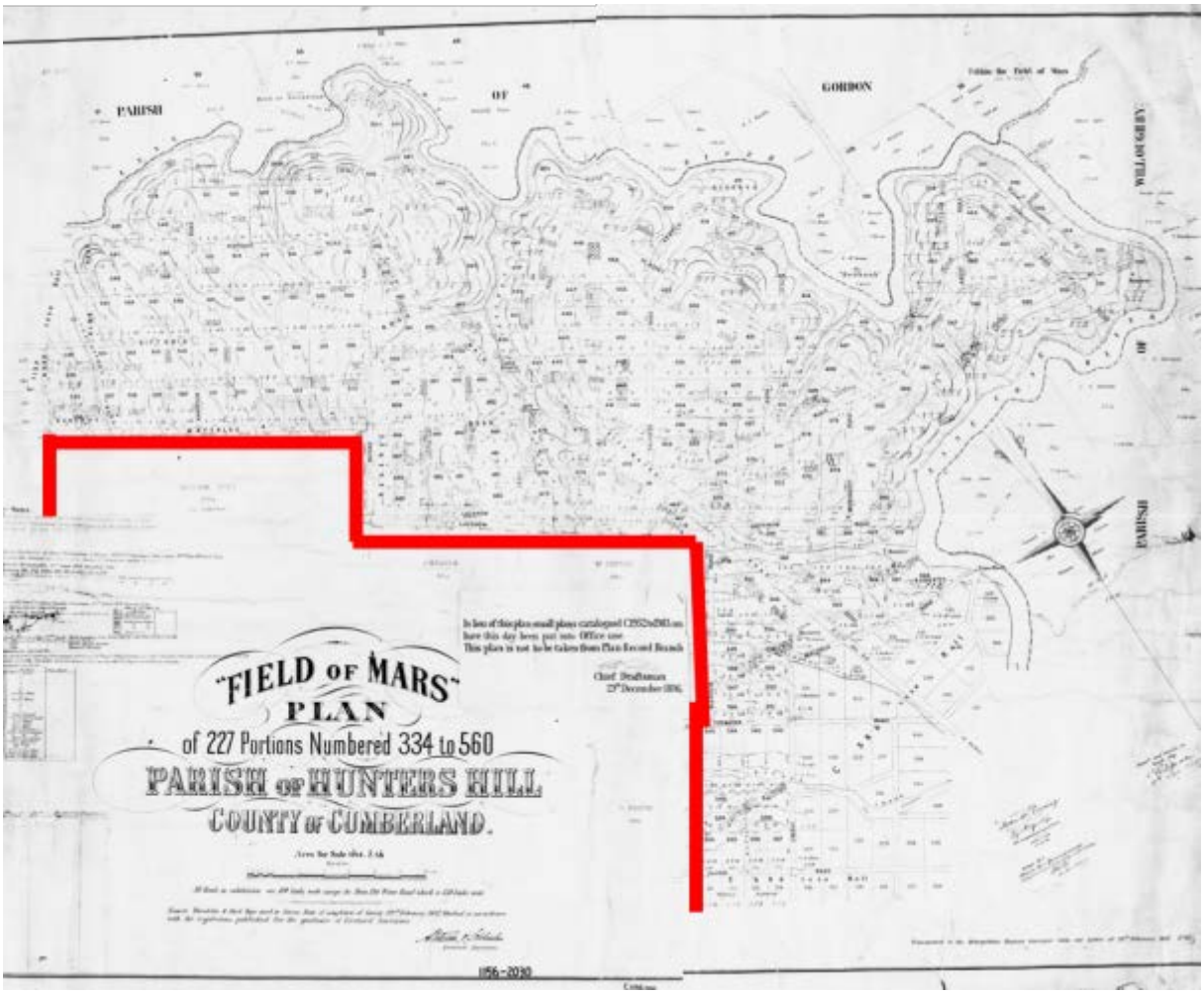
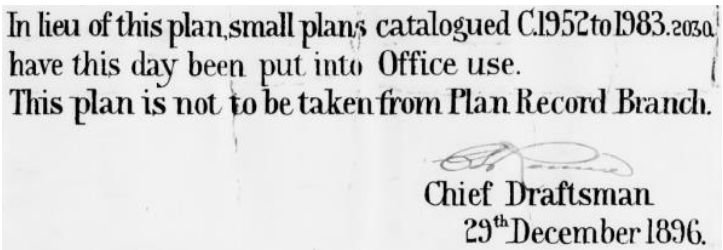


Figure 11: Crown Plan 1156.2030 of 1887, showing the limit of first grants in red.


In lieu of this plan, small plans catalogued C.1952 to 1983.2030.
have this day been put into Office use.
This plan is not to be taken from Plan Record Branch.

Chief Draftsman
29th December 1896.

Figure 12: Chief Draftsman's note from 1896.

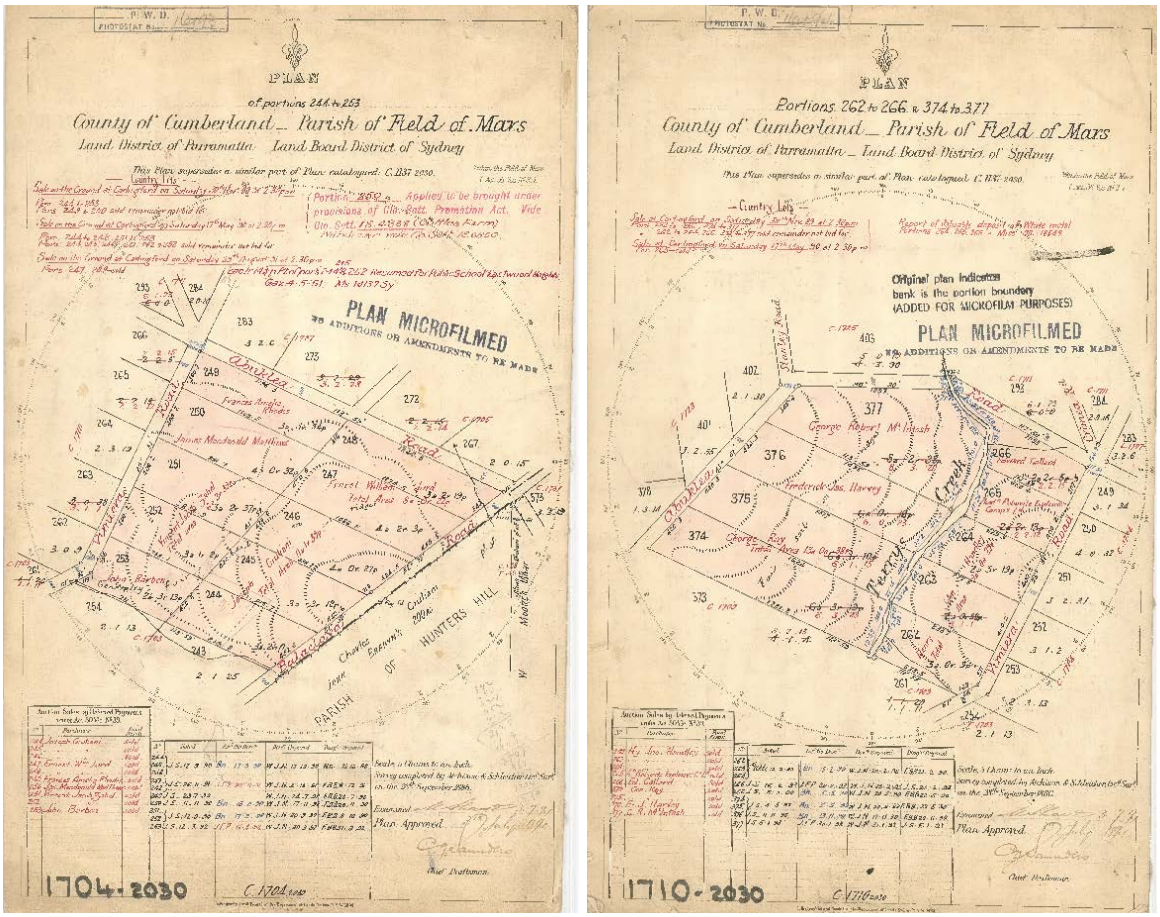


Figure 13: Redraw of part of Crown Plan 1137.2030 from 1896.

By 1887, the original land grants in Ryde were completely surrounded by the new grants. These later Crown Plans were surveyed by Atchison and Schleicher, and like Scrivener's plan, were survey accurate (Figure 14). Add to this a network of aligned streets, surveyed by Scrivener, and the framework of the modern cadastre is set… from Gladesville in the east to Eastwood in the west.

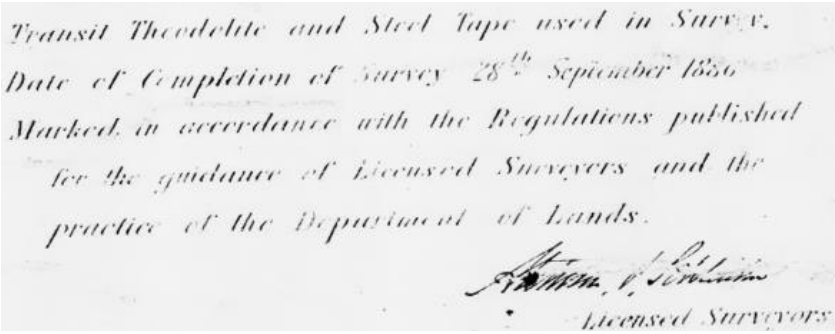


Figure 14: Surveyors' note on Crown Plan 1137.2030 from 1886 – "Transit Theodolite and Steel Tape used".

4 FINDING ORIGINAL MARKS

When reinstating boundaries, the mark hierarchy lists in order of importance: natural feature, original mark, monument and then measurement. The following examples of original marks found were all placed in the 1880s. Original broad-arrowed corner rock marks were placed by

Scrivener in Crown Plan 386.2030 (Figure 15).

Figure 15: Original corner rock marks.

Figures 16 and 17 show examples of original trigonometrical marks found in Ryde that are part of the early trig networks of the 1880s. The marks are either carving in rock or metal pins in rock. Note that the rock marks in Figure 17 do not show a broad arrow.

Figure 16: Original trigonometrical marks in Ryde.

Figure 17: Original foreshore trigonometrical marks at Bedlam Point, Gladesville.

Original dressed stone alignment posts (Figure 18) were placed by Scrivener in 1885 (de Belin, 2014). His surveys not only aligned the new streets in Crown Plan 386.2030, but also many of the roads/driftways created in the First Land Grants, plus three main roads.

Figure 18: Original stone alignment posts in North Road and Buffalo Road.

So far, a total of 82 original marks have been found: 15 corner rock marks, 8 trig station marks and 59 big stone alignment posts. Are these original marks enough to establish the basis of the modern cadastre?

5 RECONSTRUCTING THE CADASTRAL PATTERN

The position of the cadastre is locked in by original rock marks which can be easily accessed. The fact that so many of Ryde's streets were connected to the original alignment marks also means that the present cadastral pattern exactly reflects the Portions/Crown grants boundaries from 1881 to 1887. This section presents four examples to illustrate.

5.1 Rock Mark at Vimiera Road Bend

Crown Plan 1137.2030 in 1886 creates Vimiera Road containing a bend. Unfortunately, the original plan is very badly faded and indecipherable at this point. Crown Plan 1710.2030 in 1896 (re-draw), shows no mark description at the bend. DP940535 in 1920 finds the "original broad-arrowed rock mark" at the bend. DP25469 in 1946 finds an "old fence post in rock" at the bend. DP394754 in 1955 finds a "rock mark at centre of face of post" at the bend. DP408379 in 1958 finds the "original broad-arrowed rock mark" at the bend. DP210868 in 1961 finds a "rock mark" at the bend. DP217683 in 1962 finds a "drill hole and wings" at the bend.

There have been 19 plans in the 55 years since 1962. However, none of these has mentioned finding anything at the bend, relying instead on finding reference marks placed by the surveys in 1955, 1958, 1962 and later. The butt of an old square fence post (not the 70-year-old post from 1946) sits in a larger, older post hole, and the remains of the broad arrow in rock are still evident today (Figure 19), and fits with the position as re-established from all the found reference marks.

Figure 19: Remains of broad arrow rock mark at the Vimiera Road bend.

5.2 GI Pipe at Intersection of Bridge and Herring Roads

DP13850, a subdivision in 1925, found stone alignment posts in both Herring Road and Bridge Road, but left no reference marks. DP38663 in 1951 and DP36746 in 1956, both done by the same surveyor, found these same stone alignment posts in both Herring Road and Bridge Road, and placed galvanised iron (GI) pipe and concrete block reference marks. The two stone alignment posts at the intersection were removed during the construction of a high-pressure gas main shortly after 1956. However, in reconstructing the original intersection by using found reference marks, the City of Ryde survey team were able to place, in 2017, a GI pipe (under metal cover box for protection) at the original intersection.

5.3 Victoria Road Alignment Connection

DP1223761 in 2016 re-established the position of an original stone alignment post in Victoria Road by finding two concrete block reference marks, from road-widening DP337570 in 1937,

and using their shown connections (Figure 20). The comparison from this re-established point (it would have been a broad arrow cut on the dressed face) to a broad arrow found on the dressed face of another original stone alignment post is remarkable, achieving agreement to within 10 mm over a total distance of 732.12 m.

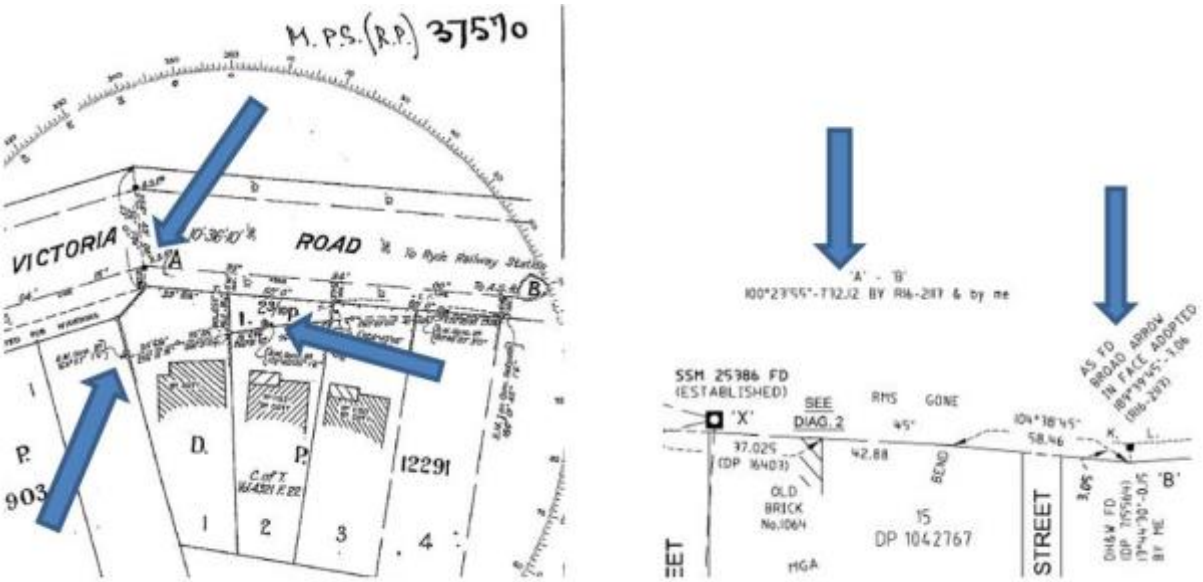


Figure 20: Detail form DP337570 in 1937 and DP1223761 in 2016.

5.4 Victoria Road Alignment Mark

Kerb renewal in Victoria Road has taken the alignment marks but the three reference GI pipes in Providence Road remain (Figure 21). Re-establishing the Victoria Road intersection is thus a straight-forward process (de Belin, 2015).

The City of Ryde survey team is currently extending investigation into the area of the first grants to reaffirm the cadastre and re-establish the street boundaries (Figure 22). Alignment marks still exist from Scrivener's work and later Roads and Maritime Services (RMS) surveys (i.e. Victoria Road widenings).

These alignment surveys effectively form an accurate control network through that area of Ryde, which covers the first grants. Many first grant corners are also shown on later, survey-accurate plans (Figure 23). Where these corners occur at street intersections, it becomes a straight-forward process to identify these first boundaries.

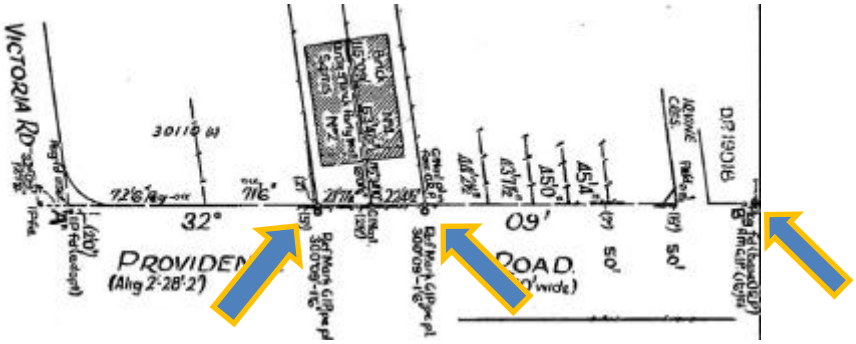


Figure 21: Detail from DP503383 in 1963, showing reference marks placed in relation to alignment marks.

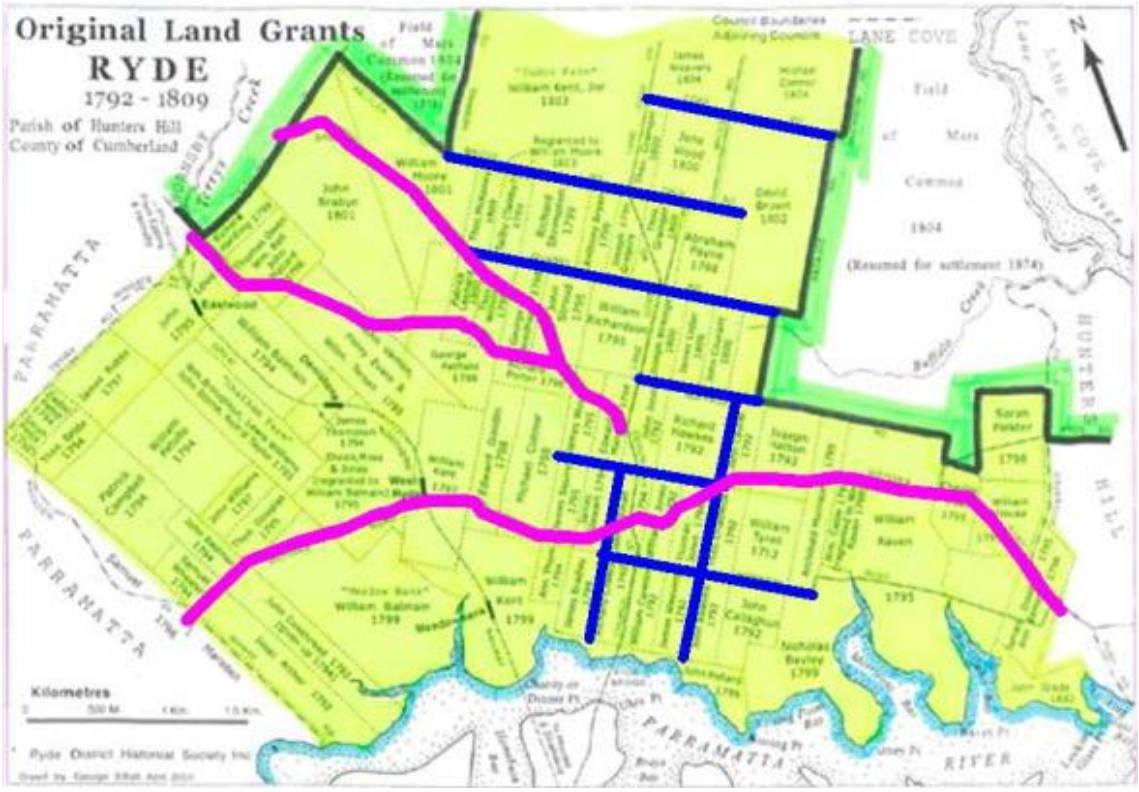


Figure 22: Alignment of original streets (blue) and later main roads (pink).

Figure 23: "Old post, SW corner Thorn's grant" from DP59986 in 1892, together with an image of the same corner in today's world.

6 CONCLUDING REMARKS

It is now possible to place the second wave of Crown Grants, which occurred during the 1880s, to almost centimetre accuracy, by finding original marks of Scrivener's work and Atchison & Schleicher's work and reinstating the boundaries between. The First Grant boundaries, although less accurate, are now becoming possible to re-instate through

investigation of the survey plan history, especially in relation to original street boundaries. Street boundaries form vital edges to large-scale areas that can then be further broken down to the present cadastre, which displays individual lots.

The importance of key boundary marks and reference marks in maintaining a sound cadastre cannot be stressed enough. One final, fine example is the reference mark (GI pipe) placed in a 1947 land subdivision by DP20789 to define a splayed corner. This reference mark has been found and relied upon over the subsequent 70 years by 12 Deposited Plans to provide definition and street fix. Surveyors have considered this point so important in defining the cadastre that, when one digs down, there are now three GI pipes in the same location (Figure 24)!

Figure 24: Three GI pipes referencing a corner, where there should be only one!

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Railway Boundary Investigations

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ABSTRACT

For any deposited plan that adjoins the railway corridor in NSW, DFSI Spatial Services requires that an approval of the railway boundary, by the relevant railway authority, be lodged with the plan. In NSW, railway land is either 'owned' by Railcorp (in the electrified area bounded by Newcastle, Bomaderry and Bowenfels and some major country stations) or Transport NSW. Property management of the country lines is one of the functions of leaseholder ARTC along with train running and maintenance. However, land management records have historically been kept by Rail Estate, now part of Sydney Trains, and all requests for the approval of a railway boundary should be directed to that entity. Only Rail Estate approves railway boundary fixes. This paper outlines the process of obtaining approval for a railway boundary and discusses a number of differing situations with the aim of showing different approaches to be adopted when railway boundaries need to be re-established and there is a shortage of cadastral information. To this end, several survey plans that have been through the approval process are reviewed.

KEYWORDS: *Railway, boundary, cadastral.*

Images Provide a Thousand Measurements

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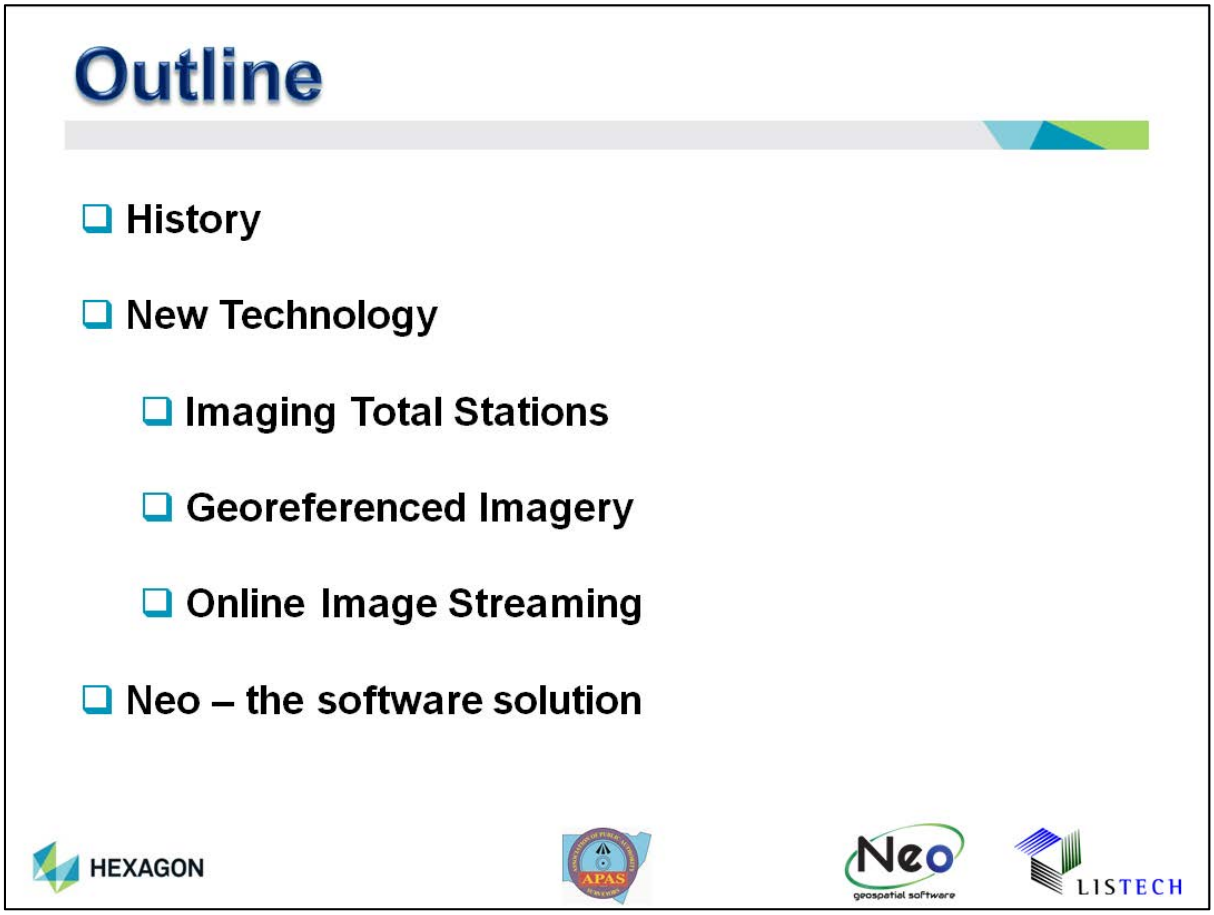
ABSTRACT

Imagery has been used in surveying and spatial applications since the early days of the camera. The advent of the digital era has seen rapid growth in the use of imagery in a variety of products. From Google Earth to NearMap, imagery has become ubiquitous in our daily lives. This presentation gives a historical context of the different use-cases and methodologies of imagery from its genesis till the present. It will also look at how spatial professionals, and more specifically surveyors, can leverage the use of imagery in their every-day workflows to maximise efficiency and help to deliver positive project outcomes.

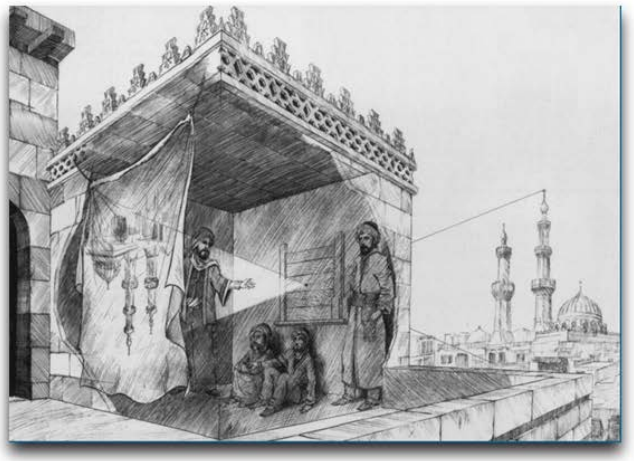
KEYWORDS: *Georeferenced imagery, image registration, terrestrial photogrammetry, satellite imagery, web service imagery.*



History

In 1038: AD - Al Hazen of Basra is credited with the explanation of the principle of the camera obscura.

Al-Haitham, known in the West as Alhazen, is considered as the father of modern optics.



Source :
Photogrammetry by A. Dermanis

HEXAGON

History

- In 1855, Nadar (Gaspard Felix Tournachon) used a balloon at 80-meters to obtain the first aerial photograph over a small French village.

- The first successful aerial photograph from a rocket mounted camera was taken by the Swedish inventor, Alfred Nobel in 1897.

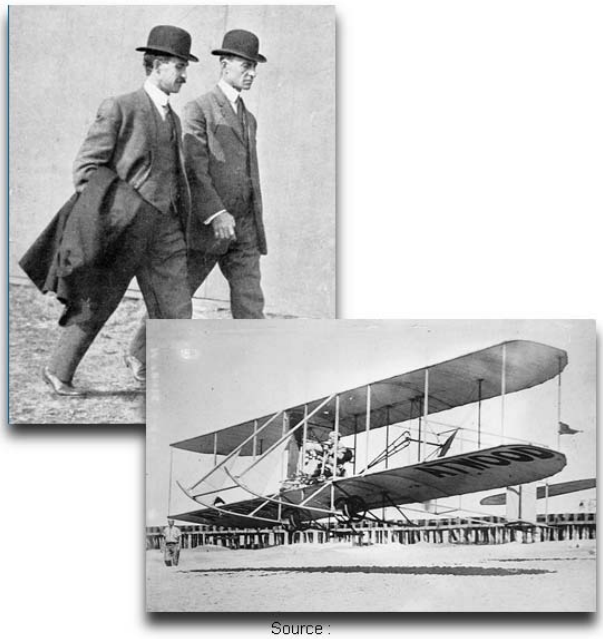
Source :
PAPA International

HEXAGON

History

- In 1903 the Wright brothers invented the airplane and in 1909 were the first to take a photograph from a plane.

- Captain Cesare Tardivo (1870 - 1953) is thought to be the first to use aerial photography from a plane for mapping purposes. (Paper presented in 1913)



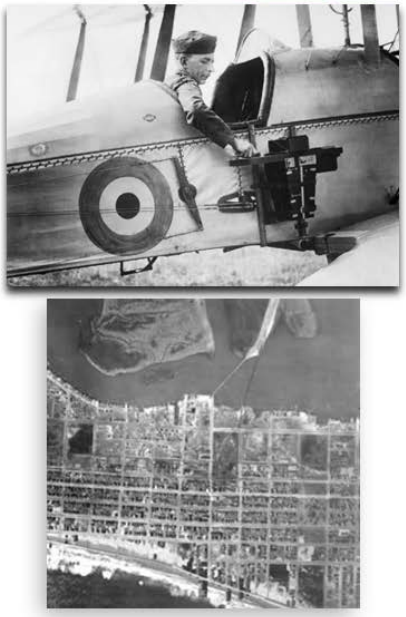
Source :
Photogrammetry by A. Dermanis

HEXAGON

History

- During World War I, aerial photography soon replaced sketching and drawing done by observers on planes or at elevated positions.
  - The battle maps used by both sides were produced from aerial photographs, and by the end of the war, both sides were recording the entire front at least twice a day.

- Following the end of the war, the aerial camera turned to non-military purposes.
  - For many it became a successful business venture as aerial surveys were found to be faster and much less expensive than a ground survey.



Source :
Photogrammetry by A. Dermanis

HEXAGON

History

Photogrammetry is the science of making measurements and creating 3D information from stereo images. It is a technique that has been used in some form since the 1850s.

There have been four major development cycles.

1) Plane table photogrammetry, from about 1850 to 1900,
2) Analog photogrammetry, from about 1900 to 1960,
3) Analytical photogrammetry, from about 1960 to 2010,
4) Digital photogrammetry, which is now throughout the industry.

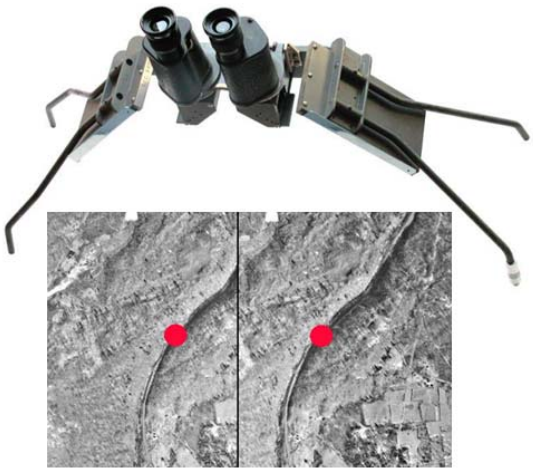
Source :
Photogrammetry by A. Dermanis

HEXAGON

History

Analog instruments are based on the concept of stereometric vision.

2 photos are relatively oriented to produce a 3D model, where details and contours were then manually drawn.



Source :
Photogrammetry by A. Dermanis

HEXAGON

History

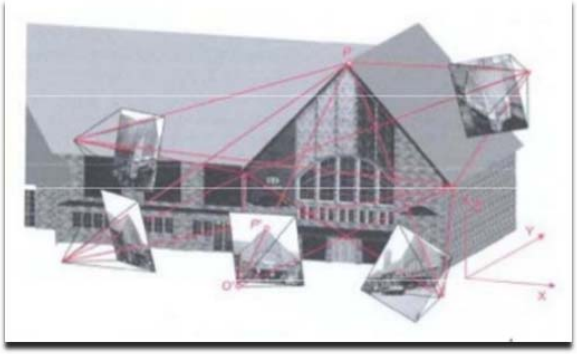
The invention of the computer is responsible for the development of analytical Photogrammetry and together with computer software can produce three dimensional coordinates of points which are then used for detail plotting and contour drawing on topographic maps.

Source :
Photogrammetry by A. Dermanis

HEXAGON

History

Terrestrial Photogrammetry deals with photographs taken with cameras located on the surface of the earth. The cameras may be handheld, mounted on tripods, or other specially designed mounts. The term close-range photogrammetry is generally used for terrestrial photographs having object distances up to about 300 m.



Source :
R.J Watson

HEXAGON

History

Digital Cameras

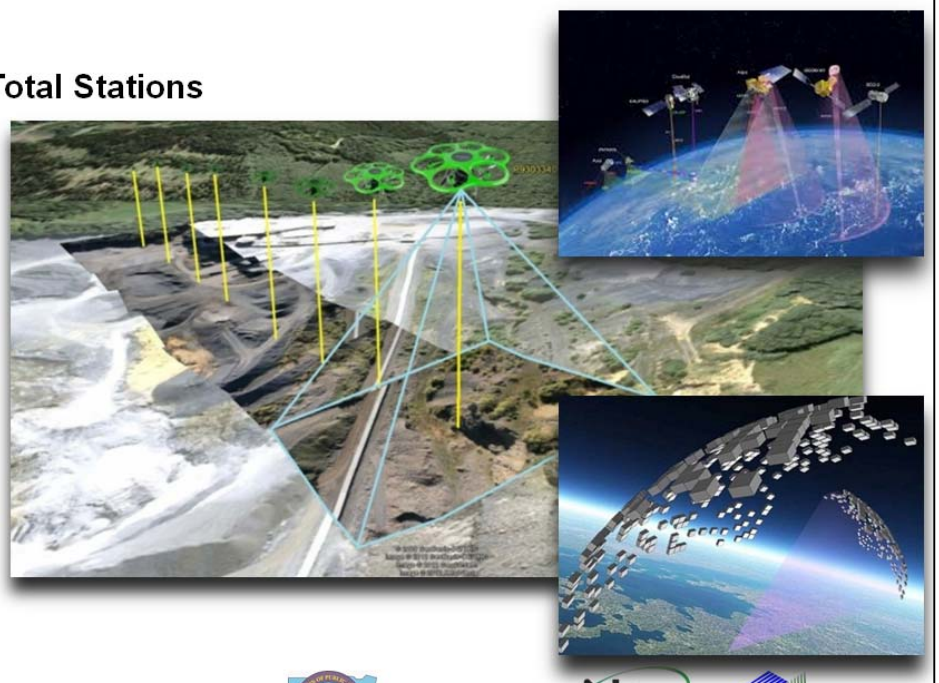
- The history of the digital camera began with Eugene F. Lally
- His 1961 idea was to take pictures of the planets and stars while travelling through space to give information about the astronauts' position.
- Unfortunately, as with Texas Instruments employee Willis Adcock's filmless camera (US patent 4,057,830) in 1972, the technology had yet to catch up with the concept.
- Steven Sasson as an engineer at Eastman Kodak invented and built the first electronic camera in 1975.

Source : *Wikipedia*

HEXAGON APAS Neo geospatial software LISTECH

New Technology

- **Imaging Total Stations**
- **UAVs**
- **Satellites**



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Imaging Total Stations

Using Modern Imaging Total Stations

- Instrument locations needs to be known relatively
- Numerous photos can be taken at each set up
- 60% plus overlap must be obtained for measurements
- Image quality can depend instrument settings and end product requirements.

Benefits

- Measure to objects that are dangerous or difficult to access
- Repeat measurements now and in the future
- Measure to surfaces that reflectorless EDMs have difficulty reading
- QA on field observations or scan data.
- Historical record of what exists.

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Georeferenced Imagery

We can use Aerial, Satellite or other available imagery

Georeference to project datum's using

- known project control for manual registration
- Pre registered for automatic registration (ECW, TIFF & JPG)

- Multiple images referenced
- View in 3D

Benefits

- Referenced backdrop to ground geometry data
- Ability to digitise information from images
- Use imagery from varying time periods to measure and analyse changes

HEXAGON APAS Neo geospatial software LISTECH

Online Image Streaming

Connect to on-line image streaming services

- FREE or subscription
- Web Mercator Projection
- Internet connection required
- View in 3D

Benefits

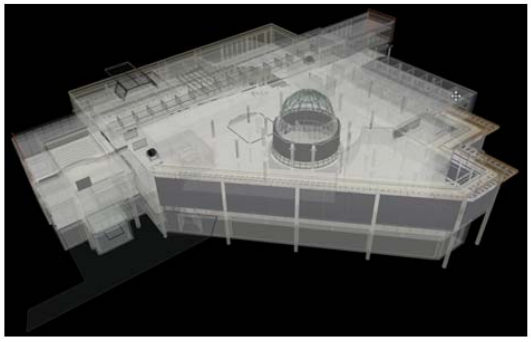
- Dynamic Image tiling
- Instant access to imagery at any location
- Ability to digitise information from images

HEXAGON

Introducing

LISTECH Neo is new generation geospatial software, that allows you to make the most of these new technologies. It offers exciting functionality with increased productivity and ease of use.

Image Xtract – Image GeoRef – Image Connect



HEXAGON

User Definable Attributes

Design and tailor attribute definitions to suit client needs.

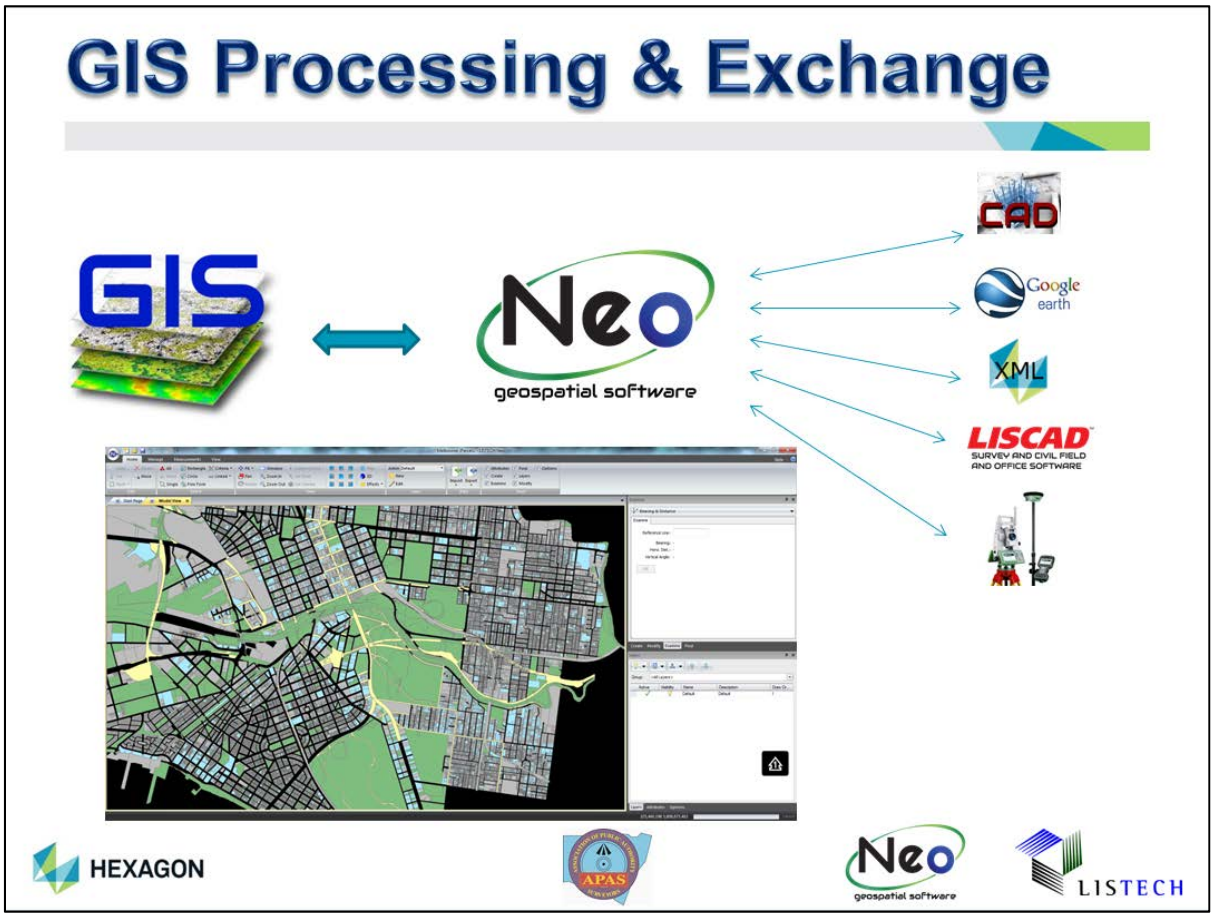
- Create attributes automatically by importing from another system
- Add and edit them
- Automatically populate with default values
- Optionally increment as objects are created

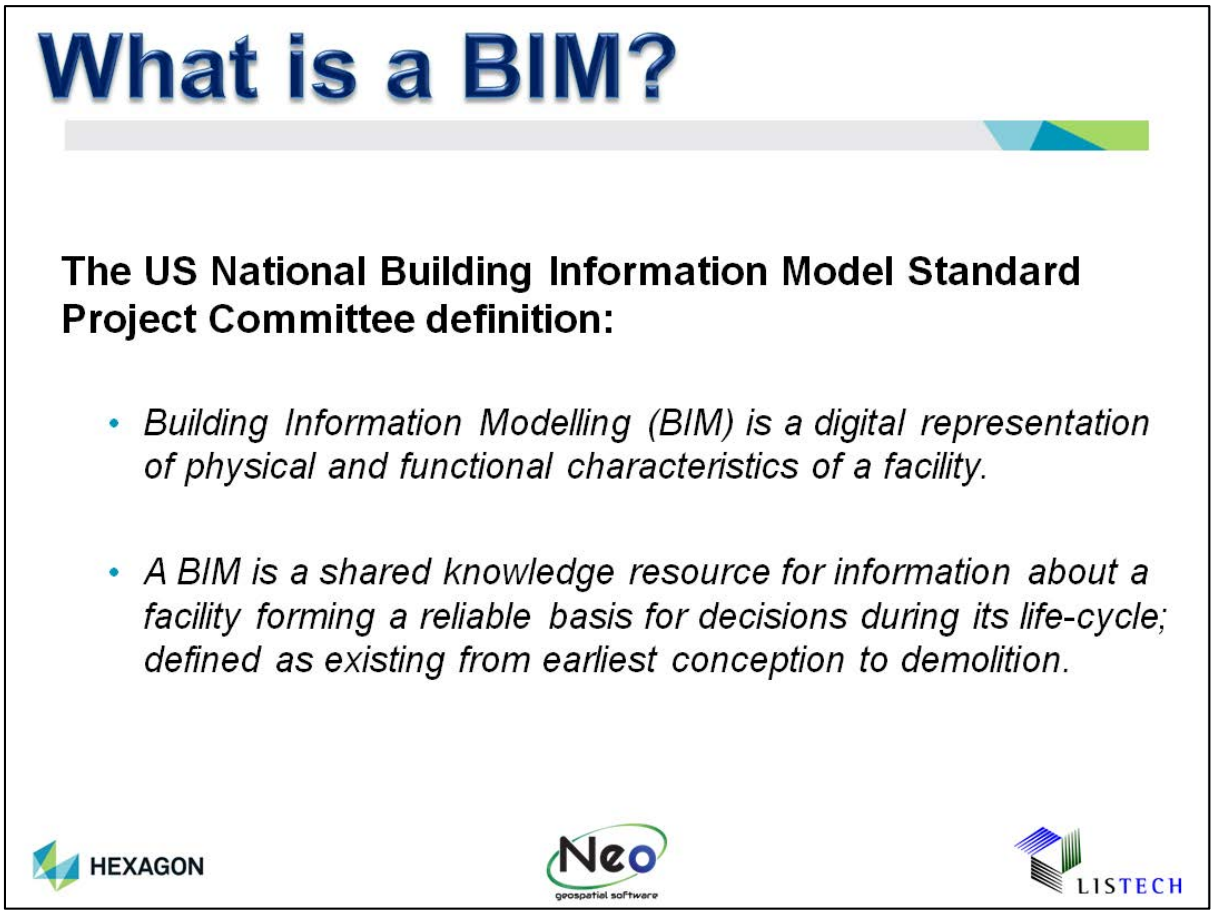
Deliver product tailored to your client needs.

HEXAGON

Seamless Transfer

HEXAGON


GIS Processing & Exchange
GIS
Neo
geospatial software
CAD
Google earth
XML
LISCAD
SURVEY AND CIVIL FIELD AND OFFICE SOFTWARE
HEXAGON
APAS
Neo
geospatial software
LISTECH


What is a BIM?
The US National Building Information Model Standard Project Committee definition:
• Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility.
• A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.
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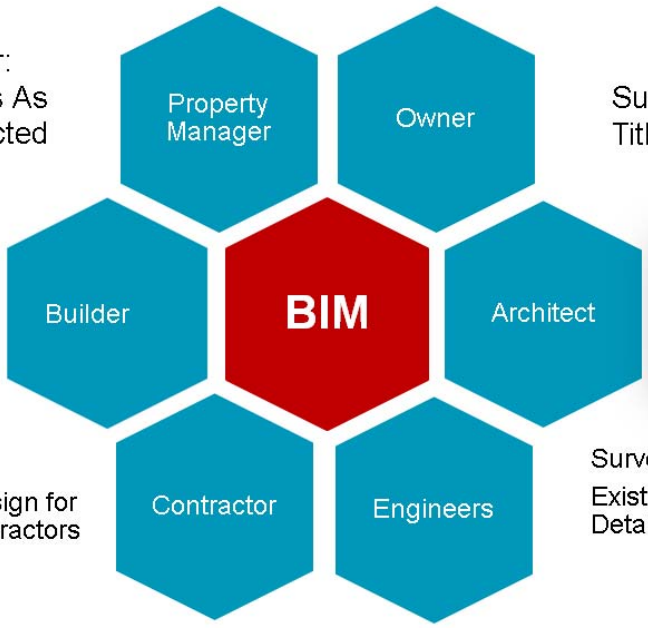
BIM and the Surveyor

Surveyor:
Performs As Constructed Survey



Surveyor:
Title Survey

Surveyor:
Sets out Design for Builder/Contractors

Surveyor:
Existing conditions / Detail Survey

HEXAGON

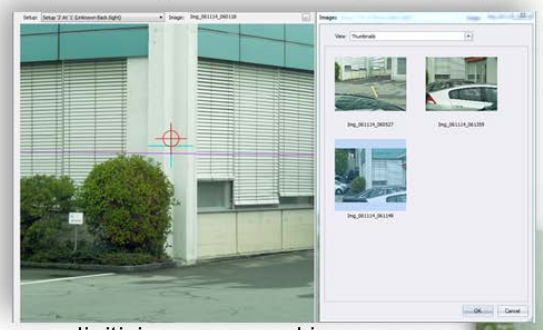
LISTECH

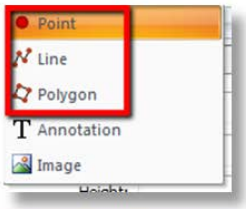
Neo Image Xtract

Create Objects from Total Station Imagery

Key Features:

- Automatic Image Selection
  - System displays all images that will compute 3D objects
- Create:
  - Points
  - Lines
  - Polygons
- EpiPolar Line
  - Makes for easy digitising on second image





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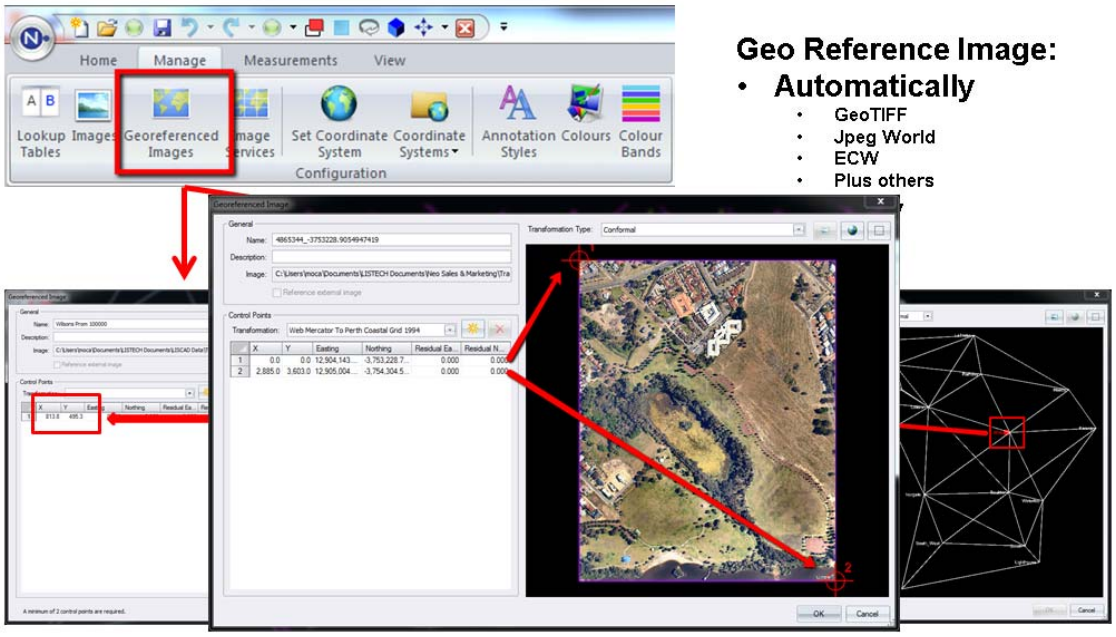
Geo Referenced Images



Geo Reference Image:

- **Automatically**
  - GeoTIFF
  - Jpeg World
  - ECW
  - Plus others

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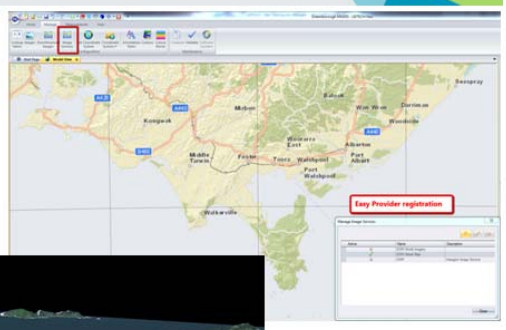
Neo Image Connect

Real Time connection to Image streaming services.

- **HxIP**
- **Esri Street Maps**
- **Esri World Imagery**
- **NearMaps**
- **Plus others**



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Neo geospatial software

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Combine Imagery

Images from GeoRef or streamed through Connect can be viewed in the same project. Could be a background map and higher resolution of a specific area.

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Integrated Measurement Database

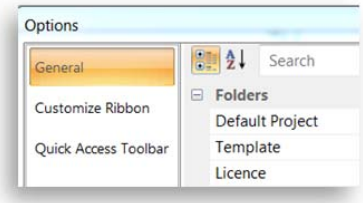
Complete control over the processing and reduction of field surveys.

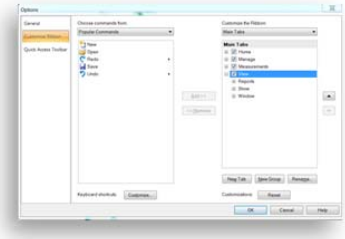
- Field data automatically imported
  - Appears in Neo as on the instrument
  - Automatic attributing
- Reprocess Measurements information
  - Update dynamically
  - Automatic Update attributing

HEXAGON APAS Neo geospatial software LISTECH

Customisable

- **Designed for global use**
  - Units
  - Precision
  - Display options
    - Ribbon
    - Toolbars
    - Dialogues
  - Annotation styles
  - Reports are configurable
  - Multiple language support





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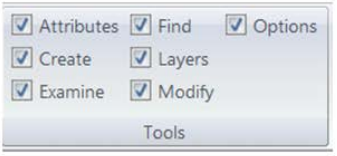
Rigorous Geodetic Computations

Rigorous geodetic computations and editing functionality

Information can be manipulated using the extensive tools available:

- Create
- Examine
- Modify
- Find

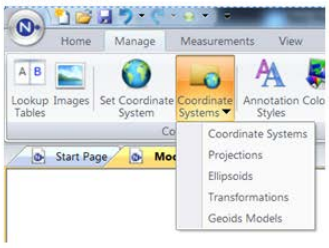


Coordinate systems may be plane or geodetic.

Transformations can be performed between coordinate systems.

Uses known Coordinate systems or user defined.

- ellipsoids,
- projections,
- transformations
- geoid models are supported.



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Template Based

Neo projects are template based

New projects with required customisation are created simply by selecting the appropriate template.

- Sample project templates are included,
- Custom tailored templates can be saved for future use.

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Modular System

Neo is an expanding portfolio of modules,

You can purchase:

- The modules for your current needs
- Additional modules at a later date when required.

Scalable subscription licensing is also available.

- Perpetual
- Subscription

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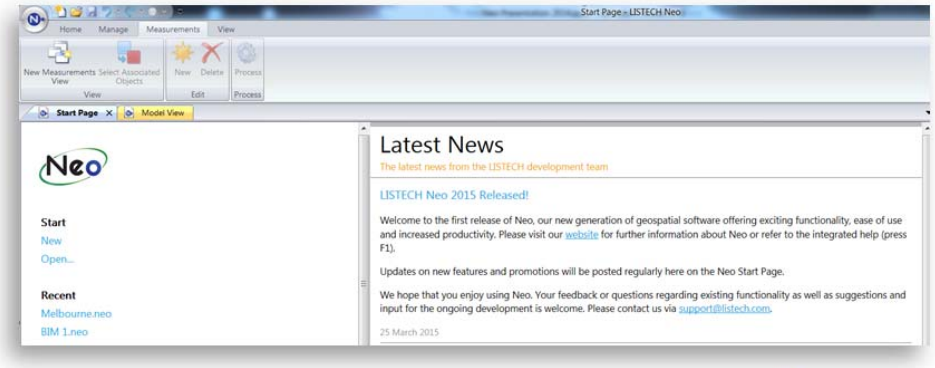
Continuous Updates

Neo is continually updated

- New features are added continuously throughout the system.
- Neo users are always aware of new features through the news section of the Neo Start page.



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Battles, Bushrangers and Bogus Surveyors: Marks Left on the Rural Landscape

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ABSTRACT

A fascination with marks on the landscape is the central theme of this presentation. It will show some of the early surveyors' recordings of the presence of European rural settlement in mainly the NSW counties of Dampier, Murray and St Vincent, but the presentation will also include examples from the wild Wicklow mountains battlefield of Glenmalure to the cemeteries of Waverley and Braidwood. The presentation makes use of the field books of James Meehan and Robert Hoddle together with numerous photographs of various survey marks and monuments found over the past 40 years. NSW Portion plans contain more than just boundaries. With the bushranging activities of the Clarke Gang in full swing, Henry Parkes in 1866 authorised four Special Constables, posing as bogus or disguised surveyors, to secretly track down these bushrangers. A humble Portion plan in the Jinden area shows the exact location where two were shot dead. The remaining constables were executed, reportedly on their knees, some distance away. These four murders are still the greatest massacre of policemen in Australian history. The actual perpetrators of these hideous crimes have never been brought to justice, and the crimes remain unsolved to this day. The details surrounding these bogus surveyors will be discussed at length.

KEYWORDS: *Surveyors, history, portion, bushrangers, marks, constables.*

NOTES

Carroll's Offer to Henry Parkes

John Carroll devised a plan to do another great service for the country and capture the Clarkes. He put a proposal to the Colonial Secretary and it was accepted. Parkes now regarded 32-year old Carroll as 'a man of very considerable experience in dealing with criminals'. But how he could equate tricking a desperate prisoner confined in a cell with the capture of the most desperate and cunning bushrangers the colony had ever experienced, on their own, turf defies comprehension.

Carroll's plan involved several interviews with James Clarke, who at this time was serving his sentence on Cockatoo Island. He gained information from him about the bushrangers' habits and connections. He even offered to be so kind as to take a letter to James' mother, a clever move that would serve as an introduction to the Clarke household.

Next he selected his men. In Darlinghurst Gaol, serving a 3-year sentence, was a man named John Phegan. He had been convicted at Braidwood in November 1863 for 'uttering a forgery'. Phegan, a printer by trade, had spent some time at Araluen where, although unsuccessful as a

miner, he was said to have lived on his wits and to be 'a very clever penman'. Phegan's conviction resulted from stealing some blank cheques from his friend Patrick Morrissey, the telegraph master at Braidwood. He forged Morrissey's signature, cashed the cheques and for this was sentenced to 3 years with hard labour. Born in Queens County, Ireland, he was now 30 years old and had been in the colony since 1840. He volunteered to join the party and was given a remission on his sentence.

The other two men Carroll selected were Patrick Kennagh and Enaes MacDonnell. Kennagh was 29 years old and like Carroll was a warder at Darlinghurst Gaol. MacDonnell was a warder at Yass Gaol, but had previously served with Carroll. At the age of 48 he was a little old for the tough conditions ahead but brought valuable experience, having served in the 'old police' at Araluen and Tarago.

The plan was to proceed to Braidwood where they would be sworn in as Special Constables by Messrs Rodd and Bennison, Justices of the Peace. They would then assume disguise as a party of surveyors and set up a camp near the Clarke house at Brick Kiln Creek, Ballalaba, where they would pretend to be carrying out survey work. From this convenient location they would befriend the family. By gaining the confidence of the Clarke women (there were no men left in the household), they would be able to make contact with the brothers and gain their confidence. Then they could take them by surprise after giving them drugged grog.

On 26 September, Parkes drew up a document which he marked 'strictly secret', detailing the terms of their service. Carroll's remuneration depended entirely on his success. The Government had little to lose. If Carroll were successful in capturing Clarke dead or alive, or in performing any similar service equal in importance to the protection of society, he would receive payment of 12/6 per day. If unsuccessful he was entitled to nothing. The men under his charge were to be paid 7 shillings per day outright and 10 shillings per day if successful. But the rate of pay was not the big incentive. The real prize was the big rewards they were hoping to collect. The reward for Tom Clarke was £500 and for his accomplices £200 each. These special police were really bounty hunters.

The Bogus Surveyors Go to Braidwood

The Carroll party made their way by steamer to Nelligen and then by coach to Braidwood. They were delayed in Braidwood awaiting the return of James Rodd, but in the meantime Phegan initiated the plan of going to see Mrs Clarke and her daughters at Brick Kiln Creek. This was repeated on three occasions. At first, according to Carroll, Phegan was treated with suspicion but this wore away on his second visit when he offered to write a petition on the family's behalf, praying for the release of son James from prison.

After being sworn in by Rodd a week after their arrival in Braidwood, the four men set up camp a mile and a half north-east of the Clarke house, ostensibly for the purpose of surveying. From here Phegan made another visit, this time accompanied by Kennagh. Carroll commented that 'altogether our plans were progressing most favourably'. So he thought.

Carroll's first report to Parkes was a letter from Braidwood dated Sunday 7 October. By this time the situation was not so favourable:

On last Wednesday morning [3 October] Tommy and Johnny Clarke passed about 200 yards from our camp, in the direction of their parents' house. They were well mounted, and we were

not in a position to pursue; nor could the pieces we had [revolvers] carry that distance with any certainty; so that, on that occasion, we were compelled to let them proceed unmolested.

On the same afternoon two of Clarke's girls rode round our camp, and had a good survey of it and ourselves. You will please remember that until this the Clarkes did not know our position, although they understood that Phegan was employed by a survey party. The girls went past us in the direction of a range in our rear, and shouted as if rounding up a mob of horses. We watched them narrowly, and shortly after they returned towards home we saw two of their dogs coming down the range near which the girls had approached.

On the following morning, early, we surveyed the range in twos, and came across a bark gunyah, constructed in such a way as not to be noticeable until one would be right on it. The gunyah presented the appearance of being recently occupied, and we found two empty bottles in it. From the circumstances of the two bushrangers having been seen by us coming from that direction, and other collateral evidence, we had no doubt of this being one of their rendezvous, and of being able to secure them in it before long; but we had a better plan in view at the time, and we were waiting its accomplishment or failure before trying their capture as before described.

Shock Attack on the Bogus Surveyors

The report continues, describing events two days later, on Friday 5 October. The Special Police received a shock:

I have now to relate a most providential escape we all had from being shot, and perhaps riddled to death. We had been surveying a flat near our camp, from 9 o'clock on Friday morning till about 4 in the afternoon. At 4 o'clock, we went in a body on a neighbouring range, where we could reconnoitre well. We returned to camp about 6, and had just finished our teas and were standing round our fire, which we always allowed to die out, when, all at once (it was very dark) we heard the report of a musket or rifle about 100 yards from us. The ball passed right between us, and entered the tree against which our fire was made, just on a level with our heads. We had our arms out in an instant, but before we could discharge them we were fired upon from two opposite directions. Thank God, none of us was touched. We each discharged a shot in the direction of the explosion by the bushrangers, for we had no other guide in aiming, owing to the night being so very dark, which was rendered denser by the mizzling rain which had been falling all day. Our first object, of course, was to get out of the glare of the fire, which was still burning sufficiently to afford a good aim at us by the bushrangers. The Clarkes and whoever were with them, had evidently lain on the ground, behind trees. I would suppose there were at least four of them. We kept up random firing for about five minutes, closing by degrees on the first position taken up by the bushrangers, who always retired on our approach, and in opposite directions.

I cannot speak too highly of the courage displayed by the party under my charge. They acted most zealously; indeed, under the circumstances, I thought rashly, in pursuing under such disadvantages. About 8 o'clock we found that our ammunition had been inadvertently left in the tent, and to return to it, from its colour and position, so close to the fire, which would throw the shadow of anyone passing so clearly as to afford a good mark for the fire of the bushrangers, appeared certain death. Kennagh however (and I cannot speak too highly of his courage), without a moment's hesitation, made a rush to the tent, under cover of our fire, and secured the ammunition. The bushrangers now directed their firing to the tent (which is

riddled), but without effect. Kennagh returned to us unharmed. After this the bushrangers ceased firing, and as we had no further clue to their position we remained in ambush the whole of the night, expecting every moment to see the tent attacked, or to be passed by some of the bushrangers. No further attack was, however, made, and when daylight came no traces of them could be found, if I except some balls and a flask half full of powder, which had been dropped by one of them. How we escaped being at least wounded is a mystery; to God we must be thankful, for a narrower escape or more dastardly attack is not in my recollection.

Carroll was at a loss to know why the bushrangers attacked them, believing that when Phegan and Kennagh last went to the Clarke house there was not the remotest suspicion of who they really were. But Carroll was naïve to think the Clarkes could be taken in so easily.

The next morning the 'surveyors' went to see Thomas Stewart at nearby Mount Elrington to seek his help. Stewart had been told about the secret mission and having heard shots the night before was not surprised to see them. However, he was surprised to discover that they were armed only with revolvers. Carroll explained the plan was to befriend the family and catch the bushrangers by surprise. Stewart later said:

I told him he was labouring under a fearful mistake [misapprehension] if he ever expected to take the bushrangers by such means, and that it was not folly merely but madness to place himself in such a position with nothing but revolvers; that he little understood the men he had to deal with. Stewart said he had been to Braidwood the day before and astonished Carroll when he told him that the news of their presence and true identity was all over town. He told Carroll that one of the Clarke girls had come into Braidwood and reported there was a party camped within a mile of their house who professed to be surveyors and said, 'We know what they are, they are a party come from Sydney to take our brothers and they need not attempt to carry that out any longer'.

Stewart also thought the Clarkes would have soon seen through their pretence of surveying, for the Clarkes knew the boundaries of the blocks and the bogus surveyors were running their lines in the wrong places. Furthermore, their equipment would have given them away. They only had a compass and chains, no theodolites. Stewart had given them a lot to think about.

Tom Connell would later tell his cellmate it was the regular police who told them about Carroll's party, the day after they arrived. Of the night of the attack he said there were three men who fired on the camp but denied that he was the third person. He said it was not their intention to wound or kill any of Carroll's party but more to test their courage under fire. After seeing the effective manner in which Carroll's party reacted to the attack it was Clarke's intention to keep out of their way, to 'keep wide of them'.

Another part of Carroll's report deserves attention. It was the first sally in his long running criticism of the police:

The police ride frequently to and from Braidwood, but we have never met them off the main road; and that the Clarkes should infest that immediate neighbourhood with such impunity, and so frequently, without being captured, would require some explanation [adding optimistically] I have every hope that when we have a supply of rifles, to bring in, dead or alive, one or the whole of the gang within a month. Parkes was not prepared to send more men but did accede to the request for more firearms, including two Tranter revolving rifles.

In the meantime, the special police spent a week visiting what they considered to be the principal haunts of Thomas Clarke and his associates. Carroll began to realise the depth and effectiveness of the bushrangers' information system.

The Search for Bodies

The next morning Ned Smith sent his boy, John Lynn, to Bells Creek with a letter, instructing him to go via the track to Guinea's and make enquiries about the Special Police. Lynn set off at about 10 am. About a mile and a quarter (2 km) from the Jinden house he found the reason the men had not returned. On the track he found the bodies of two of them, later identified as Phegan and McDonnell. Phegan appeared to have been shot through the side and was lying on his face with his head towards Guinea's. McDonnell was lying on his back about 4 feet (1.2 m) away. He had been shot through the thigh and there was a large quantity of blood on the ground near the body. Deeply shocked, the 18-year-old galloped back to Jinden house to tell Ned Smith what he had seen.

It was apparent the Specials had not heeded George Smith's warnings about keeping off the beaten tracks and the possibility of being surprised from behind trees. In fact, this was an ideal place for an ambush. Two large trees capable of concealing five or six men stood a few metres from the track. The surrounding country was open bush with a sprinkling of small gum saplings and honeysuckle trees. Immediately above the track was a slightly sloping range running parallel to the track where horses could be hidden out of sight.

Smith and an elderly workman named Thomas Gee accompanied Lynn back to the scene. Gee was left to watch over the bodies while Smith sent Lynn to Ballalaba to inform the police and himself went to Hezekiah Watt's to seek help in searching for the remaining two men. Watt and George Smith returned to the scene with Ned Smith and after searching for a while they went to Mrs McInerney's. She told them that about an hour before sunset she had heard nine or ten shots being fired. The direction she indicated pointed to the location of the bodies already found. Afterwards, about 10 minutes later, she said, she heard several more shots, not from the same direction, and further away. Finally she heard two more shots rather nearer. She had thought the firing came from the four Specials who had visited her earlier in the day, possibly discharging their weapons before returning to Jinden house. Later she told Sergeant Byrne that about 10 minutes after the last two shots were fired she heard a noise like cattle running through the bush and saw three armed men walking across the creek below her house. She could not identify them. Going in the direction indicated by Mrs McInerney, the men found the bodies of Carroll and Kennagh in the bush about a quarter of a mile away. This was about half a mile from the higher ground where the bodies of Phegan and McDonnell were found. Both men lay on their backs, about 4 or 5 yards (3.5-4.5 m) apart. Carroll had been shot through the chest and Kennagh, they found later, was shot through the neck.

Blood Money

Their attention was drawn to a clear and profound message left by the murderers. Over the wound on Carroll's chest was a neatly folded red silk handkerchief and on it lay a £1 note from the Joint Stock Bank, held down by a piece of wood to stop it blowing away. The message was clear. The murderers' motive was not robbery. It was payback. The £1 note was a symbolic payment. The Specials had got the blood money they had been seeking.

Sergeant Byrne and Party Arrive

About 2 pm Sergeant Byrne, accompanied by two constables and a black tracker, arrived at Jinden house. He had been collecting information for the electoral roll, one of the many duties assigned to the police at the time, which coincidentally placed him in the area. The police party headed out along the track to where the bodies of Phegan and McDonnell lay, under the charge of Smith's workman, Thomas Gee. Byrne inspected the site and the bodies. In his words:

I turned the first body over, and recognized it was that of Phegan's. I searched him, saw he was wounded through the right side. He was wounded twice. I found his pistol upon him. It was loaded and capped on every nipple. His vest pockets were pulled out. About four or five yards further on I recognized McDonnell's body. I found a Tranter's revolver near it, loaded and capped all round, and a hat which I recognized as belonging to special constable Kennagh. I examined the ground and found a bullet mark on a tree, close to McDonnell's body. It was a small tree, not sufficient to afford protection. McDonnell appeared to have stood behind this tree. A little higher up the tree I found another bullet mark. About twenty-three yards from the bodies, and towards Guinea's, I saw a large tree on the right hand side of the track. I discovered footmarks, and pieces of paper in which patent ammunition for a rifle had been wrapped. I found no marks of bullets on this first large tree. About ten yards further on, still towards Guinea's there was a second large tree, not so large as the first. These two trees were on the right hand side of the track going to Guinea's. At this second tree I found nothing except foot prints of men; no paper of cartridges was found there. More foot prints were at the first or larger tree than at the smaller one. I sent the old man Lynn [it was Gee, not Lynn], whom I found in charge of the bodies, to Mr. Smith for a cart, to remove the bodies. While he was away, Mr. Edward Smith (Lynn's) master came up. We waited near the first bodies till the cart arrived, and then we placed them into it. I then went with Mr. Smith, down the bush, off the track, for about half a mile, and I there saw the dead bodies of special constables Carroll and Kennagh. I first saw and recognized Carroll's; then Kennagh's. They were about five or six yards apart … I found Carroll's body lying on its back. On his left breast, in the region of the heart, there was placed a red silk handkerchief, on which was a £1 note, and on the note a piece of wood to keep it from blowing away … On examination I found some money on the ground beside the body, on the right side. His trouser pockets were turned out. About four or five yards from Carroll's body I found that of Kennagh's. He was lying on his back; his right hand was shut, clenching a match-box and a knife. I found a wound in Carroll's left breast. I could not then but afterwards saw how Kennagh had been wounded. He had been wounded in the neck. The ball having gone downwards.

It was apparent that the Specials had been ambushed together on the track, confirmed by the fact that Kennagh's distinctive hat, black with a blue flyveil, was near the bodies of Phegan and McDonnell. Their assailants had evidently opened fire on them from the cover of the two big trees near the track. Phegan and McDonnell's revolvers had not been fired. The trees behind them had marks of bullets. The bullet that struck McDonnell in the thigh broke the bone and severed the femoral artery, causing him to bleed to death quickly. Phegan had been shot twice, the second shot while he lay on the ground, probably to finish him off.

Carroll and Kennagh had retreated downslope for about half a mile before they were overtaken and had surrendered. From subsequent medical evidence it was clear they had been shot while in kneeling position only a few yards from their killers. Whether they were pleading for mercy or saying their prayers is speculation. No weapons were found with these

bodies. It was clear that the assassins had taken the two Tranter revolving rifles, while two Tranter revolvers were also unaccounted for.

A further examination of the area revealed a spot where Sergeant Byrne could distinguish the hoofprints of at least three different horses. This was about 300 yards (275 m) from the ambush site, on higher ground, and Byrne concluded this was where the murderers' horses were held. He noted that words spoken where Phegan's body lay could be clearly heard where the horses had been.

Post Mortem

The bodies were removed to an outhouse at Jinden to await an inquest. Superintendent Orridge arrived the next day at 3 pm accompanied by Coroner Griffin, Dr Pattison and a party of police. An inquest was opened on Friday, 11 January and concluded in Braidwood on 14 January. The examinations were made in oppressive heat and the situation was very unpleasant. The result of the full and careful post-mortem examination by Dr Pattison is described in his own words:

John Carroll: *I am of the opinion that death was caused by a gunshot wound, that the wounds already mentioned were inflicted by the bullet removed, which entered the body through the fourth rib anteriorly, passing through part of the left lung, upper part of pericardium, right auricle and right ventricle of heart, passing through lower lobe posteriorly of right lung, fracturing the seventh rib posteriorly close to the spinal column, the bullet lodging in the muscles of the back. I am also of the opinion that deceased must have been in a kneeling position when shot, and only a few yards from the weapon – which I believe to have been a rifle or gun.*

Patrick Kennagh: *I am of the opinion that death was caused by wounds which were inflicted by a rifle ball of large dimensions. I am also of the opinion that deceased was in a kneeling position when shot. The bullet entered through the neck and passed downward through the trachea and upper part of the gullet, passing through the upper part of left lung, and wounding vessels already described, fracturing part of the first dorsal vertebra and passing through the body posteriorly, fracturing second rib about an inch from spina column.*

Eneas McDonnell: *Wounded in left thigh about middle third, wounding femoral artery and vein, and fracturing femur. Removed portion of bullet from inner and upper surface of thigh bones. I am of opinion that deceased must have been in an erect position probably walking, and in the act of turning round when bullet entered thigh. Death must have taken place in a minute or two after infliction of wound. I am of opinion wound must have been produced by rifle ball at some distance (say twenty yards) from party firing. Only part of the bullet entered the thigh.*

John Phegan: *I am of opinion that deceased was first shot through right side, bullet passing through base of right lung, and posterior portion of liver as already described, lodging in the tissues external to the ninth rib posteriorly close to the spinal column. The bullet was a rifle bullet. A second bullet entered the body – probably when deceased was lying on the ground – passing between fifth and sixth ribs on the left side, through both lungs, wounding large blood vessels of heart, making its exit in the right side immediately above margin of lateral surface of third rib, entering right arm while deceased was lying on that arm, passing through the inner and upper part of right arm, fracturing the bone and embedding itself in the tissues.*

On Carroll's body they found £11 in notes and 4 shilling in silver. On Kennagh, no money, but two private letters signed 'Mary Kennagh' and a certificate authorising the bearer as employed on Secret Police duty, signed by Henry Parkes. On McDonnell, £14 in gold coin, one £5 note, 31 shillings in silver, and a Bank of New South Wales deposit receipt for £300, one silver watch, a knife, and a deposit and repayment bank form of receipt for the sum of £80, with a similar authority, signed Henry Parkes. On Phegan's body was 5 shillings and 3 pence and in a leather purse, a portrait of a female, with a lock of woman's hair.

At the conclusion of the post mortems, the police considered that decomposition was so far advanced owing to the hot weather that it was utterly impossible to remove the bodies so four graves were dug on a hill, a short distance from Jinden house. The bodies were enclosed in sheets of bark lashed with greenhide, 'the only material available in that out of the way spot', and committed to their temporary resting place. Three of the men were Catholics while McDonnell was a Presbyterian. They were all natives of Ireland. The prayers of the Catholic Church and a short chapter of the Bible were read over them. It was a melancholy occasion for the few who were present at the lonely burial site.

For the Special Police who had such high hopes of putting an end to bushranging and bringing law and order to the Southern District, it was a tragic end. They became victims of the lawlessness in a callous act of assassination unprecedented in bushranging history.

John Carroll was 32 years old, from Thurles, County Tipperary. He left a widow and five children. Patrick Kennagh was 29 years old, from Kildare, and left a widow and three children. John Phegan was 31 years old, from Queens County, was a widower with one child, and Eneas McDonnell was 48 years old, from the north of Ireland and single.

On his return to Braidwood, Superintendent Orridge telegraphed a detailed report to Inspector General McLerie in which he said:

I am satisfied the actual murderers are Thomas and John Clarke and William Scott though I have been unable to prove that they were seen in the neighbourhood later than the 4th instant. A fourth man probably held the horses. Three men, of whom no description is obtainable, were seen making from the spot after the second firing. No doubt Carroll's party was watched going to Jinden and up to the time of their death. Certain parties are strongly suspected of being accomplices, but it is not advisable to telegraph names. More information shortly.

Public Reaction to the News

As the news of the murders became known in Sydney, the newspapers expressed their shock and dismay along with publishing the official reports, including Orridge's telegram, which was made available through the Inspector General's office. Not everyone thought the bushrangers were entirely to blame. The newspapers recounted the coroner's report and past events involving the harbourers' trials and emphasised Carroll's allegations against the police. There was even the shocking speculation that the police were involved in some way. The 'new police' system in general was blamed for its ineffectiveness in allowing the lawless state of the district to exist in the first place and thus creating the need for Special Police to be sent. It was widely held that the Specials had been betrayed and were victims of some sort of treachery. Much sympathy was felt for them as so soon after their deaths was not the appropriate time to be critical.

Constable Woodland expressed his view:

The intelligence of the murders puzzled us … Putting the odds and ends together I came to the conclusion that a certain squatter made up the plan, that James Griffin did the telegraphing, and the Clarkes and Bill Scott the shooting part. What share Mick Connell had in it I cannot say.

Tom Connell, from his gaol cell, did not think the Clarkes shot the Special Police. He believed that the murders were committed by the harbourers and that 'his brother Michael was connected with it. If not one of the parties who done the deed he knew of it'.

Numerous editorials put forward views on how to suppress bushranging, and Colonial Secretary Parkes came under fire, being severely criticised for his use of Special Police. The Premier, James Martin, contacted him from Melbourne, pointing out that the Specials ought to have been withdrawn as soon as their identity became known. Parkes responded to his critics in his usual way and went on the attack. He ordered that the bullets extracted from the bodies be compared with the police firearms to determine whether any members of the police force had been guilty of, or in any way accessory to, the murders in question. This caused further speculation that the government suspected the regular Braidwood police were involved. But little could be proved by this move. In fact it was nonsense. Ballistic science did not exist and it was a well-known fact that the bushrangers were using weapons that were stolen from police.

In defending his use of the Special Police, in a letter to Governor Sir John Young, Parkes rejected some of the inferences suggested by Dr Pattison's evidence and pointed out that they had been well armed with revolving rifles. He wrote:

Carroll was a man of very superior intelligence for his class, of great physical strength and activity, and I believe, as brave as a lion. Both he and Kennagh knew the use of firearms well, and were thoroughly acquainted with the character and class of the men they had to deal with. They were men whose lives were not to be taken cheaply, if they had any chance of resistance, I feel assured they have been victims of some extraordinary treachery.

At present I am inclined to believe that he [Carroll] was betrayed to his death by some person who had offered to put him on the track of the bushrangers, and that the circumstances were such as rendered resistance impossible, or possibly that he was shot down in pure revenge by new enemies he had made by his late proceedings.

The term 'new enemies' shows Parkes held doubts that the obvious suspects, the bushrangers, were the murderers.

Exhumation and Reburial at Braidwood

The people of Braidwood telegraphed the Colonial Secretary, calling his attention to the disgraceful manner in which the bodies had been disposed of – without coffins, Christian burial or decent place of interment. This contrasted with the exceptional treatment that an ordinary constable would receive in like circumstances. Parkes ordered that four coffins be made and an undertaker sent from Braidwood to exhume the bodies and bring them into Braidwood to be reinterred. This action implied that Parkes agreed that the Specials had been buried with a lack of care and compassion, but the police claimed that the decision was taken

because of the heat and the distance from Braidwood, and that reinterment could be carried out later.

Arrangements were made to bring the bodies to Braidwood. The undertaker, Webb, and his assistant Bright set off with a cart at midnight on Sunday, 12 January under instructions to proceed to Jinden. Constables Walsh, Geelan and Robson set off at daylight to oversee the exhumation and provide protection if required. It was a most unpleasant task for all concerned, and the trip back to Braidwood became an ordeal.

The police claimed the undertaker got so drunk that they had to instruct the assistant, Bright, to take over and that Webb had to be placed in the cart with the bodies, but he would not stay there. Webb counterclaimed it was the police who were drunk. However, Sergeant Duffy gave evidence before the Commission of Inquiry that the police were sober when they arrived back and reported the incident to him. The unpleasantness of the task was made worse by the fact that the party had to spend a night out in the rain and the bodies, now over a week old, were in an advanced state of decomposition and emitting a most offensive odour. In Webb's defence, his behaviour was considered by Duffy to be out of character. No one got into trouble as it was just considered a bad job.

The party reached the outskirts of Braidwood just before dark on the night of Wednesday, 17 January. Originally they had contemplated leaving the bodies at the foot of Mount Jillamatong, but it was considered unsafe to leave them unprotected so they pushed on to St Bede's Church, where the groom at the church stables refused to accept them. They went on to the police stables at the other end of town where there was no alternative but to leave them in the yard. On the next day, nearby residents complained of the smell.

The next morning, shops and hotels closed and the great bell at St Bede's tolled at 10.30 am. The bodies were placed in two carts, the bodies of Carroll and Kennagh, the married victims, in one and Phegan and McDonnell in the other. A procession was formed at the Court House. A party of police under Sergeants Duffy and Smith escorted the bodies on foot. The rest of the mournful procession, consisting of about 150 people, was headed by Superintendent Orridge and another party of police, and they made their way through town to the Catholic cemetery at the southern end of the main street.

Michael Wallace, the governor of the gaol, officiated as chief mourner. The priest was away from town so Mr D.E. Finnegan, the teacher at the Catholic school, took his place and read the service. No relatives had been able to reach Braidwood in time, but the widows of Carroll and Kennagh sent for locks of their husband's hair. Volunteers from the crowd lowered the coffins and helped fill the graves.

A four-sided monument was later erected over the site, each side bearing the name of one of the Special Police, 'murdered at Jinden on 9th January, 1867, whilst in pursuit of the outlaw, Thomas Clarke'.

Integrated Reality Capture in the Rail Environment

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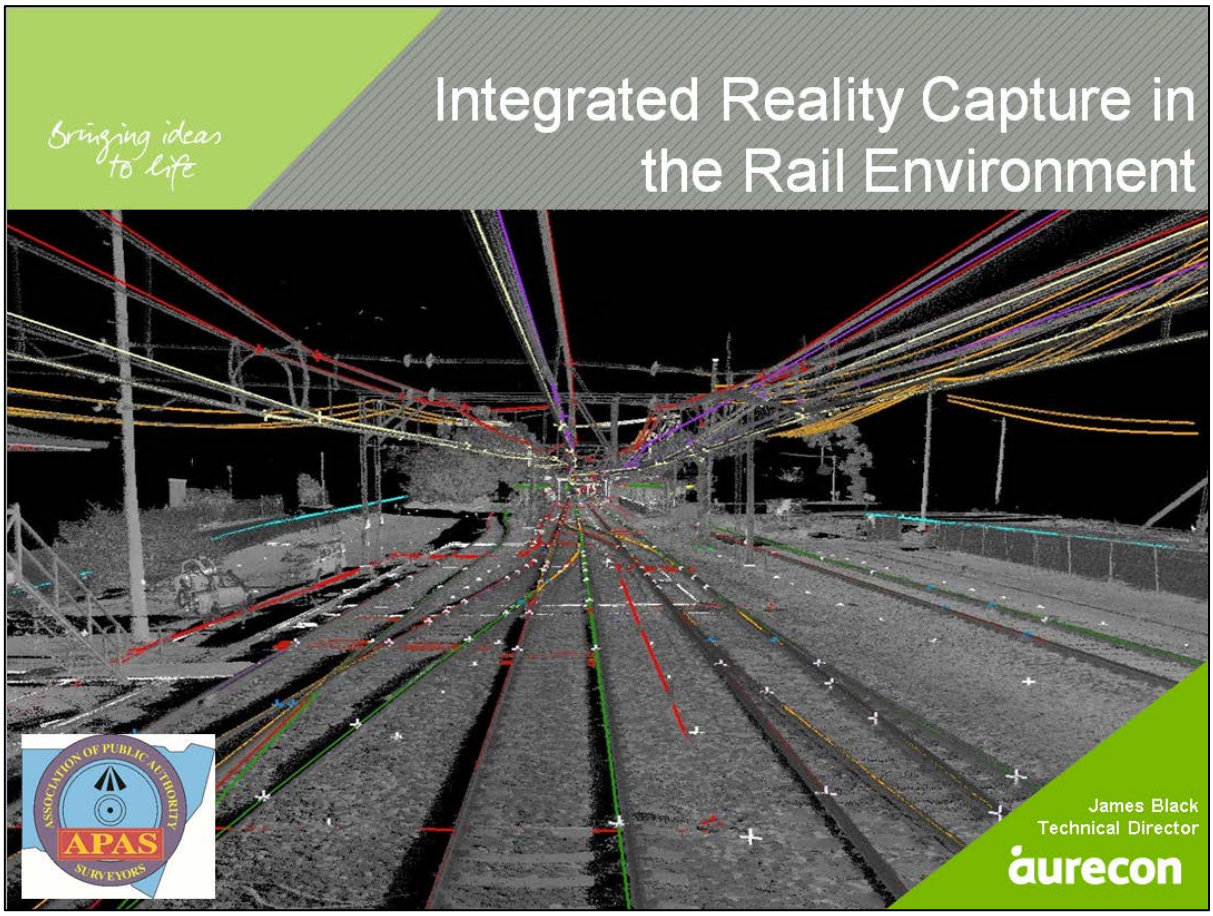
ABSTRACT

Just imagine how transportation will operate and be managed in the future. With ideas like Hyperloop (that may soon be a reality) and the plausibility of high-speed trains, we more than ever need to challenge current methods of rail design and the format of design inputs that we so heavily rely upon to ensure 'good design'. Behind all rail designs are spatial datasets, often captured by methods that provide known outcomes and certainty. However certain, the data can lack sufficient detail to make informed decisions. Efficient design workflows, creative design and option engineering often suffer at the hands of limited design inputs. Whilst there is no doubt that the existing operations and fundamental workflow structure of rail alignment and spatial positioning in the rail environment is highly successful in today's application, our question is "How can we leverage off modern technology to create design inputs which enable greater efficiency, enhance creativity and maintain spatial integrity and certainty for the future of rail design?" Terrestrial and mobile laser scanning are not new applications of spatial capture and the resultant point cloud deliverables are used widely in today's industry. That said, laser scanning accuracy and repeatability have long lived under a perception of uncertainty, which has created a reluctance of use in the rail environment. Over the last year, testing of alternative capture methods through project application has been undertaken with success. We are now looking to efficient ways of integrating and applying workflows to mobile and terrestrial laser scanning, terrestrial positioning, GNSS real-time observations and digital level runs to provide spatial certainty and enhance design capability. At present, our analysis of integrating unconventional and conventional methods of modern reality capture has provided a level of accuracy suitable for all rail design applications. We are encouraged by these findings and believe we will soon be demonstrating a path to the future of rail environment reality capture.

KEYWORDS: *Integrated survey methods, rapid data reality capture, rail corridor, mobile laser scanning.*


Bringing ideas to life
Integrated Reality Capture in the Rail Environment
ASSOCIATION OF PUBLIC AUTHORITY SURVEYORS
APAS
James Black
Technical Director
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Bringing ideas to life
"Given the pace of disruption, companies need to ready themselves for a future that is not yet written"
Giam Swiegers, Aurecon CEO
An industry of change
aurecon

Aurecon Safety

Bringing ideas to life

Because people depend on you

Awareness

Attitude

Understanding

Communication

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Current State

Bringing ideas to life

Capture through conventional methods. Why?

It works!

However, this begs the question….

What is the consequence of not pursuing new technology?

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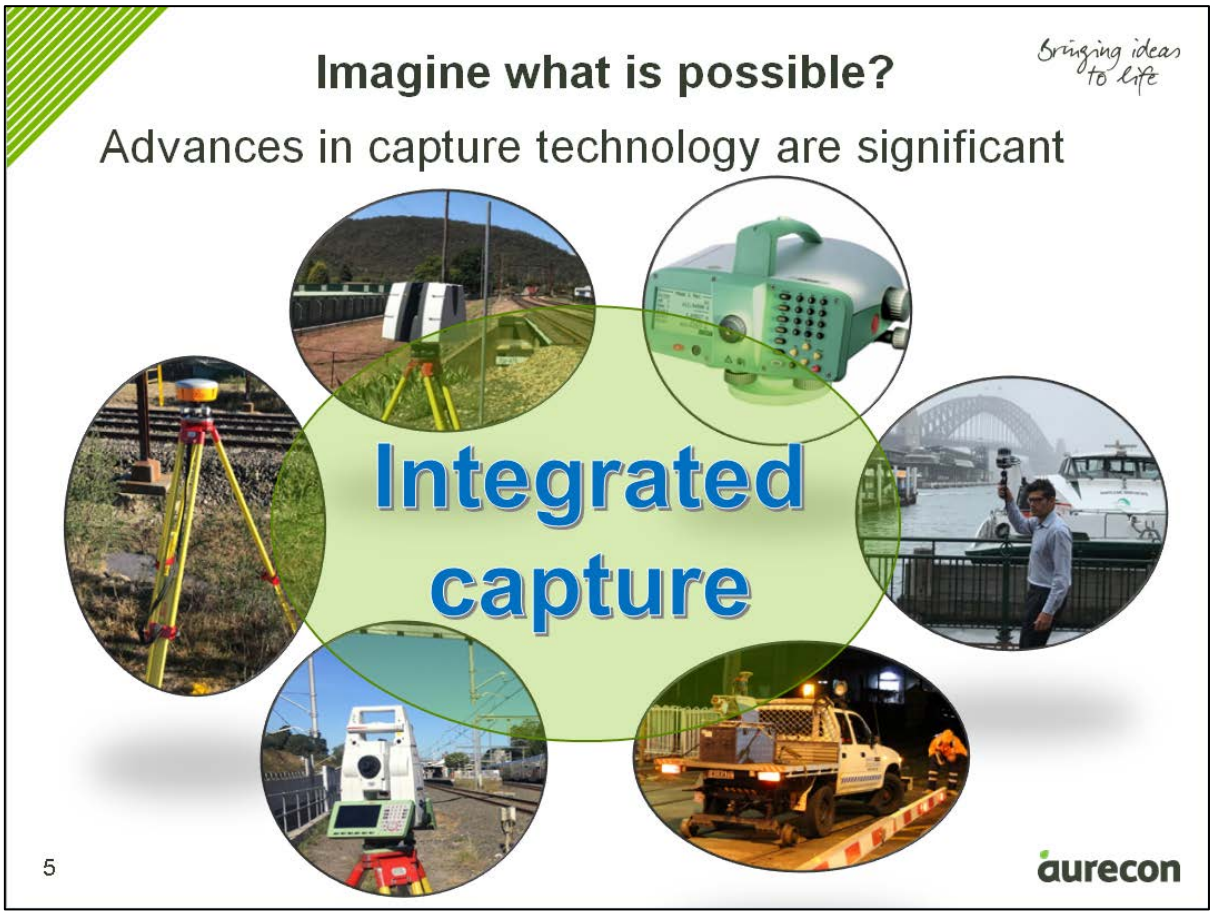
Imagine what is possible?
Bringing ideas to life
Advances in capture technology are significant
Integrated capture
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Why change?
Bringing ideas to life
Traditional capture
7
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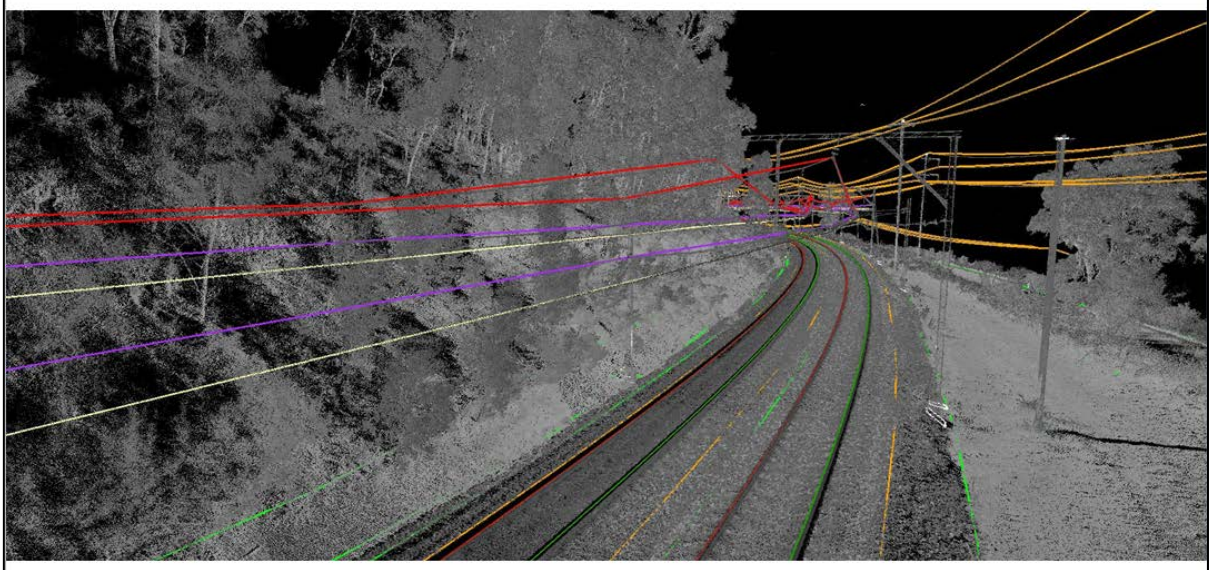
Why change?

Bringing ideas to life

Rapid data capture and extraction



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What is the outcome?

Bringing ideas to life

Complete registered point cloud – for visual purposes mostly

Usability of large point cloud data presents challenge to existing systems and software, so…

Tiled point cloud delivery 500m sections

Point cloud extraction by understanding project parameters:

Virtual surveyor – point only extraction ✓

String based solution – CAD linework ✓

Basic objects modelling– No metadata associated

Complex objects – Metadata associated (post extraction)

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Validating the results

Bringing ideas to life

Rigour around GCP locations and check point comparisons!

Considerations:

- Spacing of GCP's
- Designated check points in space – Conventional capture vs extraction
- Residual analysis and confidence
- Demonstration to all users of the data

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Conclusion

Bringing ideas to life

Application of MLS and integrated survey techniques is fit for purpose in all rail assignments

MLS is not yet suitable as a stand alone method of capture and delivery

We will continue testing on future projects to build efficiency into processes and add value to future users of rail capture

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