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Editorial

These proceedings contain the papers presented at the Association of Public Authority Surveyors Conference (APAS2014), held in Pokolbin, NSW, Australia, on 31 March – 2 April 2014. Papers were not peer-reviewed but have been subject to changes made by the Editor.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:

Janssen V. and Watson T. (2014) Current status of EDM calibration procedures in NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2014)*, Pokolbin, Australia, 31 March – 2 April, 3-15.

NSW Land and Property Information (LPI) is gratefully acknowledged for providing the front cover artwork and producing these proceedings, and for sponsoring the conference in general. The APAS committee is thanked for their hard work in organising this conference.

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Current Status of EDM Calibration Procedures in NSW

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ABSTRACT

In Australia, the legal basis for a national system of units and standards of measurement of physical quantities is provided by the National Measurement Act 1960. Under this Act, the Surveyor General of New South Wales is a verifying authority for reference standards of length measurements and responsible for ensuring that surveyors use verified measuring equipment. To this end, the Surveying and Spatial Information Regulation 2012 requires surveyors to verify their Electronic Distance Measurement (EDM) equipment in relation to an Australian standard of measurement of length at least once a year. In order to assist the profession in meeting this requirement, Land and Property Information (LPI) provides and maintains several EDM baselines across the state. LPI is currently in the process of improving this infrastructure by upgrading existing baselines and building new baselines for the calibration of EDM instruments. This paper presents the current status of EDM baseline infrastructure in NSW and outlines the data processing performed by LPI in regards to EDM calibrations. The EDMCAL program currently employed by LPI is described and compared to a popular spreadsheet calculation generated by the University of New South Wales. It is shown that both of these software tools generate comparable results. Finally, LPI's new online EDM baseline booking system is introduced. This online system should now be used by surveyors to book access to all EDM baselines in NSW in order to allow efficient and effective use of existing and future baseline infrastructure.

KEYWORDS: *EDM calibration, EDMCAL, baseline infrastructure, online booking system, legal metrology*.

1 INTRODUCTION

Metrology is the science of measurement and its application. It includes all theoretical and practical aspects of measurement, independent of the measurement uncertainty and field of application (JCGM, 2012). Legal metrology covers activities resulting from statutory requirements and concerning measurement, units of measurement, measuring instruments and methods of measurement that are performed by competent bodies (OIML, 2000). This incorporates all measurements carried out for any legal purpose, including measurements that are subject to regulation by law or government decree.

In Australia, the legal basis for a national system of units and standards of measurement of physical quantities is provided by the National Measurement Act 1960 (Australian

Government, 2013a). This Act is administered by the National Measurement Institute (NMI), which may in turn appoint organisations as verifying authorities under the provisions of Regulation 73 of the National Measurement Regulations 1999 (Australian Government, 2013b). The office of the Surveyor General of New South Wales (NSW) has been so appointed as a verifying authority for length measurement standards.

In NSW, practising surveyors are subject to the Surveying and Spatial Information Act 2002 (NSW Legislation, 2014a) and the Surveying and Spatial Information Regulation 2012 (NSW Legislation, 2014b). The latter states, for instance, that a surveyor must not use any Electronic Distance Measurement (EDM) equipment unless it is verified against the state primary standard of measurement of length by using pillared baselines, at least once every year and immediately after any service or repair. This instrument verification establishes traceability of its measurements to the national standard.

In this context it is important to explain the difference between the terms verification and calibration. The International Vocabulary of Metrology defines these two terms as follows (JCGM, 2012):

- *Verification* is the provision of objective evidence that a given item fulfils specified requirements. When applicable, measurement uncertainty should be taken into consideration. Verification in legal metrology pertains to the examination and marking and/or issuing of a verification certificate for a measuring system.
- *Calibration* is an operation that, under specified conditions, in a first step, establishes a relation between the quantity values (with measurement uncertainties provided by measurement standards) and corresponding indications (with associated measurement uncertainties) and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. This may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

In other words, verification allows surveyors to know the acceptability of their measurement results against expectations (e.g. the manufacturer's stated performance criteria) and whether further actions need to be taken in regards to their processes. Calibration is the process of comparing a measured value to a known value, e.g. by comparison to a standard of the physical quantity length.

The verification of an EDM baseline is carried out periodically with precise EDM instrumentation carrying a current Regulation 13 certificate issued by NMI (the associated meteorological equipment is also calibrated against industry standards). This process determines the 'true' inter-pillar distances and establishes traceability because the EDM baseline becomes a subsidiary standard of the International Metre. The calibration of a surveyor's EDM instrument on a verified baseline determines the corrections that need to be applied to the instrument in order to obtain the 'true' inter-pillar distances, thereby establishing traceability of its measurements to the national standard.

In order to assist the surveying profession in meeting their legal requirements, the Surveyor General has established several EDM baselines throughout New South Wales. On behalf of the Surveyor General, Land and Property Information (LPI) is currently in the process of improving this infrastructure by upgrading existing baselines and/or building new baselines for the calibration of EDM instruments.

This paper presents the current status of EDM baseline infrastructure in NSW and outlines the data processing performed by LPI in regards to baseline verifications and EDM calibrations. The EDMCAL software currently employed by LPI is described and compared to a spreadsheet calculation generated by the University of New South Wales. Finally, a new online EDM baseline booking system is introduced to allow efficient and effective use of the baseline infrastructure in NSW.

2 CURRENT EDM BASELINE INFRASTRUCTURE IN NSW

The Surveyor General has established several EDM baselines consisting of between four and seven concrete pillars throughout NSW. Current best practice has established that EDM baselines should consist of at least five (and preferably six or seven) pillars to increase the number of distances observed (i.e. higher redundancy), thereby allowing a more reliable determination of the instrument correction. As a result, LPI is in the process of rationalising and improving its EDM baseline infrastructure by upgrading existing baselines to include more pillars and/or building new 7-pillar baselines.

Figure 1 illustrates the location of the 16 EDM baselines presently maintained in NSW. The new 7-pillar Seaham baseline (constructed in December 2013) replaces the 4-pillar baseline at Newcastle, which will cease to be maintained by LPI in August 2014 (but will continue to be used for teaching purposes by the University of Newcastle). It is planned to upgrade the 4-pillar Armidale baseline to include seven pillars, and contracts have been signed to establish a new 7-pillar baseline at Coffs Harbour (replacing the 4-pillar baseline at Grafton). In addition, efforts are underway to establish new 7-pillar baselines at Wollongong (replacing the existing 4-pillar baseline) and the South Coast (replacing the 4-pillar baselines at Nowra and Bega).

Figure 1: Location of current EDM baselines in New South Wales.

All EDM baselines in NSW (current and those under construction) follow the Heerbrugg design, which features an almost equal distribution of the distances measured in all combinations over the baseline length as well as over the unit length of the EDM and permits the detection of all distance-dependent errors, including cyclic errors (e.g. Schwendener, 1972; Rüeger, 1996). For a detailed description of the substantial issues that need to be considered in the design and construction of a state-of-the-art EDM baseline, the reader is referred to Ellis et al. (2013). Depending on the location of the baseline, additional environmental aspects may have to be considered in some cases (Janssen, 2012).

LPI verifies these baselines on a 2-yearly basis and makes the current measurement reports available on the LPI website (LPI, 2014a). In accordance with the appointment as a verifying authority for length measurement standards, the least uncertainty quoted for the verified inter-pillar distances is currently 0.5 mm + 1.3 ppm at the 95% confidence interval. The field procedures prescribed for EDM calibrations in NSW are documented in Surveyor General's Direction No. 5: Verification of Distance Measuring Equipment (LPI, 2009). It should be noted that the accurate observation of meteorological data is essential for a reliable EDM calibration. An error in the measurement of 1ºC in temperature or 3 millibars in atmospheric pressure will cause a corresponding error in the reduced distance of approximately 1 part per million (ppm).

3 EDMCAL

Naturally, the processing of EDM calibrations can be performed in different ways and with different tools. The standard mathematical methods involved have been described in various textbooks (e.g. Rüeger, 1996; Harvey, 2009). In NSW, a program called EDMCAL has been used for many years by LPI for this purpose. Alternatively, a number of surveyors utilise a spreadsheet calculation developed at the University of New South Wales (UNSW). This section describes the EDMCAL software, while section 4 provides a comparison of EDMCAL and the UNSW spreadsheet in regards to processing outcomes.

3.1 History

The program EDMCAL determines the additive constant (also known as instrument/reflector constant) and scale factor of EDM instruments using the parametric method of a rigorous least squares adjustment. This adjustment includes:

- Data snooping after Baarda (1968) to enable the detection of likely gross errors, i.e. a multidimensional test on the 'a posteriori / a priori' variance factors (test 1) and a one-dimensional test on the ratios of 'residual / a priori standard deviation of residual' (test 2).
- A one-dimensional similarity transformation in which the solution of pillar distances from the calibration adjustment is transformed to previously determined pillar distances.

The original program was written in the FORTRAN programming language by J.D. Love as part of an undergraduate student project for the Bachelor of Surveying at UNSW under the supervision of Dr J.M. Rüeger. The project report was submitted in April 1978. Since then, EDMCAL has undergone numerous modifications at LPI. These include:

- Ensuring compatibility with modern operating systems.
- Improving system performance, data structure and output format.
- Providing the possibility to input the EDM's modulation frequency, carrier wavelength and unit length as an alternative to the first velocity correction parameters.

- Using the mean of forward and reverse distance observations as the distance measurement between pillars, if applicable.
- Output of individual corrections applied to the slope distances, i.e. approximate instrument/reflector constant, atmospheric correction, slope correction, height (or datum) correction and chord-to-arc correction.
- Generation of a baseline database containing verification data on all baselines in NSW.
- Additional optional output to confirm the results, i.e. scale factor computation by linear regression and output of a HAVOC (Horizontal Adjustment by Variation Of Coordinates – see LPI, 2011) input file that can be used to compute the scale factor.

The current version 5.1 of EDMCAL was created in December 2013. The mathematical and statistical procedures have been thoroughly tested over many years. During the most recent update, the mathematical algorithms used to determine the atmospheric corrections were improved to make them more readable and provide clear reference to their origin in the source code. The continuing usage and feedback from users may result in additional modifications to the statistical output in order to further improve the interpretation of results.

3.2 Operation

A sample EDMCAL input file is shown in Figure 2. It includes the following information:

- Label for the 'test number' of the program run.
- Baseline number and name.
- Observation date.
- Institution/company and operator name.
- Instrument make, model and serial number.
- Reflector make, model and serial number.
- Approximate additive constant.
- Instrument thermometer make, model, serial number and its correction.
- Reflector thermometer make, model, serial number and its correction.
- Instrument barometer and its correction (if barometers are used at the instrument and reflector, this entry should include information on both barometers and the mean barometer correction).
- Instrument standard deviation (generally set to 1 mm + 1 ppm for EDM calibrations) and 'f' factor for variance test (dependent on the number of distance observations and the number of pillars).
- First velocity correction parameters for the EDM (i.e. reference refractive index *VC1* and instrument pressure factor *VC2*) and partial water vapour pressure (default: 15 mb).
- Optional: Modulation frequency (Hz), carrier wave length (nm) and unit length (m) of the EDM.
- Optional: Linear regression option selection.
- Optional: HAVOC input file generation option selection.
- Forward observations including slope distance, height of instrument, height of target, mean atmospheric pressure and mean temperature.
- Reverse observations including slope distance, height of instrument, height of target, mean atmospheric pressure and mean temperature.

```
00 13DS1B13.cal                                      (File Name format: ##=year,AS=your initials,1=edmcal No.1,b##=Baseline code No.)
01 13 NOWRA                                          (Baseline code No. & Name)
02 13/09/13                                          (Date)
03 LPI                                               (Owner)
04 D.Sluys                                           (Operator)
05 TRIMBLE S3 DR                                     (Instrument Make & Model)
50 91210131                                          (Inst. Serial No.)
06 Leica 8812249                                     (Reflector Make, Model & Serial No.)
07 +0.000                                            (Approx. Additive Constant)
71 Thies S/No 17723                                  (Thermometer used at instrument)
72 +0.0                                              (correction to thermometer)
73 Thies S/No 17723                                  (Thermometer used at reflector)
74 +0.0                                              (correction to thermometer)
75 Negretti & Zambra S/No 932                        (Barometer used at instrument)
76 0.0                                               (correction to Barometer)
08 1.00   1.00                 1  2.200              (Instrument Std Deviation ; 2.200 ="f" factor for variance test)
09 278.3  80.7 15.0                                  (Ist Velocity Parameters for inst.; "15" = Partial Water Vapour Press.)
11 1 0.241 2 0.242 150.6548    1 1016.3 13.9         (11=Fwd Obs, Pillar No Inst, HI, Pillar No Ref, HR, Slope Dist, Flag,
12 1 0.240 2 0.240 150.6542    1 1016.5 14.2             Press(mm or mb)(Inst&Ref Mean),Temp (Inst&Ref Mean))
11 1 0.241 3 0.241 317.2696    1 1016.5 13.8         (12=Rev Obs, Pillar No Ref, HI, Pillar No Inst, HR, Slope Dist, Flag,
12 1 0.240 3 0.241 317.2694    1 1016.7 14.6             Press(mm or mb)(Inst&Ref Mean),Temp (Inst&Ref Mean))
11 1 0.241 4 0.240 580.8092    1 1016.9 14.0
12 1 0.240 4 0.240 580.8084    1 1016.4 14.2         *** NOTE:   "HI"   MUST ALWAYS be in columns 6-10
11 2 0.240 3 0.241 166.6788    1 1017.0 13.7                     "HR"   MUST ALWAYS be in columns 14-18
12 2 0.240 3 0.242 166.6786    1 1017.2 14.4
11 2 0.240 4 0.240 430.3018    1 1016.9 14.4
12 2 0.240 4 0.242 430.3012    1 1016.9 14.8
11 3 0.240 4 0.240 263.6996    1 1017.0 14.8
12 3 0.240 4 0.241 263.6992    1 1017.0 15.0
99
```

Figure 2: Sample EDMCAL input file.

The input file is first checked for correctness of the number of pillars and number of observations. The basic principle of EDM instruments is the indirect determination of the travel time of a wave of light from the instrument to the reflector and back. While the speed of light in a vacuum is well known, in practice measurements are (of course) not carried out in a vacuum. The EDM measurements must therefore be corrected for the ambient atmospheric conditions because the velocity of visible and infrared waves changes with temperature, pressure and relative humidity (for light waves, the humidity is usually ignored).

Several corrections are applied to the observed slope distances in order to reduce these to horizontal distances at the height of the lowest pillar: approximate additive constant (if input by the user), atmospheric correction, slope correction, height (or datum) correction, and chord-to-arc correction (generally zero over distances used for EDM calibrations). The standard deviations of the measured distances are then computed. This is followed by the formation and solution of the normal matrix derived from the observations and the output of the results of calibration and data snooping according to Baarda (1968). The 'null' hypothesis is tested for acceptance or rejection.

The reduced distances are used to form observation equations for a least squares adjustment (e.g. Harvey, 2009). The adjustment parameters are the distances from the first pillar to each of the other pillars and the correction to the additive constant, leading to the determination of the additive constant of the instrument/reflector pair used. It is important to note that this additive constant is valid for a particular combination of instrument and reflector only, accounting for the distance-measurement reference points of the EDM instrument and the reflector not being coincident with the vertical axes at either end of the distance.

In order to determine the scale factor (and its ppm equivalent), a one-dimensional similarity transformation is carried out using the calibrated distances as coordinates. The program output is terminated with a brief summary that also provides the differences between the 'known' verified baseline distances and the adjusted distances determined with the EDM instrument under investigation (Figure 3).

```
                                SUMMARY
                                -------

      Test number                   :  13DS1B13.cal
      Baseline used                 :  NOWRA
      Verification date             :  08 AUG 12
      Date of observation           :  13/09/13
      Name of owner                 :  LPI
      Name of operator              :  D.Sluys
      Instrument manufacturer/model:   TRIMBLE S3 DR
      Instrument serial number      :  91210131
      Refl manufacturer,model & S/N:   Leica 8812249
      Approx. inst/refl constant    :   0.0000
      Inst thermometer S/N          :  Thies S/No 17723
      Refl thermometer S/N          :  Thies S/No 17723
      Barometer serial number       :  Negretti & Zambra S/No 932

   No. of pillars on base line:  4  No. of distances observed: 12

       Corrected instrument/reflector constant = -0.0351 metres

              Scale factor = 1.0000014891 (    1.5 ppm )

                   Calibrated Distance   Adjusted Distance  Difference

Pillars 1 to 2           150.4696            150.4695        -0.0001

Pillars 1 to 3           317.0879            317.0862        -0.0017

Pillars 1 to 4           580.7327            580.7321        -0.0006
```

Figure 3: Sample EDMCAL output summary.

4 COMPARISON OF EDMCAL AND UNSW SPREADSHEET

An alternative tool for the calculation of EDM instrument calibrations was developed by Dr B.R. Harvey at the University of New South Wales (UNSW) in form of an Excel spreadsheet (Harvey, 2014). Initially created for teaching purposes in 2006, the spreadsheet is now used by several surveyors for their EDM calibration calculations. The advantage of this spreadsheet is that all equations are visible to the user (rather than hidden in source code) and calculations can be customised for special cases if desired. However, this also means that users are at risk of inadvertently changing calculations. Currently, the spreadsheet allows for the determination of additive constant and scale factor on baselines consisting of between four and eight pillars. A sample calculation of the cyclic error is also included.

It should be noted that the UNSW spreadsheet states the standard deviations and uncertainties (at the 95% confidence level) of the calibration results, while EDMCAL does currently not routinely provide any rigorous uncertainty information. For baseline verifications, LPI determines the measurement uncertainties using an in-house spreadsheet calculation based on the recommendations stated in Bentley (2005) and JCGM (2008).

This section investigates whether the UNSW spreadsheet and EDMCAL provide comparable results in regards to EDM calibrations. Several datasets observed by LPI legal metrology staff during EDM baseline verifications are used for this purpose. The comparison is mainly based on seven verification datasets for each of three EDM baselines: Wollongong (600 m, 4 pillars), Wagga Wagga (535 m, 5 pillars) and Dubbo (765 m, 6 pillars). In the absence of a history of observations on a particular baseline consisting of seven pillars, the comparison also incorporates four datasets recently collected on the 7-pillar baselines at Kingscliff (K, 721 m), Eglinton (E, 849 m) and Lethbridge Park (L, 984 m). The 25 datasets used in this study are summarised in Table 1.

Table 1: EDM baseline verification datasets used in this study.

Dataset	4 pillars (Wollongong)	5 pillars (Wagga Wagga)	6 pillars (Dubbo)	7 pillars (various)
1	Jun 2000	Dec 2000	Jun 2000	Mar 2010 (K)
2	Jun 2002	Jun 2002	May 2002	Nov 2012 (E)
3	May 2004	May 2004	Jun 2003	Jul 2013 (K)
4	Nov 2005	May 2006	Oct 2004	Oct 2013 (L)
5	May 2007	Apr 2009	Sep 2006	–
6	May 2011	May 2011	Aug 2008	–
7	Jun 2013	Jun 2013	Aug 2012	–

Generally, for standard EDM calibrations on baselines consisting of seven or more pillars, it is sufficient to observe forward distances only. However, in this case all possible inter-pillar distances were observed in order to provide maximum redundancy for the purpose of baseline verification. Most datasets were collected using a Leica TCA2003 total station, while a Leica TS30 total station was used for all datasets from 2011. Both instruments are similar in regards to the precision stated by the manufacturer (1.0 mm + 1 ppm and 0.6 mm + 1 ppm, respectively) and were set to apply zero instrument corrections. As EDMCAL does not routinely provide rigorous uncertainty information, the comparison is limited to the additive constant and the scale factor (ppm equivalent).

In this context, it should be noted that the UNSW spreadsheet requires the user to input the relative humidity for each measured line in the calculation of the first velocity correction, while this quantity is ignored in EDMCAL. However, LPI staff routinely observe and record these values in the field during baseline verifications, allowing the comparison to be undertaken without the need for estimated or externally sourced values. In this case, the mean humidity value was determined for each dataset and then applied to all measured lines in the UNSW spreadsheet. It is also worth noting that the UNSW spreadsheet requires meteorological data to be corrected before input, while EDMCAL is able to accept the raw observations and apply thermometer and barometer instrument corrections during processing.

The results of the comparison between the additive constants and scale factors calculated using the UNSW spreadsheet (no iteration performed) and EDMCAL are illustrated in Figures 5 and 6, respectively. It should be noted that the first Dubbo dataset (June 2000) was identified as an outlier and removed from the analysis. The results indicate good agreement between the two calculation tools. The additive constants generally agree within 0.3 mm for the 4-pillar (Wollongong) and 5-pillar (Wagga Wagga) baselines, while larger differences of up to 0.8 mm are obtained for the 6-pillar baseline at Dubbo. Much better agreement of 0.1 mm or better is achieved at the 7-pillar baselines, although it should be noted that three of these datasets represent the first verification after construction of the baseline and therefore use their own results as 'known' distances in the processing. The scale factors agree within about 0.5 ppm for the 4-pillar, 5-pillar and 7-pillar baselines and about 1.5 ppm for the 6-pillar baseline.

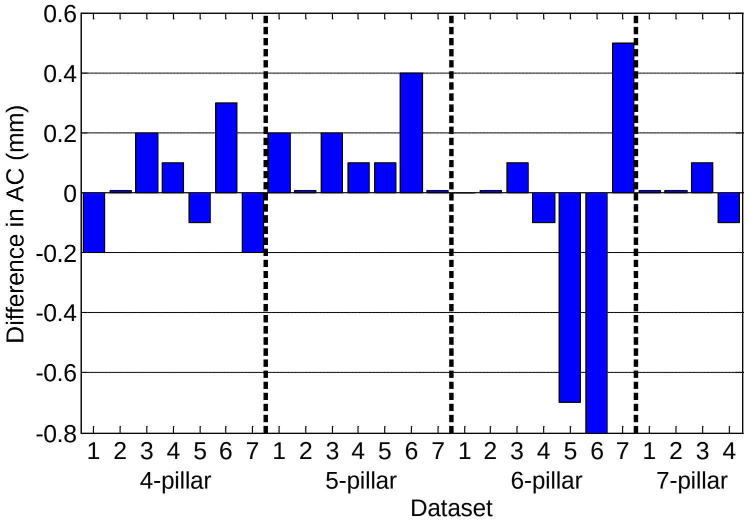

Figure 5: Difference in additive constant (AC) between UNSW spreadsheet and EDMCAL output (mm).

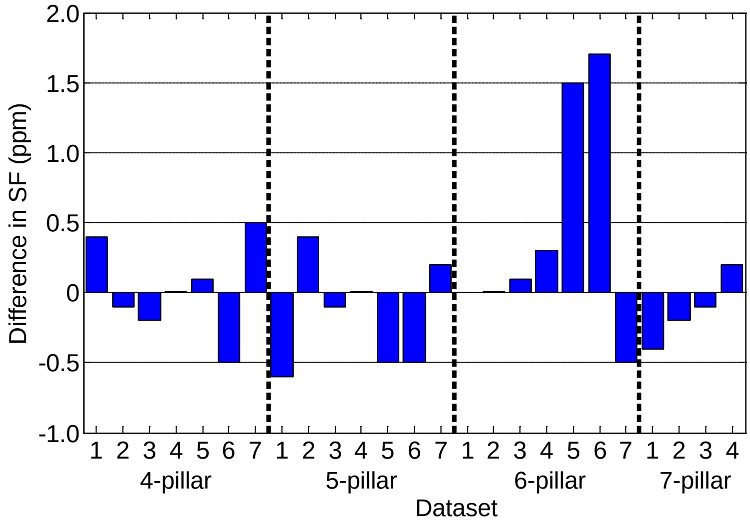

Figure 6: Difference in scale factor (SF) between UNSW spreadsheet and EDMCAL output (ppm).

It is also useful to investigate the differences in the distances relative to the first pillar after the calculated additive constant and scale factor have been applied. As already mentioned, the June 2000 dataset at Dubbo was identified as an outlier and therefore removed from the analysis. Descriptive statistics on the comparison between the output of the UNSW spreadsheet and EDMCAL are summarised in Table 2. A high level of agreement between the two calculation tools is evident, and the stated differences can be assumed negligible for most EDM calibrations in practice.

Table 2: Descriptive statistics of the differences in distances from pillar 1 between UNSW spreadsheet and EDMCAL (all values in mm).

	4 pillars	**5 pillars**	**6 pillars**	**7 pillars**
Min.	-0.2	-0.4	-0.7	-0.6
Max.	0.2	0.7	0.6	0.4
Range	0.4	1.1	1.3	1.0
Mean	0.01	0.03	-0.07	-0.04
RMS	0.08	0.20	0.33	0.19

These results show that the UNSW spreadsheet provides results comparable to EDMCAL processing for general practical purposes. However, it is important to note that recently verified distances must be used as 'known' inter-pillar distances in order to obtain reliable results. Using the latest verification results (i.e. 2012 or 2013) as 'known' distances for the processing of all datasets investigated in this study provided considerable differences not only in the resulting scale factors due to slight pillar movement but also negatively affected the relative comparison between the two calculation tools.

5 ONLINE EDM BASELINE BOOKING SYSTEM

In the past, EDM baselines in NSW were not subject to a booking requirement. Surveyors were generally able to visit a baseline at any time, provided no baseline specific access requirements were in place (e.g. prior approval and/or keys from baseline host required). Particularly at popular baselines, this can result in several surveyors attempting to use the baseline at the same time, thus negatively affecting their productivity and time management (particularly if considerable travel time to the baseline is involved).

In order to avoid these disadvantages, LPI has developed the EDM Baseline Booking System. This free online booking system is now available via the LPI website (LPI, 2014b) and allows registered users to reserve a particular time slot at the desired baseline in advance. The booking process is simple and straightforward, comparable to booking a hotel room online. A help page with instructions on how to use the system and the opportunity to make enquiries or provide feedback are also included.

A screenshot of the booking system's main page is shown in Figure 7. The process consists of the following three simple steps:
1. Select a booking date.
2. Select an EDM baseline.
3. Select an available booking time.

Once the booking is finalised, a confirmation will be sent by email, also outlining the general and baseline specific conditions of use that had to be accepted during the booking process. The user is required to carry a printout of this booking confirmation with them at all times when on the baseline site. This will provide proof of approved access to the baseline for the specified time period.

The EDM Baseline Booking System was launched on 29 October 2013 and should now be used by surveyors to book access to all EDM baselines in NSW in order to allow efficient and effective use of existing and future baseline infrastructure. The booking system will also assist LPI in monitoring the frequency of use of each baseline, thereby allowing more informed decision making in regards to the state's EDM baseline infrastructure in the future.

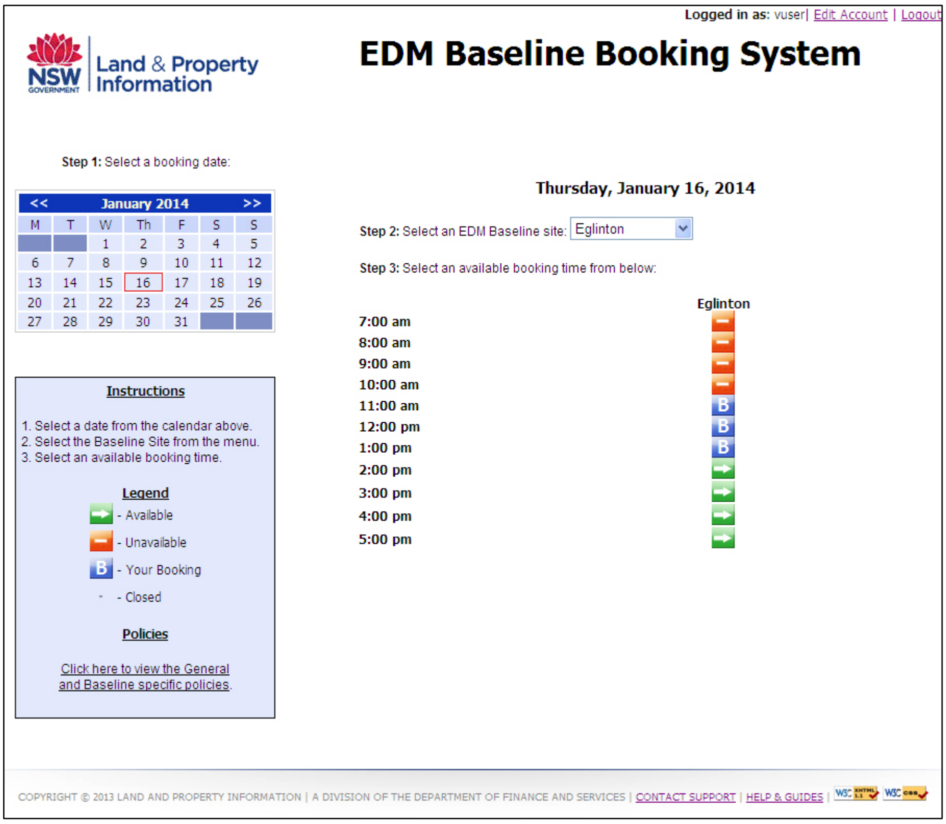

Figure 7: Main page of the online EDM Baseline Booking System (http://lpi.nsw.gov.au/edmbooking).

6 CONCLUDING REMARKS

This paper has briefly described the status of EDM baseline infrastructure in NSW, which is currently being rationalised and improved by upgrading existing baselines to include more pillars and building new 7-pillar baselines. The EDMCAL software used by LPI for the processing of EDM baseline verifications and EDM calibrations was outlined. Based on 25 datasets collected on baselines consisting of between four and seven pillars, it was shown that the EDM calibration spreadsheet developed by the University of New South Wales provides additive constants and scale factors comparable to the EDMCAL output.

Finally, LPI's new EDM baseline booking system was introduced. This free online system is easy-to-use and should now be utilised by surveyors to book access to all EDM baselines in NSW in order to allow efficient and effective use of existing and future baseline infrastructure. By allowing LPI to monitor the frequency of use of each baseline, the booking system will also assist LPI in making more informed decisions regarding the state's EDM baseline infrastructure in the future.

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A Proposed Method for Testing Reflectorless EDM

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ABSTRACT

The introduction of Electronic Distance Measurement (EDM) equipment has revolutionised survey practice. The majority of total stations available today are capable of 'reflectorless EDM' measurement, allowing surveyors to measure distances to objects other than traditional reflective targets. This technology increases the versatility of the total station and can improve the safety of field personnel. Surveyors must have a good understanding of the performance limitations of their equipment in order to produce quality work. Over the last decade, a number of studies have investigated the nature of reflectorless distance measurement, including the variable accuracy of measurements to different surfaces. However, there appears to be a lack of guidance to the surveying industry on the use of reflectorless EDM in cadastral surveying within the Australian Capital Territory (ACT). In accordance with Direction 17 of the Surveyors (Surveyor-General) Practice Directions 2013 (No. 1) (ACT), surveyors must ensure that all equipment, including their EDM, is in accurate adjustment, standardised and properly calibrated. Recently, a number of surveyors have enquired if it is possible to test the performance of their reflectorless EDM instrument at the Watson baseline in order to comply with Direction 17. This paper proposes a methodology for testing reflectorless EDM instruments at the Watson baseline. A case study of testing a Sokkia SRX3X total station using a prototype non-cooperative target is presented. Furthermore, the use of reflectorless EDM in cadastral surveys is discussed and recommendations are made.

KEYWORDS: *Reflectorless, target, EDM, cadastral, baseline.*

1 INTRODUCTION

Today's total stations are capable of measuring distances to objects other than traditional reflective prisms. This Electronic Distance Measurement (EDM) functionality is generally referred to as 'reflectorless EDM' measurement and is now another useful piece of equipment in the surveyor's toolbox. Using reflectorless EDM, distances can now be measured to all manner of objects which previously would be difficult to locate with a traditional reflective (cooperative) prism, such as high and inaccessible structures. Sensible application of this technology may lead to productivity gains in field work and the enhancement of the workplace health and safety of survey field parties. Dangerous locations such as working at heights, confined spaces, aggressive dogs, hostile neighbours, vehicular traffic and unstable quarry walls can all now be avoided by the surveyor's assistant. But can these reflectorless distance measurements be relied upon, especially if they are used in a cadastral survey?

Direction 17 of the *Surveyors (Surveyor-General) Practice Directions 2013 (No. 1)* (ACT Government, 2013) requires surveyors who perform cadastral surveys to ensure their equipment is in accurate adjustment, standardised and properly calibrated. To achieve this, a

surveyor's EDM must be calibrated at least once every 12 months on a certified baseline established by, or acceptable to, the Surveyor-General. The calibration procedure provides an estimation of the systematic index, scale and cyclic errors that are present in all EDMs (ESDD, 2012).

A review of the available literature indicates that there are many variables associated with the use of reflectorless EDM. Significant measurement inaccuracies may be encountered when observing EDM distances to non-cooperative targets due to the physical characteristics of different materials. These differences may include the colour of the material (Stiros et al., 2007), material reflectance, i.e. whether it is dull or shiny (Rüeger, 2003), the wetness of a target (Höglund and Large, 2003), the angle of incidence of the EDM beam with the target (Rüeger, 2003; Ernst, 2009; Holley et al., 2011), the illumination of the surface (Lambrou and Pantazis, 2010), and the texture of the material (Rüeger, 2003; Ernst, 2009). The measurement characteristics of various materials have been the focus of a number of studies and have not been investigated in this paper. The interested reader should refer to the reference publications for more details.

This paper aims to encourage all surveyors to employ a consistent approach when testing their reflectorless EDM equipment so the results obtained provide a reliable verification. The Watson EDM baseline is used to test three different aspects of the performance of a Sokkia SRX3X total station, i.e. (1) the divergence and alignment of the reflectorless EDM beam, (2) a comparison of a calibration in standard EDM mode and reflectorless mode, both measuring to a standard reflective prism, and (3) testing of the reflectorless EDM measuring to a non-cooperative target.

2 WATSON EDM BASELINE

The EDM baseline maintained by the Office of the Surveyor-General (OSG) is located in the suburb of Watson in the ACT (Figure 1). The baseline is a modification of the original Sprent-Zwart design (Sprent and Zwart, 1978; Sprent, 1980) and consists of 11 forced centring pillars spread over approximately 1,117 m. The baseline is within 0.04 m of being linear over its entire length and all pillars are inter-visible. A certificate under Regulation 13 of the National Measurement Regulations 1999 (Australian Government, 2013) is issued annually by the OSG, whom the National Measurement Institute has appointed as a Verifying Authority for Length (ESDD, 2012). Using a standard reflective prism, surveyors can calibrate their EDMs at the Watson baseline for compliance with Direction 17.

Calibration of measuring equipment should not be confused with the testing of that equipment. Calibration is a more rigorous process where the relationship between an instrument's measurements and a standard of the physical quantity being measured is determined. Calibrating an instrument on a verified EDM baseline allows its distance measurements to be traceable to the international standard of length. On the other hand, equipment testing provides a means of checking that an instrument's measurements are within the manufacturer's stated performance criteria. Due to the almost infinite variability of non-cooperative reflecting surfaces as mentioned above, standard procedures for calibrating reflectorless EDM equipment currently do not exist (Mazalova et al., 2010). Indeed, there is even a lack of standard procedures to test the performance of a reflectorless EDM against the manufacturer's stated accuracy!

Figure 1: Pillars 1, 2 and 3 of the Watson EDM baseline.

Nevertheless, surveyors are still required to know the accuracy obtained by their measuring equipment, and a number of surveyors have made enquiries with the OSG to see if they could test the reflectorless functionality of their EDM at the Watson baseline. The proposed procedure to test the performance of reflectorless EDM equipment, as described below, has been prepared partly in response to these enquiries, and to a certain extent address the lack of guidance to the surveying industry, as perceived by the author, on the use of reflectorless EDM in cadastral surveys. It is emphasised that the methodology presented is not an official calibration and does not provide legal traceability of EDM measurements when taken in reflectorless mode. However, by following the survey procedures described herein, it is believed that surveyors would comply with Direction 17 of the *Surveyors (Surveyor-General) Practice Directions 2013 (No.1)* with regard to their reflectorless EDM equipment.

3 DESIGN OF THE TARGET

Surveying instrument manufacturers use Kodak Grey Card as an unofficial standard when determining the range and accuracy of their reflectorless EDMs (Höglund and Large, 2003; Bayoud, 2006; Stiros et al., 2007). Kodak Grey Card is the recognised standard in professional photography for determining scene reflectance and has two sides, i.e. grey and white. The correct names for the two sides of the card are “Kodak Grey Card 18% Reflective” and “Kodak White Card 90% Reflective”, with 18% and 90% reflectance across the visible spectrum respectively. The 18% reflectance of the grey side was chosen for photography because everyday scenes and objects average approximately 18% reflectivity of light (Höglund and Large, 2003). Additionally, Kodak Grey Card is an approximate realisation of a Lambertian scattering surface, where the radiant light leaving the surface is constant for any angle of reflectance (Jensen, 2005), and in the field of remote sensing Kodak Grey Cards have been shown to be a good reflectance reference standard (Milton, 1989; Peddle et al., 2001).

The design of a non-cooperative target was an important consideration for this study, as it is envisaged that a robust target could be used as a future ‘standard’ target for the purpose of testing reflectorless EDMs at the Watson baseline. Kodak Grey Card was chosen as the non-cooperative surface. A prototype target was designed and specially constructed, based on a standard Sokkia APS34 triple prism with the reflective prisms removed. A 6 mm thick sheet of medium-density fibreboard (MDF) was mounted to the frame of the triple prism, then the 204 mm x 254 mm Kodak Grey Card affixed to the MDF, with the grey side exposed. The face of the Kodak Grey Card was marked to allow for repeatable face-left/face-right pointing. Markings were also added to each side of the MDF target for consistent height measurements. The prototype non-reflective target used in the case study is shown in Figure 2.

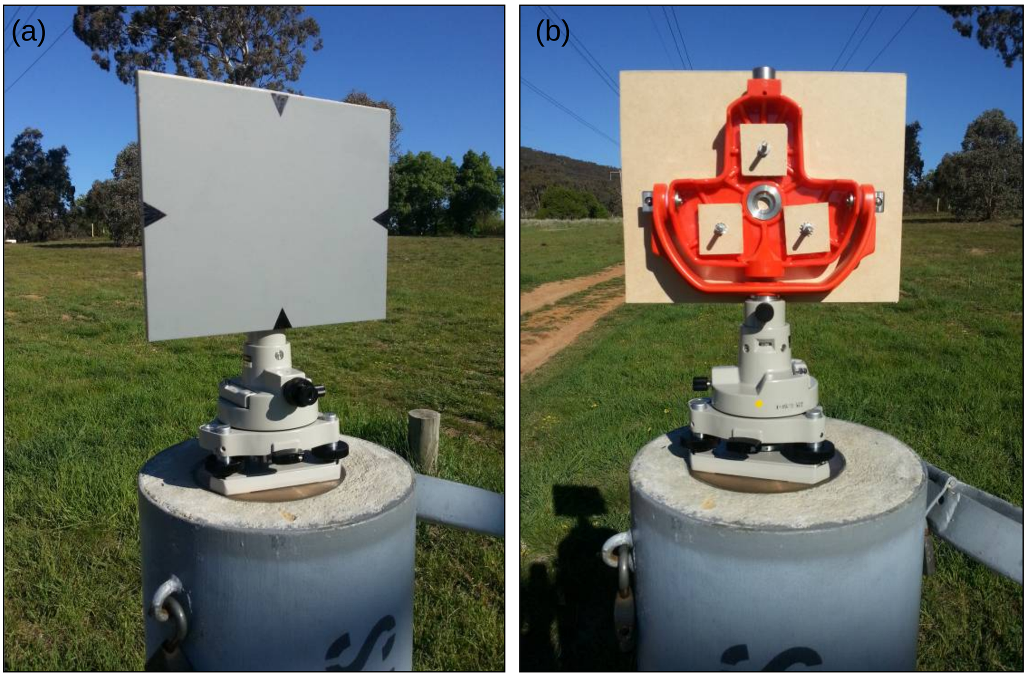

Figure 2: (a) Front face and (b) rear of the non-cooperative target used in this study.

4 CASE STUDY: TESTING OF SOKKIA SRX3X AT WATSON BASELINE

For this case study, measurements were made at the Watson EDM baseline using a Sokkia SRX3X total station (Figure 3) during October 2013, with favourable environmental conditions encountered throughout the testing. The Regulation 13 certificate on the Watson baseline was current to 15 August 2014. The surveyor must have confidence in the reliability of their reflectorless EDM measurements (Holley et al., 2011), hence this case study comprises three parts, i.e. (1) determining the size, shape and alignment of the reflectorless EDM beam, (2) comparing the calibrations of standard and reflectorless EDM measurements observed to a standard reflective prism, and (3) testing the reflectorless EDM measurements to the prototype non-cooperative target.

The manufacturer’s specified standard deviation (1σ) of the SRX3X for standard EDM observations to a reflective prism is ± (1.5 mm + 2 ppm), while in reflectorless mode it is ± (2 mm + 2 ppm) for distances less than 200 m and ± (5 mm + 10 ppm) for distances between 200-350 m. For distances between 350-1,000 m, the standard deviation in reflectorless mode is stated as ± (10 mm + 10 ppm). It should be noted that these reflectorless distance standard deviations are to Kodak Grey Card 90% Reflective (Sokkia Topcon Co. Ltd, 2006), while

other instrument manufacturers sometimes use the 18% Reflective side, as was used in this case study.

Figure 3: Sokkia SRX3X total station used in the case study.

4.1 Determining EDM Beam Dimensions

Due to non-selective scattering of electromagnetic waves in the atmosphere (Jensen, 2005), the reflectorless beam diverges as its distance from the EDM increases (Höglund and Large, 2003), resulting in reflectorless EDMs measuring an average distance to the 'footprint' on the target that is illuminated by the EDM beam (Rüeger, 2003). Therefore it is important for the surveyor to know the size and shape of the reflectorless beam at various distances.

Rüeger (2003) describes a simple procedure for determining the effective beam size, shape and its alignment with the optical cross hairs of the total station's telescope. Since this information is essential for reliable reflectorless measurements, tests should be carried out at a number of distances for both horizontal and vertical alignment. The stepped timber block used in this study was constructed to Rüeger's specifications and is shown in Figure 4. Additionally, the edge of the front of the block was marked with black texta to aid in sighting of the step. By following Rüeger's test procedure, it was determined that at 337 m (pillar 1 – 6) the reflectorless beam of the Sokkia SRX3X was approximately 35" of arc, both horizontally and vertically. Therefore, the size of the 'footprint' of the reflectorless beam approximates a circle with a diameter of 0.057 m at 337 m, and would comfortably fit on the 204 mm x 254 mm Kodak Grey Card. Furthermore, at the time of testing the reflectorless EDM beam was found to be closely aligned with the telescope's cross hairs.

Figure 4: Timber block used to determine the beam dimensions and alignment.

4.2 Calibration to a Cooperative Target

The following two calibrations were observed at the same time to a Sokkia APS12 single prism using the Sprent-Zwart observation technique described in the OSG's EDM Calibration Handbook (ESDD, 2012). Distances were first observed in the standard mode, and then the instrument was switched to reflectorless mode before the prism moved to the next pillar. By observing the standard EDM and reflectorless EDM measurements back-to-back, the influence of any differences in atmospheric conditions between the calibrations was virtually eliminated. Rüeger (2003) states that observing in reflectorless mode to a reflective prism allows distances of a few kilometres to be measured. In this test, the Sokkia SRX3X easily measured the full length of the Watson baseline (1,117 m) in reflectorless mode.

The two sets of observations were processed using the Baseline v5.6.0.6 software to estimate the systematic index and scale errors of the EDM/prism pair using least squares analysis. The mathematical model for the EDM distance correction contains a cyclic component, however modern EDMs rarely contain any significant cyclic error (Klinge, 2007). A comparison of the systematic errors estimated for the two measurement modes is given in Table 1.

Table 1: Comparison of standard against reflectorless EDM modes to an APS12 reflective prism.

	Standard EDM		Reflectorless EDM	
	Value	**Uncertainty** (95% confidence interval)	**Value**	**Uncertainty** (95% confidence interval)
Index Error	-2.1 mm	0.7 mm	-5.8 mm	0.7 mm
Scale Error	1.2 ppm	2.0 ppm	0.5 ppm	2.0 ppm
Cyclic Error	Insignificant		Insignificant	
A posteriori variance factor	0.767		0.679	

In reflectorless mode, the individual distance observations within each set had a larger range when compared to the standard mode. However, the reflectorless least squares adjustment gave an overall better fit to the known (Regulation 13) inter-pillar distances, as indicated by the lower a posteriori variance factor. Note that OSG's least uncertainty of measurement, as

specified by the National Measurement Institute (NMI) is 0.6 mm + 2 ppm. Uncertainties of calibrations performed on the Watson baseline cannot be reported below this limit, hence the scale error uncertainties for both calibrations are reported as 2 ppm.

4.3 Reflectorless Testing to Non-Cooperative Target

The observation routine chosen for the reflectorless EDM testing is a modification of the routine used on Heerbrugg designed baselines, as described by Schwendener (1972) and LPI (2009). Generally, the observation routine followed the procedures described in the EDM Calibration Handbook (ESDD, 2012), with the following exceptions:

- Distance measurements were made in both face-left (FL) and face-right (FR) to eliminate any error associated with the non-alignment of the reflectorless EDM beam with the optical cross-hairs, in conjunction with the target not being absolutely perpendicular with the line-of-sight. Although the testing performed in section 4.1 showed these to be in good alignment, five slope distances were measured in FL and five measured in FR for each inter-pillar distance.
- Ambient temperature and atmospheric pressure were entered into the SRX3X prior to observing each inter-pillar distance, thereby allowing the on-board software to apply the first velocity correction to the raw distances.
- Although the Watson baseline has 11 pillars, only pillars 1 to 6 were occupied for the reflectorless EDM testing to the non-cooperative target. The measuring sequence involved setting the SRX3X on pillars 1 to 6 in turn, resulting in 24 observed inter-pillar distances. As is the case for a standard EDM calibration at the Watson baseline, the distances between pillars 1, 2 and 3 (with chainages of 0, 5 and 7.5 m) were not observed as these short distances may exhibit non-linear behaviour, as found in the testing performed by Lichti and Lampard (2008).

The observations were again processed using the Baseline v5.6.0.6 software. The least squares adjustment of the SRX3X distance measurements observed in reflectorless mode to the non-cooperative target achieved a reasonable-to-good level of redundancy. The adjustment returned an a posteriori variance factor of 0.242. The chi-squared test on the variance factor can be used as a reliable statistical test for determining if the observations have been correctly weighted, provided that there are no gross errors in the observations (Klinge, 2007). In this adjustment, the chi-squared test on the variance factor returned a fail result, which suggests that the weighting of the observations may be tightened.

A review of the residuals and standardised residuals shows there are no gross or systematic errors present within the observations. All residuals are small and range from -1.5 mm to +1.3 mm. There are no flagged standardised residuals, therefore all values are within the 3σ rejection criterion. If the observations contain only random errors and correct assumptions for the input weights have been made, then the standardised residuals will follow the shape of a normal distribution curve (Klinge, 2007). The histogram of the standardised residuals (Figure 5) is only slightly skewed and is close to a normal distribution, further suggesting that the data are free of observational errors. However, the histogram does show some degree of kurtosis suggesting that the weighting of the observations may be tightened, as also indicated by the failure in the chi-squared test. In this instance, the a priori standard deviations assigned to the observations, i.e. ± (2 mm + 2 ppm), were considered appropriate and were not amended. The statistical analysis and the review of the residuals and standardised residuals as discussed above were deemed acceptable. The systematic errors of the reflectorless EDM, as estimated by the least squares adjustment, are shown in Table 2.

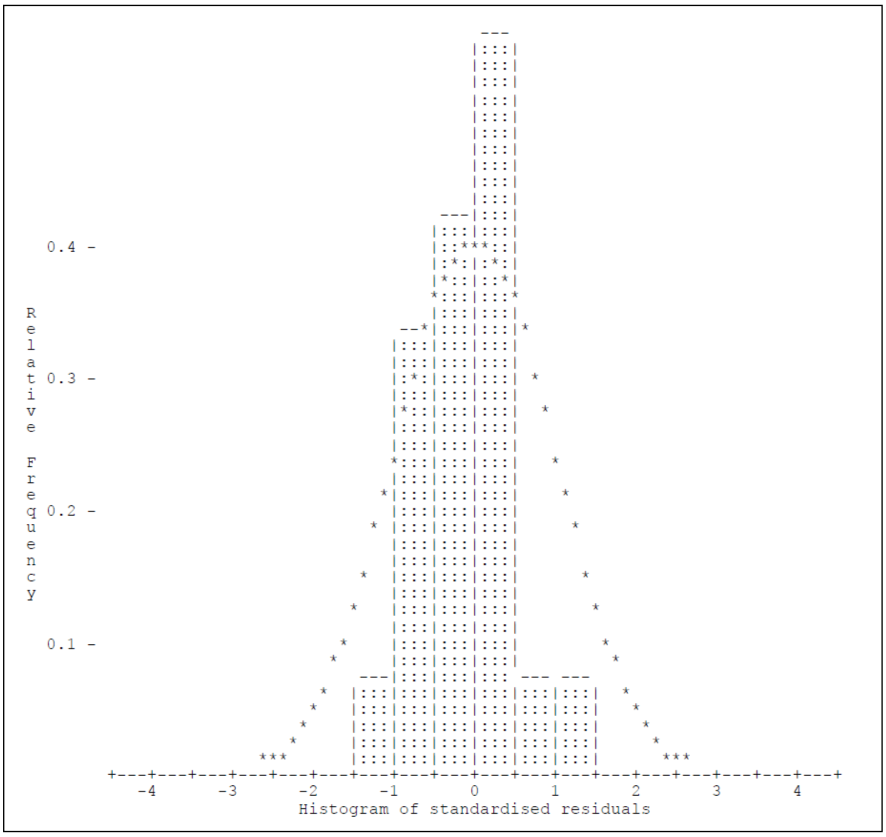

Figure 5: Histogram of standardised residuals.

Table 2: Estimated systematic errors of the reflectorless EDM.

	Value	Uncertainty (95% confidence interval)
Index Error	+32.0 mm	0.6 mm
Scale Error	-1.9 ppm	3.5 ppm
Cyclic Error	Insignificant	
A posteriori variance factor	0.242	

The design of the non-cooperative target introduces an unavoidable additive constant, as the face of the Kodak Grey Card is not aligned with the vertical axis of the Sokkia APS34 triple prism mount. Measurements taken with a calliper show this physical offset to be +31 mm ± 1 mm. Consequently, all reflectorless EDM distances measured to this non-cooperative target must be increased by 31 mm. Applying this additive constant gives an index error of the reflectorless EDM as +1.0 mm ± 1.6 mm (at 95% CI). The full reflectorless EDM instrument correction (*IC*) in millimetres (to be added to the instrument reading) is:

$$IC = 1.0 - 1.9\,D \qquad (1)$$

where D = distance (m)

Therefore, this test confirms that the index and scale errors of this Sokkia SRX3X total station are within the manufacturer's stated performance for reflectorless measurements observed to the Kodak Grey Card.

5 DISCUSSION AND RECOMMENDATIONS

5.1 Review of the Case Study

Any misalignment of the reflectorless EDM beam with the optical cross hairs, in conjunction with a non-cooperative target not being absolutely perpendicular with the line-of-sight, will introduce a systematic error in all reflectorless distance observations. It is strongly recommended that surveyors, as an absolute minimum, perform the testing described by Rüeger (2003) to check the alignment of the reflectorless EDM beam, along with the size and shape of the beam's 'footprint' at various distances. These checks should be performed as part of the instruments initial acceptance testing, and during its annual calibration. While this part of the case study was performed at the Watson baseline, in practice, it can be carried out at any convenient location.

The second part of the case study shows that it is possible to calibrate the reflectorless EDM component of the Sokkia SRX3X with a standard reflective prism, while using the traditional observation routine employed at the Watson baseline. At the time of testing, its performance was commensurate with the performance of the standard EDM beam, however the test clearly demonstrated that extreme care must be taken when mixing observations between non-cooperative targets and standard survey prisms, as the index errors are not the same. For the SRX3X used in this study, the reflectorless EDM mode measures 3.7 mm longer than standard mode. Forgetting to swap the measurement mode in the total station will introduce a constant error in distances observed to standard prisms. Note that the method of observing reflectorless EDM measurements to a standard reflective prism has not been formally investigated by NMI or the National Association of Testing Authorities (NATA), therefore it cannot yet be considered an official 'calibration' of the reflectorless EDM.

The result of the third part of this study shows that it is possible to test reflectorless EDMs on the Watson baseline using a non-cooperative target, and for the SRX3X investigated, the reflectorless EDM performed within the manufacturer's specifications. The proposed testing methodology was restricted to pillars 1 to 6 on the baseline. Including additional pillars would increase the number of inter-pillar distances required to be measured, thus increasing the time required to perform the observations and may dissuade some surveyors from carrying out the test. It is recognised that limiting the range of the test to 337 m reduces the effectiveness of determining an EDM instrument's ppm error component. However, experience suggests that reflectorless EDM is most commonly used in short range applications, and distances observed by this SRX3X would not be significantly affected by the ppm error. It is recommended that the OSG prepare a Surveyor-General's guideline to assist surveyors who wish to check the performance of their reflectorless EDM against the manufacturer's specifications.

It is recognised that the case study only tested reflectorless EDM measurements to a reflective prism and to Kodak Grey Card. Surveyors should also test their reflectorless EDM against the different materials they are likely to encounter (e.g. concrete, timber, steel and tile) as each material has an individual reflectance characteristic and will therefore have its own specific additive constant (Widjajanti et al., 2008). Stiros et al. (2007), Ernst (2009) and Holley et al. (2011) present practical methods to perform these comparisons.

5.2 Use of Reflectorless EDM in Cadastral Surveys

It has been shown that reflectorless EDM instruments can be tested against a primary standard of length in order to determine their accuracy. The uncertainties of the SRX3X measurements determined in this case study are 0.7 mm + 2 ppm to a standard reflective prism and 1.6 mm + 3.5 ppm to the non-cooperative target (both at the 95% confidence interval), and are well within ACT cadastral distance accuracy requirements, being 6 mm + 30 ppm for urban surveys and 10 mm + 50 ppm for rural surveys (ACT Government, 2013). However, given the variable reflective nature of different materials, should reflectorless EDM measurements be used in cadastral surveys?

With the widespread availability of reflectorless EDM instrumentation and with the current lack of guidance for its proper use, it is recommended that the *Surveyors (Surveyor-General) Practice Directions 2013 (No. 1)* be amended to restrict the use of reflectorless EDM measurements in cadastral surveys to instances where reduced measurement accuracies may be tolerated. Such features that could be permitted to be located by reflectorless EDM include some occupations (e.g. walls with rough faces), inaccessible structures and natural features. Objects located using reflectorless EDM measurements should require additional field checks, over and above the traditional check measurements required under Direction 31(1), in order to confirm their positional accuracy. However, in order to preserve the integrity of the cadastre, monuments and well-defined structures on or near the boundary, as well as cadastral reference marks and survey control marks, must not be located using reflectorless EDM measurements. In all cases, the surveyor must understand the capabilities and limitations of their EDM equipment and use their professional judgement to determine when reflectorless EDM measurements are appropriate.

Furthermore, under Direction 64, surveyors are required to indicate on their Plan of Survey all lines measured or derived by Global Navigation Satellite System (GNSS) observations. Given the numerous variables associated with non-cooperative targets that may be encountered in the field, perhaps surveyors should also be required to indicate the objects that were measured with reflectorless EDM on their Plan of Survey. At the very least, this information should be included in an accompanying report.

6 CONCLUDING REMARKS

Testing of reflectorless EDM equipment should be performed prior to its initial use by the surveyor, in order to determine the size, shape and alignment of the reflectorless EDM beam. Failure to do so may lead to erroneous reflectorless EDM distance observations. The results of the study indicate that it is possible to calibrate an instrument in reflectorless mode while observing to a reflective prism, and also to test the performance of reflectorless EDM to a non-cooperative target by taking a series of measurements at the Watson baseline.

Reflectorless EDM is acceptable for some survey applications where lower measurement accuracies may be considered fit-for-purpose. However, given the number of variables of reflecting surfaces encountered during survey field work, consideration should be given to amending the *Surveyors (Surveyor-General) Practice Directions* to include a new clause that limits the scope of reflectorless EDM measurements in cadastral surveys.

For those surveys where reflectorless distances are incorporated, surveyors are strongly encouraged to adopt best practice and include independent redundant observations in order to

confirm their reflectorless distance observations and to comply with Direction 31(1). Furthermore, it is recommended that surveyors who use reflectorless EDM measurements test their EDM equipment annually in accordance with the procedures described herein, in order to provide confidence in the results of their surveys and to comply with Direction 17.

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Progress Towards a New Geodetic Datum for Australia

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ABSTRACT

Limitations in the current Geocentric Datum of Australia 1994 (GDA94) have been previously demonstrated, and the spatial community is currently discussing the best way forward to a next-generation datum, here hypothetically termed GDA201x. As previously described, each state and territory is collating all available geodetic measurements for submission to a simultaneous national adjustment. The product of this national adjustment will be a homogenous 3D coordinate datum across Australia which can be easily updated when new measurements become available. Initial workshops and discussion forums have been held in each state and territory to engage users during this development stage and to understand and address the needs, difficulties and potential applications associated with developing a new datum. This paper describes the technical progress towards a new simultaneous national geodetic adjustment with a focus on the work accomplished in New South Wales.

KEYWORDS: *GDA94, GDA201x, APREF, datum, dynamic.*

1 INTRODUCTION

The motivation and early progress towards developing a next-generation datum for Australia has been previously described (Haasdyk and Watson, 2013; Haasdyk et al., 2014). Any new datum, here hypothetically termed GDA201x, would replace the current Geocentric Datum of Australia (GDA94 – GA, 2014a) and align more closely to the best available global standard, the International Terrestrial Reference Frame (ITRF – Altamimi et al., 2011). A number of drivers for a datum change are discussed, which include but are not limited to:

- Technological improvement and more precise geodetic measurements gathered since 1994 can be used to compute improved coordinates and uncertainties.
- Systematic distortions of up to 300 mm (horizontal) have been detected by modern measurements such as from Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) and 'site transformations' are currently required to agree with local ground control.

- The Australian tectonic plate moves at approximately 7 cm per year, but GDA94 is defined by coordinates locked to epoch 1994.0. GDA94 is offset with respect to ITRF and other global coordinate systems by approximately 1.5 m as at 2015.
- This metre-level offset is large enough to affect the expected positioning accuracy of mass-market devices such as smartphones and tablets which will likely determine coordinates in the latest ITRF − without direct reference to GDA94 − by directly accessing International GNSS Service (IGS) products in real time.
- The Australian tectonic plate is also rotating slowly, introducing errors which are significant for surveying and geodesy applications (7 mm on a 30 km long baseline observed over a 20-year period).
- Ground deformation is readily apparent in the subsidence due to water, coal or gas extraction. Deformation due to seismic activity is observable within the Australian tectonic plate.
- A significant 9 cm vertical bias is present between ITRF92, upon which GDA94 is based, and the current ITRF models.

In addition, improvements in computing hardware and software capabilities now make it possible to quickly perform rigorous geodetic adjustments of a virtually unlimited number of stations and measurements, without a hierarchy of fixed control. As a result, distortions within state and territory adjustments, as well as discontinuities across borders, can be eliminated and new technologies and measurements can be incorporated as soon as they are available. The phased-adjustment software, DynaNet, was discussed in this context by Haasdyk and Watson (2013). DynaNet is used for least squares adjustments in this study and will be used for the full national adjustment for the determination of GDA201x.

The difficulties and benefits of datum update have been discussed at a first-round of forums across the nation (one per state or territory) with the dual aim of educating and involving the wider spatial community. As reported by Haasdyk et al. (2014), the final realisation of any new datum is being carefully considered. A next-generation datum would need to provide a platform for a wide range of user groups and applications, including high-accuracy surveying and scientific applications, an emerging mass-market positioning community of enormous size, as well as catering for existing GDA94 datasets which cannot be economically transformed.

This paper primarily describes the progress made to date by Land and Property Information (LPI) in New South Wales (NSW), as well as progress at a national level, to prepare the available geodetic data and develop adjustment methods required for a next-generation datum.

2 METHOD

The method for gathering and assessing the NSW dataset is generally the same as previously described by Haasdyk and Watson (2013), with the addition of a few new tools and data types, and is shown in Figure 1. The data described herein comprises the second official submission (in October 2013) by LPI to Geoscience Australia in support of the national adjustment.

In brief, all available GNSS measurements have been gathered from the LPI electronic archives by automated scripts and sorted into a collection of unique of 3D vector measurements in an Extensible Markup Language (XML) format. The weighting of each

measurement is adopted from the minimally constrained adjustment of the campaign in which the data was gathered. Analysis of the data for potential outliers has been performed mainly using least squares adjustments, but more recently using the L_1 norm method described in section 3.2. Measurements which were flagged as potential outliers in the initial campaign adjustment have been 'ignored' (i.e. not been included in the adjustment), but have been set aside for further investigation and analysis.

Changes from the previous publication by Haasdyk and Watson (2013) include:

- The collection of *new* GNSS measurements by data-mining of the LPI archives performed in June 2013, as well as the inclusion of several new major control projects completed since that date and before October 2013.
- The inclusion of *all* ground marks, previously restricted to standard NSW Survey Control Information Management System (SCIMS – Kinlyside, 2013) marks such as TS, SS, PM, MM, but now including vectors between *any* mark types, permanent or temporary, to improve network connectivity. Appropriate care is taken with respect to station stability.
- The inclusion of new data analysis methods such as the L_1 norm adjustment
- The trial constraint of the network to an Asia-Pacific Reference Frame (APREF) weekly solution (refer to section 2.2.2).

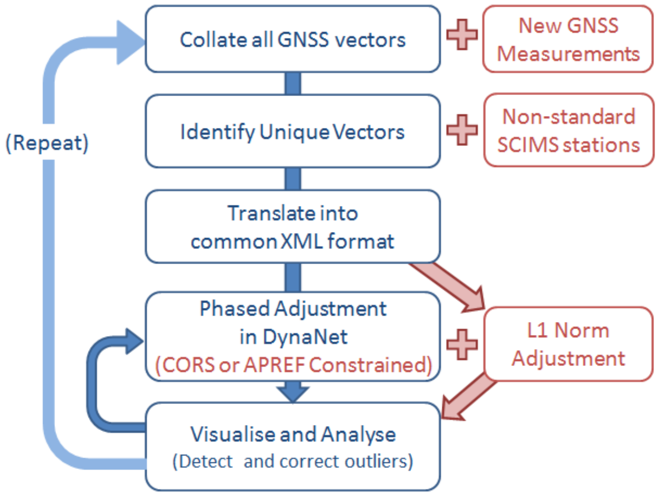

Figure 1: Flowchart of GNSS vector measurement acquisition and cleaning, with significant changes since last year (Haasdyk and Watson, 2013) highlighted in pink.

2.1 Data Sourcing (GNSS Vectors)

Table 1 indicates changes to the number of stations and measurements available from the LPI archives since last year, and since the GDA94 adjustment. Approximately 76,000 unique GNSS vectors are included in the latest dataset, which represent more than 62,000 unique baselines. The number of measurements is now 26 times the number of GPS measurements used in GDA94. Note that approximately 80% of these baselines have never been directly re-observed, and therefore gross error detection is limited to redundant network analysis. Figures 2 and 6 offer some additional description of this dataset.

Table 1: Number of stations and measurements in NSW adjustments.

(values rounded to nearest 100)	**GDA94 (NSW data)**	**APAS2013 dataset (NSW data for GDA201x)**	**APAS2014 dataset (NSW data for GDA201x)**
Stations	3,000	20,400+	24,500+
GNSS Baselines	2,900	62,000+	76,100+

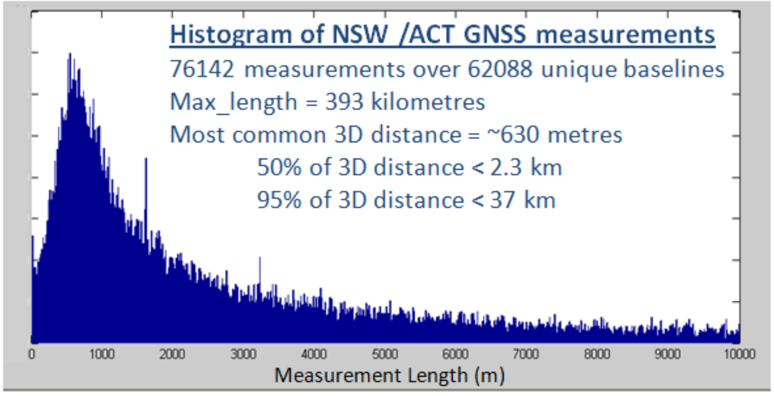

Figure 2: Histogram of LPI's current GNSS dataset for NSW (including GNSS vectors covering the ACT).

2.2 Adjustment Constraints

2.2.1 CORSnet-NSW Coordinates

Previously it was reported that a combination of Regulation 13 certified coordinates (GA, 2014b) and AUSPOS coordinates (GA, 2014c) were employed to act as network constraints. In the current analysis, the constraint is provided by the CORS network coordinates only, for the 131 CORS stations available in CORSnet-NSW (Janssen et al., 2011; LPI, 2014) at the time of analysis. These constraints were introduced with a standard deviation of 10 mm in each of the Cartesian (X,Y,Z) coordinates. The AUSPOS coordinate solutions were excluded due to some decimetre-level biases noted at multiple occupations of the same mark (data not shown), which have yet to be investigated (refer to section 2.2.3).

2.2.2 APREF SINEX

In the near future, the CORS constraints will be replaced by a weekly solution of CORS coordinates from the Asia-Pacific Reference Frame (APREF), which is a densely defined and accurate geodetic framework in the region, based on continuous GNSS data (GA, 2014d). The change to an APREF constraint is supported because the final national adjustment for GDA201x will employ APREF solution(s) as the sole constraint and will be free from external constraints. Additionally, the APREF solution is provided as a weekly solution in SINEX form (IERS, 2014). Thus, APREF provides not just coordinate values, but also the geometric relationship between the CORS and any changes that they experience over time due to the natural dynamic processes of the earth.

A sample APREF SINEX solution provided by Geoscience Australia, expressed in GDA94 coordinates, has been successfully tested as the sole constraint to the network (data not shown). However, the sample APREF solution contained only 93 of the CORSnet-NSW stations currently available, as shown in Figure 3. The entire CORSnet-NSW network is not included in this sample APREF solution as there is understandably some delay between construction of a CORS and its inclusion in the APREF solution, partly to ensure station quality and stability. It is anticipated that the remaining CORSnet-NSW network (totalling approximately 145 CORS) will be added to the APREF solution well before the national adjustment for GDA201x. At that time the APREF constraint will replace the CORS Regulation 13 coordinates as the sole constraint.

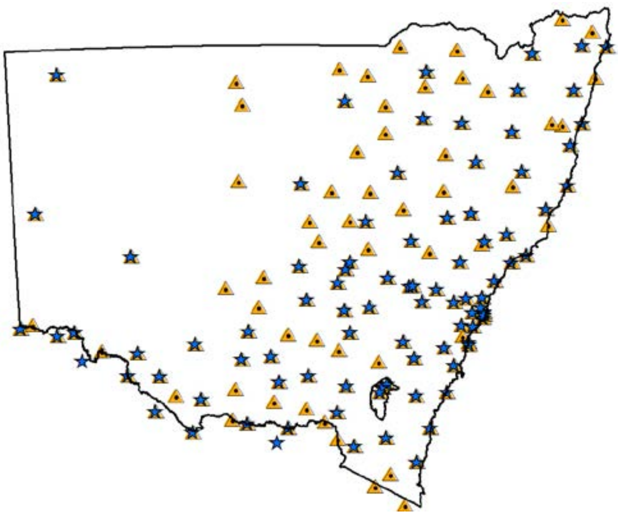

Figure 3: CORS stations from CORSnet-NSW (triangles) and from APREF SINEX sample (stars) in/near NSW.

2.2.3 AUSPOS SINEX and CORSnet-NSW Tie Surveys

AUSPOS observations of 4 hours or more (see Figure 4) have historically been submitted by each jurisdiction to a national GNSS archive and processed by the version of AUSPOS available at the time. When these measurements are included in the state-wide or national adjustment, they can serve to improve the Positional Uncertainty estimates of the observed stations (and adjacent stations connected by measurements) and/or highlight station movement.

At this time, however, some biases have been noted between multiple occupations of a small number of stations over the last decade (data not shown). The cause of these biases have not been definitively determined, but could be related to changes over the last decade in IGS satellite orbit modelling, updates to AUSPOS methodology, updates to ITRF or even station instability. For this reason AUSPOS coordinates are currently not used as constraints in this analysis. However, in preparation for datum modernisation, Geoscience Australia plans to re-process all such GNSS observations in a consistent version of AUSPOS to eliminate most sources of bias. All available CORS stations from APREF will be included in the solution, and results will be provided in SINEX format. In this way, AUSPOS measurements will provide not simply coordinate solutions as in the past, but rather a network of connections to the nearest CORS, strengthening GDA201x with connections from existing spine and sub-spine stations to the growing APREF framework.

Figure 4 indicates the location of the 1,200 AUSPOS solutions across NSW in the LPI archives, and also highlights the large number of new long-duration measurements gathered recently (250 during 2013 alone). This has resulted partly from an ongoing effort to carry out a maintenance program of NSW trigonometrical stations. Additional connections between CORS and the existing local control network are provided by the CORS tie surveys as described by Gowans and Grinter (2013). The current complement of tie surveys is shown in Figure 4b. At the time of publication, there are approximately 35 remaining tie surveys out of the eventual 145 CORS network. These will also be completed this year in preparation for the GDA201x adjustment.

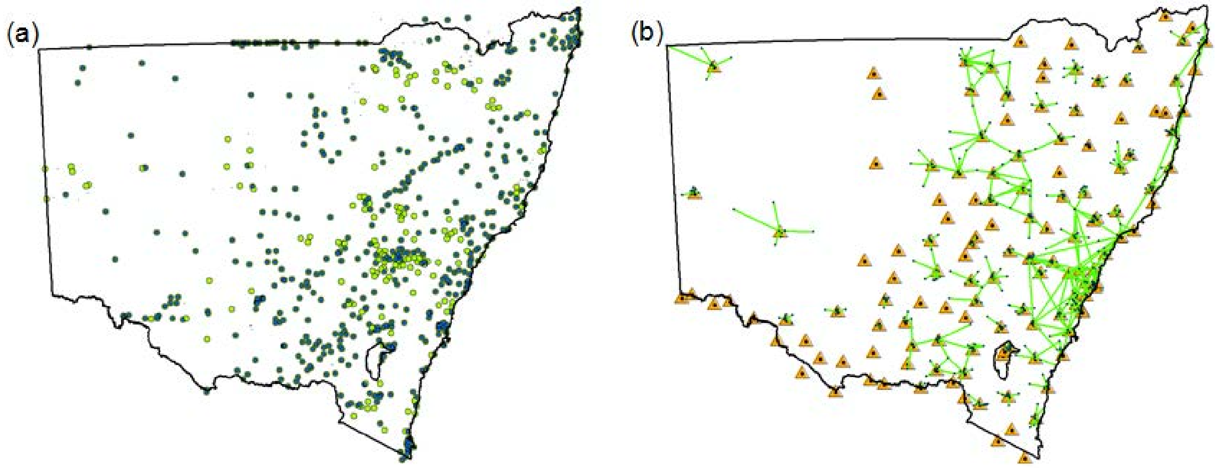

Figure 4: Connections between CORS constraints and local control: (a) location of AUSPOS (4-hour or more) solutions up to end of 2012 (blue circles) and end of 2013 (green circles), and (b) CORS tie survey GNSS connections (green lines) to local survey control points from CORS stations (triangles).

3 ADJUSTMENT AND ANALYSIS

As previously reported by Haasdyk and Watson (2013), the adjustment and analysis of the measurements in these archives is an ongoing task and employs a variety of visual and numerical analysis methods including analysis of miscloses, 'observed minus expected' differences, measurement residuals (raw and normalised) from least squares, coordinate corrections, and vertical and horizontal Positional Uncertainty to name a few.

3.1 Least Squares Adjustment

The majority of the analysis to date has focussed on the least squares solution obtained for the entire network of GNSS vectors, via DynaNet. Figures 5 and 6 show the results of the least squares adjustment as reported last year ('APAS2013 dataset') and on the current dataset ('APAS2014 dataset') respectively. Normalised residuals (NR) are computed as the adjusted measurement residual (or 'correction') divided by the adjusted measurement standard deviation. Assuming a normal distribution, 99.7% of NR values are expected to fall within ±3. Outliers are flagged as orange, magenta or red, for NR greater than 3, 5 or 10 respectively. A common rule of thumb is that NR values greater than 3 indicate *possible* gross errors requiring investigation, but do not prove that any measurement is in fact in error. This '3σ rule' is too strict for automated error detection, and can result in a loss of good measurements if strictly applied (Lehmann, 2013). In any case, the least squares adjustment method is known to spread errors into surrounding measurements, and therefore clusters of outliers are often seen in adjacent measurements, often due to the effect of a single gross error.

The improvement of the NSW dataset compared to that reported last year is demonstrated in Figures 5 and 6, and summarised in Table 2. In the APAS2013 dataset, even after significant cleaning of the dataset, almost 5% of the measurements were flagged with NR > 3, and more than 100 measurements suggested very large errors, with N stat > 10. Notwithstanding the addition of 14,000 new baselines since APAS2013, there are significantly fewer outstanding issues in the APAS2014 data: only 2.4% of the measurements have NR > 3 and none have NR > 10. Close observation of these figures will reveal some outliers from the APAS2013 dataset which have since been ignored (proven to be erroneous) or have been corrected and/or accepted (no longer flagged as an outlier).

Table 2: Numbers of measurements flagged as potential outliers.

	APAS2013 dataset	APAS2014 dataset
GNSS Baselines	62,100+	76,100+
Measurements NR > 3	3,131 (5.1 %)	1,102 (1.1 %)
Measurements NR > 5	720 (1.1 %)	252 (0.3 %)
Measurements NR > 10	102 (0.2 %)	NIL (0.0 %)

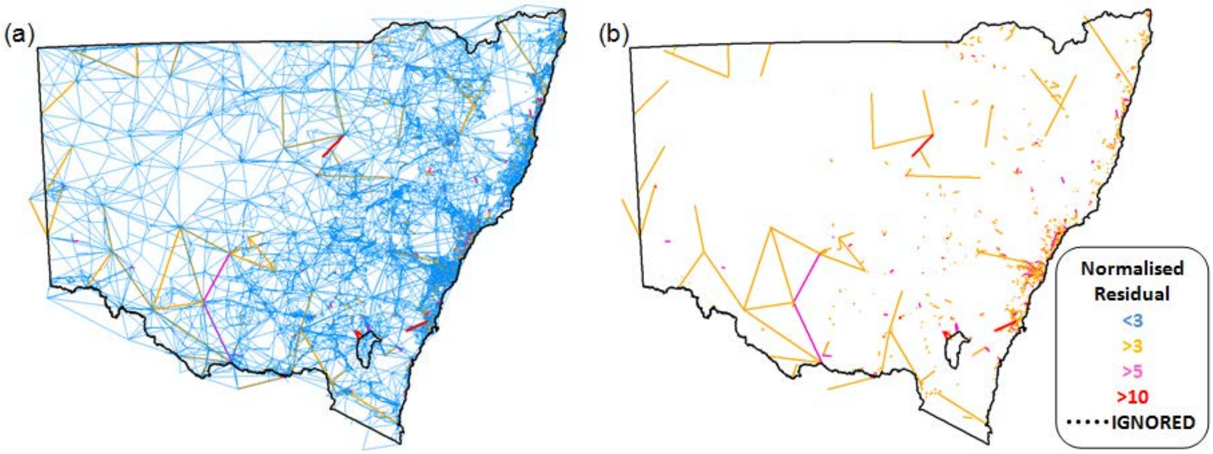

Figure 5: APAS 2013 dataset: (a) normalised residuals of least squares adjustment, and (b) as above but displaying only measurements with NR >3.

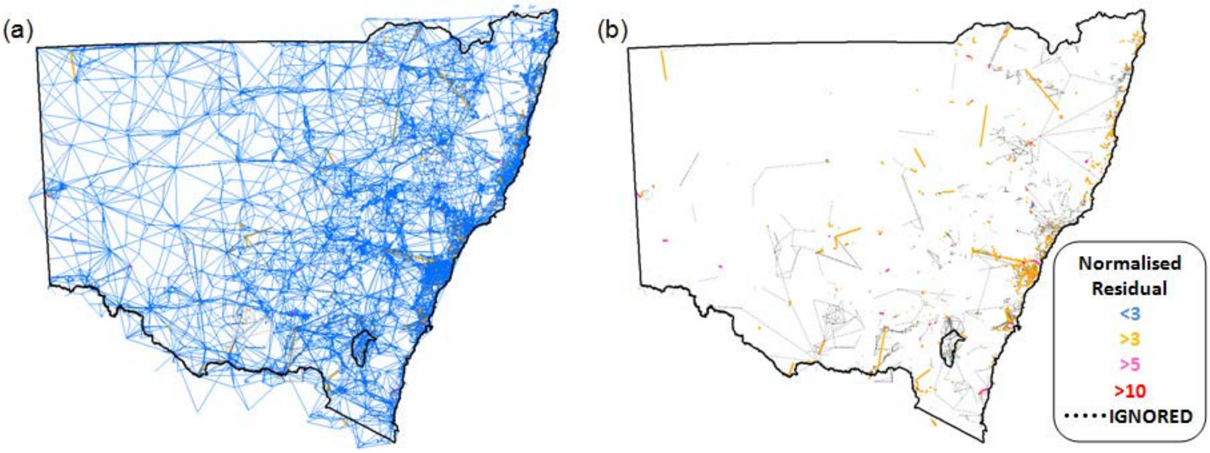

Figure 6: APAS 2014 dataset: (a) normalised residuals of least squares adjustment, and (b) as above, but displaying only measurements with NR >3.

3.2 L_1 Norm Method

Since the least squares adjustment method is known to hide measurement errors by spreading them into adjacent measurements, the detection and especially the *identification* of specific erroneous measurements can be quite difficult in such large datasets. An alternative method for analysis of the measurement data is via the L_1 norm method (hereafter simply L_1), which tends to highlight erroneous measurements (Branham, 1990; Harvey, 1993).

Unlike least squares (also known as the L_2 norm method), which minimises the sum of the *squares* of the measurement residuals, the L_1 norm minimises the sum of the *absolute values* of the residuals. In the L_1 method there is no significant penalty for assigning a large residual error (e.g. due to a large gross error) to a single measurement, whereas the *square* of the same residual represents an enormous penalty to the least squares method. As a result, least squares

skews the adjustment (and all its measurements) to better fit any outlier, in a way that L_1 does not.

As a consequence of this simple difference between least squares and L_1, the objective of the adjustment changes from finding the 'best average fit' of all measurements (as in least squares), to finding the 'best candidate set' of measurements to compute the coordinates for all stations. Essentially L_1 does not *adjust* any measurements, but only selects enough measurements to solve the problem; this chosen set of measurements will have residuals equal to zero, and the remaining measurements have the smallest sum of the absolute value of their residuals. In this way, the L_1 solution disregards the remaining measurements for the purpose of computing the station coordinates. The residuals of the remaining measurements are, however, of use for examining the quality of the network and especially for the detection of gross outliers.

To visualise the difference between least squares and L_1, consider fitting a line of best fit to a set of points as in Figure 7. The least squares solution yields a line that passes through the 'centre of mass' of all points, while the L_1 solution chooses two points that represent the 'best' available solution and passes directly through them.

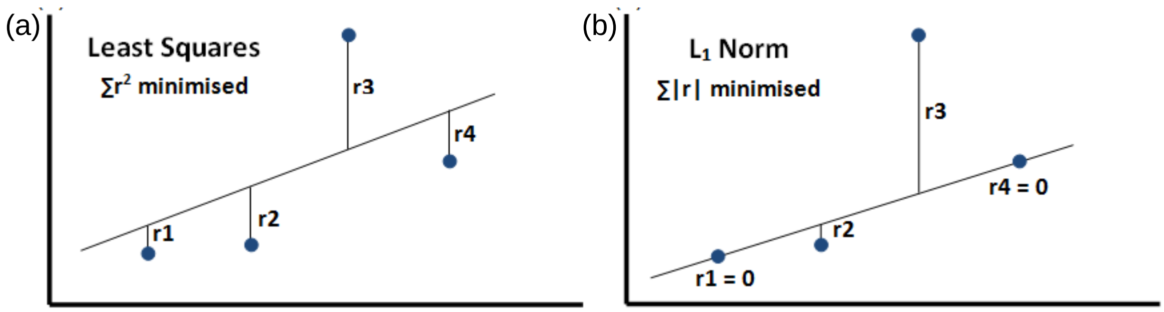

Figure 7: (a) Least squares vs. (b) L_1 norm method for fitting data points.

Figure 8 compares the least squares and L_1 solution at two locations within NSW. The least squares solution highlights a number of potential outliers in each region, while L_1 highlights a few specific observations as the most likely source of error. Indeed, analysis in these locations revealed small but significant gross errors in the L_1 outliers. The correction or removal of these offending measurements results in an acceptable least squares solution in the area.

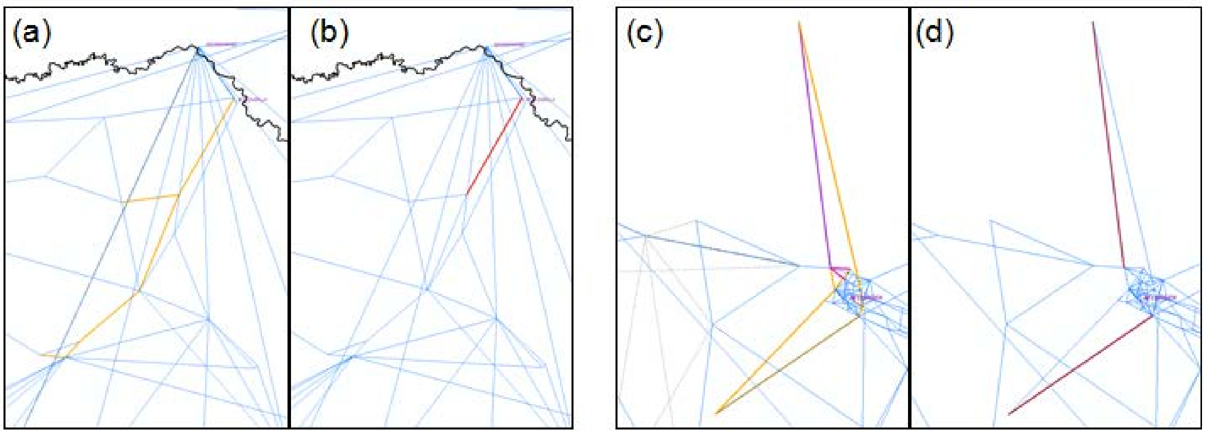

Figure 8: (a) Least squares adjustment and flagged outliers near Boggabilla and (b) L_1 of the same area.
(c) Least squares adjustment and flagged outliers near Bellingen and (d) L_1 of the same area.
Colour scheme as per Figure 5. Scale not shown.

L_1 is therefore usually considered to be a tool that is useful in addition to, but not as a replacement for, least squares. L_1 provides a very convenient tool for assessing the quality of measurements in the context of a large adjustment. In addition to detecting gross errors and station movement in the current dataset, L_1 will be useful for assessing the measurements that are currently being ignored in the least squares adjustment (i.e. those which were flagged during the initial campaign adjustments). In the future, L_1 could also be a useful assessment tool for the automatic initial vetting of new measurements from LPI or from third parties.

3.3 Positional Uncertainty

The recent adoption of the revised SP1 v2.0 standard by the Intergovernmental Committee on Surveying and Mapping (ICSM, 2014) means that it is now important to compute the Positional Uncertainty (PU) of each mark in the network. Even in the face of a small number of existing outliers, the simultaneous adjustment of the APAS2014 dataset can give a good estimation of the Positional Uncertainty of each station.

Figure 9 demonstrates that of the 24,000+ stations in the current NSW adjustment (which still represents only ~10% of the 250,000 stations in SCIMS) most have a computed horizontal PU (at 95% confidence) of better than 20 mm. The vertical results are similar, but with slightly higher uncertainties (approximately half the stations have a PU better than 20 mm, data not shown). As expected, stations in the western portion of NSW have higher PU (up to 200 mm) due to the relative scarcity of measurements. It should be noted that with the introduction of more CORS and more AUSPOS measurements, computed PU values will improve across the network. As an example, in Haasdyk and Watson (2013) the inclusion of available AUSPOS constraints reduced the horizontal PU in western NSW to approximately 100 mm.

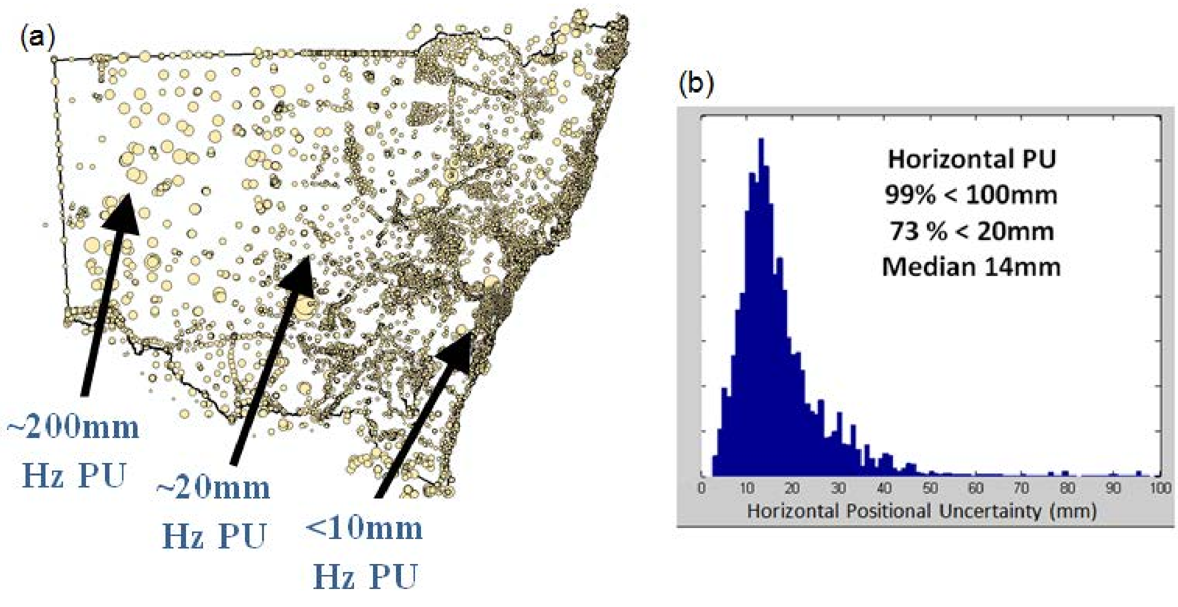

Figure 9: Horizontal PU after state-wide adjustment: ~200 mm in the Western Division, ~20 mm in central NSW and better than 10 mm along most of the NSW coast.

A number of GNSS islands still exist, which are not connected to the CORS constraints in any way. The 320 stations in these islands have very high PU values (metre-level, data not shown) by virtue of their lack of connection to the constraining stations. This state-wide analysis has enabled these islands to be identified and they are currently being connected into the existing contiguous control network, in preparation for the national adjustment.

3.4 Coordinate Differences

As a result of removing the distortions within and between jurisdictions, a transformation will be required to compare coordinates between GDA94 and GDA201x. Figure 10 shows the expected coordinate differences (after removing the systematic 1.5 m shift resulting from 20 years of tectonic motion) as computed by the simultaneous adjustment of the APAS2014 dataset, using CORS Regulation 13 constraints. It can be seen that the expected coordinate changes are systematic but not constant across NSW and would require a complex transformation such as the National Transformation (NTv2) grid method previously employed between AGD66/84 and GDA94 (ICSM, 2006).

Figure 10 shows that the majority of established marks in this adjustment (~20,300 of Class C or better) are expected to change by less than 40 mm. Any marks exhibiting significantly larger station movement (e.g. metre-level) will be investigated for gross errors in associated measurements. Again, it is salient that the stations in this adjustment represent less than 10% of the approximately 250,000 ground control marks in SCIMS (or 14.5% of the 140,000 established marks) and that additional measurements are needed to 'complete' the network.

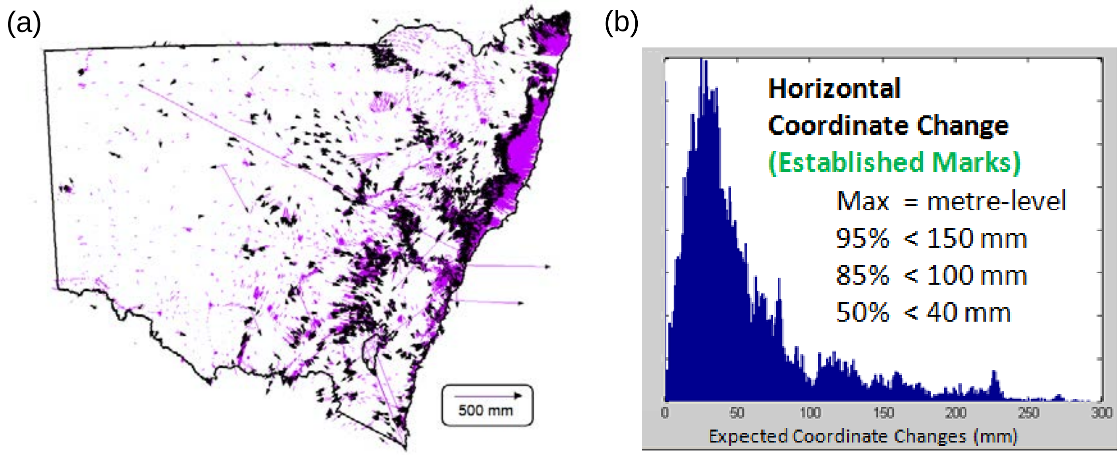

Figure 10: Horizontal PU after state-wide adjustment (~200 mm in the Western Division, 20 mm in central NSW and better than 10 mm along most of the NSW coast)

4 NATIONAL PROGRESS

4.1 Other Jurisdictional Data

In Australia, each state or territorial jurisdiction is the custodian for its own geodetic measurements and authoritative source for ground control coordinates. Consequently, since GDA94 was defined, each jurisdiction has gathered and adjusted its survey control measurements using different methods, with some jurisdictions holding fixed the geodetic control coordinates originally adopted, and others re-coordinating all control stations as new measurements become available.

Figure 11 shows some examples of similar efforts to collate and clean geodetic datasets in other jurisdictions. Victoria, for instance, will provide both contemporary GNSS and historical terrestrial measurements to the national adjustment, with a total number of measurements greater than 140,000. As with NSW, these have been gathered from an archive of measurements spanning several decades. In contrast, Tasmania has largely re-observed its

entire 70-station fiducial GNSS network to provide a new framework for GDA201x. These differences highlight the different resources, tools, processes and methods being used to gather, store, adjust and analyse the data in each jurisdiction.

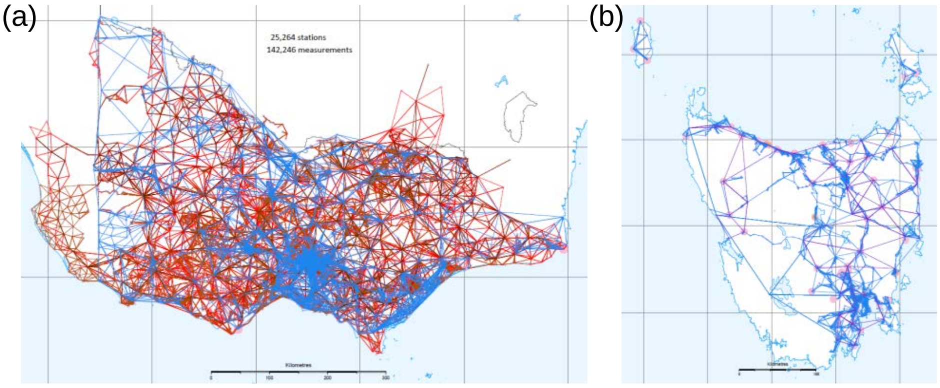

Figure 11: Datasets from (a) Victoria and (b) Tasmania. Scales vary. Colour schemes vary, e.g. Victoria data: blue = GNSS, red = terrestrial. Note that not all observations are displayed in the Tasmanian network, i.e. GNSS clusters are shown as points only.

APREF, currently with 268 CORS across Australia, will provide the geodetic framework against which all states and territories will contribute their GNSS and/or terrestrial datasets. The result will be a homogenous contiguous network, which provides coordinates at a density and quality determined by the measurements provided in each region. A universal format for the automated communication of these jurisdictional datasets and adjustment results, known as eGeodesy, is also currently under development (Donnelly et al., 2013).

4.2 National Computational Infrastructure (NCI)

Currently, the NSW dataset of approximately 70,000 measurements can be computed using DynaNet on a desktop computer in less than one hour. However, the proposed national adjustment will be carried out on a new Australian supercomputer known as 'Raijin', currently the 27th fastest computer in the world (NCI, 2014). Primarily intended for climate modelling, Raijin is available for other computationally-intensive activities of national interest.

Testing of hypothetical large national adjustments has already been undertaken in preparation for GDA201x, with a 400,000-station network comprising over 1.2 million GNSS measurements computed within approximately 50 hours. Further improvements to the efficiency of the software are planned, which have the potential to substantially reduce the duration and memory requirements of the adjustment.

4.3 User Forums

A first round of education and discussion forums has been convened by state, territory or national geodetic authorities across the country in the last two years. These forums aimed to introduce the issues and benefits of a next-generation datum to a diverse group of spatial data users, and to understand the perceived and real costs, benefits and opportunities associated with datum modernisation from the users who will be most affected by these changes.

The first forum, internally run at LPI in late 2012, highlighted the diverse groups (councils, engineering, mining, construction, research, etc.) currently utilising legacy datasets in

GDA94. The first open forum was held at the APAS2013 conference in March 2013 with predominantly surveyors (around 250) interested in centimetre-level positioning. The second, in April 2013 at the SSSC2013 conference in Canberra, was targeted at geospatial professionals and the audience included a diverse range of users. Since then, additional forums have been held in NSW, VIC, ACT, NT, TAS and webinars describing datum modernisation issues have been made available (Haasdyk and Donnelly, 2013).

The reader is directed to Haasdyk et al. (2014) for further discussion on the potential realisation(s) of a next-generation Australian datum. It is, however, reiterated here that the decision of spatial data holders to modernise their existing datasets should be dependent on readiness of their systems. For the future application of data it is important to improve metadata management, in particular information about when data was captured and the methodology and estimated precision of the data capture.

4.4 Geodetic Measurements By Third Parties

As we seek to re-observe and densify the geodetic data available for a national adjustment (and subsequent verification of station stability), the importance of third-party contributions is increasing. Outsourcing and even judicious crowd-sourcing of geodetic data collection are becoming increasingly frequent. For example, given a proper treatment of metadata (e.g. records and checks regarding equipment, antenna heights and time-stamp metadata), many GNSS measurements can contribute to the national GNSS archive for AUSPOS processing. In the future, Geoscience Australia intends to make such contributions easier by allowing contributions directly via the AUSPOS submission page, but until that time, your local survey control authority will have instructions on requirements for contributions (e.g. LPI, 2012).

5 NEXT STEPS

The previous status report by Haasdyk and Watson (2013) highlighted a number of ‘next steps’ required to complete the NSW dataset for GDA201x. Most of these, listed again in Table 3, have seen progress but are not yet complete. Some, such as in the inclusion of terrestrial measurements have been tested, but will likely require the development of additional methodology and tools. As LPI completes the installation of its CORS network in January 2014, preparation for GDA201x will become a major focus and additional resources will be devoted to completing the tasks outlined in Table 3.

Table 3: Additional labour at LPI in preparation for GDA201x.

Tasks for NSW Dataset	Progress
Include additional stations	✓
Mine new data as available	✓Methods are in place
Identify remaining gross outliers	✓Ongoing
Identify station movement	✓Ongoing
Connection of GNSS islands	✓Ongoing
Inclusion of APREF SINEX	✓Method tested
Inclusion of AUSPOS SINEX	✗ Waiting for GA solution
Mine metadata for time stamp	✗
Inclusion of terrestrial measurements	✗ Initial testing only
Review measurement weighting	✗Adopted as in archive

6 CONCLUDING REMARKS

The preparation of geodetic data in support of a next-generation Australian datum is an on-going task for all states and territories in Australia. This paper has described the progress made and the remaining tasks related to collating and cleaning the available geodetic data for a new simultaneous national adjustment. While particular focus is given to the improvements in the state-wide adjustment of a NSW-wide GNSS dataset, other state, territory and national efforts have also been discussed.

LPI has made significant improvements to the quality and analysis of the state-wide adjustment of available GNSS measurements for NSW in the past year. Significant numbers of new measurements and new stations have been included. New tools utilising the L_1 norm method have been developed and will assist with the detection of remaining outliers. LPI remains on track to submit a final cleaned and verified GNSS dataset for the initial GDA201x adjustments later in 2014.

An important product of this work is the development of a database of geodetic measurements, which will continue to assist future datum development and planning of geodetic observations. Eventually, the methods and analyses developed during the production of this GDA201x dataset will make it easier to automate (or semi-automate) the verification and inclusion of data from new campaigns and/or third parties.

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Looking at Cadastral GNSS from a New Angle

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ABSTRACT

Global Navigation Satellite System (GNSS) technology is increasingly utilised for cadastral surveying purposes. This paper presents a theoretical approach to the considerations that will affect the use of GNSS in cadastral surveying. Is it possible to measure an angle with GNSS? Can angles be derived by GNSS? Can a GNSS bearing be considered? What are the theoretical limitations of the current technology in terms of the Surveying and Spatial Information Regulation 2012? There should be an appreciation of the acceptable limits set out in the Regulation not limited to distance, but including angular tolerance and misclose tolerance. How would this translate to measurements taken by GNSS? Once this is understood, it may be possible to predict a minimum point separation for GNSS-observed points to comply with the Surveying and Spatial Information Regulation 2012. While this theory is useful, the proof is in the practical tests and the reality of observations. Two test methods are outlined to determine if the presented theory is sound.

KEYWORDS: *Cadastral surveying, GNSS, Surveying & Spatial Information Regulation 2012.*

1 INTRODUCTION

Global Navigation Satellite System (GNSS) technology has been used in surveying for the best part of 20 years. Many studies have been undertaken regarding repeatability of observations, the use for geodetic surveys and have tried to relate them to the Surveying and Spatial Information Regulation 2012 (SSIR 2012) or its predecessors (e.g. NSW Legislation, 2014a-d). These studies have mostly concentrated on the distance aspect of the SSIR 2012 and have not considered in depth the angular or misclose components that are also required to be met for cadastral surveys. Before studying the theoretical suitability of GNSS, a discussion needs to take place regarding what can be measured with GNSS.

As stated above most studies relate GNSS to distance measurement, yet in the process of obtaining the required data to determine a distance, is more information available? Can GNSS measure angles? Can angles be derived from GNSS observations? Or is it possible to consider a bearing from GNSS observations? After these questions have been considered, the standards set by SSIR 2012 need to be interpreted.

What is the purpose of the SSIR 2012 and its predecessors in relation to measurements? The SSIR 2012 clearly states the angular accuracy or angular misclose requirement of a survey. However, this is in terms of the number of traverse stations in the survey. Does this value also relate to any angle for a radiation from a traverse station? In GNSS terms, what is an acceptable error ellipse for a radiated point to comply with the SSIR 2012?

Now that the terms of reference have been identified, the theoretical suitability of GNSS for cadastral surveys can be considered. How does the current GNSS technology of 2014 measure in relation to the SSIR 2012? What methods of survey are suitable and how does point density affect the outcome? With all this theoretical knowledge, how does it compare in the real world? Two test methods have been adopted to validate the results of the theory presented in this paper.

While this paper seems to raise more questions than it supplies answers, the intention is to promote discussion on the uses of GNSS and investigate how the technology of GNSS can be integrated into cadastral surveying and to link it to the conventional measurement standards that have been prescribed by regulation.

2 ASSUMPTIONS

This paper is written with several assumptions that have been made. Best practice survey methods are observed to obtain the GNSS observations. All error ellipses are shown as radius (in circle terms) or half-major axis values. To appreciate the size of the total error tolerance, this value should be doubled, i.e. 3 mm sounds rather tight but 6 mm is about the size of a clout and is very realistic.

3 DISCUSSION OF ANGLES AND BEARINGS

Is there any difference between two end points of a traditional traverse, A & B, with the resultant closing line as a bearing and distance between the two points, as opposed to the same two points simultaneously measured by GNSS with the resultant line shown as a bearing and distance between points A & B? Is there any difference between two traditionally radiated points C & D, with a calculated line between them shown as a bearing and distance, as opposed to two GNSS points C & D with a line shown as a bearing and distance? Most people are comfortable with both concepts, i.e. measuring lines and derived lines with GNSS.

Now consider an angle. There are three points A, B & C, and with a theodolite set at B it is possible to measure the angle B. Is it also possible to measure the angle B with three GNSS receivers observing simultaneously? GNSS works for a line so why not an angle? Likewise, for three points C, D & E, traditionally radiated, an angle can be derived or calculated. However, is it reasonable to calculate the angle from three points measured with GNSS?

Is there a significant difference between measured and calculated angles and distances? How many cadastral surveys set up on a corner peg and read the angle between the streets or along the side boundary? Every cadastral surveyor radiates corner pegs and Reference Marks (RMs), and calculates the angle from the calculated definition of the streets. It is not practical excluding a green field subdivision to measure the angle as obstructions most often prevent direct measurement.

At the most basic level, a line is defined by two points and an angle is defined by three points. What is the common link between lines and angles? They are both defined by points regardless of where the points come from. In a cadastral surveying context that means the points could be a traverse station, a radiated point or a GNSS point. There is always an amount of contention about which method is more accurate but this will be discussed later.

The message to take from this discussion is that it is possible to determine an angle with GNSS. Many users of GNSS do just that but how many consider the accuracy of the results?

What about a bearing from two GNSS points? Consider a compass, within the framework of the magnetic field, a compass will provide a bearing based on the local magnetic field. The user places faith in the field and believes the field uniformly points north. History has shown this is not the case, however compasses are still used as a means of navigation and Deposited Plans have been based on magnetic north for many years. Regardless of the accuracy, a compass provides a bearing from one point to another point at some undetermined distance away. From the above discussion, it has been shown that two points define a line and therefore it is reasonable to conclude a line within a framework is defined as a bearing. GNSS works within a mathematical framework and can provide two points at a known distance apart, hence providing a line and therefore a bearing based on the mathematical framework.

On a less philosophical aspect, Surveyor General's Direction No. 9: GNSS for Cadastral Surveys (SG9 – LPI, 2013) includes several definitions about GNSS measurements. These seem to be limited to lines, however from the above they can equally be applied to angles. SG9 states "*A GNSS measurement will be deemed as a direct measurement if it is determined from a single GNSS vector which was observed simultaneously at each end of the line*." Vectors by definition have both direction and magnitude. If it is reasonable to measure two vectors simultaneously, therefore an angle has been measured by default. This requires three GNSS receivers, however the principle is sound.

SG9 states "*A GNSS measurement will be deemed as a derived measurement, if it is determined indirectly by non-simultaneous GNSS observations at each end of the line*." If it is reasonable to derive a line from non-simultaneous GNSS observations, then it should be reasonable to derive an angle from non-simultaneous GNSS observations.

SG9 further states "*GNSS observations produce either three-dimensional absolute position measurements or relative three-dimensional vector measurements between positions. These measurements must be converted to two-dimensional (grid bearing and horizontal ground distance) measurements for inclusion on the survey plan*." This statement includes the term 'bearing' which seems to validate the argument that it is possible to measure and derive angles and bearings from GNSS observations. However, before it is possible to compare angles measured by GNSS and by theodolite or total station, it is necessary to investigate how angles are measured by a theodolite.

A theodolite is used to measure an angle by two pointings, i.e. one at the reference object and the other to the foresight. Therefore there are two error ellipses to consider in any one angle. However, there is only one error ellipse on the foresight and only one error ellipse on any radiation. The SSIR 2012 has tolerances for angular misclose which will be discussed in detail shortly. By what method is it possible to convert the SSIR 2012 tolerances to a suitable tolerance for radiations?

Figure 1 shows how the allowable error is distributed in an angle when measured with a theodolite. Angle ABC has an allowable error of *E*. *E* shows the allowable error spread over the whole angle (e.g. in a triangle, each angle is allowed to have 9 seconds of error – see Table 3 for 2012), however this is not the case. The allowable error only occurs at the targets. Half this error is from the target at A and half from the target at C. Half the allowable error is noted as *E/2*. In order to determine the allowable errors in millimetres, the equations stated in

Figure 1 are used, i.e. MAa and MAc for A and C respectively. The allowable errors stated in the SSIR 2012 are relative errors; these should be considered to be a combination of the errors at both ends of the line.

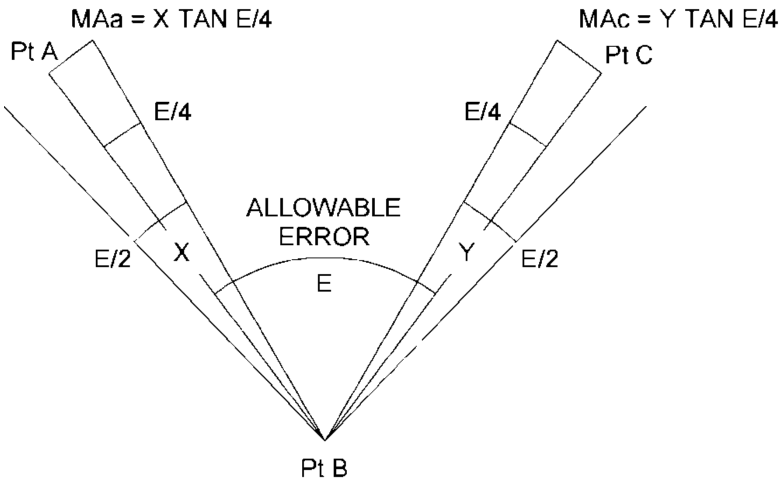

Figure 1: Allowable tolerance for angle measured by theodolite.

4 REGULATIONS AND STANDARDS

4.1 Distance Requirements

SG9 states "*Cadastral survey length accuracy (10 mm + 50 ppm) closely equates to the Class C category. Table 1 below shows the relationship between the class of surveys with relation to point error and relative errors over a line. This means that if the GNSS equipment/method being used has a stated point accuracy of no better than 0.020 m (without regard for setup errors and site considerations) to attain class C the minimum length measured should be 400 m. Using GNSS equipment under 400 m for cadastral purposes would require proof of point error accuracy through validation*."

Table 1: Class derived from station density and point error ellipse size (at 95%). The relative error ellipse size used in the determination of class is stated in parentheses (Dickson, 2012; LPI, 2013).

Point and (Relative) Error Ellipse / **Station Density (km)**	0.010 m (0.014 m)	0.020 m (0.028m)	0.030 m (0.042m)	0.040 m (0.056m)	0.050 m (0.070 m)	0.060 m (0.084m)	0.070 m (0.096 m)
0.1	C	D	E	E	–	–	–
0.2	C	D	E	E	E	–	–
0.4	B	C	D	D	E	E	E
0.6	B	C	C	D	D	E	E
0.8	A	B	C	C	D	D	D
1	A	B	B	C	C	D	D
2	A	A	B	B	C	C	C
5	2A	2A	A	A	A	B	B
10	3A	2A	2A	2A	A	A	A

The SSIR 2012 has many components that must be met before a survey can be deemed to comply. From a GNSS perspective, distance is well understood but the angular component

and misclose requirements are less studied and not so well understood. SSIR 2012 clause 25 states that all measurements must be made to ± (10 mm + 50 ppm) at a 95% confidence. This has been tested on many occasions and is well understood in terms of GNSS ability.

It is interesting to note from Table 2 that while the minimum measurement has not changed, i.e. in 1933 it was possible to measure to a 1/16 of an inch (1.5 mm) and in 2012 a high-accuracy Electronic Distance Measurement (EDM) instrument is deemed to deliver ± (2 mm + 2 ppm), yet the required accuracy in 2012 over a 30 m line is four (4) times as high as it was in 1933. In contrast, for any line over 1,000 m the expected tolerance is less than before, but not to the same extent, even though it is much easier to measure long lines with modern equipment.

Table 2: Allowable distance errors from regulations by years (all values in metres).

	1:12,000	6mm+30ppm	20mm+30ppm	10mm+50ppm
Dist	1933	1996 / 2001	2006	2012
10	0.001	0.006	0.020	0.011
30	0.003	0.007	0.021	0.012
50	0.004	0.008	0.022	0.013
100	0.008	0.009	0.023	0.015
250	0.021	0.014	0.028	0.023
500	0.042	0.021	0.035	0.035
750	0.063	0.029	0.043	0.048
1,000	0.083	0.036	0.050	0.060
2,000	0.167	0.066	0.080	0.110

4.2 Angular Requirements

The angular requirements of SSIR 2012 clause 24 are set out in terms of a traverse misclose, i.e. the number of stations determines the acceptable angular misclose. While this works well with conventional methods for the traverse, it is not able to be applied to GNSS as the methodology of measurement is completely different.

Using Figure 1, it is possible to covert the allowable error into a linear distance error ellipse. For example, consider the SSIR 2012 value for a triangle in Table 3. The total allowable angular misclose of 27 seconds divided by the number of angles equals 9 seconds per angle. Using the equation from Figure 1, i.e. $MA = Dist \tan(9''/4)$, gives the results shown in Table 4.

Table 3: Angle misclose limits in seconds, set by regulations by years.

	30+20√n	per angle	20+10√n	per angle	10+10√n	per angle
No Stations	1933 / 1996	Sec	2001 / 2006	Sec	2012	Sec
3	65	22	37	12	27	9
5	75	15	42	8	32	6
10	93	9	52	5	42	4
15	107	7	59	4	49	3
20	119	6	65	3	55	3

Table 4: Angle tolerance for 9 seconds of arc expressed as metres.

Dist	1933	2001	2012
10	0.000	0.000	0.000
30	0.001	0.000	0.000
50	0.001	0.001	0.001
100	0.003	0.001	0.001
250	0.007	0.004	0.003
500	0.013	0.007	0.005
750	0.020	0.011	0.008
1,000	0.026	0.015	0.011
2,000	0.052	0.029	0.022

4.3 Requirements for Radiations

While SSIR 2012 states angular measurement tolerance for traversing, it appears to be silent on the quality of angular radiations. SSIR 2012 clause 25 states that all distances must be checked, however there is not an equivalent statement regarding angles for radiations. It is assumed that while traversing, all angles are read in two faces as this is best practice. However, this may not always be the case, as there is a belief that electronic instruments are adjusted to compensate for the face left/face right error, although some would also argue this compensation includes pointing errors. It is much better to have a well adjusted instrument and take multiple readings. With Automatic Target Recognition (ATR) and motorised instruments it is just as quick to read three arcs, which introduces redundant observations to allow checking.

Is it reasonable to apply the same angular tolerance to all radiations from a station as is applied to the station? If this is the case and there are a lot of stations, the angular tolerance would be very small. However, if there are few stations, the tolerance is rather large by comparison (see Table 3). Should there be a set tolerance for all radiations? Is there an expected tolerance for any survey measurement already present in the profession but not documented yet? Some would argue if it falls in the material of a standard fence then it is okay. There is also a belief if the value of the land is high then tolerance is tighter than lower valued land.

Historically, surveyors used the parallel and square offset method until it was possible to easily measure longer distances, which allowed the transition to radiations. The old method kept radiations short to less than 30 m as a norm. While it is possible to measure longer radiations with a chain, it was not normally done. SSIR 2012 clause 63 states that no RM will reference any point more than 30 metres from the mark. This also adds weight to the 30-metre radiation theory. Table 5 equates angular variation to error ellipse over 30 metres (this is twice as large as an angular error because there is no backsight considered; all of the variation is applied to the foresight). Angular variation is not related to pointing error. However, this is an interesting table to consider when determining the size of allowable limits for radiations.

Table 5: Angular variation at 30 m (angle variation = 30 tan(Delta Angle)).

Delta Angle	Angle Spread	Obs Dist	Angle Variation
Min Sec	Min Sec	m	m
00’ 05”	00’ 10”	30	0.001
00’ 15”	00’ 30”	30	0.002
00’ 30”	01’ 00”	30	0.004
00’ 45”	01’ 30”	30	0.007
01’ 00”	02’ 00”	30	0.009
01’ 25”	02’ 50”	30	0.012
01’ 30”	03’ 00”	30	0.013

4.4 Traverse Misclose Requirements

SSIR 2012 clause 26 deals with survey misclose and is the third component to a cadastral survey traverse. This is a check on the survey as a whole as opposed to the previous two accuracy statements, which are for individual components of measurements. How this is applied to a GNSS survey is also yet to be determined unless it is a GNSS survey that is undertaken in a traverse methodology with each line measured independently of the previous line.

Can this be used to help define how accurate a radiation should be? Consider a 30 m radiation and suppose the check distance method from SSIR 2012 clause 25 is a small traverse of two other lines of 30 m. There is now a total traverse length of 90 m and an allowable misclose of 0.025 m under the SSIR 2012. Table 6 shows the relationship between traverse length and allowable error.

Table 6: Allowable misclose from survey regulations (all values in metres).

	1:8,000 Level	1:6,000 Undulating	1:4,000 Steep	1:3,000 Mountainous	15mm+100ppm
Dist	1933	1933	1933	1933	1990 / 2012
100	0.013	0.017	0.025	0.033	0.025
200	0.025	0.033	0.050	0.067	0.035
250	0.031	0.042	0.063	0.083	0.040
500	0.063	0.083	0.125	0.167	0.065
1,000	0.125	0.167	0.250	0.333	0.115
2,500	0.313	0.417	0.625	0.833	0.265
5,000	0.625	0.833	1.250	1.667	0.515
10,000	1.250	1.667	2.500	3.333	1.015

Again it is interesting to look at the comparison between old and new. The data in Table 6 seems to indicate that new technology is less capable to measure short lines yet better at measuring longer lines as there is a greater acceptable error for short traverses, but a smaller acceptable error in long traverses. That is if the 1933 values are a true representation of ability or whether they are the expectation of measurement quality.

4.5 Error Ellipses

By comparing the errors allowed in the SSIR 2012 for distance and angle, the angular error is much less. This results in a long skinny ellipse. This is very different from the GNSS error ellipse, which is round. Assuming a 9-second angular error, Table 7 shows the resulting error ellipse for various distances based on the discussion so far.

Table 7: Comparison of angle and distance errors according to SSIR 2012 (all values in metres).

9 Sec Angle Error vs. Dist		
	Calc	Reg's
Dist	Ang	Dist Tol
10	0.000	0.011
30	0.000	0.012
50	0.001	0.013
100	0.001	0.015
250	0.003	0.023
500	0.005	0.035
750	0.008	0.048
1,000	0.011	0.060
2,000	0.022	0.110

4.6 Error Ellipse Direction

Now that there is an understanding of the size of the error ellipses and the reasons why these are the shape that they are, consider the result of observing the same point from two stations so that the two radiations are perpendicular to each other. It can be argued that this is the best geometry to have a check radiation as it has the least error due to lines not intersecting at acute angles. By the current theory, the regulations for radiations of 30 m allow an error of 0.012 m in distance, however there is no tolerance in angle. An intersecting radiation of 30 m perpendicular to the first radiation is allowed the same tolerance but in the opposite axis. The resulting error ellipse is a circle with a radius of 0.012 m, yet this does not comply with the regulations as it fails the angular requirement. On the other hand, taking the angular argument it passes both tests, however it is unrealistic to say it is possible to measure without error. Similarly, with regard to survey misclose, while it is possible to measure three lines 30 m long, it is hardly professional to say it is only accurate to ±0.024 m.

There would appear to be a need for the regulations to define the acceptable tolerance for a radiation, in terms of its proximity to any other radiation. Currently the regulations define radiations with regard to how well they are measured from the traverse and the size of the traverse. The tolerance must be considered in two stages. Firstly with a complete disregard of any equipment used and with sole concern of the integrity of the cadastre. Secondly, with consideration of the available equipment to ensure achievable limits are set. This would be a benefit for both traditional survey methods and allow the link to GNSS.

5 REDUCING ERROR SIZE AND IMPROVING ACCURACY

Every measurement has errors. Checking measurements has a dual benefit: it finds gross errors and also improves the accuracy of the initial measurement, provided there was no gross

error and the two measurements are of equal accuracy. For every additional measurement the accuracy is increased. However, this is not a linear process. Is there an optimum? The expected error from multiple observations can be expressed as (x = error of a single observation):

$$\text{expected error} = 1/\sqrt{((1/x)^2 + (1/x)^2 + (1/x)^2)} \quad (1)$$

From Table 8, it can be shown that the starting error of one observation is 20 mm. However, by taking a second observation the error is not halved but it is reduced. To halve the error four observations are necessary. To halve that again requires a total of 16 observations. Therefore it would appear that the ideal number of observations is four to get the most benefit with least effort. As an example, a radiation distance read twice in face left and twice in face right achieves a better accuracy or smaller error than a single reading with a higher accuracy instrument. With modern instruments this is very easy to automate.

Table 8: Example of point errors for multi-observations.

No Obs	Error (mm)	
1	7	20
2	4.95	14.14
3	4.04	11.54
4	3.50	10
16	1.75	5

6 POINT ERROR VS RELATIVE ERROR

Every point measured has its own error. However, the error of a line as relative error is not as simple as adding the two point errors together. The relative error is calculated by the following formulae. This could also be reversed to find the allowable point error from a line tolerance. The relative error can be calculated from point errors as (see Table 9 for examples):

$$\text{relative error} = \sqrt{(x^2 + x^2)} \quad (2)$$

$$\text{point error} = \sqrt{(z^2/2)} \quad (3)$$

where x = error of a single observation and z = error of a line.

Table 9: Example of line error from point errors (all values in millimetres).

Line Error	Point Error
4.24	3
5.66	4
7.07	5
8.49	6
9.90	7
11.31	8
12.73	9
14.14	10

7 DETERMINING POINT SEPERATION FOR GNSS POINTS

Consider Figure 1 again, but this time from a GNSS perspective. The points ABC are now (or about to be) measured with GNSS with an estimated point error. This point error can be converted to a relative error and used to calculate the missing variables to be tested against the SSIR 2012. This can be achieved a few ways, e.g. calculate the angle *E/4* from Figure 1 and compare this result to the SSIR 2012 value or use the *E/4* value and the estimated relative error to calculate the minimum point separation *X* from Figure 1.

8 EXPECTED ERRORS FOR CURRENT TECHNOLOGY

Current technology is manufactured to meet the standards set in ISO 17123. Parts 3 and 4 refer to theodolites. For the test undertaken by this standard a confidence level of $1-\alpha = 0.95$ is assumed (Zeiske, 2004). Table 10 shows point error ellipses for points measured relative to GNSS Continuously Operating Reference Stations (CORS), using single-base Real Time Kinematic (RTK) from the closest CORS as well as using Network RTK (NRTK). The error ellipses are not dependant on the distance between the points being measured in the local vicinity of the survey, but are generally dependent on the distance to the surrounding CORS. For example, two points 100 m apart will have an error dependent on the distance to the nearest CORS. It is important to note that the values stated in Table 10 refer to NRTK cells of different sizes (Janssen and Haasdyk, 2011).

Table 10: RTK and NRTK 95% confidence interval deviation from mean (in metres) – interpolated from graphs shown in Janssen and Haasdyk (2011).

Dist to CORS	**0.01 km**	**6 km**	**12 km**	**15 km**	**22 km**	**41 km**	**50 km**
RTK	0.008	0.015	0.022	0.029	0.024	0.027	0.050
NRTK	0.007	0.013	0.013	0.025	0.013	0.025	0.035

Table 11 has been constructed by calculating the line error budgets from manufacture specifications and adding centring tolerances. Then the values were converted to a point tolerance from the line tolerance calculated. This table assumes the instrument is on a tripod and the reflector is on a bipod. The purpose is to allow some comparison to the error ellipses in Table 10, remembering the distances between points should be read from Table 11. The author acknowledges this is not a true comparison, as it is a comparison between field data and manufacturer's specifications, however it does show the generic expected accuracies of each instrument.

The expected error ellipse for static GNSS is one of the key drivers behind this paper. The author has limited experience with static GNSS reductions. From reading various sources, possible errors in the region of ± (10 mm + 2 ppm) at 95% are expected, yet other sources suggest errors of 18 mm at 95% for lines up to 1 km. It will be interesting to investigate the ability of static GNSS for lines below 500 m in length.

Table 11: Theoretical point error budgets for total stations (all values in metres).

Spec	2" 2mm / 2ppm		3" 3mm / 3ppm		5" 5mm / 5ppm	
Dist	**Angle**	**Dist**	**Angle**	**Dist**	**Angle**	**Dist**
10	0.004	0.004	0.004	0.004	0.004	0.005
30	0.004	0.004	0.004	0.004	0.004	0.005
50	0.004	0.004	0.004	0.004	0.004	0.005
100	0.004	0.004	0.004	0.004	0.004	0.005
250	0.004	0.004	0.004	0.005	0.006	0.006
500	0.005	0.004	0.006	0.005	0.009	0.006
750	0.006	0.004	0.009	0.005	0.013	0.007
1,000	0.008	0.005	0.011	0.006	0.018	0.008
2,000	0.014	0.006	0.021	0.007	0.034	0.011

9 LOOKING AHEAD: PROVING THE THEORY

This is all well and good in theory but how does it work in real life out in the field? To test the ability of GNSS to measure or derive angles, a test area has been selected to allow the points to be measured by both methods and the difference in angles compared. The test site is a large triangle with sides approximately 400 m long with two triangles inside it, having sides of 150 m and 250 m. Each angle will be measured by both methods on the same day. The method for measuring the angle will be the same as a standard survey, i.e. total station measuring three rounds. GNSS static observations will be collected for 10 minutes observed twice at least 30 minutes apart. The three sides will be measured with GNSS, processed and adjusted using least squares. This will estimate an error ellipse for each point. RTK measurements will also be made for comparison. Each triangle will be read as a separate observation. Therefore three independent angles will be measured each time. The test will be repeated many times to get an average expected result.

The second test will be a traverse test where GNSS will be used to measure each line independently. Both angular misclose and closure misclose will be calculated. This test will use both static GNSS and RTK/NRTK as independent traverses.

10 CONCLUDING REMARKS

Firstly it must be emphasised that the purpose of this paper is not to discredit GNSS, which is recognised as being a very useful tool used in the appropriate circumstances. What those circumstances are is what is being considered. From the above discussion, it would appear that under the current regulations GNSS is not capable of measuring angles where the vertices are closer than approximately 1 km. This requires three observations being less than 6 km to the closest base station or the use of a quality static survey with small error ellipses. These long baselines are not practical or useful from a field perspective in cadastral surveying. The long baselines are a result of the combination of the uncertainty of the point measured and the angular tolerance in the regulation. From examination of the SSIR 2012, it would appear that there needs to be more discussion regarding all of the tolerances in regard to the cadastre, not the ability of the current technology. However, some regard must be taken to consider the technology to ensure achievable limits are set, even though this may require multiple observations. There is also a need to devise a point tolerance (like the SP1 class system) to allow radiations to be included in the regulation rather than an assumption that they are

covered by virtue of the traversing standards. It will be interesting to process the results of the field tests and determine the likely and expected angular results when using GNSS to measure or derive angles, particularly in the range below 500 m.

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Surviving in the Pilbara

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ABSTRACT

The Pilbara is a large, dry, thinly populated region in the north of Western Australia known for its Aboriginal people, its landscapes, the red earth and its vast mineral deposits (iron ore in particular). Surveyors in the Pilbara often work in remote areas and weather conditions where the risk of being involved in a survival situation is higher than usual. Moxies, cyclones, bushfires, cattle and snakes – the risks are always present and cannot be taken for granted. Vehicle and equipment preparation are fundamental to surviving a crisis. However, survival is more than just remaining injury free. Survival can be as much a mental challenge as a physical one, and good mental preparation is as important as physical preparation. Surviving the Pilbara is about working in an alien environment, fitting into the lifestyle and then going home physically and mentally intact. This paper explores what survival means in the Pilbara, the survival equipment carried for an emergency and the basic procedures and policies in place. It also examines what mental challenges are faced and how people cope with their work environment. Lastly, some real scenarios are presented (some serious, some humorous) that have been encountered in some of the most stunning scenery in Australia.

KEYWORDS: *Pilbara, remote surveying, survival.*

1 INTRODUCTION

1.1 Background

After 20 years as a Teacher of Surveying at TAFE, I had a desire to return to the field and be a practicing field surveyor again. Nothing though could prepare me for the journey of the last three years. As I sit here in my donga at West Pilbara Village typing these words, I reflect on the whirlwind of experience and learning that has typified this journey to date and I have to say I am very much looking forward to the journey ahead. Before I begin, I have to express a sincere thanks to TAFE for the journey and experiences I enjoyed with them and to AAM P/L for offering me a position as Senior Surveyor and affording me the opportunity for this next adventure. So here begins this part of my journey, 4,500 km from home and a 1,000 years from TAFE.

I have to stress that this paper is not meant as a definitive guide to survival techniques – there are numerous publications, videos and websites about survival available in bookstores and on the internet. This paper is about what I have experienced, seen, enjoyed and come to respect – all in a relatively short time. This paper will look at two main areas of survival, surviving the Pilbara itself and surviving the lifestyle. In both sections consideration will be given to what can harm you and what can save you.

1.2 Where is the Pilbara?

We often hear of the Pilbara in the press but where is it? The Pilbara is part of Western Australia (WA) and covers an area of 507,896 m^2 (Figure 1). There are about 50,000 people who live permanently in the Pilbara but FIFO (Fly In - Fly Out) workers can take this population to 85,000 or more (GA, 2013). It is also home to about 17% of the world's iron ore recourse, 97% of Australia's iron ore reserves (GA, 2013) and currently for two weeks out of three it is part-time home to me.

Figure 1: Regions of WA.

1.3 West Pilbara Village

My part-time home at the moment is the West Pilbara Village (WPV), about 100 km from Tom Price WA. This is where I live in a 'donga' (a temporary, usually transportable, dwelling), eat in the 'dry mess' and occasionally drink in the 'wet mess'.

WPV is one of a number of villages within the Brockman mines precinct (Brockman 4, 2 and Nammuldi) including WPV (formerly Brockman 4 Village), Brockman, Boolgeeda, Weelamurra and Jerriwah villages. These villages are of a high standard to ensure employees enjoy a quality lifestyle while they are away from home. Villages typically have a swimming pool, sporting courts (used for tennis, soccer, volleyball, lawn bowls and other sports) and a wet mess. Employees have their own air-conditioned accommodation units, with en-suite bathrooms, television, telephone and internet connection. Employees' units are cleaned twice a week. Meals are provided in mess facilities – main meals include a selection of hot and cold dishes, and healthy low-fat options are always available (Rio Tinto, 2014).

2 SURVIVING THE PILBARA

2.1 What Does FIFO Mean?

FIFO stands for 'Fly In - Fly Out' and each swing as we 'fly in' there is an unspoken understanding that we should 'fly out' in the same state of wellbeing (physically and mentally) as we arrived. Survival is more than just words; it is core to our work practices and ethics. There are a number of considerations to survival and depending upon the circumstance the relevance of these considerations can vary. The following list is not in any particular order, e.g. snakes can be a serious consideration when we are doing remote surveying but have less of an impact on the surveying work we do within the mines. Water is plentiful within our current work environment but is arguably the most critical consideration in other circumstances.

2.2 What Can Harm You?

As mentioned, the following are not in any particular order, but all of these items are not to be taken lightly.

2.2.1 Moxies (and Vehicles in General)

Vehicle interactions are an issue on sites and therefore there is a lot of planning that goes into keeping light vehicles (LV) separated from heavy mining equipment (HME), but unfortunately incidents do occur. Minor incidents can involve LV's being on a HME haul road when not permitted. Major incidents can involve vehicle collisions ranging from panel damage to complete destruction of vehicles and loss of life. When an HME collides with an LV you can imagine who comes off the best.

Figure 2 shows what happened when BHP *deliberately* ran over an LV to highlight the fact that your chances of surviving such an incident are extremely slim (pardon the pun). The dump truck in question was empty; the impact would have been far more significant if the dump truck had been full.

Figure 2: (a) Dump truck impacting on a light vehicle and (b) the aftermath (Mining Mayhem, 2010).

Moxies (articulated dump trucks originally manufactured by Moxy Engineering in Norway but now typically used to refer to any articulated vehicle) and dump trucks have similar issues with visibility. Only once you have sat in the cab, you realise how limited the view actually is. Figure 3 shows a diagram of the areas (in grey) where a truck driver cannot see a 6' tall worker.

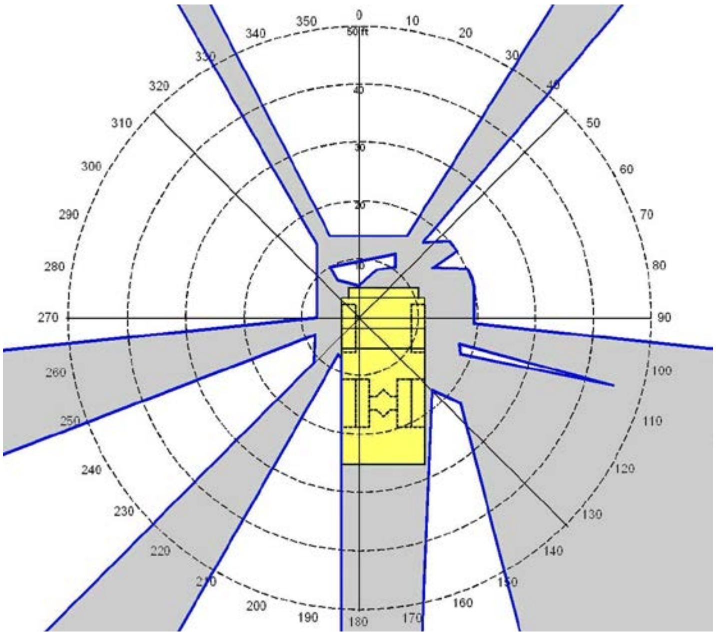

Figure 3: Dump truck blind spots (Office of Mine Safety and Health Research, 2012).

2.2.2 Cyclones

Cyclones are an ever present risk to the Pilbara, particularly along the coastal regions. According to BoM (2014), the Pilbara coast experiences more cyclones than any other part of Australia. Since 1910 there have been 48 cyclones that have caused damaging wind gusts in excess of 90 km/h in the Karratha, Dampier and Roebourne region. On average, this equates to about one cyclone every two years. About half of these have an impact equivalent to a category one cyclone. Ten of these (i.e. 1925, 1939, 1945, 1954, *Shirley* 1966, *Sheila-Sophie* 1971, *Trixie* 1975, *Chloe* 1984, *Orson* 1989 and *John* 1999) have caused very destructive wind gusts in excess of 170 km/h. Along the central Pilbara coast, the cyclone season runs from mid December to April peaking in February and March.

If you are on site, there is a system of cyclone warnings similar to the one depicted in Figure 4 (note that warning systems can vary from site to site). Depending on timing, you may be demobilised or have to remain on site. On site you will have to tie down equipment, make safe vehicles etc. If the warning is about to reach ‘red alert’, you take your survival pack (including food, water, *no* alcohol) and remain in your donga until the ‘all clear’ is given.

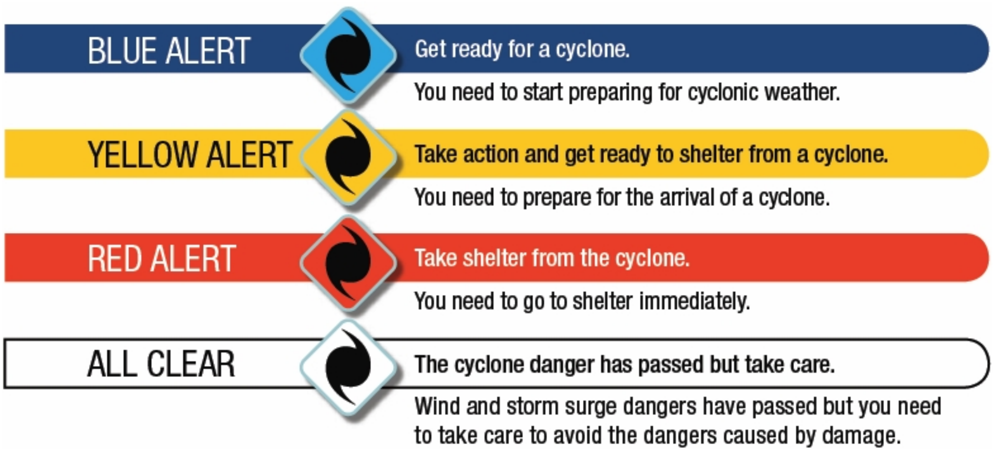

Figure 4: Cyclone alert levels (Shire of Derby / West Kimberley, 2014).

2.2.3 Bushfires

In summer, there is an increased risk of bushfires (Figure 5). Late October to mid November 2013 saw a number of dry lightning strikes in the Pilbara around the Brockman mines. Spectacular and yet a minor inconvenience mostly. Other sites were not so fortunate, e.g. bushfires caused considerable disruption at Cloudbreak (FMG site) where 1,500 people had to be evacuated on 25 October 2013 (ABC News, 2013).

Figure 5: Bushfire adjacent to Brockman 2 to Brockman 4 road.

Bushfires tend to be fast moving and spectacular, and our role is to monitor the radios and follow directions as required. Water carts are kept fuelled and full in case they are required, but the actual fire fighting is the domain of our emergency services.

2.2.4 Cattle

Many mining sites are within pastoral leases and cattle can be an issue for drivers. All our vehicles have bull bars fitted and driver training includes strategies for dealing with cattle (and other animals). Nonetheless, they can be unpredictable, particularly when there are calves involved. In more remote areas some of the cattle have not even seen people, so cattle should be treated with caution. The bull shown in Figure 6 was standing amongst bushes as we pulled up to take a comfort break, and it was so still that it was not even seen until we had started to get out of the truck. Needless to say that we chose to move on!

Figure 6: Wild bull.

2.2.5 Snakes

An ever present danger in the Pilbara is snakes. Among others, taipans, king browns, western browns and death adders share our work space. Our training includes first aid and our crews have bite and first aid kits in the vehicles at all times. In a recent toolbox meeting, we were

presented with various scenarios regarding snakes and bites and as a consequence our team focused training on the first critical 5 minutes after a bite. Along with refresher training regarding first aid and snake bites, our team also now carry a radio and constriction (snake bite) bandage whenever away from the vehicle. What really brought home the need for being careful and vigilant was the discovery that the bike and walking track from WPV to the adjacent Brockman 4 mine (a distance of about 10 km) has sign posts every 500 m and each sign post has a bite kit attached – just in case (Figure 7).

Figure 7: Distance marker with attached bite kit.

2.2.6 Dehydration

Working a 12-hour shift in 40+°C heat is stressful. Doing so without water is suicidal. All vehicles carry water for daily use and in case of emergencies (10-20 litres per person per day), and at both the villages' and the work sites' water and ice are plentiful. As well as the water containers in the vehicles, all our team have 2- or 3-litre camelbacks and hydration is a regular topic at our toolbox meetings. We look after our mates in the field, and back at the offices and workplaces we have constant reminders about hydration. A common check point is for staff to monitor the colour of their urine. You cannot go to any toilet on site without seeing a urine colour chart (Figure 8).

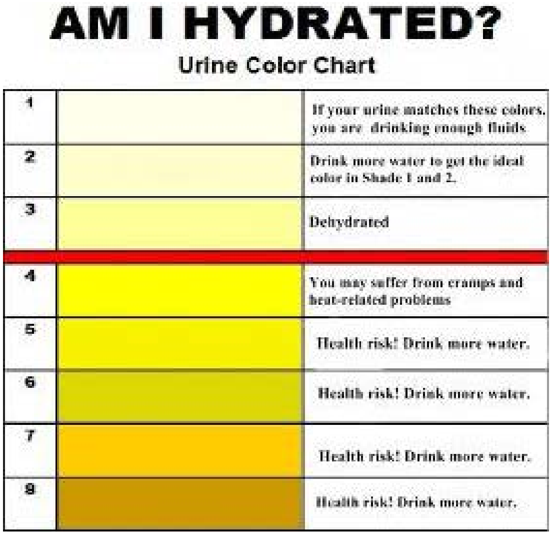

Figure 8: Hydration sign.

If that is not enough, there are also random hydration tests for all workers. Training and information regarding hydration is common. Good, filtered water is plentiful, ice is readily available, water containers are free and camelbacks are part of most companies' Personal Protective Equipment (PPE). There is really no excuse for allowing yourself to become dehydrated.

2.2.7 Flash Floods

Storms are sudden and often very spectacular in the Pilbara, and flash flooding is also a real risk. Driver training includes dealing with flood water and there are rules regarding how deep water can be and still be able to be safely crossed. This was brought home to me when I was involved first-hand in a flood event. In February 2013, a particularly sudden downpour turned the road between Brockman 2 (our workplace) and WPV into a quagmire and at one point, due to a flooded creek crossing, we were unable to proceed or turn back. We parked up on high ground, walked down and assessed the flooded river crossing. Deciding that it was impassable, we contacted emergency services and prepared to wait it out. Another vehicle arrived and the driver decided that his vehicle, being heavier and larger than ours, would make it through the flooded creek crossing. We watched the other vehicle cross the first of two adjacent crossings then as it rounded the bend for the second crossing we lost sight of it. An hour or so later we were rescued by a front end loader that drove through the flooded creek and took us to safety (Figure 9).

Figure 9: The rescue vehicle.

We considered that it was fortunate that the front end loader was nearby. Only after we had safely crossed the creek, we discovered that the front end loader had been there as part of an emergency to rescue the driver previously mentioned. The second crossing (out of sight to us) was more significant and the driver and passenger had to be rescued from their overturned vehicle that had been swept downstream.

2.2.8 Stupidity

Probably the greatest threat on site is people's own stupidity. In the previous example, the driver should not have proceeded (Figure 10).

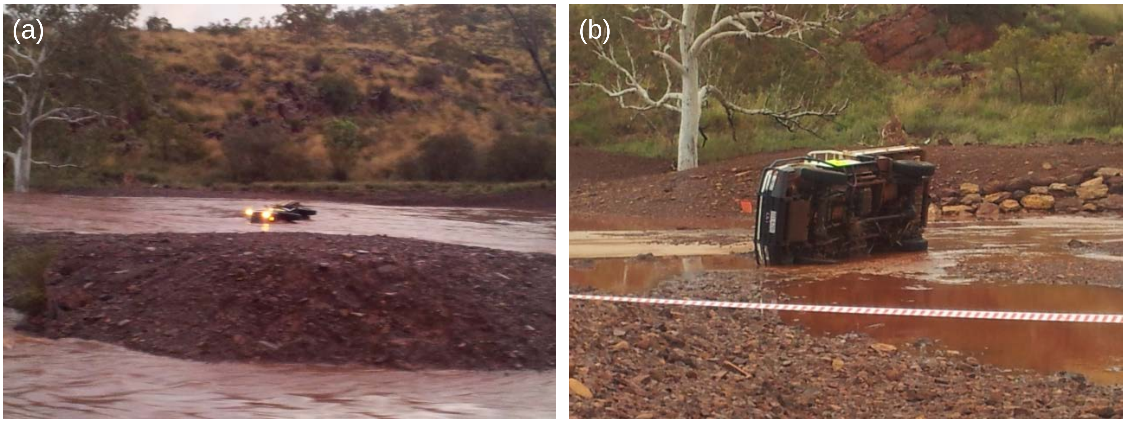

Figure 10: (a) Vehicle washed downstream and (b) same vehicle 12 hours later.

2.3 What Can Save You?

There are a number of risks to your survival in the Pilbara, and there are a number of things that can be done to safeguard yourself.

2.3.1 Preparation

Having in place the training and resources needed to survive are paramount. The following list is the training undertaken in the last 12 months as part of working in the Pilbara:

- First Aid certificate (refresher).
- Operate and maintain a 4WD vehicle.
- Operate a 4WD in rugged terrain.
- Defensive driving on gravel roads.
- Sect. 44 training.
- Lock holders.
- Isolation Officer.
- Medicals (4).
- Drug and alcohol test.
- Roy Hill induction.
- Rio Tinto rail access.
- Lycopodium induction.
- Rio Tinto induction.
- Site-specific inductions.
- Fire certificate.
- Drivers licence.
- Isolation theory.

2.3.2 Procedures, Notices and Warnings

There are procedures for just about everything. The procedures are simple and designed to minimise risk, maximise outcomes and keep people safe. The procedures can include Standard Work Practices (SWPs), which outline the safe practices relating to a particular task and form a guide for work procedures. Notices are regularly sent out to notify staff about road changes, movement of heavy loads, works in progress that impact on day-to-day activities, energisation of plant or buildings, etc.

Being on a mine site also brings special notices regarding ongoing production of iron ore. The most common are blast notices, which indicate when and where blasts are to occur and the associated exclusion zones. Blasts are almost a daily occurrence at mine sites, and a blast notice is issued on the day before the blast. These notices inform us about the time, location and nature of the blast and clearly indicate the exclusion zones (Figure 11).

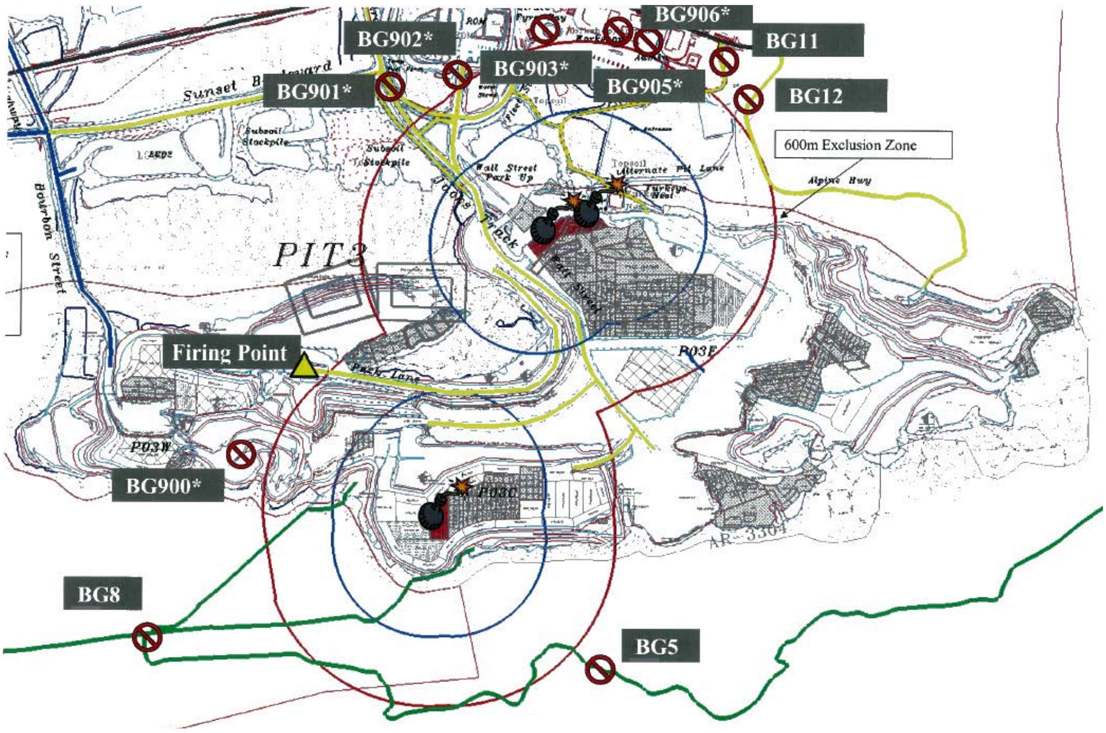

Figure 11: Blast notice example.

2.3.3 Equipment

The nature of our work means that we have to be self-sufficient when in the field. Along with our survey equipment, we also carry basic survival equipment. Figure 12 illustrates examples of some of the equipment we carry when working remotely.

Figure 12: Safety equipment.

All our vehicles have to be 'mine-spec', which means they typically are configured with the following features:

- Roll-over protection.
- Two spare tyres and associated tools.
- 2-way radios.
- Dual SRS air bags.
- ABS brakes.
- Steel tray and external ROPS (roll-over protection system).
- Mine lights.
- Two-pole battery isolator.
- Steel bull bar.
- 'Auto On' headlights.
- Mud tyres.
- Fire extinguisher.
- Mines flag (jockey whip).
- Seat covers.

2.4 Attitude

Attitudes like "she'll be right" and "it can't happen to me" are dangerous and your attitude is critical. A positive and safe attitude to your work is your ultimate survival tool. As an example, accidents can happen to anyone and therefore the first thing to do when starting any job on site is to make sure you have all the correct procedures in place (and you understand them). Then do a 'take 5', i.e. a short, 5-minute appraisal of what the job involves, the required tools, permits, skills etc. and an assessment of the work environment. It is not fool-proof but meant to make you stop and think. A 'take 5' can be a great safety tool (good attitude) or a waste of time (poor attitude). It is up to you how you view it.

A positive attitude falls into three main areas:

- Yourself: Every day of your swing (2 to 3 weeks of 10-12 hours per day) brings opportunities, threats, challenges. Having a positive attitude to why you are here and what you have to achieve is fundamental.
- Your mates: Your mates watch your back. That can be as simple as asking if you have had enough to drink on a hot day or as significant as being on the lookout for the approach of heavy vehicles.
- Your family: Being 4,500 km from your family is hard. Being 4,500 km from a family member in need is devastating. How your family copes with your absence can make such a huge difference to your working life. Coping mechanisms, strategies and finding time to call your loved ones is all part of the family attitude that contributes to the FIFO lifestyle.

3 SURVIVING THE PILBARA LIFESTYLE

3.1 What Else Does FIFO Mean?

To put it bluntly, FIFO also stands for 'Fit In or F!@# Off'. Just that. In a typical working week on site, I can spend up to 100+ hours with my work mates. In my week off, given my partner's work commitments etc. I do not get to spend anywhere near that much time with her. On site, we have to be able to work together, socialise together and generally get on.

Multiply that by the number of workers on site that you come in contact with and you get some idea of how there is a need to fit in.

Survival is about being part of the team, getting on and working together. The consequences of not getting on are obvious: safety and productivity are the corporate goals, while health, income, safety and sanity are the personal goals. Maintaining the right attitude and fitting in are the means to achieving your goals (whatever they are) in the Pilbara, and the consequences of getting it wrong have significant ramifications. The most extreme is the serious injury or potential loss of life from a major incident on site, but there are other 'career-limiting' consequences of not fitting in or following the rules. The euphemism is getting a 'window seat' – doing something wrong that gets you permanently removed from site and most likely never allowed to work on the site (or any other site of that company) again.

3.2 What Can Harm You?

You can get a window seat for a multitude of reasons, some of which are outlined in this section.

3.2.1 Safety

Any breach of safety is taken seriously on site. Any deliberate breach is almost certain to get you a window seat.

3.2.2 Speeding

Most sites have a strict speeding policy, and there is no room for argument. Speed zones can change throughout work sites and you have to be aware. Running late and letting your speed creep up will get you fined on a highway and you will lose points. On a work site, you can be fined and lose your job.

3.2.3 Blowing Numbers

'Blowing numbers' is a euphemism for having a blood alcohol reading above zero. On most sites any number above zero is reason for a window seat. You *might* be lucky enough to work on a site that will accept 1 minor (0.01) reading, but the rule is becoming zero for most sites. For example, our team has a compulsory breathalyzer test every morning before work. You can then be subject to a random alcohol (or drug) test at any time during the day.

3.2.4 Drugs

Like alcohol, drugs and work sites do not mix. All workers typically are screened for drug and alcohol at employment, after any break of more than 30 days and at random times (and places) on site.

3.2.5 Flaunting the Rules

There are rules on site covering almost every aspect of our daily activities. There has to be order to maintain the environment that we work and live in. It is not hard to fit in for most people, but there are people who flaunt the rules. If you do, you can get a window seat, as simple as that.

3.2.6 Attitude

When it all boils down to it, your attitude is what will either keep you employed or get you a window seat. Life here is not easy, but how you approach it and how you view your work is what it is all about.

3.3 What Can Save You?

Staying fit and healthy is an important part of surviving the Pilbara. There are a number of strategies that people adopt to maintain a fit and healthy lifestyle.

3.3.1 Health and Fitness

My personal favourite is bike riding. There are loan bikes on site but I have brought my own mountain bike to site. The local track is 19 km from WPV to the Brockman 4 mine site. Some people ride to work, but I ride every day or so casually. Riding after work is cooler and a great way to relax and wind down. There are good gyms at every site and support staff to help you if required (Figure 13). The gym is a popular place both before and after work and again a great way to keep fit.

Figure 13: Gym facilities.

3.3.2 Eating Well

Food on site is plentiful and healthy – sometimes too plentiful. Eating well is not always easy, but again there is support available. The management staff have health and lifestyle councillors available on most sites, and there are often nutritional classes run during the weeks.

Figure 14: Typical mess facilities.

3.3.3 Staying Focused and Attitude

It is often the simple thing that catches you out. With the number of kilometres we travel daily and the number of vehicles on site, vehicular accidents are common. Traffic, road conditions and wildlife can all catch you out, and there is often little or no warning. At the commencement of a shift, particularly in the morning, visibility can be compromised and you have to stay focused and alert (Figure 15).

Figure 15: The importance of staying focused.

Many injuries occur the day after arriving on site and the day before leaving for break. Staying focused is often a major part of avoiding such injuries. There are a number of strategies that can be adopted on site. For example, at the iron ore mines in South Australia returning staff are not allowed to drive in the pit on their first day back on a swing. This is one way to get staff to acclimatise to the environment.

The lead up to Christmas is also a time of increased injuries. Consequently, common toolbox presentations during this time are about staying focused and going home safe. Again, your attitude (and that of your mates and families) is your main survival tool.

4 CONCLUDING REMARKS

The challenges and rewards of working in the Pilbara are great. So are the risks and threats. It is pointless trying to earn good money for yourself and your family if you get yourself injured (or worse) in the process. Survival is about preparation, attitude and having the right equipment. “Going home, safe and sound, is everyone’s goal” is not just a throwaway line, particularly in the Pilbara.

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Subsidence Standardised Information Management System (SSIMS)

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ABSTRACT

The Subsidence group of the NSW Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS) receives, analyses and archives surface monitoring data relating to subsidence movements associated with underground coal mining activities. To date, the data is received attached to emails in non-standard formats. The number of files archived is forever growing, as is the size of the files, generating increasing complexities in data management. Subsidence analysis is largely empirically based due to the number of variables involved and their uncertainty. A deep knowledge of mining history and conditions is required to select appropriate sets of data to undertake analysis. As the data received is presented in formats specific to each operator, analysis requires processing the raw data manually in order to run comparisons between the datasets. This is a lengthy process, further hampered by many sets of data being incomplete. While this information is available for recent extractions when requested, it is often impossible to complete for older datasets. In order to resolve these issues, a standardised data format was developed along with a central database repository for existing and future data. The project is funded by the Australian Coal Association Research Program (ACARP) and Mine Safety Operations and started in March 2011. A database was designed for data storage and a web application developed to manage and load the data. The standardised data stored in the database provides for easy filtering and data queries as well as undertaking complex analysis. The collieries use the web browser front-end to submit the monitoring data in an XML format, which is then parsed and validated by the server application. Meanwhile existing archival data is being reformatted and also loaded into the database in bulk. As of October 2013, over 3,000 surveys have been processed. The system facilitates submissions and storage of surface monitoring data and allows for the data to be consistent, accurate and complete, and improves analysis of subsidence.

KEYWORDS: *Subsidence, surface deformation monitoring, data standardisation, data management.*

1 INTRODUCTION

The Subsidence group of Mine Safety Operations NSW collects monitoring survey data received from active underground collieries. The role of the data is to provide up-to-date land deformation information caused by the extraction of underground coal. The monitoring includes surveys of ground surface and infrastructure such as highways, railways, communication cables, electricity towers, sewer systems, dams and pipelines. Monitoring plans including the extent and frequency of the surveys are proposed by the collieries and approved by Mine Safety Operations. Data is generally submitted to Mine Safety officers as Excel spreadsheets.

The number of MS Excel files received and archived is forever growing. Searching the data is only possible with a good knowledge of the folder structure. Moreover, analysis requires an advanced knowledge of what the folders contain and of mining parameters (e.g. overburden height and mining geometry) in order to select files for relevant analysis. The size of the Excel files itself has grown with many files received now over 10 Mb. Some older files cannot be opened with modern versions of MS Excel.

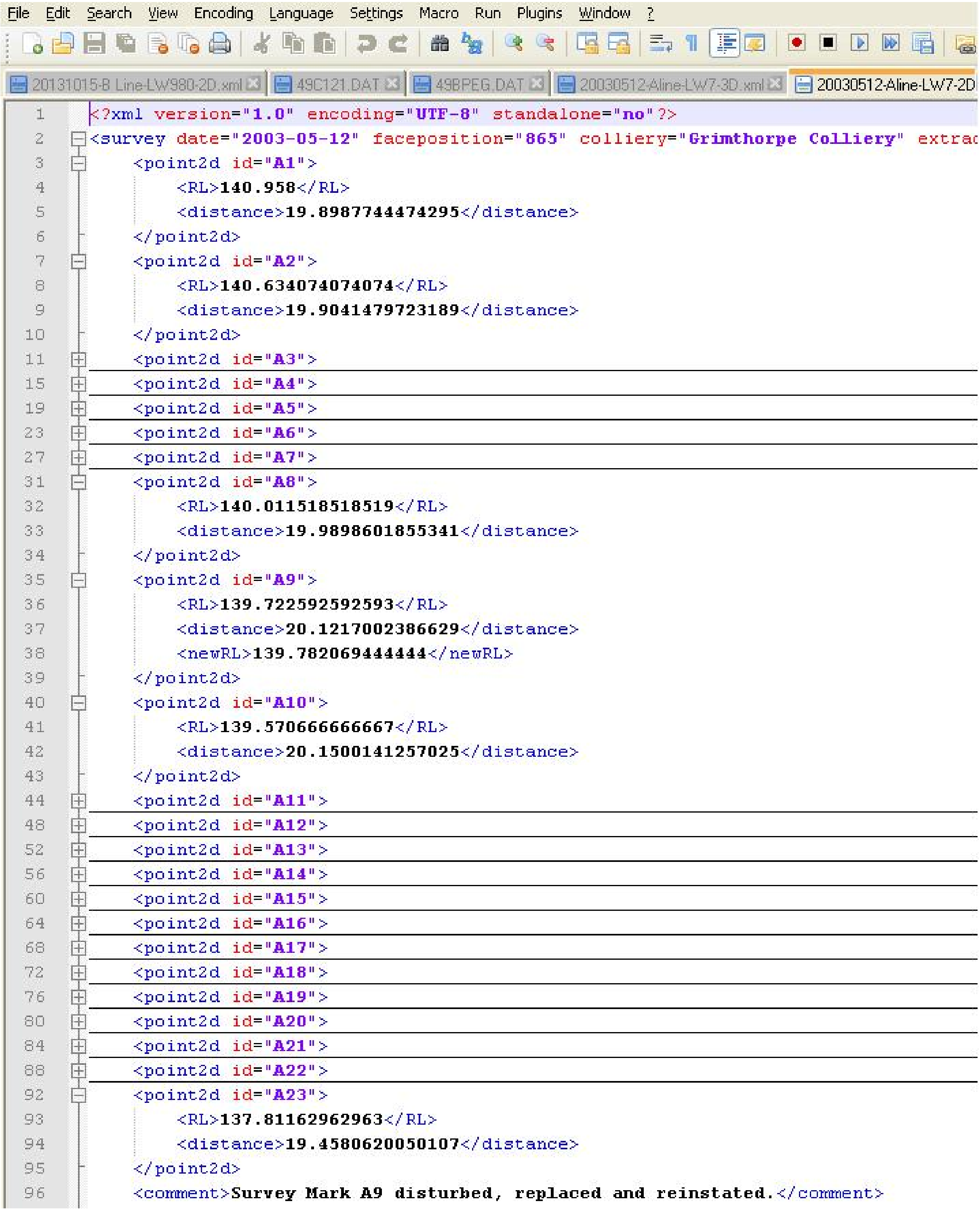
Hence the birth of a project to revisit the data management of the subsidence monitoring results. The project started in March 2011. This paper provides a short introduction of the database solution developed by the Subsidence group at Mine Safety Operations, a branch of the NSW Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS), Division of Resources and Energy.

2 DATABASE DESIGN AND FEATURES

2.1 Standardisation

Standardisation refers to the content of the submission and its format. The standardised submissions from the colliery include the date, extraction status on the survey date (i.e. the position of the coal face), the raw data and the extent of the data, with optional comments.

Figures 1 and 2 show examples of standardised Extensible Markup Language (XML) submissions in 2D (RLs and bay distances) and 3D (3D coordinates, MGA or local coordinate system), respectively. It should be noted that survey marks destroyed or disturbed can be reinstalled to ensure continuity of the monitoring (see Figure 2, lines 38-39).




```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<survey date="2003-05-12" faceposition="865" colliery="Grimthorpe Colliery" extrac
    <point2d id="A1">
        <RL>140.958</RL>
        <distance>19.8987744474295</distance>
    </point2d>
    <point2d id="A2">
        <RL>140.634074074074</RL>
        <distance>19.9041479723189</distance>
    </point2d>
    <point2d id="A3">
    <point2d id="A4">
    <point2d id="A5">
    <point2d id="A6">
    <point2d id="A7">
    <point2d id="A8">
        <RL>140.011518518519</RL>
        <distance>19.9898601855341</distance>
    </point2d>
    <point2d id="A9">
        <RL>139.722592592593</RL>
        <distance>20.1217002386629</distance>
        <newRL>139.782069444444</newRL>
    </point2d>
    <point2d id="A10">
        <RL>139.570666666667</RL>
        <distance>20.1500141257025</distance>
    </point2d>
    <point2d id="A11">
    <point2d id="A12">
    <point2d id="A13">
    <point2d id="A14">
    <point2d id="A15">
    <point2d id="A16">
    <point2d id="A17">
    <point2d id="A18">
    <point2d id="A19">
    <point2d id="A20">
    <point2d id="A21">
    <point2d id="A22">
    <point2d id="A23">
        <RL>137.81162962963</RL>
        <distance>19.4580620050107</distance>
    </point2d>
    <comment>Survey Mark A9 disturbed, replaced and reinstated.</comment>
```


Figure 1: XML 2D standard submission.

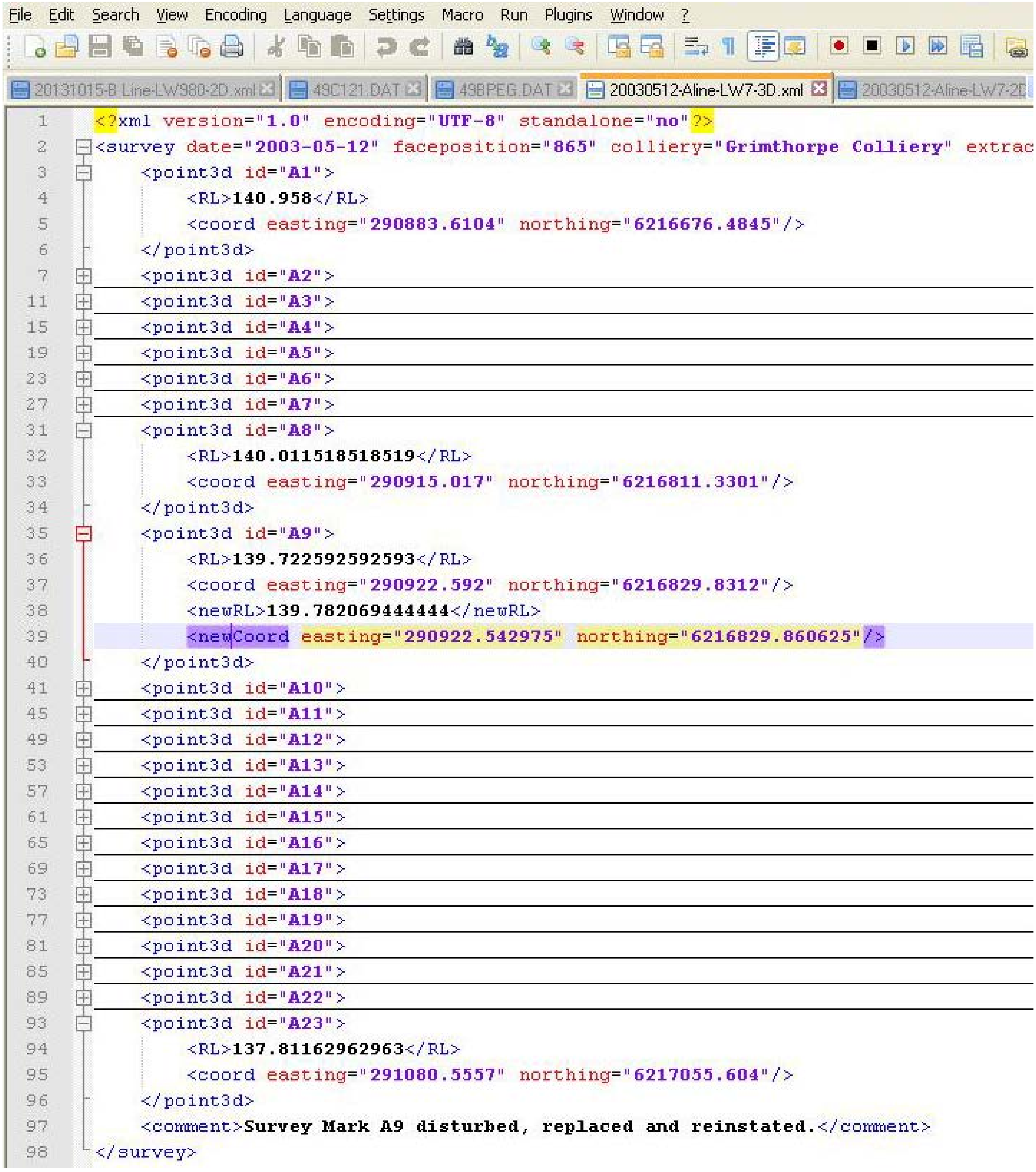


Figure 2: XML 3D standard submission.

The data for the web portal submission is in XML format. The size of the files is up to 800 times smaller than the same data in MS Excel. Upon submission through the web portal, some calculations are undertaken and plotted on the web page at the submission end, to detect possible outliers. Warnings are also displayed for awareness of missing information. Once uploaded, the data is kept in a 'waiting room' for compliance inspection and acceptance (or rejection) by a Department officer.

A template (Figure 3) is provided to the collieries to assist in generating the file in standard format. The template allows generating both 2D and 3D submission files. This template was used to generate the files shown in Figures 1 and 2. Some collieries have built the macro into their results, allowing the XML files to be generated directly out of their own MS Excel

spreadsheets results.

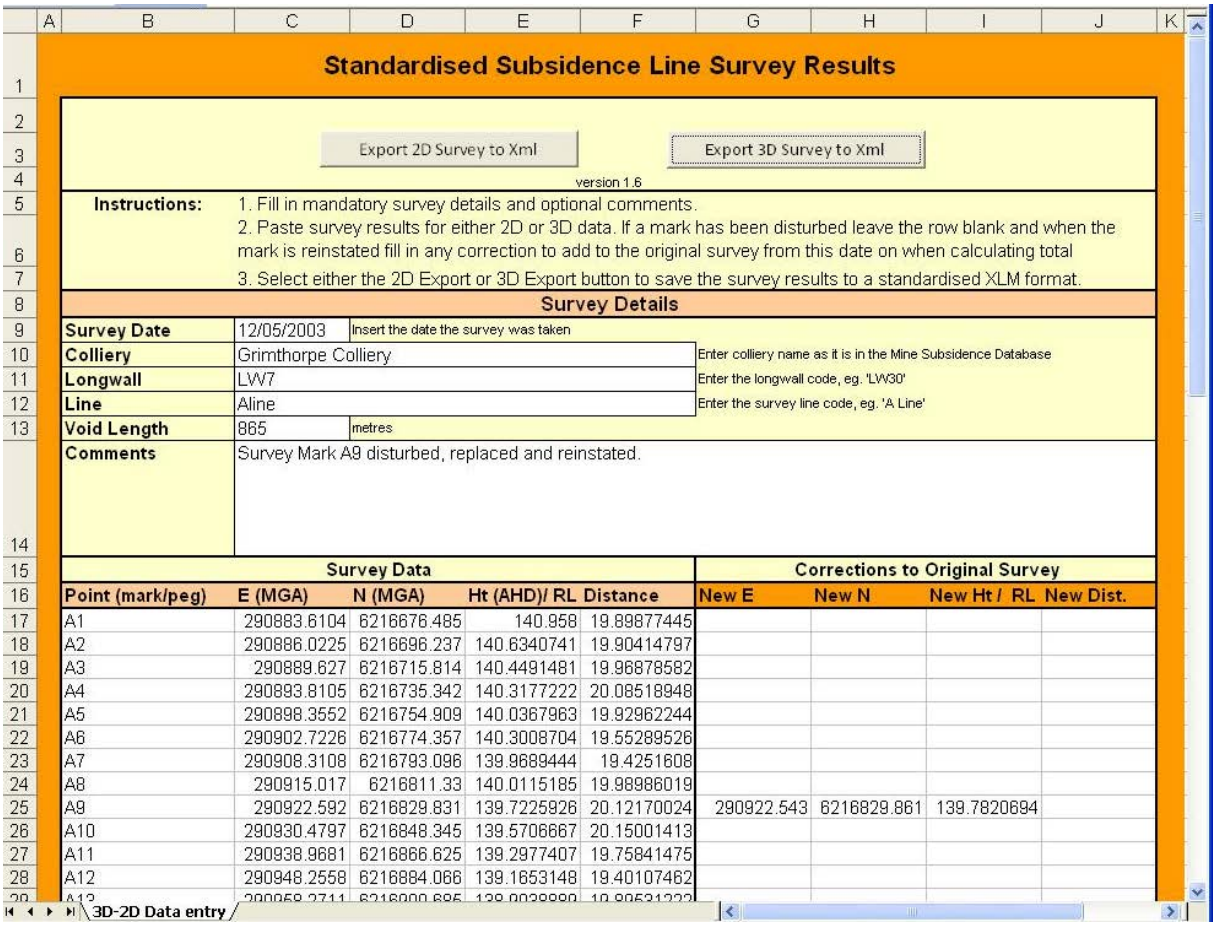


Figure 3: Excel template for 2D and 3D data.

2.2 Mine Parameters

The Department enters some data, such as panel names and panel coordinates, seam extracted and the depth of cover under each survey marks. The coordinates of the longwalls determine the geometry of the extraction. The coordinates order also determines information such as the starting end of the longwall and the position of the main gate.

The depth of cover (overburden) under each survey mark is calculated by a script, which executes a Delaunay triangulation of the seam floor data (departmental records received from collieries separately) and calculates the RL of each survey mark at the seam floor level by planar interpolation. The depth of cover is then the difference between the RL of the mark on the topographic surface and its level at the seam. The coordinates of survey marks where MGA information is not available are estimated manually.

2.3 Database and Web Portal

A database was designed to accommodate the mine parameters and to accept and manage the survey submissions. This database was implemented in Microsoft SQL Server 2008 R2 and is hosted by the Department. A web portal was also designed for subsidence surveyors to submit compliance surveys on a regular basis, and to allow the Department to manage and analyse this data. This web application was implemented in ASP.Net MVC 4 and is hosted on

Windows Server 2008 R2.

Due to the standardisation of survey data, implemented in XML, it is also possible for future implementations to allow colliery systems to directly submit the mine subsidence system via a web service. The web portal has been in operation since May 2013, following a 6-month trial with three collieries. All NSW underground collieries are now submitting their survey data via the portal in a standardised format.

Work is underway to add analytical capabilities to the web portal to plot aggregate data, which will assist future mine applications in better predicting land deformation.

3 DATABASE CAPABILITIES

3.1 General

The database project allows the management of a large quantity of survey data. Filtering the data permits searching the database. Filtering replaces the manual selection of files, resulting in a thorough systematic search not based on an individual officer's knowledge of historical mining. Filtering for example can assemble complete tables of data according to the coalfield, a range of depth of cover, in a very short time. This type of work is time consuming if undertaken manually. Moreover, the data exported is in a standard format and includes all of the information necessary for immediate analysis.

3.2 Analysis

Although development of this aspect of the database capabilities has just started, the database is already proving to be a valuable tool for analysis. The data can be filtered to allow the assembly of tables to proceed to complex analysis tasks.

Subsidence prediction is essentially an empirical science as it involves many variables not easily identified and built in the analysis. Predictions are used commonly to prepare new subsidence management plans and new monitoring proposals.

The aim of the project is:
(a) To allow collieries to access their own data in aggregate format.
(b) To allow all the collieries to access pre-analysed statistical data in order to help with subsidence predictions for new extractions. Examples of types of subsidence effects, subsidence monitoring and analysis of results can be found in Kratzsch (1983), Whitaker and Reddish (1989), Holla (1991), Holla and Barclay (2000) and Peng (2006).

4 CONCLUDING REMARKS

Faced with an ever-growing number of larger land deformation monitoring files, the Subsidence group of Mine Safety Operations NSW has opted for a database solution in early 2011. The database and portal now in place are the result of the close collaboration between departmental subsidence data experts and an IT database consulting firm. Two keywords characterise the project: standardisation and data management. This is a long-term project due to the large number of archived data to be imported. A web portal is used by departmental

engineers to import the data. The same portal is also used by the collieries to submit new data to the department, in the standard format adopted for the database.

ACKNOWLEDGEMENTS

The project team includes the NSW Principal Subsidence Engineer Dr Gang Li (project director), the project manager Dr Russell Frith, the database administrator Dr Robert Pâquet who also processes archival data, the IT consultant Mr John Perceval, as well as Mr Phil Steuart, Mr Ray Ramage and Mr Richard Bale, Departmental Engineers who work on some aspects of the database such as coordinates and depth-of-cover estimation and setting-up analysis. The project is funded by ACARP (Australian Coal Association Research Project) and by Mine Safety Operations, a branch of the NSW Department of Trade and Investment, Regional Infrastructure and Services, Division of Resources and Energy.

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Implementing the Australian Standard for Subsurface Utility Information – AS5488

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ABSTRACT

The Australian Standard AS5488-2013 provides a framework for the classification of subsurface utilities and their location via a set of four easy to understand quality levels. The intended audience are those agencies and organisations that own, operate or regulate utility infrastructure, and those that collect, depict and map such infrastructure. The standard facilitates good risk management strategies to be applied when working with or close to subsurface utilities. Subsurface utilities present a high risk for a range of civil construction activities. The risk is often realised via cost overruns in design and construction, work health and safety incidents, and service interruptions to affected utilities. The Australian Standard AS5488 aims to provide a consistent format and definition for information relating to subsurface utilities and help minimise these risks. Use of 'information brokers' such as Dial Before You Dig has become standard practice (and a legislative requirement in New South Wales prior to excavation in the vicinity of electricity and gas). However, the information provided by various asset owners via this pathway is of varying quality in terms of spatial accuracy, and sometimes information is withheld for reasons of security. Existing workflows tend to be focused on short-term outcomes related to project work. The typical workflow outlined in this paper is derived from Roads and Maritime Services guides. Analysis of the workflow highlights the additional steps that are required to capture information to meet the standard. The AS5488 standard provides a 'simple common language' for information captured relating to a subsurface utility. This can be disseminated for people who need to work with and around an asset in the future. This paper will explore strategies to incorporate this standard into existing workflows across a variety of disciplines.

KEYWORDS: *Subsurface, utility, Australian standard.*

1 INTRODUCTION

The recently published Australian Standard AS5488-2013 Classification of Subsurface Utility Information (SUI) provides a national framework to enable the collection and management of subsurface information (Standards Australia, 2013). However, the standard does not indicate how various organisations can implement AS5488-2013. This paper examines existing systems within Roads and Maritime Services (RMS) New South Wales (NSW) and identifies some of the challenges and changes required to adopt the standard.

AS5488-2013 (referred to in this paper as SUI – subsurface utility information) provides a simple common language to enable all involved with the asset lifecycle a clear understanding of what information has been collected and when. At the heart of the standard are four quality levels that quickly convey the level of certainty about a subsurface asset. An executive

summary of the standard is provided in section 2.1. Collecting information for SUI at quality level A or B is not significantly different to performing a typical works as executed survey that is routinely performed as part of engineering projects. The main differences with the SUI standard are (1) the format of the information and (2) collecting some additional attributes associated with each surveyed point. This second point means that more people may need to be consulted in the collation of the information.

RMS (the road authority for the state of NSW) has the overall responsibility for the provision and maintenance of approximately 18,000 km of road network. Within this network there is a significant amount of subsurface infrastructure. This includes over 4,500 traffic signals, intelligent transport systems (variable message signs and traffic monitoring), regulatory systems (detection cameras for speed and oversize vehicles), street lighting, storm water, rock anchors and other structural elements. The vast majority of these assets are located in the more heavily populated areas along the east coast. Not surprisingly, other subsurface asset owners also congregate in proportion to population density.

Collecting and recording Subsurface Utility Information (SUI) is relatively straightforward. However, applying SUI to a vast set of existing assets is not a trivial task. This is further complicated by the distributed nature of the infrastructure lifecycle and awareness of SUI processes. This paper examines typical workflows relating to the installation and upgrade of traffic signals within the RMS environment. It is hoped that by highlighting the critical points within these workflows, other subsurface asset owners can identify similar points in their workflows and take advantage of information presented in this paper.

2 INVESTIGATION OF EXISTING TECHNICAL DOCUMENTS

2.1 SUI – Executive Summary

The Australian Standard AS5488-2013, published by Standards Australia (2013), provides a set of four easy to understand quality levels. The intended audience are those agencies and organisations that own, operate or regulate utility infrastructure, and those that collect, depict and map such infrastructure. The standard facilitates good risk management strategies to be applied when working with or close to subsurface utilities. The scope of the standard is limited to subsurface utility infrastructure and associated surface features that facilitate the location and identification of the infrastructure. Some of these features include access chambers, stop valves, hydrants and terminal pads. It does not extend to above surface infrastructure such as overhead wires.

The quality levels provide a simple common language, indicating the type of information known about a subsurface utility. Quality level A is the highest level, while quality level D is the lowest. The higher the quality level, the more is known about that subsurface utility, and the more accurate and more complete that information is.

Quality Level D (QL-D) is the lowest quality level and default level if any of the other quality levels cannot be satisfied. This information may be compiled from existing records, cursory site inspection or anecdotal evidence. There is no requirement for a spatial tolerance, only a general indication of location.

Quality Level C (QL-C) uses any available information from QL-D and correlates it with surface features. These features may be access points on the surface such as hydrants, stop valves, access chamber lids, or points where utilities enter the subsurface domain (e.g. an electricity cable travels down a power pole and then becomes a subsurface electrical cable). Subsurface utilities may be offset from the alignment of surface features, thus QL-C does not provide a spatial tolerance on location, as for QL-D, only a general indication of location is implied.

Quality Level B (QL-B) provides relative subsurface feature location in three dimensions. Relative location refers to a distance or depth from another feature, e.g. a water pipe may be 2.4 metres from the edge of a footpath and 1 metre below the surface level. QL-B information requires specialist equipment and locaters skilled in tracing utilities (detection via an induced signal along a subsurface utility). The relative spatial positioning for QL-B is ±300 mm horizontal and ±500 mm vertical.

Quality Level A (QL-A) is the only quality level that defines a subsurface utility as 'validated'. The location of points surveyed on the surface and subsurface features are measured in terms of absolute spatial positioning with a maximum horizontal and vertical tolerance of ±50 mm. Other attributes that are relevant to QL-A are utility owner, type (e.g. communications or gas), status (e.g. in service, redundant or abandoned), material, size and configuration, date of installation, date and details of person(s) capturing the information, surveying methods used, and survey control used to determine absolute spatial position.

The standard has informative sections in appendix A and B that recommend several implementation practices including limitation of each quality level, standard paint and line colours, standard feature codes, and standard attributes for each of the quality levels.

The implementation of AS5488-2013 requires a multi-discipline approach. The work crews that work around and install subsurface utilities are not all equipped with all of the skills to collect all of the required information. To implement the standard and gain the maximum benefit, asset owners, installation crews, the wider construction industry, locaters, surveyors, engineers and project managers all need to be aware and work together. Development of efficient methods to 'harvest' this vital information, and supply of this information to those that need to know it, is possible. All of the services we use in the 21st century are increasingly more and more important. The benefits of collecting this information and thus protecting this vital infrastructure are realised across all of society.

2.2 RMS Specifications and Guides relating to Traffic Control Signals

Traffic Control Signals (TCS) have existed on the road network in NSW since 1933, when the first signals were installed at the intersection of Kent and Margaret Streets, Sydney. These signals were turned on at 11:00 am on Friday, 13 October 1933 (RMS, 2013a). Since then, over 3,700 traffic signals have been installed across NSW. Traffic signals provide a means of organising and controlling traffic for safe and efficient travel by users of the road network. The Sydney Co-ordinated Adaptive Traffic System (SCATS) was developed in the 1970s to enable real-time control of traffic signals across the network. Thus traffic signals typically require two types of services, i.e. electricity and communications.

RMS has developed a set of guides and specifications that cover every technical aspect of traffic signals. This ranges from the overall geometry of the roads and speed zones to the

standards for electrical wire used in the cables between the various elements of the signals. The following documents were reviewed for their relevance for the proposed capture of works as executed information:

- RMS QA Specification R155 Design and Construction of Underground Cableways (2013).
- Manage WAE Drawings Technical Procedure Version 1.3, ILC-GEN-TP0-104 RMS (2008).
- RMS Specification D&C R155 Design and Construction of Underground Cableways (2013).
- RMS Revised Traffic Signal Cable Installation and Connection Technical Direction (2013).

One of the daunting prospects in a large organisation such as RMS is the sheer volume of documentation. These documents are not referenced elsewhere in this paper, they are provided here for information purposes. The main documents relating to the design and installation of traffic signals in NSW are:

- RTA Specification SI/TCS/8 Revision 1 (2003).
- RTA Traffic Signal Design (2008).

Section 4 of the Traffic Signal Design document deals with plan requirements (RTA, 2012). As far as Dial Before You Dig (DBYD) is concerned, the information required to complete a traffic signal project is a cable installation plan. This is the plan that ultimately is delivered with a DBYD request. In practice, the cable installation plan is an updated version of the design plan and generally does not include surveyed ‘as built’ information.

The most relevant (and up-to-date) document detailing the associated workflows is the Installation of Traffic Control Signals Technical Procedure RMS (RMS, 2013b). This procedure lays out the whole process of TCS installation from a road network ‘needs’ perspective, design, construction, commissioning and handover to the asset manager. A subset of this document is used to analyse how to best identify the critical points in the process where SUI can be adopted.

3 EXAMINATION AND ANALYSIS

3.1 Reasons to Implement SUI

This section examines the reasons why organisations should adopt SUI. Risk management is central to this discussion. An argument for SUI to be adopted as part of a toolkit of risk management tools is developed below.

As urban spaces grow and develop, competition for space in the road reserve increases. This is further compounded by polices such as the deregulation of communications. Where there was once one government asset owner for communications, there are now often three or more communication asset owners sitting side by side and competing for space in the road reserve. Ongoing growth and development compounds these issues.

Many of the issues relating to the coordination of works around subsurface are addressed in the United States of America (USA) by the Common Ground Alliance (CGA). This organisation has representatives by way of stakeholder seats for electric, engineering/design,

equipment manufacturing, excavator, gas transmission, gas distribution, insurance, locator, one call centre, oil, public works, railroad, road builder, state regulator, emergency services and telecommunications. This organisation was formed in the interest of bringing all parties together. One of the 'shining light' outputs from the CGA is the Best Practices 10.0 guide (CGA, 2013). In this document, two major lessons are highlighted: (1) Communication is the key to ensuring safety and free-flowing communication allows all stakeholders to focus on common goals, and (2) cooperation is essential and it works. The equivalent standard to SUI in the USA is ASCE 38-02 Subsurface Utility Engineering (SUE). SUE is a key element in the Best Practices 10.0 guide in terms of enabling effective communication.

Many asset owners outsource the management of the physical network. This means that the days of consulting a local work crew that often knows the detailed history of an asset are gone. The contractor is now responsible for a defined scope of asset installation or maintenance that often does not extend to long-term stewardship. Nor do these contractors gain access to all the information relating to the asset they are managing. Often the contract to manage the physical network is limited in duration. So the current contractor is judged on whatever performance criteria has been set into the contract. A future maintenance contractor may not gain access to a previous maintenance contractor's records. SUI (i.e. a standard) helps with the consistent formatting of information. Therefore the use of many hands (resulting in loss of information), a symptom of contracting, can be reduced.

On construction projects, Works As Executed (WAE) plans are nearly always produced. But in amongst the competing priorities on a construction project, the WAE plan is often a simple mark-up of the design plan. Holding up a construction project while in progress, for any reason, is not popular. In order to efficiently implement SUI in the WAE domain, the workflow needs to be understood by all those involved. This is an extension of the reasons outlined in CGA (2013). In this paper, the WAE plan that includes SUI, is referred to as WAE SUI.

The incidence of utility strikes and the consequences of such are routinely reported in the media. While published data in Australia on the cost benefit of SUI (or similar processes) is virtually non-existent, several overseas studies point to significant project savings when a system such as SUI is adopted (Table 1).

Table 1: Cost benefits of SUI-like processes.

Name of Study	Benefits Realised
Federal Highway Administration-USA (1999): Cost Savings on Highway Projects Utilizing Subsurface Utility Engineering	$4.62 in avoided costs for every $1.00 spent on SUE
Ontario (Canada) Sewer and Watermain Contractors Association (2004): Subsurface Utility Engineering in Ontario: Challenges and Opportunities	$3.41 in avoided costs for every $1.00 spent on SUE
Pennsylvania DOT (2007): Subsurface Utility Engineering Manual	$21.00 in avoided costs for every $1.00 spent on SUE

In emergency conditions, emergency workers (i.e. first responders such as ambulance, fire fighters or police) can make more informed decisions in the heat of the moment if they have access to the best possible information. The current model of risk management concerning subsurface utilities revolves around the national DBYD service. This places the responsibility onto those performing work near existing assets to prevent damage. Those doing the work often complain about the lack of detailed information on DBYD plans provided by asset owners.

SUI can be adopted as part of an investigation process that is examining existing conditions. Currently an investigation will typically involve a detailed desktop review, followed by field investigations that may extend to potholing for subsurface utilities. This sometimes does not result in clear results for the task at hand. This is often a reflection on poor communication, or the complex nature of the problem at hand. The initial adoption of SUI will no doubt focus on investigation as part of specific projects.

This paper argues that Quality Level A (QL-A) information should be obtained at the time of construction or installation wherever possible. There may be occasions where Quality Level B (QL-B) is the only information that can be obtained (e.g. under boring roads and rivers).

As the available SUI dataset is limited by the very fact that this is a new standard, the initial benefits seem very limited. So the natural reaction is to skip the extra work required to produce a detailed WAE plan (including QL-A SUI). The benefits of implementing SUI at the time of installation include reduced cost, more accurate information on the type of materials installed, exact date of installation etc. Where to best store this information remains a key question, however it should not be used as reason not to produce WAE plans with SUI.

Implementing SUI uniformly across all asset owners into all DBYD plans is an ideal that may seem a far stretch from current day practices. The waypoints on the road to realising this ideal are implementing SUI initially at a project-by-project level and then across the subsurface utility industry.

3.2 Examination of RMS Workflows

This section examines an existing workflow within RMS. The workflow selected is the current workflow model used by RMS to install Traffic Control Signals (TCS). This workflow model is similar to many asset owners where the construction of the asset is provided by an external construction company. In the decades since the first TCS was installed in NSW, the process has been refined and is in part captured by the flow chart in Figure 1. The process outlined in this flow chart has been derived from the Installation of Traffic Control Signals Technical Procedure RMS (RMS, 2013b).

Figure 1 shows two phases between the start of construction and the completion of commissioning. As can be seen, the site cable plan being made available to DBYD is part of the final Works As Executed (WAE) drawings. Another point to note is that Figure 1 presents the workflow with steps and interactions that are the direct responsibility of RMS personnel. It does not break the major steps down into smaller steps that detail the installation of new underground services – this is further analysed below in section 3.3.

Examination of the steps in the construction phase shows an initial hold point before the start of construction. After the start of construction, the Construction Manager (an RMS representative) is routinely consulting with those performing civil works, however the WAE drawings are not supplied as an output until construction is complete.

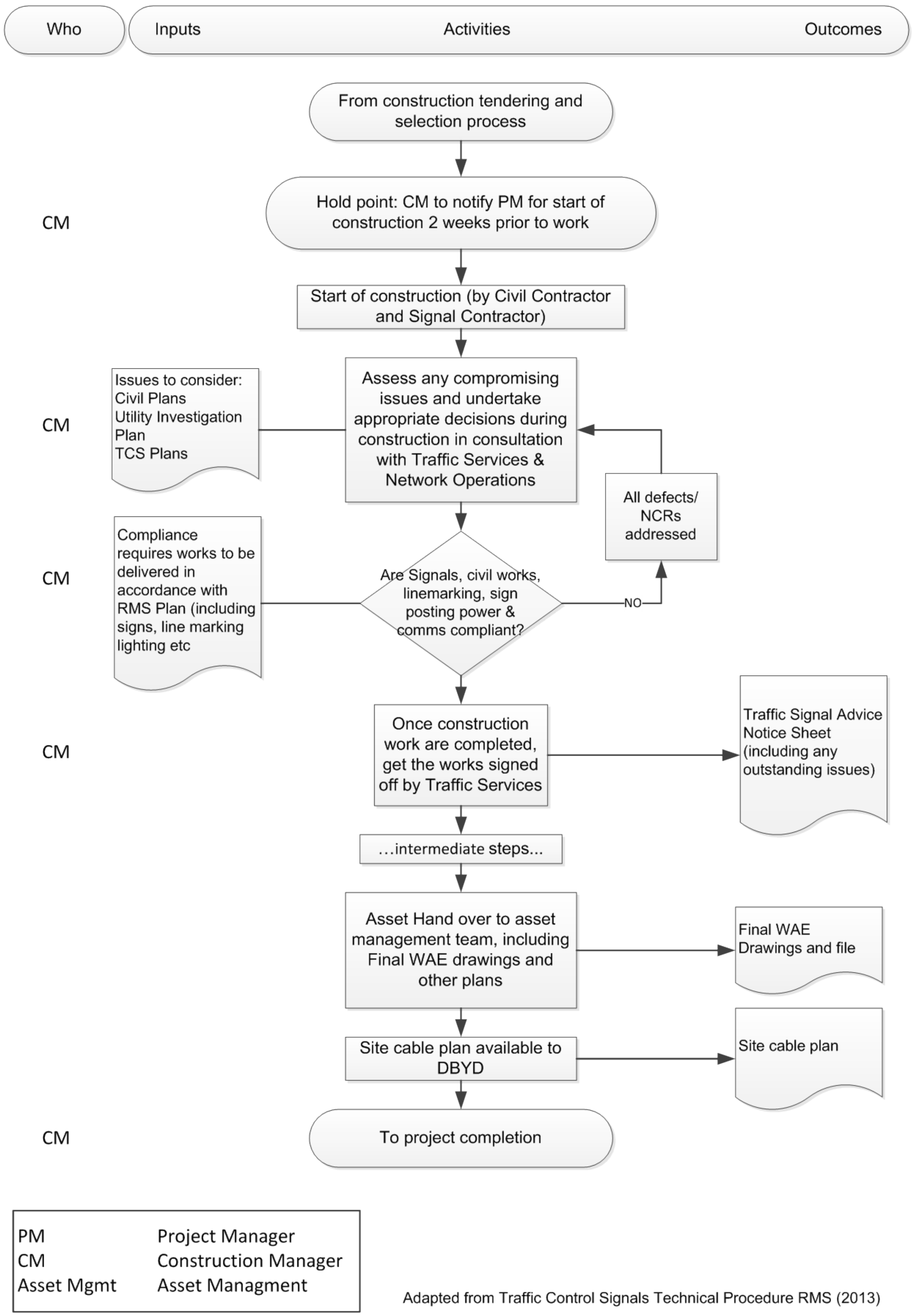

Figure 1: Flow chart of TCS installation – commissioning.

3.3 Adapting SUI into RMS Workflows

This section analyses and suggests an adapted workflow to include the critical points to facilitate the capture of WAE SUI information. At a strategic level, changing an established workflow is not going to happen overnight.

The proposed sequence to implement this change in three steps is detailed below, noting that some flexibility plus support both at a management and technical level will be required:

1) Documenting the workflows (documentation of workflows required to achieve WAE SUI QL-A or QL-B – this goes hand-in-hand with education across the industry).
2) Engaging and educating the various stakeholders
3) Updating RMS contracts to require WAE SUI processes. This may require a financial incentive to comply with new requirements. In practice, this should not differ from any of the other requirements be they technical, environmental or work health and safety.

As can be seen in Figure 2, the additional requirements for WAE information capture have been added to the previous workflow. A sample WAE information capture plan has been provided in Figure 3. This plan is an attempt to provide clear guidance on how the WAE SUI information can be captured at installation time and thus maximise accuracy. The sample illustrates a situation where the work is staged across multiple days. In practice, the format of this document will develop as it is reviewed and trialled.

Several scenarios can be expanded on this method to allow for pick-up after the services are buried. This may include inserting PVC tubes vertically above the conduits as laid. A surveyor can then at a later time capture the spatial data in bulk. Various methods to efficiently capture this information can be developed and expanded.

The WAE information capture plan also needs to include contact details of the relevant people that are going to be on site and very clearly identify each person's role. Ideally, the WAE information capture plan should be part of the normal project planning and sequencing. If the construction program changes, the WAE information capture plan should be updated and distributed accordingly. An induction process into the WAE information capture plan process for civil contractors, signal contractors and surveyors will establish the ground rules, and what is expected by the other parties. Care needs to be taken in planning and supervision of this process such that it is not used as a variation excuse, although some provision for transitioning to this method is required.

The basic conditions to capture QL-A information need to be well defined and where there are exceptions to these rules, reasons have to be given, e.g. top and centre of conduits to be surveyed at kerb line, crown(s) of road, and exit points from service pits. In addition, conduits are to be surveyed every 10 metres or where there is a change of direction or grade that would lead to a difference of greater than 50 mm between the true top of conduit and a straight line between the sampled points.

A process of performing quality checks at random on the spatial results needs to be developed. This may require additional support, surveillance and/or follow-up investigations. The temptation to 'manufacture' results can be tempting, particularly when there is significant effort or re-work required to verify the results.

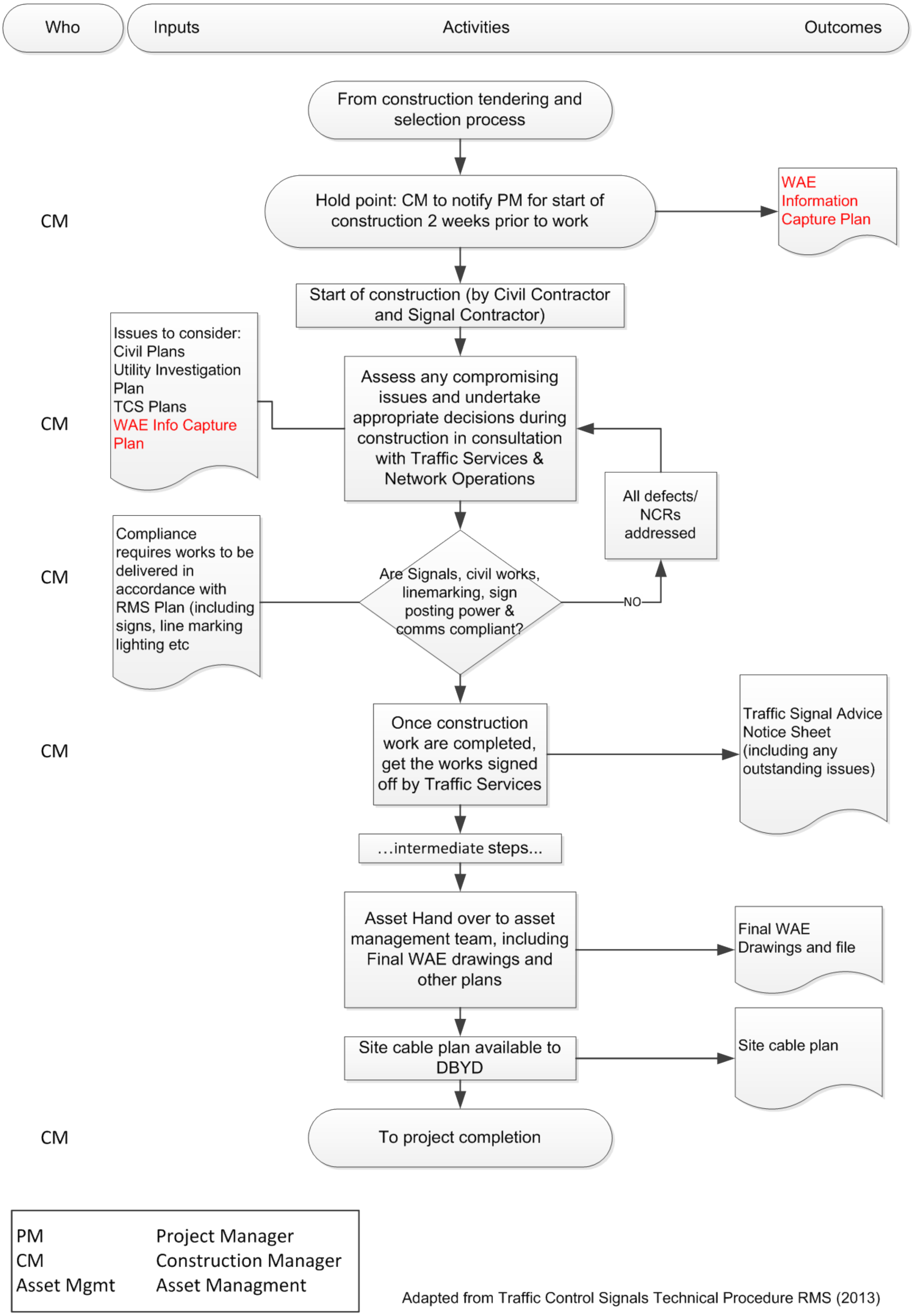

Figure 2: Flow chart of adapted TCS installation – commissioning.

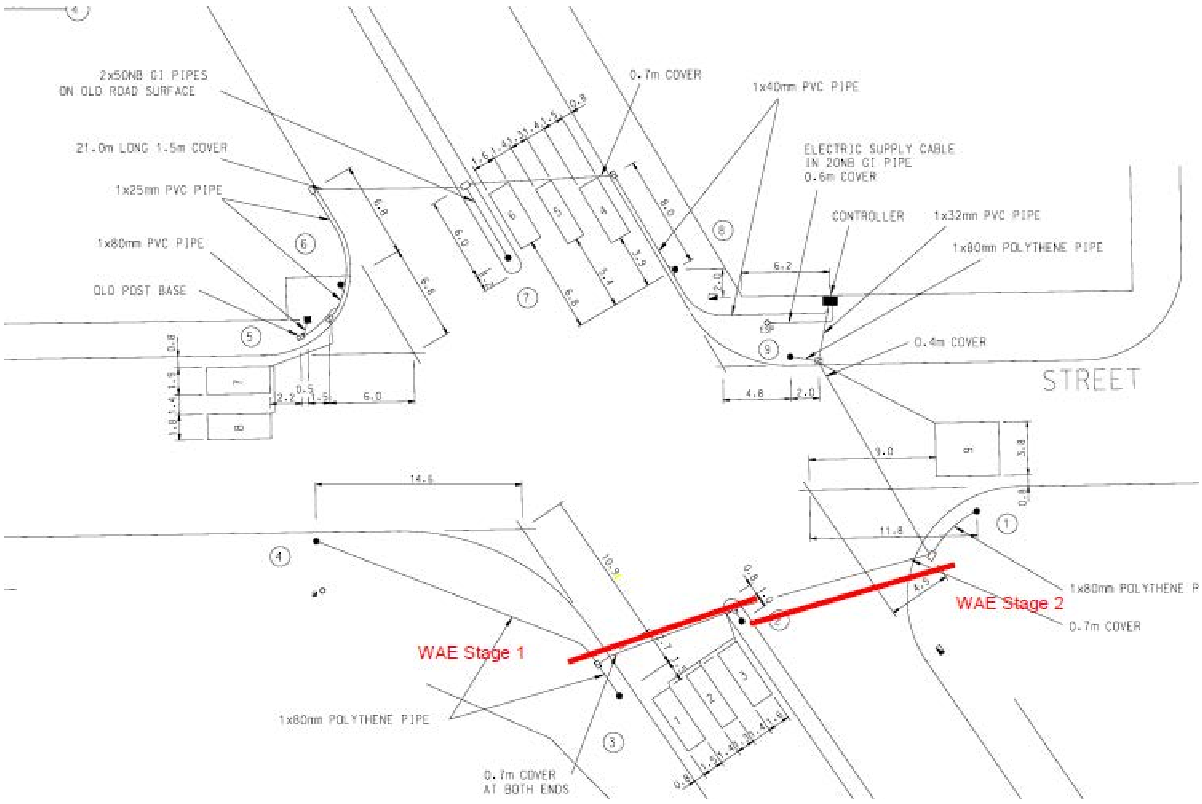

Figure 3: Sample WAE information capture plan.

An example of additional information for WAE capture is given below:

- Contacts:
  Construction Manager: Fred Smith 0415 … …
  Civil Contractor Contact: John D…. 0424 … …
  Signal Contractor Contact: <same as Civil contractor>
  Surveyor: Chris A…. 0438 … …
- Stage 1 proposed works: 24 Feb 2014 from 20:00 to be confirmed.
  Install twin 80 mm electrical conduits across carriageway.
- Stage 2 proposed works: 26 Feb 2014 from 20:00 to be confirmed.
  Install twin 80 mm electrical conduits across carriageway.

A sample list of attributes to be collected for each surveyed SUI point is given in Table 2. At this time, the easiest format to store this information in is CSV (comma separated variable). This allows for simple exchange of information as part of survey metadata. The data can readily be extracted and fed into a Geographic Information System (GIS) for further use. A sample is provided in Figure 4.

Table 2: Suggested SUI attributes to capture for QL-A points.

Attribute Name	**Attribute Description**
PtId	Point Id
Easting	Easting coordinate
Northing	Northing coordinate
RL	Reduced Level
QualityLevel	Quality Level as defined in AS5488-2013
Limitations	Any of the QL limitation, e.g. concrete encased, electricity marker tape, underbore – inaccessible point
RelativeVerticalPosition	Vertical distance from ground surface

Attribute Name	Attribute Description
DateOfCapture	Date that information was captured
SourceOfInformation	Particulars on who was on site, e.g. RMS Survey – Nathan B.
Material	Material as documented on WAE Info Capture Plan and confirmed with site foreman
Size	External dimensions – if one number is specified it is assumed to be a cylinder; if rectangular configuration specify W x H, e.g. 450 mm W x 150 mm H
Configuration	How the utility is configured, e.g. 2 W x 3 H 100 mm PVC conduits laid in trench
LocatingMethods	Potholing / surveyed at time of installation / electronic detection
SurveyControlInformation	A reference to the survey control datum and any permanent marks adopted
SurveyedPoint	Top centreline / invert / obvert / edge of bank – ### Not specified in AS5488, however required for complex configurations ###
PhotoRef	Filename link to jpg file
Notes	Any other notes
Owner	Entity that owns the asset
Status	In service / in construction / redundant / abandoned / unknown – contact asset owner
UtilityType	Code as per AS5488 Table B2
FeatureCode	Code as per AS5488 Table B3

```
SUI Data Block:
===============
Source Of Information: RMS Survey Parramatta
Date Information Obtained: 18-Jan-2014
Survey Control Information: RMS Survey Control Diagram ABC
LocatingMethods: Surveyed at service installation

SUI point data Schedule:
========================
PtId,Easting,Northing,RL,QualityLevel,Limitations,RelativeVerticalPosition,DateOf
123,294076.153,6234526.027,110.424,A,,870mm deep,2014-01-18,RMS - Nathan B,White
124,294074.784,6234526.042,110.77,A,,570mm deep,2014-01-18,RMS - Nathan B,AC 150m
125,294066.707,6234531.904,110.836,A,,,2014-01-18,RMS - Nathan B,200mm DICL,Syd W
126,294058.496,6234522.506,110.694,A,,,2014-01-18,RMS - Nathan B,150mm DICL,Syd W
127,294057.367,6234521.05,111.058,A,,,2014-01-18,RMS - Nathan B,White PVC 50mm Di
128,293966.16,6234377.353,105.242,A,,,2014-01-18,RMS - Nathan B,450mm Diameter Co
129,293967.421,6234376.176,104.044,A,,,2014-01-18,RMS - Nathan B,100mm DICL,Syd W
130,295081.404,6235692.005,104.533,A,,,2014-01-18,RMS - Nathan B,200mm DICL,Syd W
131,295080.327,6235692.732,104.657,A,,,2014-01-18,RMS - Nathan B,375mm CICL,Sydne
132,295079.171,6235695.227,104.721,A,,,2014-01-18,RMS - Nathan B,AC 150mm Diamete
133,295086.493,6235704.61,104.112,A,,,2014-01-18,RMS - Nathan B,AC 150mm Diameter
134,295088.453,6235702.29,103.874,A,,,2014-01-18,RMS - Nathan B,375mm CICL,Sydney
135,295090.001,6235700.982,104.11,A,,,2014-01-18,RMS - Nathan B,200mm DICL,Sydney
136,295097.246,6235697.651,103.52,A,,,2014-01-18,RMS - Nathan B,AC 150mm Diameter
SUI Schedule version 1.01 5-Dec-2013 11:00,,,,,,,,,,,,,,,,,,,,,
[AS5488-Schedule-SAMPLE.xls]AS5488 Schedule_UT2862,,,,,,,,,,,,,,,,,,,,,
```

Figure 4: Sample SUI point schedule.

4 CONCLUDING REMARKS

4.1 Benefits of Implementing SUI

This paper presents a considered approach to integrate the SUI standard into existing documentation and construction workflows. The benefits of implementing SUI at the time of installation include reduced cost, more accurate information on the type of materials installed, and exact date of installation. If access to this information is relatively straight forward, it can be used for the many future projects that will enviably eventuate.

Experience of overseas models, referring to CGA (2013), highlights successful collaboration across different disciplines is achieved when the overlap between the disciplines is well defined. Having a standard that all parties can adhere to provides the common language to enable this collaboration.

SUI can be integrated into other engineering and asset systems such as Building Information Modelling (BIM). Clash detection and simulation can be applied to each stage of constructing and operating an asset. Performing investigations on some subsurface assets after construction is very complex and thus costly. Some assets are inaccessible after installation, e.g. concrete encasements. This is further compounded by the need to keep some of these assets running 24 hours a day, seven days a week.

4.2 Barriers to Implementing SUI

Inertia is probably the biggest barrier to SUI becoming widely adopted. Existing processes already produce a result in terms of some record ending up in DBYD. The status quo is often the default position.

To fully maximise the benefits of SUI, education across industry is required. This may require different education packages depending on the different groups that interact with SUI. This may involve a general awareness education with additional modules for specific disciplines that are more heavily involved in the processes, e.g. designers, surveyors and GIS practitioners. There are benefits in having collaborative sessions with the more involved disciplines as often different issues can be raised and answered on the spot.

How to provide incentives for existing civil and traffic signals contractors to participate in this change? This requires that those that are engaging these contractors are convinced that this is a deliverable that adds value. After all, in their eyes the process is established, so why change?

Managing security issues associated with high risk, vulnerable and sensitive assets is another barrier. Currently details for most assets are available via DBYD. Some high-risk assets such as high pressure oil require the work area to be defined in DBYD. A representative of the asset owner can then assist with asset location and supervision of the proposed works. There may be a solution where asset owners can indicate that SUI information exists via the DBYD channel.

It is recognised that increasing pressures exist to recover all costs incurred by the asset owner. The potential consumers of SUI need to be identified, i.e. mainly existing users of DBYD information (e.g. design and construction and associated disciplines).

4.3 Expectations

For some, the expectation is that SUI will start appearing on DBYD plans. In some cases, this may well happen. However, there are many limitations to this happening:

- Asset owners have existing systems to provide DBYD information, and changing these systems represents an additional cost. The case to change these systems to be SUI compliant needs to be demonstrated.
- Asset owners will want to maintain the status quo where the user of DBYD information bears all of the risk and responsibility.
- Asset owners may have security concerns.

The take-up rate of the SUI standard is likely to be relatively slow as many organisations believe they are already providing SUI. To some extent these organisations are investigating using some of the SUI techniques (e.g. potholing, surveying, consultation with utility owners). Case studies that clearly demonstrate the steps to apply to produce SUI to a defined level are required.

4.4 Conclusion

The ability to modify the existing workflow and implement the proposed changes requires consultation with all parties involved. This proposed modification to the workflow and the underlying contract process will only naturally receive some resistance. It may require escalation to gain acceptance at a higher level within an organisation such as RMS.

Areas concerning WAE SUI that require further exploration include:

- Validation and acceptance of the suggested process, i.e. is this approach to capturing WAE SUI acceptable to RMS at a wider organisational level?
- What is the best format to store and present WAE SUI?
- Where in the organisation is the best place to store and maintain WAE SUI?
- Identification and targeting of projects lending themselves to early adoption of WAE SUI.
- What type of education resources should be prepared?
- How to update the relevant contracts to include WAE SUI as a requirement?
- Does the information in this paper relate to other assets, owned by RMS or others?

The benefits accrued from implementing WAE with SUI have been identified. The ideal points in a construction project to plan for and capture WAE SUI have been identified. The steps required to capture WAE SUI are not technically difficult, nor should they add significant costs to a project. The main challenge is one of inertia and changing accepted practices.

Future projects and research could investigate the implementation of some of these steps in a pilot project. However, without clear support from higher levels of management within an organisation such as RMS, any success of such trials will go unnoticed.

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Estimating and Predicting Carbon Sequestration in a Vineyard using Precision Viticulture Techniques

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ABSTRACT

The aim of this paper is to estimate and predict the carbon footprint of a vineyard, on a yearly basis, by employing precision viticulture techniques to investigate the carbon sequestered in the vineyard and by analysing carbon emissions from the vineyard. Soil surveys, vine measurements and a Geographic Information System (GIS) were used to estimate the carbon in the vineyard. The project vineyard, located near Orange, is approximately 300 hectares in size and constitutes 18 blocks. It has 8 different grape varieties grown on it. It was determined that the vineyard has a positive carbon footprint of approximately 69 tonnes per year, and soil carbon accounts for about 70% of the total carbon sequestered. The vineyard manager would have a possibility to save $1,100 per year if the Carbon Farming Initiative was implemented for viticulture, however this would likely be outweighed by the management costs required to evaluate the carbon performance on an ongoing basis. Precision viticulture technologies such as GIS, soil surveys and spatial measurements have facilitated an understanding of the vineyard, and have aided in establishing that the vineyard has a positive carbon footprint. This paper demonstrates that vineyards have the capability to promote a carbon neutral environment by the inclination of perennial vines to sequester carbon and to stimulate long-term storage of carbon in the soil, hence proving the ability of grape vines to have a positive impact on climate change.

KEYWORDS: *GIS, precision viticulture, carbon sequestration, carbon cycle*.

1 INTRODUCTION

1.1 Background

With the introduction of spatial technologies, Precision Viticulture (PV) has evolved in the pursuit of higher quality wine and consistent yields. PV has been available since 1999, when the first commercially available grape yield monitor came onto the market (Bramley and Hamilton, 2004). Spatial data is being used by viticulturists who are currently using Geographic Information Systems (GIS) to help them accurately understand the parameters that affect their yields and quality of grapes from different vineyards (King et al., 2005).

The idea of PV has been utilised in this study with an emphasis on measuring the ability of vineyards to either successfully sequester carbon (hereafter referred to as C) from the atmosphere, or release C into the atmosphere, hence measuring the C footprint of vineyards. A C footprint can be defined as a comprehensive measure of the amount of greenhouse gases

produced and consumed, and is used to determine whether or not individual operations are contributing to the increase of greenhouse gases in the atmosphere and therefore global climatic change (Carlisle et al., 2009). For this reason, developing vineyards with neutral C footprints can be reasonably defined as a long-term vineyard practice that would contribute to global sustainability. Furthermore, in 2011 the Australian Government introduced the Carbon Farming Initiative scheme, which allowed land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on their land. Whereas the implementation of a carbon tax is highly dependent on political will, a methodology needs to be devised to prove the C footprint, the foundations of which are laid in this paper.

1.2 Literature Review

Precision viticulture technologies were introduced to the Australian wine industry in the late 1990s, hence they are relatively new for viticulturists. In 2005, the Cooperative Research Centre for Viticulture conducted a study to identify the factors influencing the adoption of three Precision Viticulture Technologies (PVTs). The technologies studied were soil mapping, vigour mapping and yield mapping.

From the study it became clear that few growers used PVT in planning and management of grape yield variability and grape quality variability. This is mostly because the growers were satisfied with the way they were managing the variability using well established techniques, and saw little advantage in managing their vineyards at a more detailed level. It is also understood that the growers that had used PVTs were using them to inform decision making such as confirming problems or mapping the areas of variability in fruit yield and quality within the vineyard (Hill et al., 2005). PVTs address variations through the use of Global Navigation Satellite System (GNSS) technology and GIS, coupled with tools for measuring and monitoring vineyards at high spatial resolution, such as remote sensing, yield monitors and high-resolution soil surveys (CSIRO, 2006).

There is currently tremendous uncertainty concerning the quantity of greenhouse gases produced and consumed in vineyards (Carlisle et al., 2010). Maintaining a vineyard emits greenhouse gases through operations such as tractor driving and other sources of fossil fuel combustion. In contrast, the growing of perennial vines has the propensity to sequester C, through photosynthesis, into its woody matter and also into the soil for perpetual storage. However, long-term cultivation has greatly depleted soil organic carbon compared to the forest ecosystems from which many vineyards were established (Suddick et al., 2010).

Williams et al. (2011) evaluated carbon stocks and woody plant diversity across vineyard blocks and adjoining woodland ecosystems for an organic vineyard in northern California. C was measured in soil from 44 one-metre deep pits and in above-ground woody biomass from 93 vegetation plots. GIS was used to analyse how a suite of variables affects C stocks, including tree and shrub species, topographic variables (slope, elevation and aspect), maps of soil and vegetation type, and remotely-sensed spectral data. Overall, Soil Organic Carbon (SOC) varied 1.7-fold among vineyards. Within vineyard tracts, there were no correlations found between SOC and vine age, slope, aspect or elevation.

Practices that conserve soil organic matter and reduce soil disturbance will protect the largest single reservoir of C in the farm system. Reducing soil disturbance has been shown elsewhere to decrease C loss (Paustlan, 2000). The small differences in soil C between paired woodland and vineyard sites, compared to another study that compared woodlands to conventional

vineyards (Carlisle et al., 2006), suggest that the no-till, cover cropping practices and organic matter management used in this study system are conducive to soil C retention.

The above-ground C in the wood of grape vines was estimated for all tracts (management units) on the five ranches using the age and number of vines per tract. Vine wood volume was estimated based on vine age, which was calculated from a regression analysis based on samples of different ages. For each sample, measurements were taken for main trunk height, main trunk diameter at 0.5 m above the ground surface, cordon lengths from the main trunk, and a standard estimate of cordon diameter using age (2.5 cm of growth in the first five years, then 0.25 cm each additional year). Vine trunks and cordons were assumed to be straight cylinders of constant diameter. From these measurements, Carlisle et al. (2006) formulated a regression equation:

$$volume = 179.19 \text{ x } age^{1.3303} \tag{1}$$

This equation was derived by fitting a power function to the relationship between vine age and above-ground wood volume for 29 vineyard tracts, for vines under the age of 23. Vine biomass was then calculated by multiplying volume by wood density. Vine wood density was based on an analysis of Chardonnay vines on one of the ranches and given as 0.95 g dry weight/cm^3 fresh volume. Carbon content for vine wood was estimated as 50% of dry weight (Birdsey, 1992; Smith et al., 2003).

Keightley (2011) illustrates the contribution of viticultural carbon to that of agriculture at large, which can be used for gauging offsets to fossil fuel carbon emissions. A vineyard was sampled with a terrestrial laser scanning technique, paired with soil sampling and fruit yield. This study found that vines averaged 1.93 kg of dry biomass and when combined with root biomass, constituted only 2% of the total perennial vineyard carbon. The approach taken in this study was based on research by Williams and Biscay (1991), Clingeleffer and Krake (1992) and Mullins et al. (1992), which took into account the roots as a proportion of vine biomass. Roots, trunk and cordon biomass values are measured separately in these studies and provide biomass partitioning ratios. Among the three studies it was found that root, trunk and cordon biomass were approximately equal, providing a basis for estimation of root biomass from measures of above-ground biomass. The method set vine organic carbon mass at 45% of the oven-dry biomass and assumed that the roots were to be approximately 30% of vine biomass.

Increasing SOC can improve soil health and can help to mitigate climate change, and although there is a limit on the amount of organic carbon that can be stored in soils, large losses in the past mean that many Australian agricultural soils have the potential for large increases (Chan, 2008). A carbon footprint can be defined as a comprehensive measure of the amount of greenhouse gases produced and consumed, and it is used to determine whether or not individual operations are contributing to the increase of greenhouse gases in the atmosphere (CSWA, 2009).

It has been recognised that vineyards both produce carbon emissions and consume carbon emissions, which gives the opportunity for vineyard operators to actually consume more carbons than they emit, in turn decreasing the effects of global warming. Vineyards produce carbon emissions from agricultural activities such as tractor driving and electricity usage. However, carbon emissions are consumed by the growing of grapes through photosynthesis

by the long-term storage in vegetative structures and soils. Therefore it is important to look at viticultural management procedures that can increase the total carbon consumed.

Thus the objective of this work is to estimate and predict the C footprint of a vineyard, on a yearly basis, by employing PV technologies to investigate the C sequestered in the vineyard and by analysing C emissions from the vineyard. Section 2 firstly presents the methodology used for estimating the soil and vine carbon levels and the corresponding volume of carbon sequestered each year. It then details the methodology for estimating the volume of carbon emitted from the vineyard each year. Section 3 presents the experimental results and infers the overall carbon footprint. The conclusion follows in Section 4, along with recommendations for improving the carbon footprint of similar vineyards.

2 CARBON FOOTPRINT ESTIMATION

The vineyard investigated in this study is managed by Jarrett's Wines and is a small to medium (300 hectare) vineyard located 30 km south-west of Orange, NSW – approximately 300 km west of Sydney, Australia. The vineyard has a total of 18 blocks, and over 178,000 vines. In each of the blocks a different variety of red and white grape vines are cultivated, including Chardonnay, Sauvignon Blanc, Riesling, Pinot Gris, Shiraz, Cabernet Sauvignon Merlot and Pinot Noir (Figure 1). The tools used to assess the vineyard's C footprint were a combination of land surveys, soil surveys, soil laboratory analysis, measurements of vines, and GIS management.

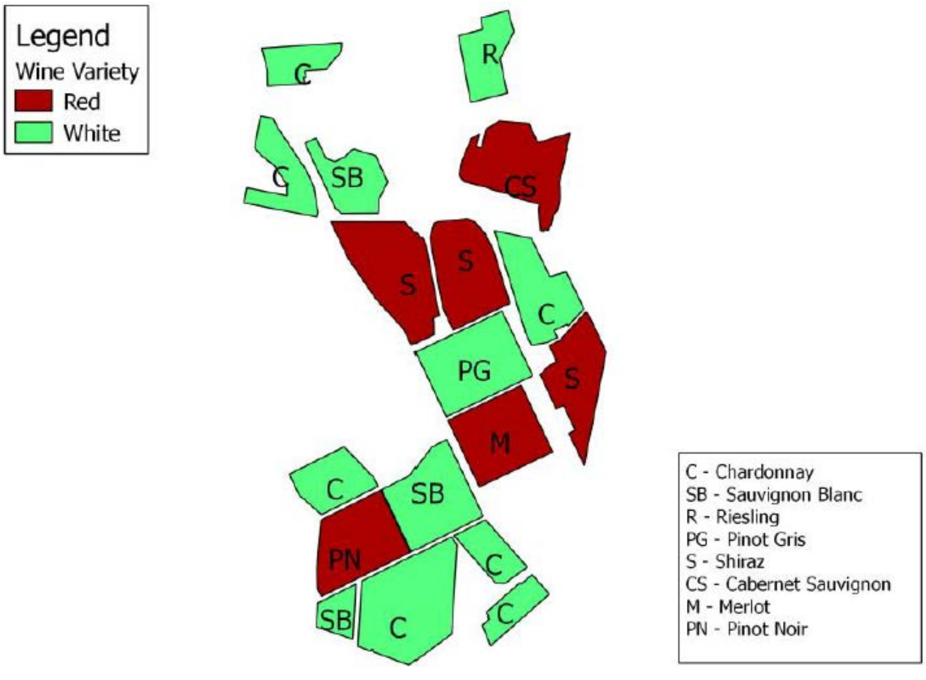

Figure 1: Wine varieties grown at Jarrett's of Orange.

Mapping the geographic boundaries of the study area was the first step to correctly identify where the C estimation was situated. The investigation into C sequestered was comprised of analysing the amount of soil and vine C. The inquiry into C emitted from the vineyard was done by an analysis of vineyard practices, including electricity usage, fuel usage and fertiliser applications. The emergence of all of these aspects resulted in a carbon footprint. The footprint was estimated on a yearly basis with prediction models from all of the obtained data.

2.1 Soil Carbon Sequestration

2.1.1 Field Survey and Baseline

The boundaries of each block were surveyed in December 2011 using differential GPS to a horizontal accuracy of 10 centimetres – the accuracy stated in the Carbon Farming Initiative (CFI) spatial mapping guidelines (Australian Government, 2012).

Numerous soil surveys had previously been undertaken on the vineyard to assess soil limitations of root growth and to provide management recommendations that optimise soil conditions for wine grapes within each management unit (Figure 2). More so, soil samples from the surveys were sent to a laboratory to specify the SOC content of the soil. The original field surveys were conducted in 1998 and 2010, which allowed the baseline C to be assessed. SOC contents derived from these surveys was used to calculate the amount of C per block, and hence the amount of soil C without the introduction of viticultural activities. In 2009 and 2012, carbon testing was conducted on soil samples from each block and analysed to give SOC values after the introduction of viticulture. The baseline SOC and the SOC values from the later years were used to compare and calculate how much C was sequestered or emitted from farming activities.

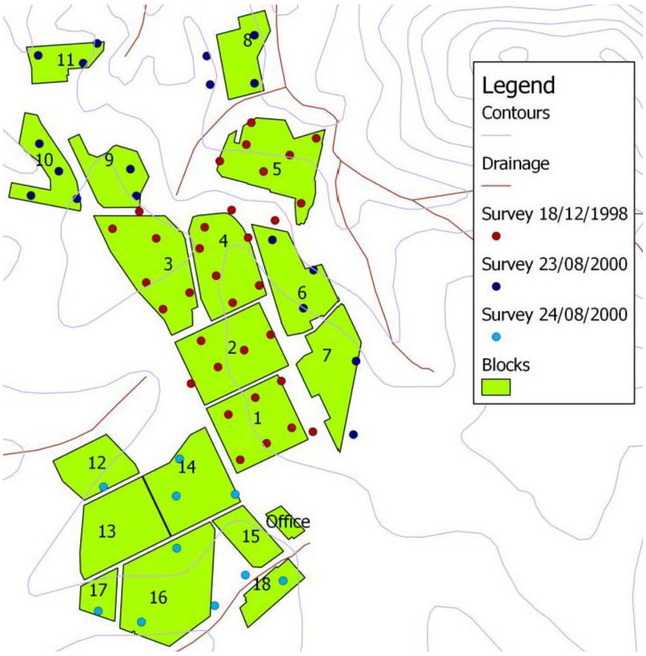

Figure 2: Locations of soil samples from baseline surveys.

Laboratory analysis of the soil samples at depths of up to 30 cm provided the organic carbon content, or SOC, using the Walkley-Black method as well as an estimate of the bulk density of the soil (McKenzie and McBratney, 2001). Chan's formula (Chan, 2008) was then used to calculate the baseline of C per hectare and per block.

2.1.2 Volume of Carbon Stored in the Soil

To evaluate how much C has been sequestered into the soil, soil samples from subsequent years were analysed. In 2009, soil samples from each block were taken and sent to the laboratory. Vineyard manager, Justin Jarrett, took samples from 20-30 locations on each block, at depths of 30 cm. Each sample within the designated block was combined, giving a

good average soil sample to be analysed at the lab, for each individual block. In 2012, soil samples using the same method were taken from blocks 4, 9 and 16. A sample was also taken from unused land at the front of the vineyard lot to detect an SOC value for unused land in the area. The soil samples were sent to SESL Australia and the SOC was determined by the Walkley-Black method. The total C per block was then calculated and the difference between this and the baseline was found, showing the net carbon stored in the soil by the vineyard.

2.1.3 Predicting Soil Carbon Sequestration

The soil C was predicted by using the SOC values measured at the baseline, and setting a linear regression to the SOC values taken in 2009. Using this regression allowed for rough predictions into future and past years. Blocks 4, 9 and 16 had SOC samples taken in 2012; the predictions were compared to these sampled values, which is discussed in section 3.1.2.

All of the data was imported to QGIS to spatially analyse the results for soil and vine C. TIN interpolations enabled the spread of the soil C to be spatially visualised for the baseline and surveys undertaken in 2009. The difference in the spread endorsed an understanding in the change of soil carbon over the years after the vineyard was assembled. The spatial variation in vine carbon was also visualised and managed with the GIS.

2.2 Vine Carbon Sequestration

2.2.1 Measuring of Vines

The ideology of the process of measuring the vines was to find an average volume of each vine, to the best of our ability, to estimate the total carbon on the vineyard. An independent measurement of each vine was next to impossible as there are a total of 178,000 vines on the vineyard. Over the 300 ha vineyard, one vine from each corner of each block were measured, to give a total of 4 vines per block where possible. The following parts of the vines were measured: trunk diameter, trunk height, cordon diameter and cordon length (Figure 3).

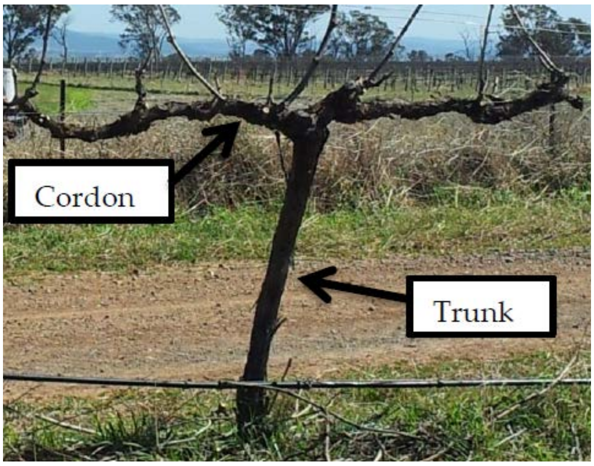

Figure 3: Vine with perennial trunk and cordon.

2.2.2 Volume of Carbon Stored in Vines

The volume of the vine wood, and the biomass of the vine wood, needs to be considered before calculating the C content of the vine. The total volume of each of the vines was determined by assuming that the cordon and the trunk are both perfect cylinders.

The dry biomass needs to be determined after the total volume is calculated; to do this vine wood density for the vines has to be resolved. The vine wood density was determined to be 0.95g dry weight/cm^3 fresh volume based on an analysis of Chardonnay vines in a study by (Williams et al., 2011). The value determined by them for the vine wood density was used for this study. Vine biomass is then calculated by multiplying vine volume by wood density.

Whole vine perennial biomass was expressed as 1.42 times the above-ground biomass, as described by Mullins et al. (1992), Clingeleffer and Krake (1992) and Williams and Biscay (1991). Roots were assumed to be approximately 30% of vine biomass based on the reported biomass values for roots, trunk and cordons (roots averaging 30% of the sum of all three categories) (Keightley, 2011).

The C content used for the vine wood was 45% of dry weight (Schlesinger, 1997). The C content per vine was determined by multiplying the biomass of the vine by 45%. The amount of C per block was estimated by multiplying the C content per vine by the number of vines in the block.

2.2.3 Predicting Vine Carbon Sequestration

To predict the vine C sequestration, the average vine volume per block was fitted to a power function, the form of which is given in equation 1. The equation had not been validated for vines older than 23 years, so this was the maximum prediction during the project. Individual parameters of the fit were recorded for each block based on the current vine measurements.

2.3 Farm Carbon Emission

The carbon footprint of the vineyard is assessed on a yearly basis according to:

$$\begin{aligned}\text{total } C_n &= [\text{Carbon Sequestered}] - [\text{Carbon Emitted}] \\ &= [(VC_n + SC_n) - (VC_{n-1} + SC_{n-1}) - (SC_{BL})] - [Elec_n + Fuel_n + Fert_n] \qquad (2)\end{aligned}$$

where n is the year of interest, BL is the baseline, VC is the vine carbon, SC is the soil carbon, $Elec$ is C emissions from electricity usage for the year, $Fuel$ is C emissions from fossil fuel combustion for the year and $Fert$ is C emissions from fertiliser applications for the year. Total C_n is the C stored for the year, where a negative value is C emission and positive value is C sequestration.

The positive contributors (sequestration) were all calculated in the methods explained in previous sections, and by summing the amount of C stored in the vines with that stored in the soil. The negative contributors (emissions) of C into the atmosphere were calculated using the Australian Wine Carbon Calculator (WFA, 2014). The region for the spreadsheet was set to NSW, and values used were from the management records of the vineyard. All of the values obtained were from 2011/12 and used as an average for other years.

The fuel and electricity usage was obtained by probing into the vineyards administration database to get values for the average amounts of fuel and electricity used per year. The vineyard also has solar panels in place, so the offset of electricity generated was utilised as well, significantly decreasing the total amount of electricity used. It must be noted that if electricity generation outweighs the total amount of electricity used, then it can be used as a positive contributor to the C equation.

Fertiliser use was obtained from the job sheets over the year. Each time the fertiliser was used, the amount used was recorded on the time sheet. The nitrogen content and the quantity used for each different brand of fertiliser enabled an estimate of how much C was emitted from the fertiliser usage (WFA, 2014).

3 RESULTS

3.1 Soil Carbon Sequestration

3.1.1 Survey Results

Figure 4 shows the SOC baseline measurements, all of which fall in the range between 0.5 and 3.5. The majority of the SOC content is between 0.5 and 1.5, with a medium amount between 1.5 and 2.5, and a slight amount between 2.5 and 3.5. A small amount in the red range is expected because an SOC between 2.5 and 3.5 is considered to be relatively high (DEPI, 2011). However, the blue range of SOC is considered to be low by the same reference, even though this is the majority of the SOC over the vineyard. The values between 2.5 and 3.5 could be considered outliers. The interquartile range was calculated for the samples and it was determined that values above 2.25 could be considered outliers, however the values were kept as it cannot be proven that the sample was taken incorrectly.

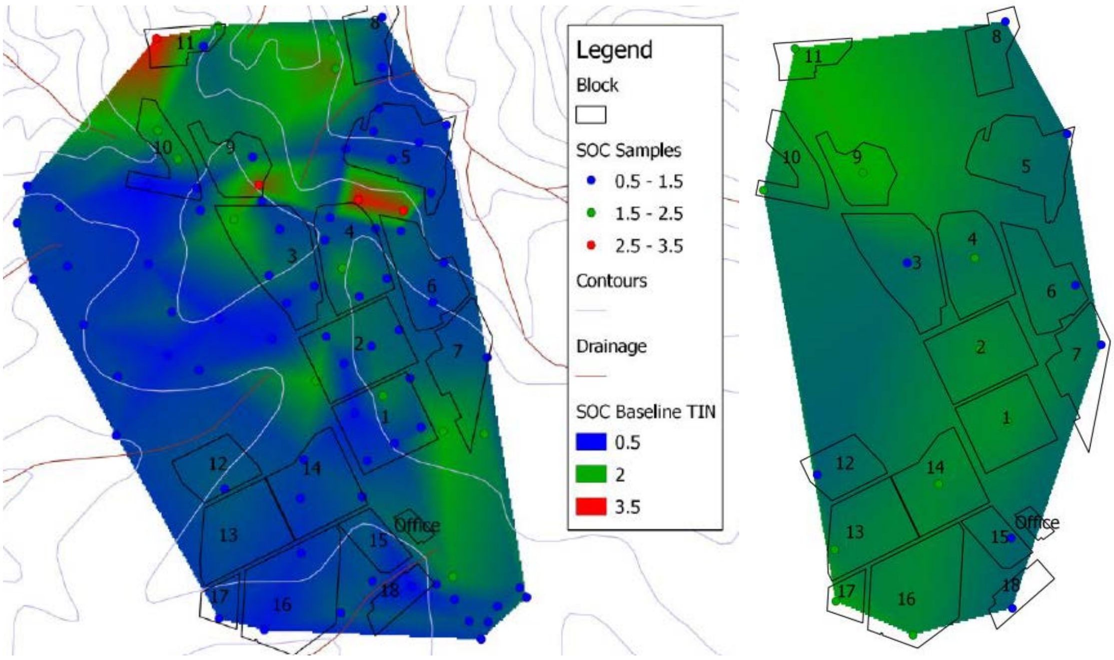

Figure 4: SOC levels extrapolated over the study area with the baseline values at left and 2009 survey results at right. Evidence of an overall increase in the SOC is shown by the general shift from blue to green.

The contours and drainage lines on this map paint an interesting picture. At the end of the drainage lines there is an inclination towards a higher SOC content (generally in the 1.5 – 2.5 range) compared to the majority of the soil. The higher SOC contents at the end of the drainage line conjectures SOC may be transported in heavy rains to the bottom of catchment areas. Also, the extrapolated map indicates that the bulk of the higher SOC contents is at the northern end of the vineyard, during the baseline samples. It appears that the top end of the vineyard has a more condensed catchment for water draining off the higher slopes, again suggesting that the higher SOC is from drainage.

The map generated for the 2009 samples suggests that overall the soil C has increased. However, the higher SOC values around 3.5 which were measured in the baseline were not determined. The results of the 2009 survey shows that again the northern part of the vineyard has the highest soil C. However, the southern part of the vineyard has now increased its C storage (in comparison to the baseline). When the baseline was surveyed, the SOC was generally in the range of 0.5 – 1.5, and in 2009 the values mostly ranged from 1.57 – 2.07. This clearly shows a significant increase in C sequestered in the soil due to the introduction of viticulture in the area. The average SOC increase per year for each block is shown in Figure 5.

In the entire vineyard there are no SOC values less than 1.32, where before this was the majority of the SOC. Conversely, there has also been a drop of SOC in some areas. There are no values in the 2.5 – 2.5 range, while there were four of these values in the baseline data. This could be due to farming activities, or solely because those higher values in the baseline were outliers. The 2009 survey consisted of taking 20 – 30 samples from each block to determine an average SOC, so it is quite likely that there were higher SOC samples, but the average used is better to determine a complete SOC value for the block.

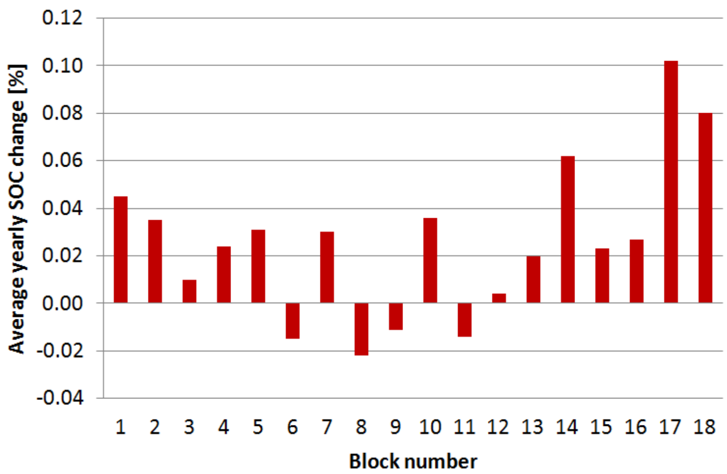

Figure 5: Average SOC increase per year in each block.

3.1.2 Prediction Results

In 2012, soil surveys were performed at blocks 4, 9 and 16 to calculate an average SOC value for each block. The recorded values were compared to the predicted values as shown in Table 1, allowing for the accuracy of the linear prediction to be realised and to also enforce whether the C for the subjective block actually increased or decreased as predicted with the linear regression. The evidence would have been more substantial and implicating if surveys were carried out on every block again, but this data was not available.

Table 1: Error in SOC prediction when compared with 2012 soil sample.

Block	2012 Prediction [% SOC]	2012 Measurement [% SOC]	Error [% SOC]
4	1.57	1.70	0.13
9	2.02	1.70	0.32
16	1.93	1.10	0.83

The 2012 sample showed that the prediction was 0.83 off and it agreed that the SOC in Block 4 is increasing compared to the baseline. However, the rate at which it is increasing is

significantly slower than the prediction, and from 2009 to 2012 the results suggest that there has been a substantial decrease in the SOC value. It could be that the C is actually tending to decrease as of 2009 in this block. However, the decision to use a linear fit was simply because there is not enough data to support evidence of another regression fit; any of these results could be an outlier.

The total soil sequestered per year is estimated to be 81.54 tonnes, and makes up the majority of the C sequestered in the vineyard. The estimation per year is at a constant because of the linear fit to all of the SOC values interpreted; this would more than likely not be the case if samples were taken in each year because SOC stowage is unpredictable. The percentage of soil C, in comparison to vine C, decreases each year because the prediction of vine C storage slightly increases per year, while soil remains constant.

3.2 Vine Carbon Sequestration

3.2.1 Survey Results

The analysis on C in the vines is based solely on the single measurements completed in 2012 (Table 2). There were no measurements taken in other years, so each block has been fitted to the same growth formula at different scales. In order to keep the analysis at a constant, the vines have been investigated at 13 years of growth, since this was the age of the majority of the vines when they were measured. Blocks 6 – 18 were all measured at 13 years old. However, blocks 1, 3, 4 and 5 were measured at 14 years old, and block 2 was measured at 2 years old. The volumes of these vines at age 13 have been predicted by the growth formula. It must be noted that the prediction of block 2 at age 13 is very uncertain because that is 11 years in the future.

Investigating the spatial variation of the volume of vines per block shown in Figure 6, there does not appear to be any pattern for the growth in the vines. Nevertheless, the two highest volumes of vines per block are right next to each other (blocks 14 and 15). This could be a coincidence, or it could be due to reasons such as more sunlight and readily available water.

Table 2: Measured vine carbon.

Block	Variety	Type	# Vines	C per vine [kg]	Total C [t]
6	Chardonnay	White	10,750	1.89	20.31
10	Chardonnay	White	7,096	1.55	11.03
11	Chardonnay	White	6,832	1.62	11.04
12	Chardonnay	White	6,116	1.84	11.23
15	Chardonnay	White	4,139	3.33	13.77
16	Chardonnay	White	16,092	1.86	29.90
18	Chardonnay	White	3,683	2.18	8.02
9	Sauvignon Blanc	White	7,470	1.11	8.31
14	Sauvignon Blanc	White	11,054	3.34	36.88
17	Sauvignon Blanc	White	2,760	1.30	3.59
8	Riesling	White	6,849	1.44	9.86
2	Pinot Gris	White	15,900	0.78	12.34
3	Shiraz	Red	15,078	2.53	38.14
4	Shiraz	Red	12,482	2.21	27.53
7	Shiraz	Red	10,524	2.82	29.64
5	Cabernet Sauvignon	Red	13,742	3.11	42.75
1	Merlot	Red	12,960	1.90	24.62
13	Pinot Noir	Red	14,478	1.27	18.35

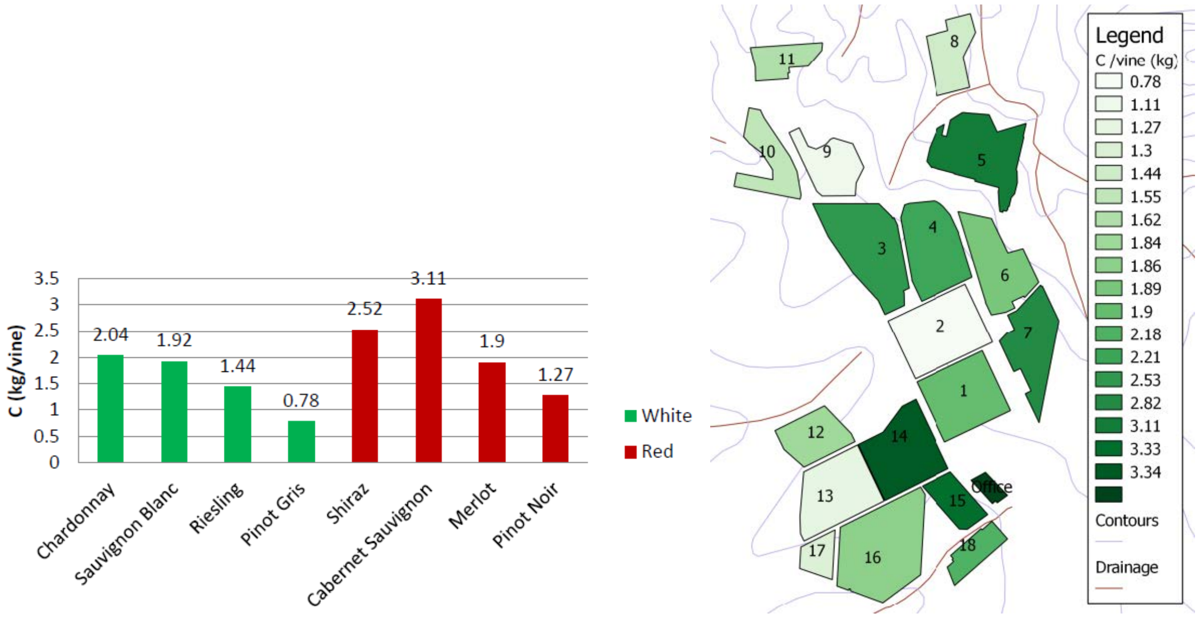

Figure 6: Vine carbon by variety (left) and location (right).

3.2.2 Prediction Results

From the vine measurements in 2012, the calculation estimates that the vines will store 36.14 tonnes of C, i.e. 30.7% of the expected total C sequestered. The predictions for the following years have an increase of 1 tonne, 0.93 tonne, 0.88 tonne and 0.84 tonne consecutively with a decreasing rate of change. This is due to the nature of the power regressions used to fit the growth of the vines. However, the sequestration of vine C for the whole vineyard is a lot more linear than a per block basis, and a linear fit is more suitable than a power regression for the prediction. It must be noted that all of the predictions are only derived from one measurement which is set to a power regression (Williams et al., 2011). To determine the C sequestered per year more veraciously, it is ideal to measure the vines each year and with more true estimation methods (see section 4.3).

3.3 Farm Carbon Emission

3.3.1 Data Sources

The emissions of carbon dioxide into the atmosphere were calculated using the Australian Wine Carbon Calculator (WFA, 2014). The region for the spreadsheet was set to NSW, and values used were from the management records of the vineyard. All of the values obtained were from 2011/12 and used as an average for other years. If the emissions per year need to be known more accurately, it is strongly advised to use the true values per year to delineate the total emission offset for the year.

3.3.2 Fuel

An average of 12,800 litres of diesel fuel per year was combusted in agricultural activities. This amounted to a calculated value of 35 tonnes of C emitted per year. In a more accurate analysis, the exact fuel usage per year would be used.

3.3.3 Electricity

The electricity usage for year 2011/12 was determined from the electricity consumption records of the vineyard. A total of 28,466 kWh of electricity was used. However, there are solar panels located on the vineyard to help offset electricity usage on the farm, for both cost and C reduction, by generating their own electricity from the sun. It was concluded that the solar panels generated 13,580 kWh of electricity. So, there was a total of 14,886 kWh of electricity used from the power grid, resulting in 13.25 tonnes of C emitted.

3.3.4 Fertiliser

The fertiliser was computed by investigating how much of each fertiliser was used per block by the job sheets. All of the fertiliser used per block was added together to give a total amount of each fertiliser used in the year as given in Table 3. The emissions were calculated in the Australian Wine Carbon Calculator, which took into account the N content and an emissions factor. A total of 0.16 t of C was emitted from fertiliser use.

Table 3: Fertilisers used on the vineyard and total carbon emitted from them.

Fertiliser	Fertiliser Applied [kg]	N content [%]	Total emissions [t]
SprayGro (K)	40	5 (SprayGro, 2012)	0.02
Budmate	501	5 (SeaMagic, 2012)	0.04
Sea Magic	1304	5 (Agrichem, 2007)	0.10

The pie chart in Figure 7 shows that fuel usage is the major contributor to C emissions, and emissions from fertiliser use on the vineyard are insignificant. It should be noted that the electricity usage includes the offset from the solar panels. Overall, 48.41 tonnes of C were emitted in 2012.

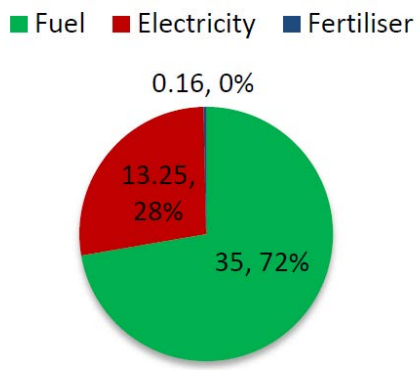

Figure 7: Overall carbon emissions in tonnes.

3.4 Overall Carbon Footprint

From equation 2, the total C footprint of the farm was calculated to be 69.3 tonnes in 2012. After deriving exactly how much C is stored for the year and determining the predictions, a price can be set to the amount of money earned/saved if the Australian Government's CFI is implemented in the vineyard. Despite recent uncertainty regarding such an implementation, we have taken a C price of A$15/t as a nominal value for the purpose of this analysis. Table 4 shows the estimated savings per year, assuming a price of A$15/t using the predictions of the overall C footprint as detailed above.

Table 4: Carbon footprint and savings estimated.

Year	C footprint [t]	Savings [A$]
2012	69.3	$1,040
2013	70.3	$1,055
2014	71.2	$1,068
2015	72.1	$1,082
2016	72.9	$1,094
2017	73.7	$1,106
2018	74.5	$1,118

4 CONCLUDING REMARKS

4.1 Discussion

PV technologies such as GIS, soil surveys and spatial measurements have facilitated an understanding of the vineyard and have aided in establishing that the vineyard has a positive carbon footprint. This study demonstrates that vineyards have the capability to promote a C neutral environment by the propensity of perennial vines to sequester C and to stimulate long-term storage of C in the soil, hence proving the ability of grape vines to have a positive impact on climate change. The effect of fossil fuel combustion, electricity usage and fertiliser applications on greenhouse gas emissions has been analysed, and it has been corroborated that these factors do have a negative effect on the vineyard's C footprint.

Overall, the results show that the vineyard is sequestering more C than it is emitting per year. It has been demonstrated that the vines store about 30% of the total C sequestered over the entire vineyard, and no concrete conclusion could be drawn for the variation of vine volume. The soil C accounts for the remaining 70% of total C sequestration. There are only four blocks in the vineyard that show a decreasing rate of C, while the remaining 14 blocks appear to have an increasing rate of C. It has been estimated that this vineyard has the potential to save A$1,100 per year if a CFI methodology for viticulture was in place. This is significantly less than the time and labour required to obtain the measurements on a regular basis to quantify the actual C footprint.

4.2 Recommendations for Improving the Carbon Footprint

The vineyard investigated in this study incorporates organic and biodynamic farming principles and boasts a record of management procedures to decrease C emissions and increase sequestration. This has been proven by the fact that the total C sequestered in the vineyard has been confirmed to be increasing at a rate of 120 tonnes per year. The vineyard uses a majority of organic fertiliser and in turn uses a minimal amount of nitrogen fertiliser, only emitting around 0.16 tonnes per year which is insignificant compared to electricity and fuel usage. There is a minimum-tillage management scheme in place on the farm, and this has also endorsed a cover crop management with the use of perennial grass. The prolonged subscription to this method has actively sustained C in the soil. Also, pruning and thinning techniques take place on a seasonal basis, absorbing more C into the soil.

Electricity emits on average 13 tonnes of C per year, considering the offset from the solar panels. Even though the vineyard manager has gone to great extents to install solar panels to save money and reduce C emissions, electricity usage could still be restricted by altering irrigation techniques. Drip, flood or furrow irrigation could be implemented in place of the

current irrigation system of using electric pumps (CSWA, 2009). This would reduce C emissions by limiting the use of electricity. The highest C emission source on the farm is from the combustion of fossil fuel, resulting in around 35 tonnes of C per year. Reducing fuel usage is one of the most obvious and effective ways to reduce the vineyard greenhouse gas footprint. Additionally, although diesel has a greater energy content per unit volume, it produces more greenhouse gases than gasoline, natural gas or propane. An introduction of hedgerows and more native vegetation such as trees would also have the effect of absorbing more C into the perennial wood and the soil, further offsetting the vineyard's C footprint. All of these management procedures have been shown to implement a positive C footprint within vineyards (Carlisle et al., 2006).

4.3 Future Work

The results for the vine C were based solely on measurements piloted in one year and fitted to a model from a study on another vineyard (Williams et al., 2011), so more measurements would increase the accuracy of the estimations. The soil survey methods from the years 1998 and 2000 were different to the soil surveys completed in 2009 and 2012. The earlier methods were conducted as an official survey and only 61 samples were taken from where the blocks were located. The later methods were comprised of the vineyard manager taking 30 samples from each block, in a spaced manner. The dry combustion method is also a more accurate method to determine the SOC content of soil in a laboratory, compared to the Walkley-Black method (Mikhailova et al., 2003).

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Development of a Template for the Preparation of a Survey Brief

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ABSTRACT

With the current 'right sizing' of many organisations (both government and private), a significant amount of survey work that was previously carried out in house is now being carried out by contractors. The common protocols that guide these practices require competitive market practices. The result of these two cases is that survey companies are frequently bidding on work and others are trying to assess that the right survey will be undertaken in the right manner. The authors have faced a similar situation, with no in-house field survey capability. Survey tasks are outsourced and the challenge has been to get the right survey. This paper describes many of the areas where assumptions from the client were not matched with the proposed survey methodology of the survey company and how these conflicts can be removed with careful detail in a survey brief. There are also many associated issues that can affect the conduct of a survey. This paper lists many such areas for consideration for inclusion in a survey brief. This list can become a template for the preparation of such a brief. Results to date have been very positive with survey firms having a clearer understanding of what is required and project managers having a clear understanding of what they are getting.

KEYWORDS: *Survey brief, instruction, sub-contract.*

1 INTRODUCTION

Are your survey resources being constantly cut? Do you often here comments like "*Why do we need our own surveyors?*" or "*Why don't we just contract in the survey resources as we need them?*" Are you looking for work outside your regular (often internal) clients? Do you respond to tenders and requests for quotes for survey work? If the answer to any of these questions is yes, you will have or are likely to come across issues that have faced the authors of this paper over the past few years.

There are three major areas to be covered in a survey brief. These are the administration (including safety and permits), the type of survey, and the deliverables. Each of these areas may have a number of sub-areas to be covered in the brief. Each area is briefly covered in this paper. Those preparing a survey brief should consider each of the sub-areas for potential inclusion in the brief. A summary list that can be used as a checklist is also included. This list is still growing but has proven useful in creating survey briefs that are now much clearer than those being supplied at the beginning of this process.

2 ADMINISTRATION

The administration section of the brief should cover all the processes and details required to understand what is required and what the surveyor should do when something unexpected happens. All safety requirements appear in the administration section. This section also covers what documentation needs to be in place before the survey begins.

2.1 Purpose of the Survey

The purpose of the survey should be clearly stated. This will aid in the interpretation of many other sections of the brief and help the surveyor to identify any details found in the field that were not known when the brief was prepared. This should be short and succinct so that it can be kept in mind throughout the survey.

2.2 Overall Location of the Survey

The overall area and location should be made clear. Often mark-ups on existing mapping can be useful. In NSW, more detailed background information for Google Earth is now available through the NSW Globe dataset (LPI, 2014b). A similar dataset is available for Queensland. This mark-up should show the area of the main survey, together with sufficient information to find the site. The mark-up may also include access points to the site and any other key locations within the site.

2.3 Contact Person for Technical Input and Decisions

The contact person for technical input should be clearly identified to allow rapid resolution of any technical issues during the survey. Details should include email and mobile phone numbers where appropriate to aid in information flow and timely responses.

2.4 Contact Person for Administration and Finance Issues

The contact person for administration and finance should be clearly identified to ensure correct information flow during the survey. Again, details should include email and mobile phone numbers where appropriate to aid in information flow and timely responses.

2.5 Safety Requirements to be Followed

There have been a number of papers presented on work health and safety for surveys over the years. Some surveys may need to incorporate a number of areas including roads, railways and underground services. Other possible areas include remote areas, sensitive areas and fire prone areas. Any safety systems that are to be incorporated in the surveyor's safe work methods should be listed in the brief.

2.6 Inductions Required to be on Site

Many sites require some form of induction before personnel are allowed to work on the site. These inductions may be carried out on site or they may be conducted at a separate location. Details should be provided to allow more certainty in the response to the brief.

2.7 Protocols Before Entering the Site

Some sites will have protocols to be followed before entering the site. For surveyors who are often on site before site compounds are established, these protocols may include notification to a central office of the entry and exit to the site. Each site is unique, and the specific protocols should be stated in the brief.

2.8 Protocols to Follow Before Entering Private or Restricted Lands

Surveys often extend into adjoining lands. Often the project team includes people charged with managing the relationships with the adjoining land holders. Such teams will have established protocols to be followed. These protocols should be clearly stated in the brief.

2.9 Protocols Before Placement of Survey Marks

There may be specific protocols to be followed before placing survey marks. These would be in addition to the Dial Before You Dig (DBYD) requirements. Any such protocols need to be clearly stated as the placement of survey control is often one of the early tasks in a survey.

2.10 Required Qualifications of Key Personnel

There may be qualifications required for key personnel. These qualifications need to be detailed, including any restrictions on the makeup of a field party. An example of this might be that a particular qualification (or level of experience) must be in the field whenever certain tasks are being undertaken. Consideration could also be given to possible audit of such a requirement.

2.11 Required Insurances

The survey company will be required to have certain insurances. The level of these insurances needs to be stated. Examples of these could include professional indemnity, public liability, WorkCover, vehicle and equipment.

2.12 Documentation to be Provided Before Personnel go to Site

Project teams often require some documentation to be supplied to the office before the commencement of any survey work. Some documentation will be required to be with the field party on each day of field work. Items in this section could include:

- Safe Work Method Statements (SWMS).
- Permit to break ground.
- Copies of insurance certificates.
- Any required permits to work.
- Documentation to be with the field party.

3 TYPES OF SURVEY

There are a number of different types of survey that might be required. Each of these appears in the template together with the details that are typically required for each type.

3.1 Control Survey

The first type of survey required is a control survey. Some amount of control is required in most surveys but the clients often do not consider control surveys or are not concerned about the control. In most engineering surveys, the surveyor is in the early groups of people to visit the site and the purpose of the survey is to gather information to enable design of various types, through the various design stages and into the construction, and often ongoing maintenance over the infrastructure lifetime. Establishing sound control to the appropriate accuracies for the various stages of the project can be seen as unnecessary expense up front. Managing the client expectations at this stage can produce a solid foundation in ensuring spatial correctness for all future surveys.

Consideration needs to be given to the durability of the control marks, the ready identification of control marks in future stages, the location of the marks from a usability point of view through all stages of the project, and public access to control marks during and after the project. The surveyor will require specific instruction on each of these aspects of the control survey marks to be placed.

The accuracy of the control survey needs to be specified. This specification could be a particular class of survey as defined in ICSM's standard for control surveys (ICSM, 2013) and NSW Surveyor General's Directions (Dickson, 2012; LPI, 2014a), e.g. to allow new control to be included into the state's Survey Control Information Management System (SCIMS), or other levels as required for the project.

3.2 Coordinate System and Datum

The choice of coordinate system and datum should be made early. For detailed discussions on this topic, the reader is referred to the available literature (e.g. Janssen, 2009; Butler, 2012; Haasdyk and Janssen, 2012). It may be necessary to bring control in from nearby or some distance away. If the control coordinates are to be used for a long-term project, there may be requirements to ensure a reliable source that can be re-established is used. There may be legislative requirements for using a particular system. Surveys for NSW government and local government are required to meet the Surveying and Spatial Information Act and the accompanying Regulation (NSW Legislation, 2014a, 2014b). This may mean that legislation requires to use the Geocentric Datum of Australia (GDA94). In a similar way, some organisations have standards that require particular coordinate systems and datums. For example, the Australian Rail Track Corporation (ARTC) standard ETD-00-04 (ARTC, 2011) allows surveys to be performed on the Map Grid of Australia (MGA94) and the Integrated Survey Grid (ISG). Linear coordinate systems may also be required. This is typical for infrastructure surveys of linear assets like road, rail, pipeline and transmission line surveys. The origin of this linear coordinate system should also be specified.

3.3 Surface Detail

Survey information to define the ground surface may be required. The brief needs to indicate the accuracy that the surface definition needs to be captured to, and the interim and final products to be produced form this information. Additional built environment information including top and toe of batters, drains, paths and roadways, changes in surface type (concrete-asphalt-grass), buildings, pits and cable routs, poles and aerial wires, fences, walls and sometimes site specific information may be required. Sometimes it may be sufficient to

indicate that something is there and at other times specific identification is required. Specific identification will often require some type of library describing the name (code) and properties. This can be in the form of photographs of typical infrastructure and the name. When unusual items are found, the brief should require that the survey include a photograph of the item to allow later identification.

Some additional information may also be required for some infrastructure. This might include measurements around a headwall including the size and shape of the opening or attributes like the text on a sign or names of buildings or pole numbers. Specific trees may need to be individually located. These trees should be identified in the brief or the properties that make a tree one that needs to be individually located.

3.4 Engineering Detail

Specific engineering detail may be required. For a pipeline survey this might have to do with an existing pipeline and the associated infrastructure, for a road widening the existing pavement extent and level, and for rail the existing rail and clearance infrastructure. The brief needs to identify the engineering information required, the accuracy requirements which may be different to other detail, and specific information about the existing infrastructure.

3.5 Built Environment – Buildings, Bridges and Other Structures

There can be various requirements for items of built environment. These requirements may lead to special data collection including terrestrial photogrammetry, terrestrial laser scanning, fine and detailed measurements of infrastructure not visible from a survey instrument (e.g. bridge bearings). Survey information may also be required for the inside of buildings, the change in building finish, and evidence of date of construction.

3.6 Underground Services

Surveys for the purpose of engineering design often require the location of underground services. These services need to be located by authorised personal. There may be a range of services and not all locators are authorised to locate all services. Recently AS 5488-2013 Classification of Subsurface Utility Information (SUI) was released (Standards Australia, 2013). This standard covers many of the issues in surveying underground services from spatial location through to service metadata. The survey brief needs to cover who engages the service locator, and the type of location required (remote detection or physical exposure). The accuracy of service location needs to be specified and any special detail that may be required for the particular survey.

3.7 Aerial Photography

Although aerial photography libraries now cover an extensive area, some projects require updated aerial photography and often at a higher resolution. When aerial photography is required, the brief needs to cover the age, the resolution, spatial accuracy, and the ground model resolution for ortho-rectification. There should also be some direction to do with shadows and time of day for photography.

3.8 LiDAR

If LiDAR is required, the brief should clearly indicate the extent of the LiDAR coverage, the

accuracy and density of the LiDAR data and the deliverables. Any necessary ground truthing of LiDAR data should be specified, together with how this should be compared. It is recommended that some ground truthing in the form of cross sections across the flight lines be considered to ensure that both datum and tilt errors are kept within desirable parameters.

3.9 Cadastral Survey

Most engineering surveys require some form of boundary location. The boundaries may need to be located for identification purposes, or if there is planned infrastructure near the boundaries, they may need more extensive definition. Some projects may also include land acquisition and also establishment of temporary leasing of surrounding land areas to allow for vehicle movement, stockpile and site compounds during construction. The survey brief needs to indicate the extent of the boundary definition required and the purpose of this definition to allow the surveyor to carry out the appropriate level of work. There are also increasing requirements for the preparation of a Survey Accurate Cadastral Model (SACM) covering a project. Again, the extent and purpose of such a model needs to be stated, together with the attributes that are required for each boundary and land parcel.

3.10 Monitoring Survey

When monitoring surveys are required, the survey brief needs to indicate what is being monitored, and what movements are expected. The rate of movement and the pattern of movement will also need to be given. The brief should also indicate the time frame that the movement is expected to occur over and any possible zone of influence. The brief should also specify the minimum number of base epochs to establish a base and noise level before engineering works that might cause movement can commence. The survey can then be designed to include sufficient stable survey marks and well-designed techniques to provide the sensitivity required to detect the expected movements.

3.11 Asset Mapping Survey

Asset mapping surveys often require different accuracies. Asset mapping surveys need a library of assets to allow field identification, together with a list of attributes for each asset and the possible values for each attribute. Where the accuracies or geographic extents differ between different assets, these need to be clearly stated. The library of assets should include a photo example of each type of asset (or more than one photo if there are variations for a particular asset type like variations in cars, i.e. all are cars but the can look very different).

4 DELIVERABLES

A number of different deliverables may be required. Each deliverable should be listed in the brief to avoid later difficulties where the client expected one thing and the surveyor expected a different thing.

4.1 Plans

Most surveys require delivery of plans. Such plans need to be specified. The plans can be delivered in hard copy or soft copy. It should be stated at what size the plans are to be prepared (typically A3 or A1 but other sizes might also be specified). This is relevant even when soft copies are specified as it will dictate text sizes that are readable without having text

overwriting. The scale of plans should also be specified. If required, one should allow for detail plots at smaller scales. The client (or project) may also have a document management system that specifies drawing numbers. If this is the case, the brief should indicate the numbering system and either allocate available drawing numbers or give details about how these numbers are to be numbered. Some clients also specify particular title blocks to be used and rules for what goes where in the title block. If this is the case, the brief should include this information or a reference to this information.

4.2 CAD Files

Most surveys for engineering purposes are also required to be delivered as Computer-Aided Drafting (CAD) files. These CAD files are used as a background to the design, and data is often extracted into design software. Some projects and client organisations also have CAD manuals that specify how survey information should be delivered in the CAD files. If this is the case, the survey brief should include this information or references to this information. Often the final plans need to be delivered as one CAD file per drawing. This may require two sets of CAD files to be delivered. The format of the CAD files and the version should be included to ensure that those receiving the data can correctly read the data and not require any translation.

Where the survey includes a surface model, the brief should include a separate triangle file for the surface model to ensure that designers use the surface supplied by the surveyors and not one they have created themselves. Break lines should also be supplied together with an external boundary of the surface model.

4.3 Survey Report

One or more reports should be specified. There could be a report or section of a report for each type of survey. These reports are valuable to the users of the information as they give the surveyor an opportunity to pass on any information about limitations of the survey due to field conditions present at the time of the survey. This could include comments like long thick grass that made the ground surface not visible and therefore less certainty of the surface in between the survey points. The report may also indicate areas where the surveyor was unable to detail a limited area due to some onsite issue that may include flooding, unstable ground, archaeological or environmental restrictions.

4.4 Reports

There should also be a number of reports. These could include daily logs of the field work indicating date, time, start, finish and any unusual incidents, contact with neighbours and the public, any delays caused by outside influences, safety incidents or near misses, and any other incidents that might be relevant.

4.5 Survey Control

Reports should include adjustment reports, sketches and photos of control marks and also a control survey plot showing the network. In some cases, the survey observations used in the adjustment can also be a deliverable. If this is the case, the format should be specified in the survey brief, or how this is to be agreed. A final list of the survey control marks and their coordinates should also be supplied as a text file or spreadsheet.

4.6 Detail Survey

During the course of a detail survey, often some unexpected infrastructure is encountered. This may not be covered in a specified coding system. When this is the case, the survey report should identify such infrastructure with a photo and assign an unused code for this infrastructure. There should also be direction on how to show any attributes collected in the engineering detail. It should also be specified how profiles are to be presented.

4.7 Re-Survey

During the course of a detail survey, sometimes a re-survey is required due to a change in the surface during the survey. When this occurs, the survey report should show the extent of the re-survey.

4.8 Access Issues

During the course of a survey, sometimes access is more difficult than expected. This might be due to geography or it could be due to human interface issues. In both cases the report should indicate what difficulties were encountered and what solution was implemented to overcome the difficulties.

4.9 Aerial Photography

The format of the aerial photography should be specified. This could include any required tiling, geo-referencing and compression.

4.10 LiDAR

The brief should indicate what LiDAR processing should be carried out. The supplied data could include a raw point cloud, a classified point cloud, a subset ground surface point cloud, and a Digital Elevation Model (DEM) at a specified resolution.

5 SURVEY BRIEF CHECKLIST

5.1 Administration

In regards to administration, the following items should be covered in the survey brief:
- Purpose of the survey.
- Overall location of the survey – use existing maps / aerial imagery.
- Contact person – technical.
- Contact person – administration.
- Safety requirements – including dedicated safety personal if required.
- Required inductions, including safety inductions.
- Authority to enter site.
- Authority to enter adjaent lands.
- Approval before placement of survey marks.
- Qualifications of key personnel.
- Insurances required.
- Documentation pack before commencing survey – SWMS, permits, insurance certificates.
- Documentation to be carried in the field.

5.2 Survey

Control survey items to be covered in the brief:
- Geographic extent of control survey.
- Types of control marks.
- Locations (or frequency) of control marks.
- Accuracy of control survey.
- Documentation of control marks.
- Documentation of control network.
- Documentation of control adjustments.
- Coordinate system and datum.

Surface detail items to be covered in the brief:
- Geographic extent of the surface detail.
- Accuracy and any variations.
- Library of infrastructure.
- How additional information is to be captured.

Engineering detail items to be covered in the brief:
- Geographic extent of the engineering detail.
- Specific engineering items to be located.
- Required attributes for each type of item.
- Accuracy requirements for each type of item.

Built environment items to be covered in the brief:
- State items of built environment having special requirements.
- Purpose of the survey of the items of built environment.
- Specific parts of the items to be located.
- Required attributes for each type of item.
- Accuracy requirements for each type of item.

Underground services items to be covered in the brief:
- Geographic extent of the underground service survey.
- Purpose of the survey of the underground services.
- The coding and identification required for underground services.
- How services that could not be located should be indicated on the output.

Aerial photography items to be covered in the brief:
- Geographic extent of the aerial photography.
- Age of the aerial photography.
- Resolution of the aerial photography.
- Spatial accuracy of the aerial photography.
- Ground model to be used for ortho-rectification.

LiDAR survey items to be covered in the brief:
- Geographic extent of the LiDAR dataset.
- Horizontal and vertical accuracy.
- LiDAR density.
- LiDAR check survey.

Cadastral survey items to be covered in the brief:
- Geographic extent of the cadastral survey.
- Purpose of the cadastral survey.

Monitoring survey items to be covered in the brief:
- Extent of the monitoring survey.
- Expected movements.
- Expected time frame of movements.
- Expected stable areas.

Asset mapping survey items to be covered in the brief:
- Geographic extent of the asset mapping survey.
- Spatial accuracy for each type of asset to be mapped.
- Library of assets to be mapped and how to recognise assets.
- Attributes and pick lists for each asset and field.

5.3 Delivery Documentation

Delivery documentation to be covered in the brief:
- Logs of daily activity in the field.
- Logs of any issues.
- Reports for each type of survey.
- Hard copy plans.
- Soft copy plans.
- CAD files.
- Models.
- Sketches.
- Aerial photography.
- LiDAR.
- Cadastre.
- Assets with attributes.
- Monitoring and movement detection.

6 CONCLUDING REMARKS

The checklist presented here is both a generalised list and a live document. As further areas of misunderstanding come to light and as new types of surveys are considered, the list will alter and grow. There are also sub-sections for more specific surveys that contain more detail than is appropriate in such a generalised list. This list has come about as two parties have interpreted requirements differently and friction has occurred. The result of having a detailed survey brief provides both a more harmonious and efficient use of specialist survey resources. The list presented here will continue to grow as long as those preparing survey briefs understand the survey environment and field surveyors keep up an open dialogue with the clients.

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Game of Stones... The Big Stone Alignment Posts of Ryde

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ABSTRACT

From 1833, legislation was in place for the Surveyor General "to set out the breadth of the carriageways and footways in the town and cause the footways to be marked by posts at the corners and intersections". Hardwood posts, 150 mm square, were used for alignment and these appear to have been successful for almost 50 years. Wrought stone alignment posts were first used in Ryde in 1885 when it was recommended to Council, by a Lands Department staff surveyor, that sandstone posts be used in preference to wood, with the dimensions of the stones being stated "12 inches square 3 feet in length". In 2009, the City of Ryde Heritage Committee, with assistance from the local community, identified nine remaining stone alignment posts. At this point the survey team at Ryde became very interested! Since 2009, a further 28 stone alignment posts (in varying states of preservation and condition) have been located. This paper deals with the finding of these additional stone posts and answers such key questions as: Why are these stone posts so big (they each weigh upwards of 240 kg)? Why has no effort been made in the past to preserve these stone posts? How do we preserve them now, as most are still survey accurate? And who was that Lands Department staff surveyor?

KEYWORDS: *Alignment stones, preservation, Ryde, heritage.*

1 ALIGNMENT POSTS

In 1833, legislation was introduced requiring the Surveyor General "*to set out the breadth of the carriageways and footways in the town and cause the footways to be marked by posts at the corners and intersections*" (Marshall, 2006). Consequently, alignment posts are survey marks (monuments) placed at intersections and bends in the roadways to indicate the kerb lines. The first alignment posts were 6 inch (150 mm) square, dressed hardwood timber posts and appeared in Sydney City from 1836 when 400 posts were ordered and placed (Figure 1).

Figure 1: Timber alignment posts shown in an 1871 photograph of Buckingham Street, Sydney.

The Council of the Municipality of Ryde was similarly placing timber alignment posts in 1875 (Figure 2).

Figure 2: Part of alignment plan by Mr Surveyor George C. Hedgeland dated 1875, showing placement of timber posts at Belmore Street, Ryde.

The Council minutes of 30 August 1878 (Council of the City of Ryde, 2007) record correspondence from the Lands Department stating "*that alignment posts should be provided as soon as possible*" and Council proposing "*that a specification be prepared for alignment posts, the said posts to be sawn timber delivered in one lot and each post to have one coat paint*" (Figure 3).

Figure 3: Typical timber alignment post – photo taken at Blayney, NSW in 2013.

2 STONE ALIGNMENT POSTS

The first mention of stone alignment posts in Ryde occurred in the Council meeting minutes of 30 May 1884: "*that the works committee confer with surveyor as to road and streets to be aligned and consider whether stone or wood shall be used to show alignment*" (Council of the City of Ryde, 2007). At the next Council meeting on 13 June 1884 it was stated "*that he met the surveyor and presented him with a list of all the roads for alignment and that the said*

surveyor recommended that stone posts should be used for the alignment – 12 inches square 3 feet in length".

However, back in April 1881 the notion of using stones to mark section corners in Crown Land subdivisions was raised by a "*Mr Surveyor Bucknell asking if any stones … had been prepared by Municipality in accordance with an agreement*". To which Council responded in May 1881, informing him "*that no stones had been prepared by the Council to mark corners of sections in the subdivision of Crown Lands ... neither had any agreement been made ... to provide any such boundary marks*" and in July 1881 "*that a reward of two pounds be given on conviction of any person found disfiguring or damaging alignment posts or any other property of the Council*".

At a Council meeting on 25 July 1884 (i.e. 3 years later), a letter was tabled "*informing Council that it is customary to survey for alignment only those streets that are urgently required for public convenience and which the Council are about to form or expend money upon ... and to undertake to erect thoroughly substantial alignment posts in accordance with specifications enclosed ... and that alignment posts will be provided by Council*". Unfortunately, the enclosed specifications have not been located. A proposal was put, by the Mayor, at a Council meeting on 8 August 1884 "*that permission be sought to use stone instead of wood for alignment purposes*", and a letter was sent "*to Under Secretary Department of Works asking whether there would be any objection to stone being used for purposes of alignment in lieu of wood*". At the same meeting, the Council Works Committee stated "*that no other works of importance be entered into by the Council this year unless it be for alignment posts*".

At a Council meeting on 19 September 1884, Council received a letter from "*surveyor enclosing plans of stone alignment posts*" and at the next meeting on 17 October 1884 approved payment for "*two alignment posts (specimen) 1 pound 0 shillings*". At a Council meeting on 23 December 1884, Council proposed to accept "*the tender of P. McCarthy for furnishing 100 alignment posts at 5 shillings and 9 pence each*". At a Council meeting on 23 January 1885, Council then approved the payment to "*P. McCarthy 28 pounds 15 shillings for 100 alignment posts*" (and in May 1885 to "*J. Hicks for providing 55 alignment posts at 5 shillings and 5 pence each*"). At the same meeting in January, a letter was received from the surveyor "*pointing out that some of the alignment posts supplied were not dressed square*". Figure 4 shows part of an alignment plan with placed alignment post indicated, while Figure 5 shows a photograph of the same intersection.

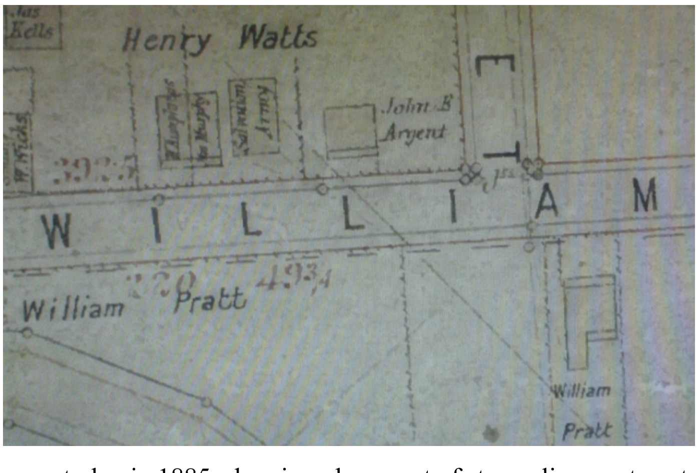


Figure 4: Part of an alignment plan in 1885, showing placement of stone alignment posts at a street intersection.

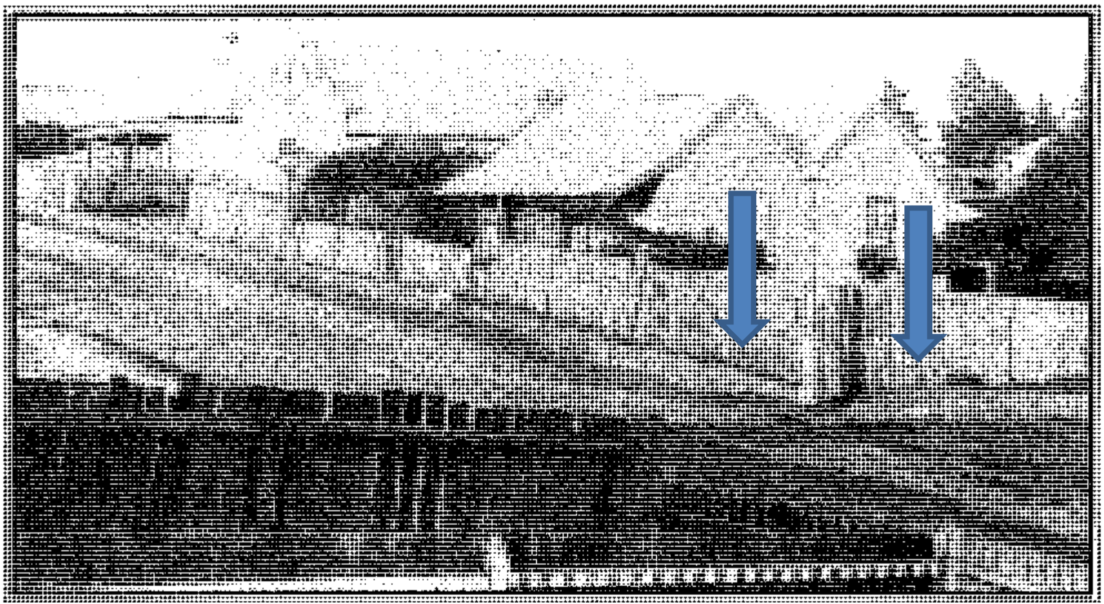


Figure 5: A photograph from 1898 of the same intersection, showing the stone alignment posts and the same buildings in position.

3 HERITAGE LISTING

In 2009, the City of Ryde Heritage Committee, with assistance from the local community, identified nine remaining big stone alignment posts. A report was tabled at the Heritage Committee which described the stone alignment posts as boundary markers (Mitchell, 2009), similar to the stone boundary markers of Sydney City and Parramatta, and steps were taken by the City of Ryde Council to heritage-list these nine known stones. At this point, the Council's survey team became very interested. Besides educating the Council as to the real purpose of the stone posts, the survey team took up the challenge to add to the list. Since 2009, a further 28 stone alignment posts (in varying states of preservation and condition) have been located. A sample from these first nine big stone alignment posts is shown in Figures 6-11. (The stone's 'number' refers to its order on the Heritage List.)

Figure 6: Stone 2, on North Road, Eastwood, showing the square dressed faces and weathered domed top. The stone has a broad arrow cut into one face, indicating that it was originally placed on a bend in the kerb line. This stone is in its original position.

Figure 7: Stone 3, on Blaxland Road, Eastwood, showing the square dressed faces, domed top and rough-hewn base. The stone has a broad arrow cut into one face, indicating that it was originally placed on a bend or crest in the kerb line. The orientation of the broad-arrowed face indicates that the stone is not in its original position but has been moved and rotated.

Figure 8: Stone 6, on Pittwater Road, North Ryde, showing the square dressed faces and domed top. The stone has had one face removed, but a shallow excavation reveals the true extent of the remainder of the stone. This stone is in its original position.

Figure 9: Stone 7, on Badajoz Road, Ryde, showing the square dressed faces, weathered domed top and rough-hewn base. The stone has a broad arrow cut into one face, indicating that it was originally placed on a crest in the kerb line. This stone is in its original position.

Figure 10: Stone 8, on Parkes Street, Ryde, showing the square dressed faces, weathered and damaged domed top and part of the rough-hewn base. The stone shows damage from vehicle scrapes, however painted line markings on the roadway have since helped to preserve the stone from further car strikes. This stone is in its original position.

Figure 11: Stone 5, on Pittwater Road, Gladesville, showing the square dressed faces, weathered domed top and a startling revelation. This stone post is only 230 mm by 230 mm square (the sole stone post found in Ryde to date being of a smaller size). This stone is in its original position.

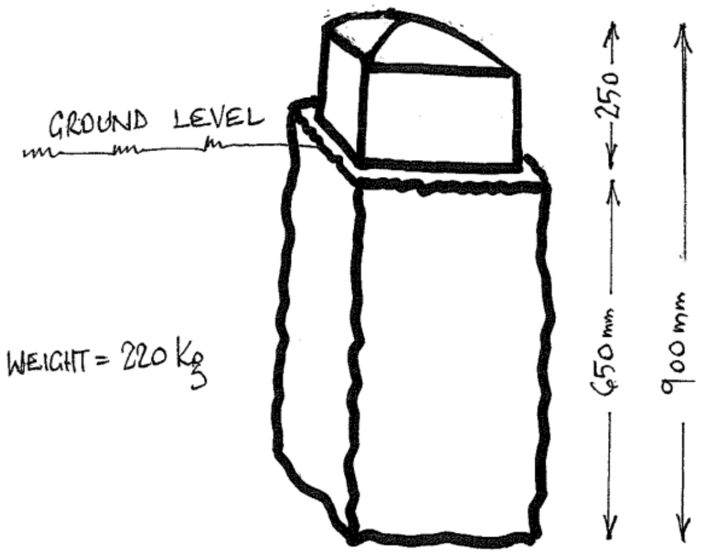
4 THE BIG STONE ALIGNMENT POSTS OF RYDE

Then a moment of magic! Four stone posts were found in bushland at the site of an 1882 road intersection, waiting to be placed on alignment under the supervision of a Lands Department surveyor. The road is still unformed. This stone, which was never set into position, is in excellent condition (Figure 12) but does not fit the criteria to be heritage-listed. It provides the classic shape and dimensions of the big stone alignment posts of Ryde (Figure 13). This stone post, which has been donated to Land and Property Information (LPI) in Bathurst for inclusion in their survey mark museum, was retrieved from the idyllic bushland setting. One other identical stone post, to be used by the City of Ryde, was also retrieved at the same time. The two other stone posts were left in situ.

This was the first time Council's survey team was able to see several entire stones. The dimensions of each stone were identical. They were a massive weight, upwards of 240 kg each – estimated by using house brick volume and weight, but verified by a stonemason who quoted 2.6 tonnes per cubic metre as the norm for this type of sandstone. None of the four stones showed any broad arrow marking. The four stones had been laying there in the open for 128 years!

Figure 12: Stone 17, in Kitty's Creek bushland, East Ryde.

Domed top with dressed faces 300 mm x 300 mm.



Rough-hewn base 350 mm x 350 mm variable.

Figure 13: Classic shape and dimensions of the big stone alignment posts of Ryde.

As mentioned earlier, alignment posts are survey marks placed at intersections and bends to define the boundaries of roads, with one dressed face being aligned with the kerb line. When a stone alignment post was used to define a bend or crest in the road then a broad arrow mark was cut into one dressed face to indicate the bend in the kerb line. Why four dressed faces if only one is needed? The dressed top of the stone post stands above ground level and is therefore visible, so it may have been a matter of aesthetics.

At this point the Ryde Council survey team became interested in how much bigger these stone posts are when compared to the stone alignment posts found in other metropolitan locations (Figure 14). Although stones were used for alignment posts in these diverse districts, their size is much smaller: 230 mm x 230 mm square dressed faces. This results in the weight of the stone being half that of the big stones of Ryde. Could this have been a contributing factor in the downsizing? It would be interesting to find out if these smaller stones were, in fact, placed after 1885.

Figure 14: Alignment posts of (a) Hornsby, (b) Stockton, (c) Hunters Hill and (d) Parramatta.

Still the questions remained: Why stone, and why so big? Was the local council trying to make a statement? Was the surveying industry making a statement? After 50 years, had timber alignment posts had their day? Were the timber alignment posts rotting and deteriorating and was therefore a more durable material needed? One person recently suggested that it was to deter surveyors from souveniring them for their own office displays!

The Lands Department surveyors, during a major land release at North Ryde in 1882, requested Council to supply stones with which to mark the section corners. Council declined. Three years later, however, when the alignment surveys were requested by Council, stone posts were to be used. Land surveys in Ryde through to the 1950s and 1960s always used the alignment posts to fix the street boundaries. Adopt a pair, and you only have to worry about fixing side boundaries. Then road and drainage works had a major impact. Raising or cutting of the road shoulders, to allow full pavement width for road surfaces, and construction of concrete kerb and gutter meant the stone alignment posts were buried, trimmed, damaged or removed and effectively ignored.

5 PRESERVATION

How can the remaining big stone alignment posts be best preserved? Figures 15-17 provide some examples. Another idea, yet to be trialled, is to erect a metal barrier or guard at any stone that is situated in the footpath zone in order to minimise the risk of trip hazard.

Figure 15: Stone 14, on Bridge Road, Ryde, showing a complete stone post which has been relocated sometime in the past and preserved to be used as a property corner post. This stone post cannot be heritage-listed as it stands on private property.

Figure 16: Stone 11, on Quarry Road, Ryde, showing that the domed top and dressed faces have been removed while the rough-hewn base still remains. Road works have raised the ground surface level, so a metal cover box enables access to the stone. Note that the survey mark (i.e. the dressed face) is gone, however comparative measurements, on all stones discovered so far suggest that an offset of 30 mm or 35 mm from the rough-hewn base closely approximates the position of the original dressed face. This stone is in its original position.

Figure 17: Stone 31, on Wolfe Road, East Ryde, showing domed top and 30 cm dressed faces. The stone has a broad arrow facing the road, indicating that it was originally placed on a crest in the kerb line. The stone has been buried for many years and now resides under an improvised metal cover. This stone is in its original position and in perfect condition.

However, the Ryde Council survey team's best attempt at preservation has occurred at the Forrest Road / Malvina Street intersection (Figure 18). Here, seven of the original eight stones were found in place. It is intended that this intersection be maintained as a heritage site.

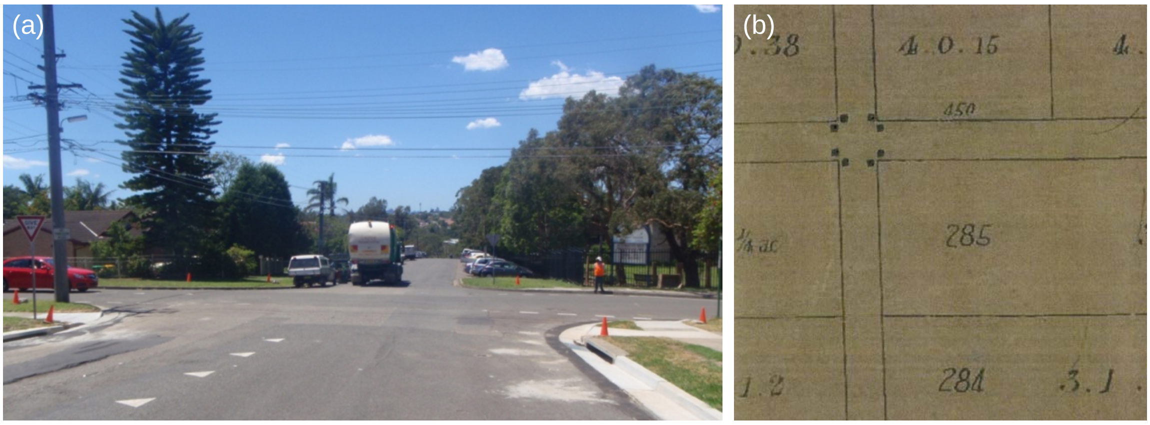


Figure 18: (a) Orange cones indicating the location of each of the stone alignment posts, and (b) part of an 1885 tracing showing the alignment survey at the intersection.

During 2013, major road works were planned for Forrest Road. The works included replacing the existing concrete kerb and gutter on each side of the road. The damaged remainder of an 1885 stone alignment post was visible on the southern side of the intersection and had been incorporated into the old kerb (Figure 19). It was decided to replace this stone with one retrieved from Kitty's Creek bushland in order to have a full sized alignment post, with dressed faces, to enhance the intersection as a heritage site (Figure 20). It was, after all, a stone from the original 1885 alignment survey!

Figure 19: Damaged remainder of an 1885 stone alignment post on the Forrest Rd / Malvina St intersection.

Figure 20: Setting of the replacement stone alignment post, which is now incorporated into the new kerb.

At the other end of Forrest Road, removal of the old kerb had already exposed the base of an original stone alignment post. The dressed top had been removed by the previous construction. This remnant was left in place and re-hidden beneath the new kerb. However, a distinctive survey mark was placed above in the new concrete gutter by the Ryde Council survey team to indicate the position of the road alignment (Figure 21).

Figure 21: Remnant base of an original stone alignment post and distinctive survey mark placed above in the new concrete gutter.

No stone was visible on the northern side of the Forrest Road intersection, and it was unknown if any part of that stone alignment post remained beneath the old kerb. A dig exposed stone remains, although badly damaged by previous drainage works (Figure 22).

There was so little left of this stone that it was decided to re-instate another. One other previously retrieved stone alignment post was available from the 1885 survey (stone 28), which has a substantial part of its base removed and a large post-hole drilled into its domed top. Construction of the new kerb and gutter incorporated the replacement stone alignment post (Figure 23). So yes, the new concrete kerb is laid on the kerb line! A patch-up job to fill the hole to restore the domed top is currently underway.

Figure 22: Badly damaged alignment post remains on the northern side of Forrest Road.

Figure 23: Construction of the new kerb and gutter, incorporating the replacement stone alignment post.

It should be noted that sometimes, in the absence of human disturbances, stone alignment posts are remarkably well preserved by nature itself (Figure 24).

Figure 24: Stone 34, on Pittwater Road, North Ryde, showing remarkable preservation after so many years. This stone is in its original position.

6 RESTORATION

What to do with the damaged stone alignment post retrieved from the southern intersection? It was removed with the mad idea to re-dress one end of it into a domed top with four squared faces. Ryde Council has a stonemason by happenstance, who agreed to give it a go, using basic hand tools. Just how difficult would it be to replicate the work of the 1885 artisans? The exercise of recreating a dressed stone post took the stonemason about one day (Figure 25). As yet, no plans have been made to use this stone at any site.

Figure 25: Dressing of a stone alignment post using traditional methods and hand tools. Firstly, an even surface from which to measure is created. Then the four squared faces are chiselled and the domed top is created.

7 FOOTNOTE IN HISTORY

And just who was that Lands Department staff surveyor who, so many years ago, recommended that stone alignment posts be used in Ryde, and that they should be so big? He was registered in 1880. In 1881-82 he undertook Crown Land subdivision work at Ryde, followed in 1885 by numerous alignment surveys in the same area (Figure 26).

Figure 26: Part of his 1885 tracing showing alignment of roads in Field of Mars Common.

His name...? Charles Robert Scrivener (Figure 27)!

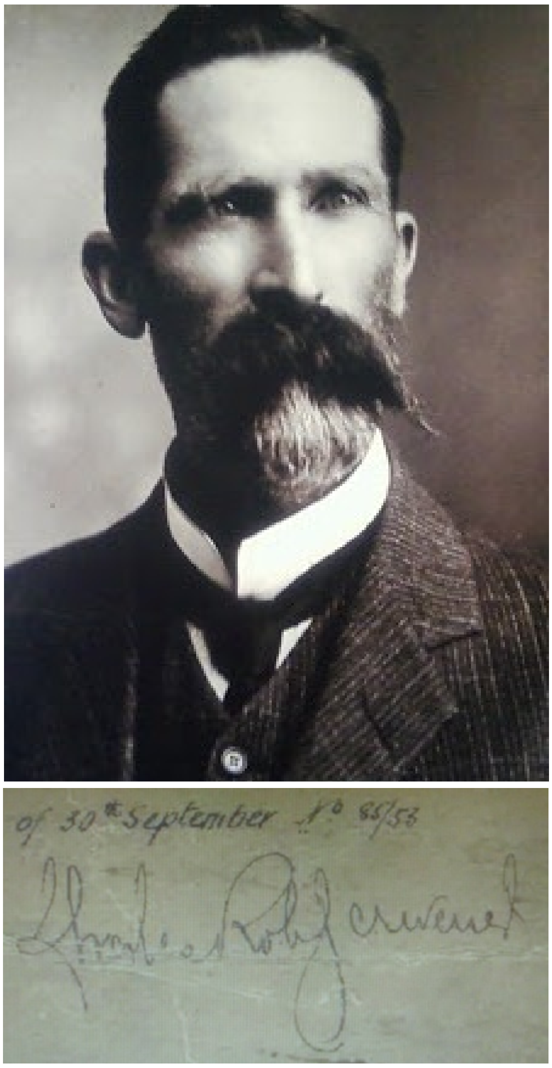


Figure 27: Charles Robert Scrivener and his signature on said 1885 tracing.

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Maintaining the Integrity of the Cadastre in the Port Macquarie-Hastings Local Government Area

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ABSTRACT

In 2013, the Port Macquarie-Hastings's Survey and Design Section reviewed Council's practices in relation to survey infrastructure in the Local Government Area. The review found that survey marks have been lost or disturbed when works have occurred within land owned or managed by Council, roadways or on land subject to a development application. As a consequence of this, determination of boundary position, mapping, planning and construction works become more difficult and costly. Also Council or Council's contractors could be fined for breaching the Surveying and Spatial Information Act, which states that it is illegal to "remove, damage, destroy, displace, obliterate or deface any survey marks." In order to reduce the number of survey marks being destroyed, it was decided that new workplace practices needed to be implemented. This paper documents these new practices as well as detailing the importance of survey marks and how survey marks may fit into the cadastral reform framework.

KEYWORDS: *Survey marks, policy, procedures, Local Government, cadastre.*

1 INTRODUCTION

In the current climate of Local Government review and limited funding, councils need to ensure any funding received is spent wisely, and will strengthen their communities' economy and social position. One of the areas needing careful consideration is the relevance of councils managing the cadastre in their Local Government Area (LGA) now and into the future. With this in mind, Council's management may consider the following: Why is it important for a council to maintain the integrity of the cadastre in their LGA? Should ratepayers foot the bill for the upkeep of an asset that is managed by State Government bodies? Should ratepayer's money be diverted, from areas that are deemed essential services, to survey related services?

1.1 The Meaning of Maintaining the Integrity of the Cadastre

The Macquarie Dictionary provides the following keyword definitions to explain the meaning of maintaining the integrity of the cadastre:

- Maintain: to keep in due condition, operation, or force.
- Integrity: the state of being whole, entire and undiminished.
- Cadastre: an official register of property, with details of boundaries, ownership, etc.

Hence, to maintain the integrity of a cadastre, the boundaries of land and associated property information need to be kept free from error by long-term upkeep and repair. To ignore any part of the cadastre is risky, as a discussion between the Registrar General of NSW and the

Institution of Surveyors in the early 20th century highlighted (Crundwell et al., 1995): "...*Williams conceded some of the surveyors' arguments and risked undermining the popularity of the Torrens System. After all his certificates did incorporate a land description and diagram, but the Institution was now saying loudly that these were useless without the backing of accurate surveys*."

1.2 Council's Important Role in Maintaining the Cadastre

The majority of tasks relating to the maintenance of the cadastre are the responsibility of the Registrar General and the Surveyor General of NSW and their departments. For example, one of the main responsibilities of the Registrar General is to maintain the Torrens Land Register, and the Surveyor General is the overseer of cadastral surveys in NSW and the associated legislation. (These departments cannot show that they are partial to a particular LGA when maintaining the cadastre.) However, this does not mean that local government or private surveyors are free from responsibility to the cadastre and councils can play a crucial role in maintaining the cadastre as they are at the ground roots level, have their ratepayers' interests at heart and view their LGA as one contiguous entity. On the other hand, survey plans, the majority prepared by private surveyors, represent a small isolated part of the cadastre.

Council is a public authority, but it is not one of the public authorities that are directly responsible for managing the cadastre in NSW. As mentioned earlier, the majority of tasks relating to the maintenance of the cadastre are performed by the Registrar General and Surveyor General of NSW and their departments.

Cadogan (1997) noted the following about the service the City of Sydney surveyors offer to their council (and the possible demise of the service of these surveyors): "*Some private surveyors with extensive city practices are dismayed at the impending demise of the custodians, and the data and marks they provide. They have neither the time, the background, or the interest in maintaining the system (which they need and whose absence will add substantially to the time taken and hence the cost of surveys in the city). In any case, no man can serve two masters – there is the private interest (in the land abutting) and the public interest (in the streets themselves) and the dividing lines between these often competing interests are alignments. To put this another way: What would you do if you owned a very large elongated parcel of the most valuable real estate in Australia? This land has extensive boundaries in common with a great many neighbours. These neighbours pay you for access (among many other services) and are continually changing, redeveloping and upgrading your common boundary occupations. In relation to these activities, you already have in place the data, the infrastructure, and the small, specialised and experienced staff to supply a certain service to these neighbours and at the same time, to protect your own interests. This service is to define or supervise, or supply data from which every millimetre of those boundaries may be defined, horizontally and vertically, at any time. Your predecessors and you have provided this service since the beginning of settlement...*"

Many local councils do not have the extensive boundary records or alignment survey control network of the City of Sydney, but the principles of valuing the infrastructure that relates to the boundaries of the council's owned and managed land is the same. Also, the service of defining council common boundaries is of value to any council.

1.3 Role of Port Macquarie-Hastings Council in Maintaining the Cadastre

Over the years, Port Macquarie-Hastings Council has employed surveyors. These surveyors have been employed in different roles, e.g. registered surveyors, engineering surveyors, designers, technical managers and Geographic Information System (GIS) specialists. Like many other councils, there have been long periods of time where surveyors with extensive cadastral survey training have not been in management roles. Hence, decisions about the management of the cadastre have been made by GIS, property and engineering staff.

When practices relating to the cadastre were reviewed by members of the Council's survey and design staff in April 2013, it was found:

- No Council policy existed relating to the preservation of survey marks.
- The majority of preservation of survey marks work focussed on the maintenance and preservation of state control marks.
- Work practices were dependent on individual surveyors, designers or team leader initiatives.
- The majority of education work had been done by the local geodetic surveyor, not by an employee of Council.
- There was no adopted Council documentation on procedures.
- Surveyor General's Direction No. 11 (LPI, 2004) had not been followed when re-establishing survey control. Hence, many new survey control marks had no associated coordinate information and were allocated class U in the Survey Control Information Management System (SCIMS).
- Replacement survey control marks were generally positioned after the original mark had been destroyed.
- Protection of boundary marks and boundary reference marks was not being considered during the construction process.
- About 10% of all state survey control marks in the Port Macquarie-Hastings LGA have been reported as destroyed, uncertain or not found (L. Gardner, 2013, email comm.).
- Boundary reference mark database information was lacking.
- Survey marks were not considered as a council asset.

On a positive note, a minority of cases did comply with Surveyor General's Direction No. 11 and with Survey and Spatial Information legislation. The GIS department of Port Macquarie-Hastings Council has also been instrumental in creating a survey-accurate Digital Cadastral Database (DCDB) for about ⅓ of the parcels in the LGA. The term survey-accurate cadastre relates to a DCDB created using dimensions of lots stated on a survey plan and connections from the lots to state survey control marks (Todd et al., 1999).

It was clear in the review that the ratepayers of the Port Macquarie-Hastings Council area are being adversely impacted by limited resources being allocated to preserving survey infrastructure and managing the cadastre in the LGA. It should also be remembered that survey marks and the cadastre are not the exclusive domain of the survey services. If these items are not managed properly, they will affect other council sections that deal with any land (whether a road, lot or waterway). It therefore makes sense for councils to use funds to protect survey marks in the LGA and strengthen the cadastre, which will in turn protect one of Council's most valuable assets – land.

Benefits of improving practices related to the cadastre include:

- Preserve an asset that benefits Council.

- Preserve horizontal and height control across the LGA.
- Minimise boundary disputes between Council and property owners.
- Minimise the financial loss Council experiences due to the destruction of survey marks.
- Improve the value of the cadastre in the LGA.
- Provide a clear idea of the area of an acquisition at the planning stage of a project.
- Sustain the value of land in the LGA.

1.4 Changes to Practices

A preservation of survey marks project was started shortly after the review of practices in April 2013. This project includes the development of council policy and procedures relating to the preservation of survey marks and the implementation of the new policy and procedures. After the preservation of survey marks project has been finalised, a more general Boundary Improvement Project (BIP) will be commenced. This project will be developed by the Survey and Design Section, in conjunction with the property and GIS departments of Council.

1.5 Future of the Cadastre in the Port Macquarie-Hastings LGA

Like the rest of NSW, Port Macquarie-Hastings Council will have a simpler boundary system, a quicker starting point for boundary surveys, and all employees will have easy access to complete property information about a land parcel.

Bennett et al. (2010) outlined how the cadastre will change in the future: "*Firstly, [there] will be a need for survey-accurate cadastral data; secondly, a shift in focus from land parcels to property objects. Third will be a need for height and time information, and fourth for real-time updating and accessing cadastral databases*."

It is essential that surveyors consider how the cadastre will be in the future, when considering how to manage the cadastre today. Practices adopted by current surveyors must be able to be built on by surveyors in the future. Present day surveyors must also consider the currency of adopted practices and if the practices are delivering the desired outcome.

2 THE CADASTRE

Cadastral systems are used for land tax and ownership purposes but are also used for facilities management, base mapping, value assessment, land use planning and environmental impact assessment (Kaufmann and Steudler, 1998). From a surveyor's perspective, the cadastre would be a group of parcels where the boundaries of those parcels are as per the intention of the cadastral survey that created the parcel.

A modern cadastre (or a cadastre of today) as defined by Kaufmann and Steudler (1998) will:
- Show the complete legal situation of land, including public rights and restrictions.
- Abolish the separation between 'maps' and 'registers'.
- Model (not map) the cadastre by sourcing different databases.
- Be computerised.
- Be highly privatised with public and private sectors working closely together.
- Be cost recovering.

This definition extends the cadastre to include the title registers and traditional, private and public land dealings and rights. In the future, understanding all the land-related issues affecting a parcel will be simpler.

2.1 Graphical Representation of the Cadastre

One of the first graphical representations of the cadastre was created by the Lands Titles Office in the late 1980s. This was the inception of the DCDB managed by Land and Property Information (LPI) (Crundwell et al., 1995). The DCDB is classified as a graphical cadastre, while other representations of the cadastre include the upgraded graphical cadastre, survey-accurate cadastre, reinstated cadastre and legal cadastre (Todd et al., 1999).

Graphical and upgraded graphical cadastres are created by digitisation of cadastral maps. The main difference is that an upgraded graphical cadastre is referenced to a datum. The survey-accurate cadastre uses dimensions from survey plans ('metes') and connections to the datum. The reinstated cadastre uses both dimensions from survey plans ('metes') and the 'bounds' or monuments described on survey plans or deeds. A legal cadastre is a 'fixed boundary system', where coordinates define the corners of a parcel and interests (Kaufmann and Steudler, 1998; Todd et al., 1999).

2.2 Boundary Determination in NSW

A reinstated cadastre closely reflects how boundaries are determined in NSW. Prior to the adoption of the Torrens Land System in 1863, NSW had adopted the common law system of deeds from the United Kingdom. Land was described on a deed by a 'metes' and 'bounds' description. 'Metes' are the dimensions of the land and 'bounds' are objects (or monuments) used to describe the position of a boundary line. An example of a 'mete' in a deed description is "*bearing south fifteen degrees six minutes west sixteen feet three inches*" and an example of a 'bound' is "*to the south-west face of brick wall*".

Instead of using a 'metes' and 'bounds' description of land, modern Torrens title refers to title diagrams. These title diagrams relate to the survey plan that created the parcel. These survey plans show the dimensions of the lots (to be created) and have connections between permanent survey marks and boundary reference marks and the lot corners. The nature of the boundary marks is also shown on the plan.

A hierarchy of marks, defined by Gordon and Allen (2005), is used by surveyors in NSW to help determine the positions of boundaries. This hierarchy includes:
- Natural features.
- Original Crown markings of grant boundaries.
- Monuments.
- Original undisturbed markings of private surveys.
- Occupations.
- Measurements.

The main aim for a surveyor is that the boundary position can be reproduced with confidence, and reflect the original surveyed position.

2.3 The Cadastre and Port Macquarie-Hastings Council

The DCDB used as a base layer in Council's GIS is a combination of an upgraded graphical cadastre and a survey-accurate cadastre. The limitations of this system include:

- Varying accuracies of boundaries.
- Cadastre not reflecting current subdivision layout.
- Incorrect utility (e.g. sewer, water, stormwater or street light) boundary offset representation shown.
- Incorrect proposed works to boundary offsets shown.
- Inability to use layer for survey and design work.
- Easements and other encumbrances not shown.
- Misinterpretation of data.
- Unclear picture of property acquisition.

On the other hand, the survey-accurate cadastre model reflecting the current subdivision layout is a powerful tool used by all sections in Council. Significant efficiencies have been gained in the planning and design stages of many projects by being able to utilise this model. Generally, lot corners are accurate to about 0.07 m, which is an acceptable accuracy for design work. Surveyors also use this layer as a base to help locate cadastral survey marks, stake boundaries at construction sites or as a starting point for boundary definition surveys. As surveys are conducted in any location in the LGA, there are many occasions where a digital representation of the cadastre is not available. In these cases, surveyors need to rely heavily on existing survey infrastructure. In some areas, survey infrastructure is lacking, thereby making boundary determination difficult.

3 SURVEY INFRASTRUCTURE

Until another boundary system is realised in NSW, survey infrastructure plays a vital role in determining boundaries and hence the cadastre. Consequently, the Survey and Design Section made preservation of survey infrastructure a primary objective when maintaining the cadastre in the Port Macquarie-Hastings LGA.

The two types of survey infrastructure mentioned in the Surveying and Spatial Information Act 2002 are permanent survey mark and survey mark (NSW Legislation, 2014a). These marks are used by the surveyor to "*locate or relocate boundaries*" and connect to the state control network (NSW Legislation, 2014b). The definition of a permanent survey mark under the Act is "*a survey mark that is in a form or style declared by the regulations to be the form or style for a permanent survey mark under this Act*", and a survey mark is defined as "*a mark that is in a form or style declared by the regulations to be the form or style for a survey mark under this Act*" (NSW Legislation, 2014a).

The Surveying and Spatial Information Regulation 2012 splits survey marks into the following forms and styles: boundary marks, reference marks, bench marks and permanent survey marks (NSW Legislation, 2014b). It should be noted that the regulation also refers to broad arrows, which are survey marks only used when authorised by the government. Boundary marks are used to mark boundary lines and corners. Reference marks make reference from a survey mark placed to a boundary corner, angle or line. A bench mark is a survey mark with an allocated height. A permanent survey mark is a mark used or placed by surveyors when connecting to the state survey control network. Each of these groups of marks

is described in separate schedules, appended to the Regulation. A monument is described by the Regulation as "*a natural or artificial object, or a point on a natural or artificial object, that is shown on an existing survey plan held by a public authority for the purpose of locating or relocating a boundary or point in a survey*".

Like most jurisdictions, NSW has laws relating to the protection of survey marks. Under section 24 of the Act a "*person must not remove, damage, destroy, displace, obliterate or deface any survey mark unless authorised to do so by the Surveyor General*". If found guilty, the maximum fine a party will be required to pay for destroying a survey mark in NSW is $22,750 (NSW Legislation, 2014a). This is equivalent to about a third of the average yearly wage in NSW.

As applications for authorisation to remove survey marks (mentioned in section 88 of the Regulations) only applies to "*permanent survey marks and reference marks*", this would infer that some bench marks and boundary marks are not protected under the Act. An application for authorisation has to be lodged at least 14 days before survey marks are going to be impacted. The template Survey Mark Report can be used as an application form to seek authorisation from the Surveyor General. Authorisation would probably be given if the removal or alteration is deemed necessary – see section 20(1) of the repealed Survey Co-ordination Act 1949 (NSW Legislation, 2002).

3.1 Who is Responsible for Survey Marks?

In NSW, the Surveyor General and LPI are responsible for establishing, improving and maintaining the State's geodetic and survey control network. Both public and private surveyors add permanent survey marks to the network.

After notice has been given by the Surveyor General to a public authority, who manages or controls the land on which permanent survey marks are located, that authority must maintain and repair those marks "*identified in the notice*". A public authority can apply to the Minister and the duty may be reallocated to the Surveyor General (section 9 of the Surveying and Spatial Information Act 2002). The notice given to the public authority by the Surveyor General is in the form of a locality sketch of the permanent survey mark, which is required to be drawn by the surveyor placing the permanent survey mark. Hence, if a permanent survey mark exists on a council managed or controlled road, the council needs to pay for any repair out of Council's maintenance budget for the road.

3.2 Who are the Main Users of Survey Infrastructure?

Anyone who is involved in the science, management and development of land may use survey infrastructure. Permanent survey marks also include Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS), which are used to realise the national and state datums and provide fundamental positioning infrastructure for a wide range of applications across the State, e.g. via CORSnet-NSW (Janssen et al., 2011, 2013). GNSS CORS networks allow users to derive accurate coordinates by using only one receiver. This has substantially increased the market and affordability of GNSS-operated machinery.

Permanent survey marks are also used on any projects where accurate horizontal coordinates and height values are needed. These projects may be in the field of asset management, mapping, GIS, cadastral surveying, infrastructure construction, building, planning and design.

Even if a permanent survey mark is not an established survey mark (as described in the Surveying and Spatial Information Regulation 2012), the mark is still used for cadastral surveying, engineering surveys, plan and design applications and could be coordinated at a later stage to help provide an accurate digital cadastre model in the locality or aid with the development of the area.

Unlike permanent survey marks, boundary marks, reference marks and bench marks (generally) do not have allocated coordinates in SCIMS. The purpose of these marks is to define the cadastre, i.e. to locate and relocate the boundaries of land and any restriction limit.

Councils, sometimes unknowingly, require contractors or customers to use the survey infrastructure in their LGA. At Port Macquarie-Hastings Council, the following drafting requirements for Council's Computer-Aided Drafting (CAD) standards and specifications are imposed (Port Macquarie-Hastings Council, 2004):

- All works shall be provided on the Map Grid of Australia (MGA).
- The adopted height datum for all plans shall be the Australian Height Datum (AHD).

Development Applications and Construction Certificates also require boundary setbacks to be shown between proposed or existing structures and the boundary line or easement or encumbrance. Especially in the case of permanent survey marks, survey marks are directly or indirectly used by many industries in Australia. Even though land surveyors (i.e. cadastral surveyors, engineering surveyors and geodetic surveyors) and geodesists are the two main groups that place, measure and maintain survey marks in NSW, the information obtained benefits everyone in the community.

3.3 Placing a Monetary Value on Survey Infrastructure

One realises the value of survey infrastructure, when a Class A and Order 1 (high) accuracy permanent survey mark is destroyed or disturbed during construction works. Survey information and infrastructure lost, when a high-accuracy mark is destroyed or damaged, includes:

- A survey marker.
- Established survey mark near job site.
- Very accurate horizontal coordinates and height information.
- Measurement data between the destroyed mark and other marks.
- Measurement data between the destroyed mark and the boundary (if referenced on a plan).

Once the value of each of these items is added up, the above mentioned mark would be worth at least $10,000. Table 1 provides an approximate fee estimate of the costs associated with re-establishing a new mark.

Hence, the cost of losing a survey mark and re-establishing a high-accuracy survey mark to the same accuracy of the original mark that was destroyed is about $20,000. If the existing mark was kept and was able to be used to re-establish the new mark, costs are reduced. Figure 1 shows the different traverse requirements, specified in Surveyor General's Direction No. 11, which illustrates this point.

Table 1: Summary of estimated job costs for re-establishment of a high-accuracy survey mark. Calculations are based on an average charge-out rate of $200/hr and an 8-hour day.

Item	**Estimated Time**	**Cost**
Lost time (contractors)	¼ day	$800
Lost time (Council's works engineer)	¼ day	$400
Lost time (Council's registered surveyor)	½ day	$800
Lost time (Council's survey technician)	½ day	$800
Directing the re-establishment of survey mark works and calculations (LPI's geodetic surveyor)	1 day	$1,600
Re-establishment of survey mark (contractor's survey team)	2 days	$4,800
Allocation of temporary mark coordinates and registration of locality sketch (LPI's SCIMS staff)	½ day	$800
Allocation of mark coordinates (LPI's geodesy section)	1 day	$1,600
Total	**6 days**	**$11,600**

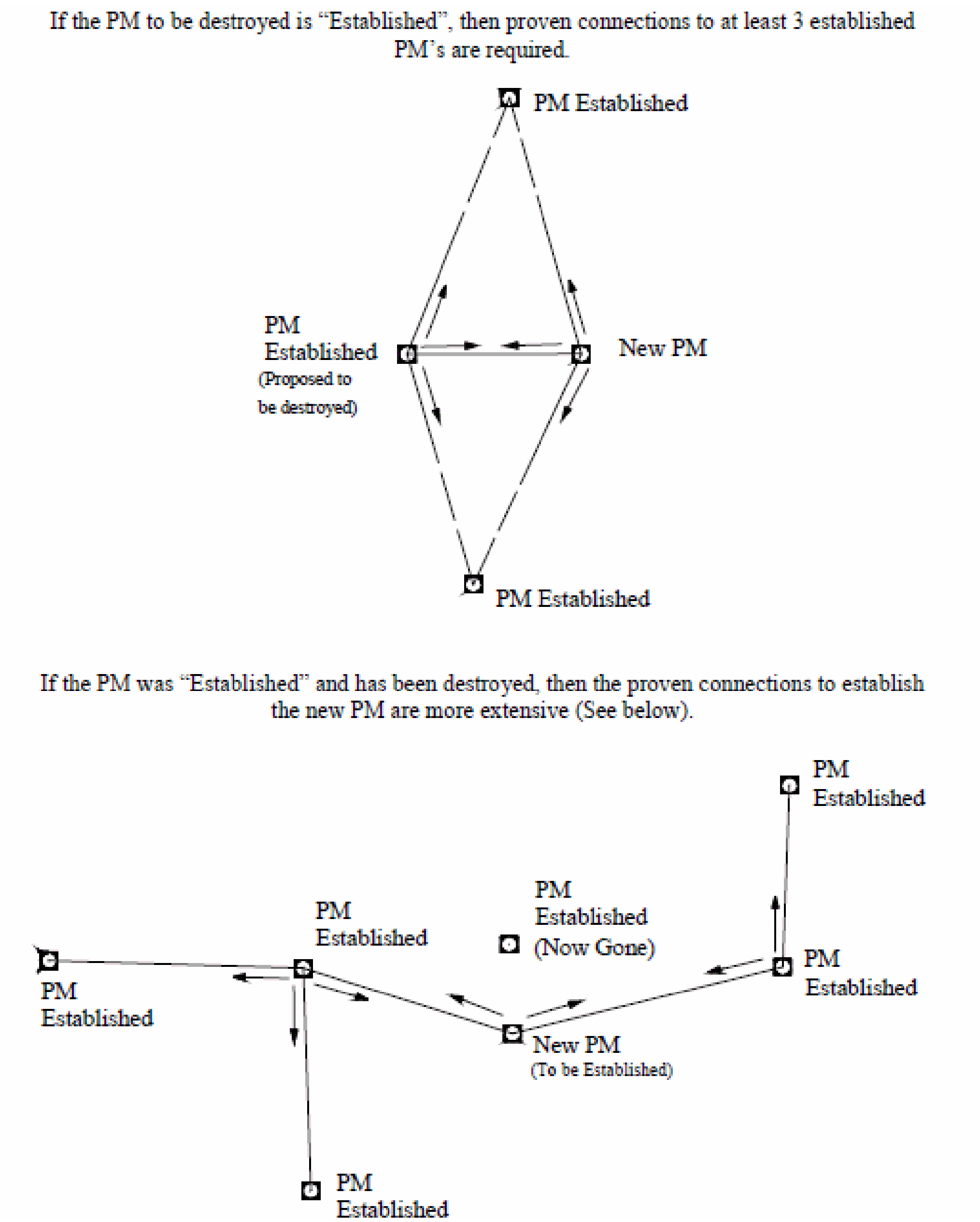

Figure 1: Establishing a new permanent survey mark (original mark existing vs. original mark gone) (LPI, 2004).

It has been stated that the cost to replace a survey mark after the original mark has been removed is four times higher than if the mark is replaced before removal (L. Gardner, 2013, email comm.). As well as the legislation relating to survey infrastructure, NSW has a number of directions and guidelines relating to survey infrastructure. These documents set out the standards for establishing survey marks of varying accuracy. For example, high-accuracy marks require numerous sets of observations, rigorous calculations (including least squares adjustments) and error analysis.

In the Port Macquarie-Hastings area, it is estimated that the average cost to establish new permanent survey marks to replace the marks that have been destroyed is $40,000 per annum (L. Gardner, 2013, email comm.). This amount does not include the extra survey costs that arise when boundary marks, reference marks and bench marks are destroyed or the long-term cost of depletion of survey infrastructure in the LGA. Given there are about 3,500 listed SCIMS marks in the Port Macquarie-Hastings LGA, even if a very conservative value of $1,000 was given to each of these marks, the cost of constructing this survey infrastructure is $3.5 million. A 5-to-1 benefit-to-cost ratio was determined, by Price Waterhouse for the Land Information Centre, when assessing the survey control network (L. Gardner, 2013, email comm.). Hence, the overall value of the survey control network for the Port Macquarie-Hastings LGA is about $18 million.

Unlike permanent survey marks, very little database information exists about other survey infrastructure in NSW. In the Port Macquarie-Hastings LGA about 20 Cadastral Reference (CR) marks have been included in SCIMS. Other database information about reference marks exists in LPI's DCDB. Otherwise, reference mark information needs to be extracted from survey plans on public record. A gross estimate of the costs incurred to establish each of the existing reference marks in the Port Macquarie-Hastings LGA is $3.5 million. This calculation is based on each parcel having one reference mark, a mark value of $100/mark and 35,000 parcels existing in the LGA.

3.4 Cost of Establishment, Maintenance and Repair for Council

In the last seven years, Port Macquarie-Hastings Council has spent $10,000 on the establishment of survey control marks (Brierley, 2013). Very little money has been spent on maintenance and repair work (J. Thompson, 2013, pers. comm.). Figure 2 shows a trigonometric station that was repaired by Council. Materials for the new vane were sourced from LPI. Total time taken to repair the trig, including travel time, was about half a day.

Figure 2: Trigonometric station repaired by Port Macquarie-Hastings Council.

3.5 Why is Survey Infrastructure Destroyed?

There are a vast number of reasons why survey infrastructure is destroyed but the main reasons are lack of planning and ignorance. Non-surveyors generally underestimate the value of a survey mark, are unable to identify survey marks or do not know where survey marks most probably occur on a site. Unlike services, survey marks are sometimes not considered in the planning and design stage. This means, during works, survey marks are either destroyed or disturbed or construction is stopped, so the required fieldwork can be completed.

Maintenance work, which has a minimal planning stage, is performed quickly without consulting surveyors or checking if any survey marks will be impacted by the works. Even slashing, which generally does not affect other services, has damaged survey infrastructure when the machinery has run over a mark or hit a mark that is set on a concrete pillar. Another reason is that it is difficult for surveyors to place survey marks in a safe location that is unlikely to be disturbed as there is no service allocation space for survey marks within footpaths. Other service authorities have various sections of the footpath allocated to them for their service. In 1933, survey marks were allocated the 2-foot strip from the road boundary but the Post Master General's Office (now known as Telstra) used their overriding powers to place their cables in the 2-foot strip reserved for survey marks (Beaver, 1980). Survey marks are often placed in the kerb line, which has a finite lifespan, or on roadways, which make the marks very hard to access and expose them to resurfacing works.

3.6 Who Destroys Survey Infrastructure?

As the majority of survey marks are within the roadway or on council reserves, these marks are destroyed by anyone performing works within this area. Following is a list of workers, who are most likely to destroy survey marks – some of these workers may not physically destroy the mark but the mark is destroyed due to their actions (or lack of actions):

- Engineers
- Designers
- Site foreman
- Civil construction workers
- Surveyors
- Trades persons
- Handymen
- Slasher operators
- Tree loppers
- Project managers
- Excavator operators
- Home handyman
- Farmers
- Sucker truck personnel
- Maintenance crews

3.7 Asset Management and Survey Infrastructure

Land is already recognised as an asset. Survey infrastructure is just a subset of this asset. Hence, one way to better managing land as an asset is to manage survey infrastructure effectively as an asset. Appreciation or depreciation values can be placed on each survey

mark. The location of each mark can be stored in one central database. For example, a drill hole and wing will depreciate in value as the kerb moves or the kerb is due for replacement.

3.8 How are Survey Infrastructure and Boundaries Currently Being Managed?

The Surveyor General and LPI manage survey infrastructure in the following ways: legislation, directions, guidelines, fines, work programmes, audits, advice, the SCIMS database and other databases.

Councils manage survey infrastructure by making survey infrastructure information available to all council employees, abiding by and following relevant acts, regulations, directions and guidelines, and by maintaining and repairing permanent survey marks. The City of Sydney Council has extensive boundary and survey infrastructure records, while North Sydney Council has a development condition relating to the preservation of survey marks. Ryde Council has adopted a practice of placing cover boxes over buried reference marks or reinstating drill hole and wings (de Belin, 2012).

Private surveyors manage survey infrastructure by purchasing survey infrastructure information from LPI and abiding by and following relevant acts, regulations, directions and guidelines. Also, these surveyors may choose to seek approval from the Surveyor General to defer the placement of survey marks, if the proposed construction works are going to impact the newly placed marks.

4 MANAGING SURVEY INFRASTRUCTURE INTO THE FUTURE

How can survey marks and boundaries be better managed in the future? These are some of the things the State could consider in this regard:

- Review and consider adopting some of the practices of Land Information New Zealand.
- Improve the accuracy of the DCDB.
- Allow 2-way exchange of cadastral model data between LPI and councils (or other organisations), to avoid duplication of work relating to the improvement of the DCDB.
- Reconsider being a Dial Before You Dig (DBYD) provider by offering spatial data at a discounted price to DBYD, in exchange for them wavering their fees.
- Keep moving forward to a realisation of Cadastre 2014.
- Make ePlan compulsory in 12 months' time (and assist surveyors whose software provider has not come on board by using saving provisions or providing surveyors with temporary licences for other software packages).
- Establish a 'mark destroyed' hotline to LPI for councils.
- Work with councils and surveying organisations to develop a preservation of survey marks training package (including a short induction video starring the Surveyor General).
- Include 'preservation of survey marks' clauses in the LGA and Roads acts (Noad, 2013).
- Review the nature of current reference marks.
- Encourage increased use of the Cadastral Reference (CR) mark type in SCIMS and consider adopting CR marks as a fourth level of mark in SCIMS to allow movement of these marks to be monitored.
- Flag survey control marks, which have been used as boundary reference marks, in SCIMS.
- Have one integrated land administration database, e.g. combine SCIMS and DCDB databases in the future.

- Include questions related to the preservation of survey marks in the Board of Surveying and Spatial Information (BOSSI) exam for the engineering project as part of the registration process.
- Have less compiled plans (especially in rural areas).

Councils may consider adopting the following practices:

- Targeted 'preservation of survey marks' induction training to be undertaken by all council staff and contractors involved in any council works programmes.
- Develop a training package with LPI and surveying organisations.
- Develop project plans, relating to the preservation of survey marks and boundaries, to review and improve services in these areas.
- Design plans to show all survey infrastructure.
- Survey infrastructure to be considered in the planning stage of projects.
- If required, include a 'plan of survey information only' in the future capital works drawing sets (G. Randall, 2013, email comm.).
- Ensure all relevant survey information is captured at the preliminary stage of the design process to allow appropriate consideration to be given to this information in the preparation of design information (G. Randall, 2013, email comm.).
- Have all state survey marks and boundary reference marks (shown on registered plans) in Council's mapping software, such that operational staff and engineers can view the mapping system for potential survey impacts due to maintenance works ahead of commencement (G. Randall, 2013, email comm.).
- Highlight the location of all survey marks prior to construction by placing indicator stakes adjacent to a survey mark or cover boxes over survey marks (de Belin, 2012; LPI, 2012).
- Use cadastral modelling software to improve the DCDB and add reference mark information to GIS.
- Get CR mark numbers allocated to critical reference marks.
- Collaborate with LPI on DCDB accuracy improvement.
- Help establish a fixed survey-accurate cadastre over the whole of the LGA.
- Include conditions about preservation of survey marks in development consents.
- Audit survey marks pre and post construction (L. Gardner, 2013, email comm.).
- Identify areas where boundary marks are lost and redefine boundaries in these areas.
- Coordinate unestablished permanent survey marks with connections to boundary corners.
- Have a cadastral vision for the LGA.
- Develop policy and procedure documentation.
- Include survey marks as an asset to be considered in land access notices.
- Include 'Is a plan of survey information only needed?' as a checklist item in development applications, construction certificates and reviews of environmental effects.
- Review rolling and capital works programmes to isolate projects that may impact survey marks.
- Assess survey human resources in the organisation and whether succession planning will be required in the near future.
- Assess if any survey marks have historical value.
- Hand out LPI's *Survey marks: All about protecting them* brochure (LPI, 2012) to all contractors, including engineers.

Private industry surveyors and industry bodies representing surveyors and spatial scientists might consider adopting the following practices:

- Provide more Continuing Professional Development (CPD) events relating to the preservation of survey marks.
- Audit marks pre and post construction (L. Gardner, 2013, email comm.).
- Allocate a surveyor to be responsible for survey infrastructure on a construction site.
- Ensure all relevant survey information is captured at the preliminary stage of the design process to allow appropriate consideration to be given to this information in preparation of design information (G. Randall, 2013, email comm.).
- Show all permanent survey marks and reference marks on detail survey and design plans.
- Include survey mark notes on design plans or reports.
- Lodge mark status reports.
- Contact Council or LPI before marks are destroyed and advise of works that may impact survey marks.
- Be aware of any survey marks that have been destroyed on the site you are project managing.
- Include 'Is a plan of survey information only needed?' as an item in design plan checklists.
- Understand the lack of human and time resources in councils.
- Assess the knowledge base of your local council's survey department.
- Be aware if a survey department does not exist at your local council.
- Make sure your council has a cadastral vision for their area.
- Consider having workplace policies and procedures relating to the preservation of survey marks.
- Inform the council surveyor of any areas where lost boundaries exist.
- Hand out LPI's *Survey marks: All about protecting them* brochure (LPI, 2012) to all contractors, including engineers.

5 CONCLUDING REMARKS

Survey infrastructure remains an essential element of land administration in NSW. The value of infrastructure needs to be clearly understood by all surveyors, as well as people who directly and indirectly benefit from the existence of this asset. Due to current NSW legislation, survey infrastructure is a component of the cadastre. This needs to be communicated to all surveyors, spatial scientists and any other users of digital cadastral databases. A series of small steps is required for cadastral reform in order to progress into the future. For example, this includes registered land surveyors taking an active role in the development of the DCDB of their LGA and being aware of the direction their council is heading in relation to boundaries and survey infrastructure. Prior to changing the methods of locating or relocating boundaries, it is required to gather as much information as possible about existing permanent survey marks and reference marks, including the marks' MGA position. This information can also be used in the planning stages of future works.

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Railway Track Reconstruction

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ABSTRACT

RailCorp / Sydney Trains have been moving towards significantly reducing rail track (PerWay) maintenance and associated maintenance costs for a number of years. Almost all of the suburban and inter-urban networks now consist of heavy duty rails and concrete sleepers, requiring minimal on-going maintenance. However, where trains change from one track to another via a 'turnout' or a 'cross-over', train impact as well as rail and component wear are such that renewal of these major pieces of infrastructure is necessary on a 10-15 year cycle. Because each of these renewals requires 'possession' of two or more tracks, the work is almost always performed during a weekend (or longer) 'closedown'. These pieces of infrastructure are critical to the safe and on-time running of trains, so each renewal must be completed in time for trains to run on Monday morning. Surveyors play a key role in the process, performing several tasks: (1) Initial site survey and horizontal and vertical alignment design, (2) setting out for the off-site construction of the turnout or cross-over, (3) setting out for final installation, construction and tamping support (tamping being when the rails are moved into their final design location), and (4) updating alignment and Track Condition Model (TCM) records and permanent marking. This paper outlines the role of the surveyors, and the interaction between the surveyors and designers and constructors, at the various stages of the process by reviewing the techniques and methods used by the surveyors and shows examples of the way the work is carried out.

KEYWORDS: *Railway surveys, track maintenance, Sydney Trains.*

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Surveying the Barham Bridge Using 3D Laser Scanning

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ABSTRACT

The Spatial Division of Sinclair Knight Merz (SKM), along with Astute Surveying and Roads and Maritime Services (RMS) surveyors, has recently completed an ambitious project to survey and document a 109-year old heritage-listed bridge at Barham over the Murray River in south-western NSW for planned upgrade, remediation and ongoing maintenance programs for the RMS South Western Region. The project demonstrates the use of dynamic and diverse technologies to allow stakeholders, far remote from the site, to make confident decisions based on quality data that is available at their fingertips. Using survey tools that captured the bridge and surrounds completely has provided the ability to future 'data mine' critical information from the captured data to allow intelligent decision making in relation to ongoing planning, remediation and maintenance programs without the need to undertake costly and time-consuming revisits to the bridge site. SKM's innovative approach to overcome the deficiencies of a traditional survey approach and deliver within an acceptable time frame was to implement a program involving the following technologies: (1) Terrestrial Laser Scanning (TLS) to capture the critical elements of the bridge structure, (2) Mobile Laser Scanning (MLS) for acquisition of underneath bridge structure and river banks from a boat in addition to capturing the adjacent road corridors from a vehicle, (3) bathymetry (depth sounding) of the Murray River bed to identify underwater structure and definition of the river bed upstream and downstream of the bridge, and (4) traditional field survey for establishing and confirming the existing survey control network on which the 3D laser scanning and bathymetry would be based in addition to providing independent calibration and quality control for the MLS and TLS datasets. This collaborative approach, combined with the application of state-of-the-art technologies, has not only provided an easily accessible and extremely useful dataset for RMS, but also helped introduce the concept and the benefits of fit-for-purpose spatial information within the wider RMS group. Since the completion of the Barham Bridge project, SKM and Astute Surveying have teamed together to supply similar services to RMS on four other bridge sites in the Hunter and mid-coast regions of NSW.

KEYWORDS: *Laser scanning, bathymetry, data mining, bridge survey.*

1 INTRODUCTION

Barham is a small town on the southern New South Wales (NSW) border, around 823 km south-west of Sydney. Its Victorian twin town of Koondrook is joined to Barham by a steel and wooden truss bridge, designed by NSW Public Works engineer E.M. De Burgh. It is a lift span bridge containing a central section that lifts up to let river traffic through. Members of the Sinclair Knight Merz (SKM) survey group were teamed up with Astute Surveying and Roads and Maritime Services (RMS) surveyors to conduct a survey to collect information relating to the bridge for heritage documentation, remediation upgrade and ongoing maintenance work.

The difficulties in surveying a bridge that was built 109 years ago are numerous. The measurement of different types of materials, which have settled, corroded and been replaced, as well as getting clear and visible access to the required parts of the bridge, and safety of personnel working near water, at heights and with constant traffic, made the project challenging but rewarding for the team involved. The remoteness of the bridge in relation to both the RMS and SKM offices meant that certain techniques were used to help engineers and planners using the data from a remote environment, hundreds of kilometres away, with complete confidence.

1.1 History

The area around Barham was developed into grazing country from 1840 onwards, and with the development of the large stations came a need to move goods and stock across the river and down to Melbourne, being the closest port, or to Adelaide via paddle steam. Much of this trade was done by paddle steamers, but the movement of stock created the need for bridges over the Murray. The Barham Koondrook Bridge was one of twelve bridges built across the Murray around the time. It replaced a ferry system that had been in place since 1884.

The Barham Koondrook Bridge was completed in 1904 and is composed of a lift span in the centre with two De Burgh composite trusses on either side connecting the lift span with the river banks (Figure 1). Originally the lift span was so well balanced that the bridge could be raised and lowered by a single person by means of a gear system. It was built by Sir John Monash who went on to become commander of Australian forces in World War I. The lift towers were raised by 2 metres in 1925 to allow for larger water craft to pass under its span. In 2012, the NSW and Victorian governments set aside funds for the restoration of the bridge, to ensure its continued operation into the future. This work involved, among other things, the replacement of bearings, gears and wires on the lift span, as well as some abutment work.

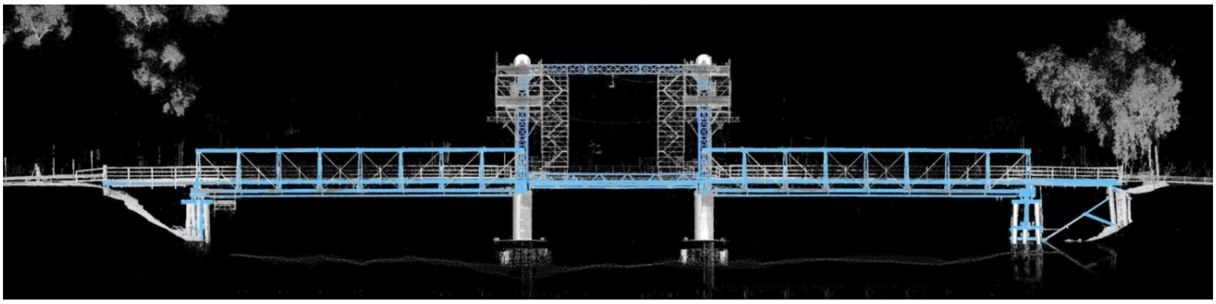

Figure 1: Point cloud and bathymetry data with 3D modelling of Barham Bridge.

1.2 The Project

SKM's Spatial Division, along with Astute Surveying and RMS surveyors, has recently completed an ambitious project to survey and document the 109-year old heritage-listed Barham Koondrook Bridge over the Murray River in south-western NSW for planned upgrade, remediation and ongoing maintenance programs for the RMS South Western Region**.** The project demonstrates the use of dynamic and diverse technologies to allow stakeholders, far remote from the site, to make confident decisions based on quality data that is available at their fingertips. By using survey tools that captured the bridge and surrounds completely, facilitating the ability to future 'data mine' critical information from the captured data to allow intelligent decision making in relation to ongoing planning, remediation and

maintenance programs without the need to undertake costly and time-consuming revisits to the bridge site.

SKM's innovative approach to overcome the deficiencies of a traditional survey approach and deliver within an acceptable time frame was to implement a program involving the following technologies:

- Terrestrial Laser Scanning (TLS) to capture the critical elements of the bridge structure.
- Mobile Laser Scanning (MLS) for acquisition of underneath bridge structure and river banks from a boat in addition to capturing the adjacent road corridors from a vehicle.
- Bathymetry (depth sounding) of the Murray River bed to identify underwater structure and definition of the river bed upstream and downstream of the bridge.
- Traditional field survey for establishing and confirming the existing survey control network on which the 3D laser scanning and bathymetry would be based in addition to providing independent calibration and quality control for the MLS and TLS datasets.

This collaborative approach, combined with the application of state-of-the-art technologies, has not only provided an easily accessible and extremely useful dataset for RMS, but also helped introduce the concept and the benefits of 'fit-for-purpose' spatial information within the wider RMS group. Since the completion of the Barham Bridge project, SKM and Astute Surveying have teamed together to supply similar services to RMS on four other bridge sites in the Hunter and mid-coast regions of NSW.

2 SOLUTION

2.1 Control Network and Datums

Before starting any survey, a local control network needs to be established. RMS is continually monitoring the Barham Koondrook Bridge as part of an ongoing maintenance program and has a series of stable marks surrounding the bridge. Before each monitoring exercise the control is checked and re-established, which was performed by Chris Miller from RMS in the days leading up to SKM's arrival at site and also assisted SKM survey teams in the following day's during the project execution. The monitoring has been going on for many years and the network was originally set up in an Integrated Survey Grid (ISG) datum. Due to the low scale factor involved, it was chosen to adopt this network and datum for the project. It should be noted that most bridge surveys are done in a plane datum, due to their limited length and need for accuracy.

2.2 Terrestrial Laser Scanning

To capture all of the components on the bridge, from the wooden trusses to the gearing at the top of the lift spans, a Leica HDS 7000 phase-based terrestrial laser scanner was used. Under typical conditions, these instruments are able to produce results of better than 3 to 5 mm for horizontal and level position.

A reflectorless total station has the advantage of not relying on the use of a reflector to capture features. This means that points on the bridge structure that are inaccessible can be captured for position and height by simply pointing at the feature to be captured and recording the measured data. Figure 2 illustrates the instruments used for this project.

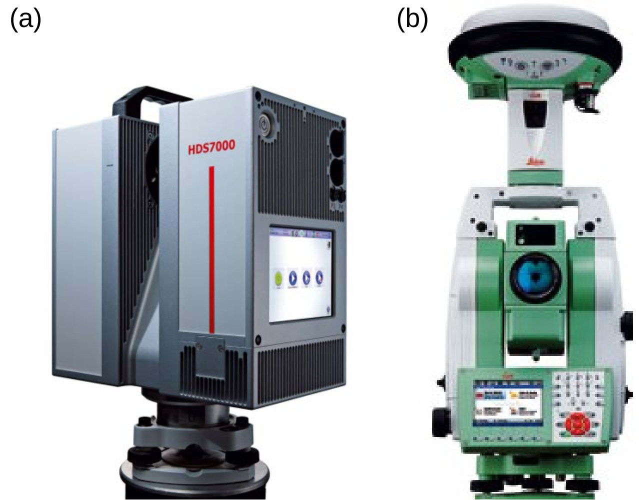

Figure 2: (a) Leica HDS 7000 laser scanner and (b) Leica total station.

The 3D scanner can be positioned anywhere adjacent to or within the site. The HDS scanners have a full 360-degree field of operation in the horizontal plane and 310-degree field of view in the vertical. Thus the operator can be specific in determining the limits of the scan and the operator can determine the density (resolution) of the 3D point cloud that is about to be observed. A minimum of three targets is placed within the scanned area, and these can be tripod-mounted or stick-on targets. The targets are also located by total station from the control network to derive 3D coordinates of the target points. These targets are also included in the 3D scan of the subject area and also very accurately scanned individually as a target control point after the initial scan. SKM more recently has successfully enhanced the registration process by also using common features within individual scans as part of the registration process to give a more robust solution to the merged dataset. The field process is illustrated in Figure 3.

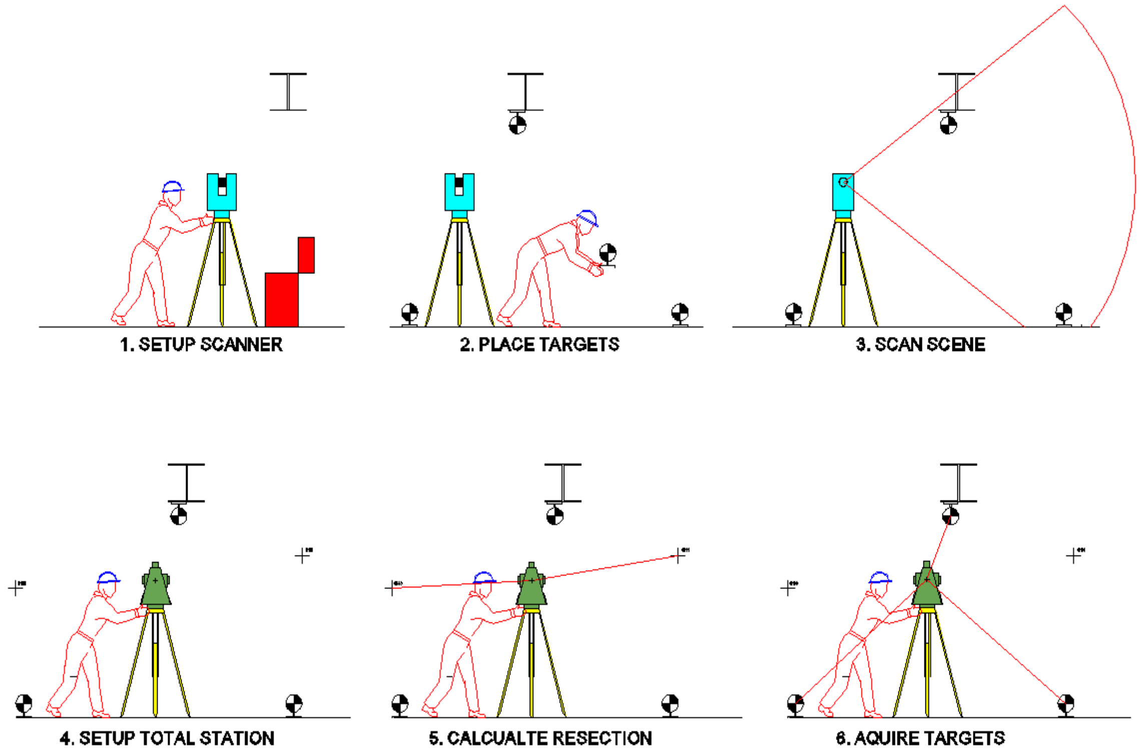

Figure 3: Field process.

The 3D software can then process the scans to link the point cloud to the control network, thus each of the thousands of points observed in the scan has individual xyz coordinates. Multiple scans from different viewpoints using the same targets allow the scan to be merged into a seamless 3D point cloud which is a true representation of the structure and features that have been scanned. Each scan can vary from 10 to 30 minutes depending upon the field of view including the target location; however many millions of points are captured. This is both quicker and far more detailed and efficient than traditional survey methods.

32 scans of the bridge were taken. 12 on the deck and approaches, 10 from scaffolding erected on the top of the lift span and 10 from the banks and piers in the middle of the river, taking two days. The scanning made every attempt to capture all elements of the bridge for later modelling (Figure 4).

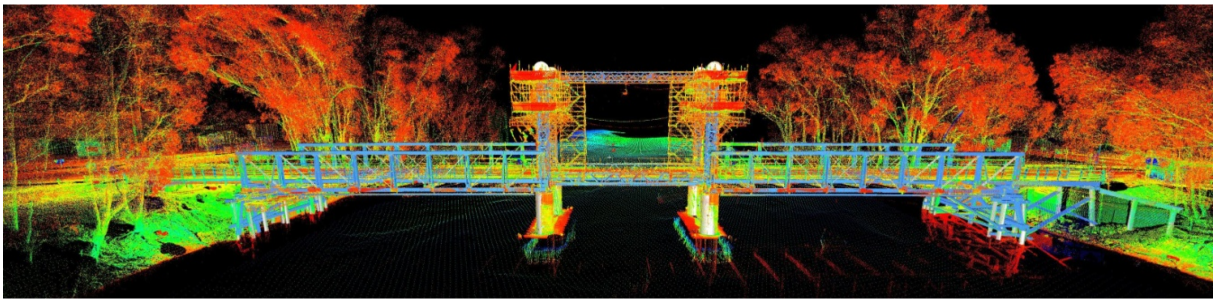

Figure 4: Barham Bridge scan data.

The underside of the bridge presented a challenge, as depending on the level of the river, access to the underside was always going to be a problem. Some concepts were brainstormed in the office, such as using a upside-down tripod, some sort of arm that could be lowered off the side of the bridge, or attaching the scanner to parts under the bridge with a specially made 'claw'. The claw is a special mounting tool that can clamp to objects and was used for two of the scans, attached to the wooden abutment (Figure 5).

Figure 5: Laser scanner mounted using the 'claw'.

With the high rainfall of the previous summers and the water-level controlling weir system that is on the Murray in that area, it was always going to be a gamble as to how much of the underside of the bridge it would be possible to acquire. It transpired that the water level was such that scans could be taken from the water's edge with little foliage obstruction and from the river's piers. Access to the piers was enabled by a boat which was being used for bathymetric surveys at the time.

Often a true colour point cloud is requested by clients, and in this case due to the picturesque nature of the area and bridge, it was decided to perform colour photography from each scan location. The photos were taken with a camera mounted on a special mount, which places the focal point of the camera at the scanner's aperture location. Using a wide-angle fisheye lens, 18 photos were taken which were then combined into a spherical panorama, and then 'burnt' onto the point cloud data (Figure 6).

Figure 6: Coloured point cloud data.

Leica TruView software (free ware) is an additional useful tool in that it too can be rotated and zoomed in a similar fashion to the point cloud data allowing a full detailed image of the roads and adjacent street furniture and building structures to be viewed by planners, engineers and designers to get a detailed understanding of the features of the structure (Figure 7).

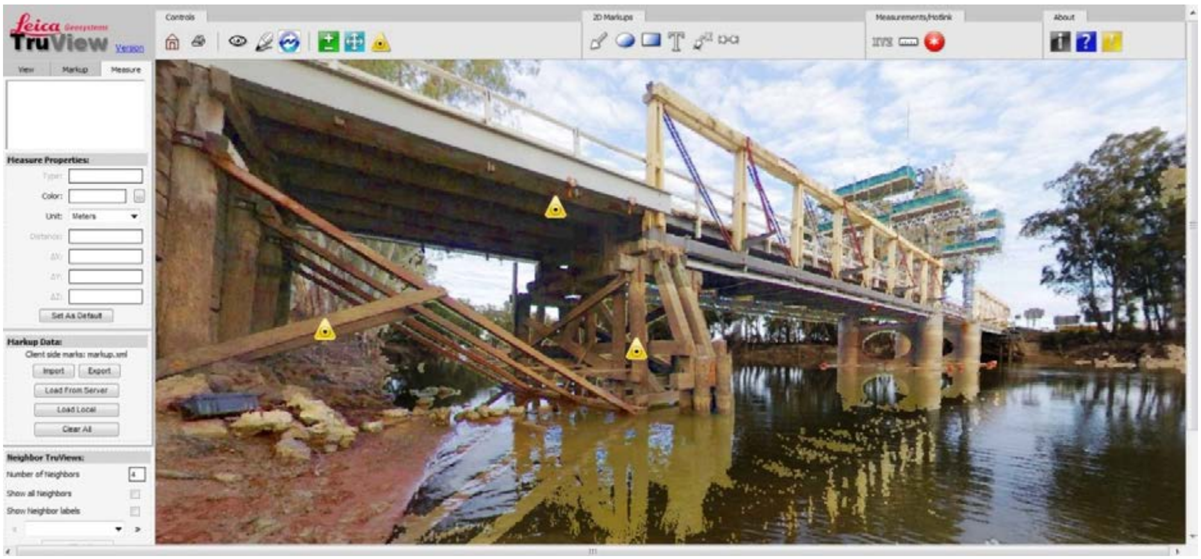

Figure 7: Leica TruView of Barham Bridge.

The resulting point cloud data can be modelled using various applications within both Cyclone and CloudWorx. The data can be easily exported to both AutoCAD and Microstation CAD packages. Sections and elevation drawings can be easily determined by sectioning the resulting point clouds. Individual structures can be quickly converted into models for export

into CAD applications. The advantage is that each structure is fully detailed and located in its true position in three dimensions. Another advantage of this methodology is that in capturing the whole structure, areas or items that may not be evident now as being critical to the design, but are later identified as being required, are captured as part of the process. This can negate the need to revisit the site for further survey as is often the case in using traditional survey data capture methods.

The fact that the data can be captured quickly and accurately and in such detail, without the need to place survey personnel on the structure, remove many of the Work Health and Safety (WHS) issues that would be applicable using traditional survey techniques. In essence, the above methodology represents the most complete solution to the capture and presentation of the existing structures. It removed the guesswork as to which are the important features to locate because with the scanner every detail within the scanner's range is located.

2.3 Bathymetric Survey

To provide RMS with a complete picture of the bridge and its surroundings, Ben Gray from Astute Surveying was engaged to provide bathymetric modelling of the river bed. Ben's boat is equipped with a multi-beam echo sounder and side-beam sonar and is certified as a bathymetric survey vessel. The position of the boat is positioned by a Real Time Kinematic (RTK) Global Positioning System (GPS) receiver, connected to a base station on the shore, supplemented with an Inertial Measurement Unit (IMU) to compensate for the pitch, roll and yaw of the boat.

The bathymetric survey (Figure 8) was completed over a couple of hours. It involved first measuring the with the multi-beam echo sounder which points downwards, and them using the side-beam sonar to get the areas close to the bank where it was too shallow for the boat to operate. The survey was made more difficult by the low water level of the river, making snags and hidden logs a real danger to both survey and nautical equipment. Careful navigation of the river was necessary to ensure that data was captured in these areas, even though access was quite limited.

Figure 8: Bathymetric survey.

As the name suggests, multi-beam hydrographical surveying uses a Multi-Beam Echo Sounder (MBES) to generate multiple sound beams through water. These beams are aligned perpendicular to the hydrographical survey vessel in a swath or fan shape. It is possible to

generate between 120 and 420 beams 14 times per second. This method of surveying can achieve what is known as 'full bottom coverage'. The amount of coverage per transect is also related to the depth of water and can be calculated by multiplying the depth of water by approximately 2.5. Therefore, the deeper the water the more river bed can be surveyed more efficiently. This makes the MBES ideal for larger survey areas and deeper waters.

2.4 Mobile Laser Scanning

SKM is one of only a few companies that own and successfully operate a mobile laser scanner. A vehicle-mounted Riegl VMX-250 consisting of two 3D laser scanners supplemented by the on-board navigation system including a GPS receiver, a fibre optic gyro based IMU which takes into account roll, pitch and yaw, and velocities in x, y and z axes. The IMU and the latest Direct Inertial Aiding (DIA) to assist in areas of poor GPS reception were deployed to scan the existing road pavements, adjacent road furniture, vegetation and river embankments in far greater detail and much quicker than achievable by traditional survey methods.

Two mobile scan sorties were performed for the Barham Bridge project. The first was a standard vehicle-mounted scan where the scanner was used to scan the approaches to the bridge and surrounding cross streets out to a distance of 600 m. While conventionally this would be a large area to capture using traditional survey methods, the capture of the laser scan point cloud was done in just over one hour. The advantage of using the mobile scanner to capture the information was RMS had mentioned they were only interested in the immediate approach to the bridge, but might be interested in expanding the survey further out in the future. By capturing the data while on site, the actual survey strings that RMS use in the MX program can be extracted as needed any time in the future, and the data could be extracted in less time than it would take for an RMS surveyor to drive to the site and back.

The second sorties were performed by mounting the mobile laser scanner on the back of the bathymetric survey boat, for scanning the banks of the river and to provide infill data under the bridge structure that could not be captured from the terrestrial laser scanners located on the river banks or bridge piers (Figure 9). Survey of river banks can be difficult due to excessive vegetation caused by the continual water supply. Lines of sight are limited, and the terrain is generally steep and tough-going for any surveyor. Most of the time, the best that can be extracted is a top and bottom of bank, while the area between may undulate significantly.

Figure 9: Equipment mounted on the bathymetric survey vessel.

By mounting the mobile scanner on the back of a boat, the banks were captured from the water side of the bank, as opposed to the landward side. This gives an aspect that is rarely captured using conventional survey techniques, without the surveyors getting their boots wet. The surveyors operating the scanner had difficulties getting the IMU initialised, and originally had initialised the machine while the boat was mounted on the trailer, but due to tree cover at the boat ramp degrading the GPS, the initialisation had to be performed out in the river. This involved doing fast turns, loops and accelerations on the boat, i.e. 'circle work' and there where quite a number of odd looks from the spectators on the bank.

There was difficultly placing control markers for the mobile laser scan to tie to, so the scan processors came up with the novel idea of using the terrestrial scan data and beams on the underside of the bridge to tie the trajectory down to achieve the required accuracy.

2.5 Work Health and Safety

The main risks associated with the project were traffic, water, height and remoteness (Figure 10). A risk assessment was conducted before leaving the office, with controls and measures outlined in a job safety and environment analysis. Signs were placed to alert motorists crossing the bridge that people were working in the area, and spotters and good communication plans were outlined at the start of each day and at the different work areas. When working on the boats, near the banks or on the piers, all personnel were required to wear life jackets, and all persons involved were competent swimmers.

Figure 10: Working close to water.

At all times the work was able to be performed from safe areas on scaffolding or behind rails on the bridge deck, but a working-at-heights kit was on standby if needed. The remoteness of the site meant that long travel was required. A travel plan was formed, with breaks and driver changes every two hours, and the travel was split into two days to limit fatigue. Each morning, a quick and informal toolbox talk was conducted to outline the day's work and give the personnel time to assess risks and hazards that could not be identified from the office.

3 DATA PROCESSING

The scan datasets needed to be first registered and tied down before the extraction could begin. The terrestrial data needed to be extracted from the compressed format, then have the targets identified in the cloud, spherical panoramas needed to be stitched together and applied to the scan cloud positions, and then the separate clouds tied together and combined into one

usable overall cloud (Figure 11). The mobile scan data needed to be uncompressed and have a processed trajectory applied to it, then tied down using the control points, and exported to a cloud extraction package (Figure 12). The results of the individual movements for each run and the overall residuals are reported out to identify any outliers which may require further attention as part of the full calibration report and residual check (Figure 13).

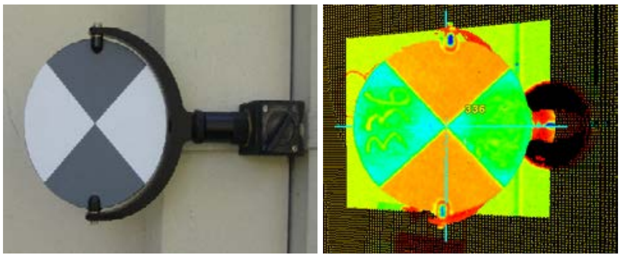

Figure 11: Black and white target photo and laser scan.

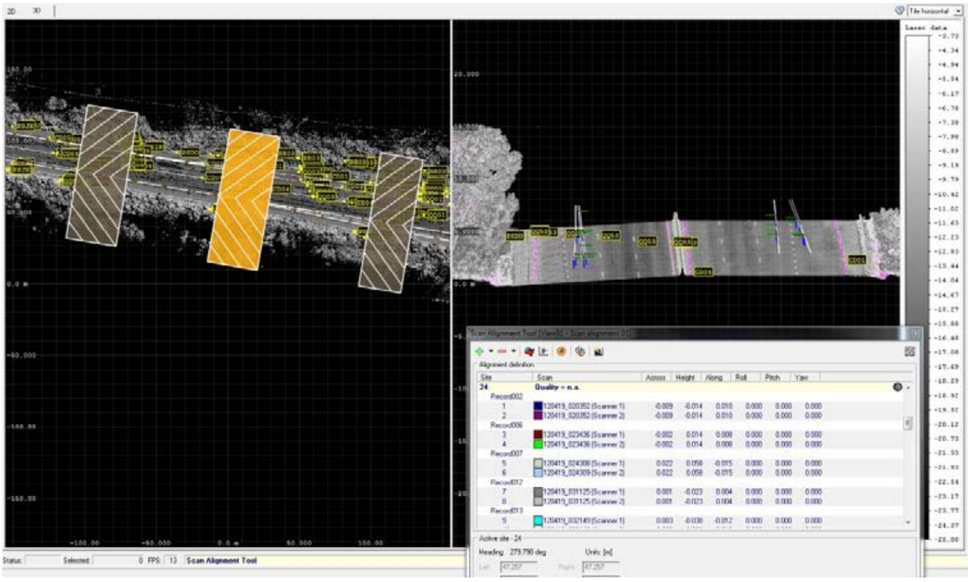

Figure 12: Scan alignment view with relative shifts per run.

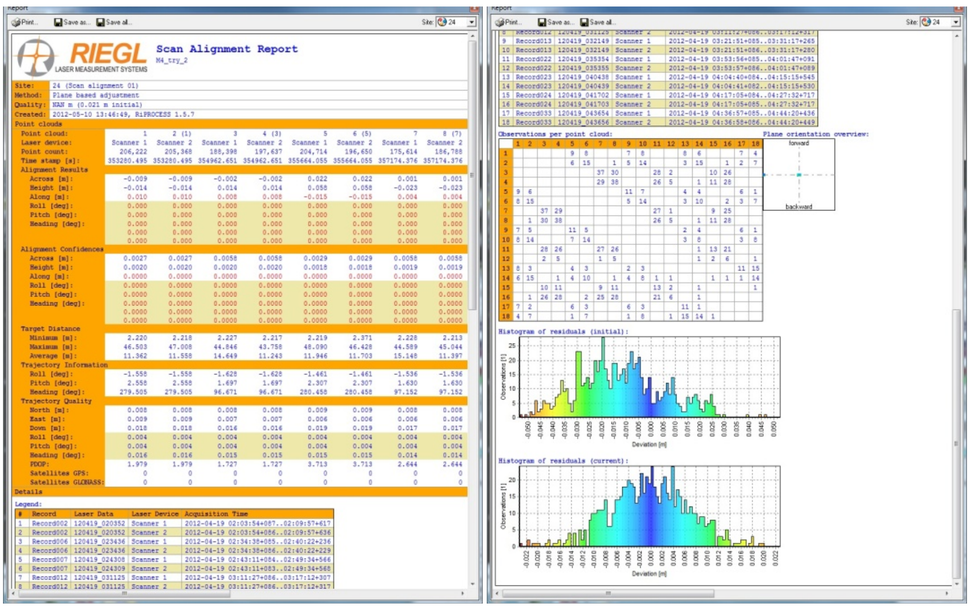

Figure 13: Scan alignment report showing shifts and residuals between runs.

The bathymetric data needed to be uncompressed and then tied together. The data related to obstacles in the river was removed and the resulting data sub-sampled down to a usable grid size. Then it was converted to the plane ISG grid system and imported into 12d software where a Digital Terrain Model (DTM) of the river bed was created. This was subsequently contoured and merged with the river bank DTM allowing cross sections to be extracted at required locations (Figure 14).

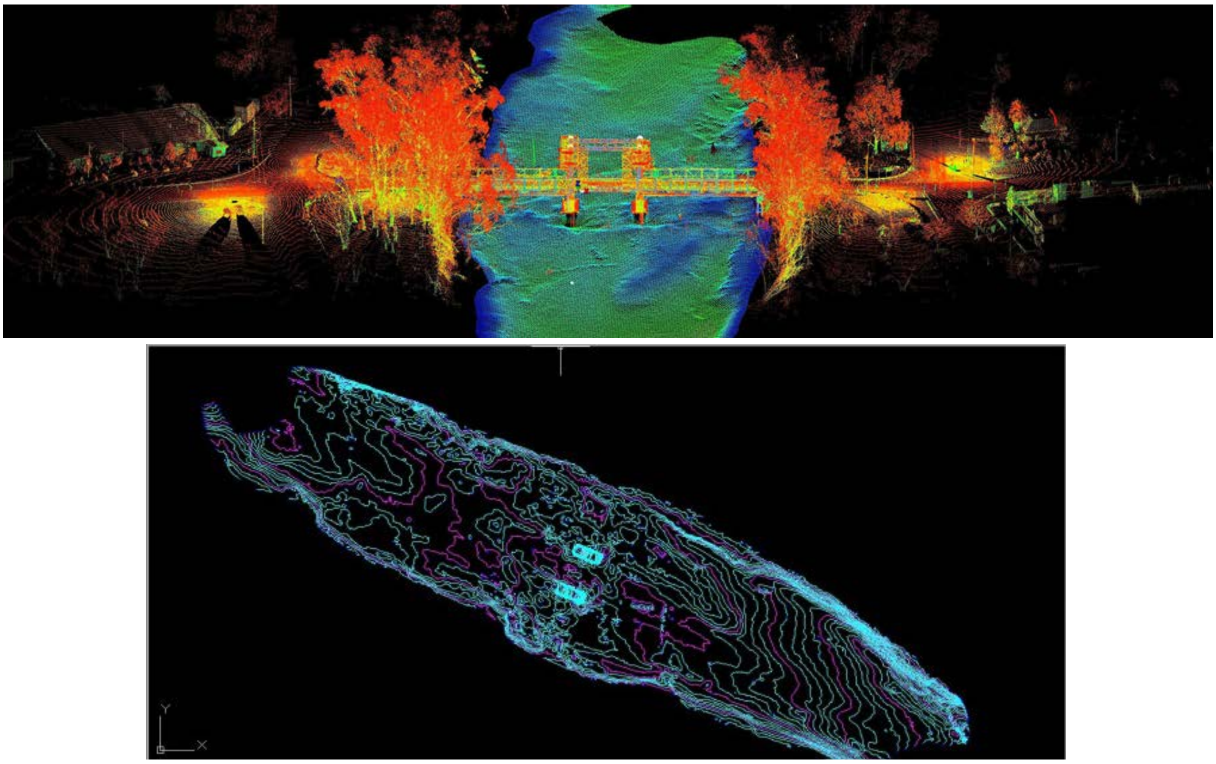

Figure 14: Bathymetry data of the river bed (top) and contours (bottom).

3.1 Extraction

With all types of point cloud capture, one of the main costs to projects is the extraction of usable data from the cloud. With terrestrial scanners, extraction can take a minimum of 3 times the amount of time spent in the field. The advantage is that the data can be 'farmed' out to many users to extract data, i.e. the data captured in the field by the one piece of equipment can be used simultaneously by many users in the office. In this case, three scan processors were used to extract the data from the bridge and surrounds. One processor was working on the lift span, the second on the truss spans, and the third on extracting conventional survey data on the deck, along the banks and in the approaches to the bridge.

The extraction was performed mainly using the Leica Cyclone and CloudWorks packages. Specialist parts tables are used to apply real shapes to the components of the bridge (Figure 15). As the bridge is over 100 years old and the specialist steel parts for the bridge where constructed at the Euston foundry, as well as the standard components being designed using out-dated British standard sections, special parts tables needed to be created. Another problem was created by the upgrade in 1925, which used a different parts table, after which, as structural members have been replaced since, more modern parts tables have been used. SKM has collected a significant library of old parts tables from steel manufactures that apply to existing structures in Australia, and it is common to find structures that are a conglomerate of different manufactures and sizes. In this bridge, some of the girders were of a size that was

not in any existing parts table, but by checking the old plans with assistance from RMS bridge engineers their correct size was able to be established.

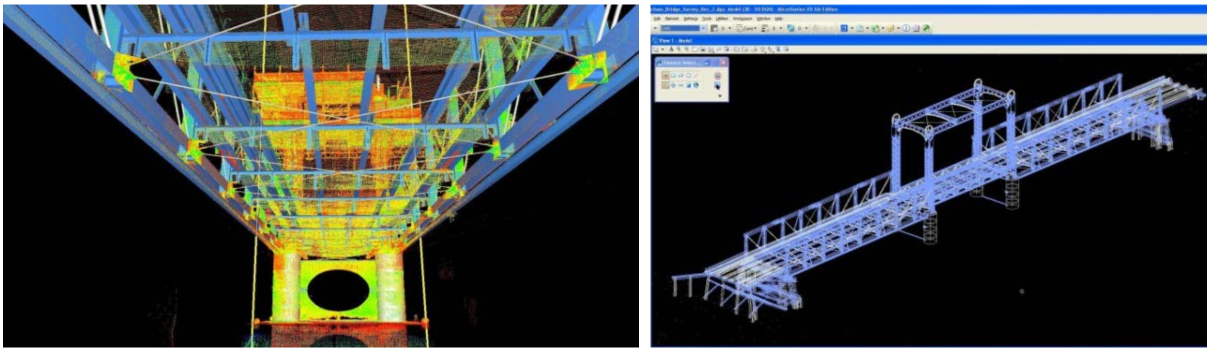

Figure 15: Modelling of steel beams.

The wooden components of the bridge also created challenges for the modellers (Figure 16). In an attempt to try and get the beams to conform to standard inch sizes, wooden beam parts tables were established. The problem with this was over the hundred years the beams had shrunk, warped, and were probably not originally hewn to a fine tolerance, meaning fitting them to standard tables was difficult. In critical areas, some beams had to be re-examined in the cloud and converted to their actual size, and represented with a twist or warp in the beam. The end result of all this modelling was a 3D model in AutoCAD, which was then dimensioned and projected into plan and sectional views.

Figure 16: 3D modelled beams from point cloud data.

Using a specialist program that has been developed in-house, known as Virtual Surveyor for AutoCAD, the standard detail strings that are used in MX were extracted over the deck, approaches and river banks. This involved loading the cloud and identifying features both in plan view as well as in profile to assign the correct height. This was combined with the specific required bridge features, translated from the 3D model into an MX format, which is the standard deliverable required by RMS (Figure 17).

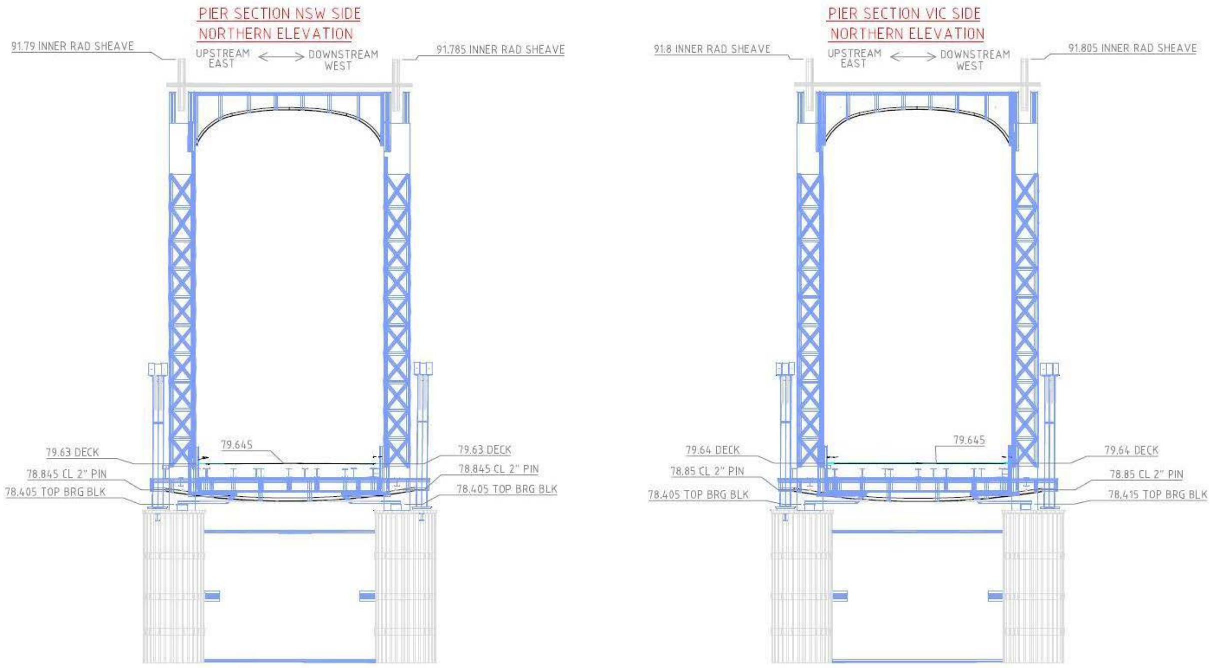

Figure 17: Sections extracted from 3D models.

4 CONCLUDING REMARKS

The difficulty of access to an old structure located a long way from any client office, with very few accurate existing plans posed a significant challenge to deliver a cost-effective and long-term solution to the ongoing maintenance of a critical heritage bridge linking two towns and providing a vital transport link between two states. Previous efforts had necessitated numerous long trips back to the site by both survey teams and engineers to continually seek spatial data to adapt solutions to maintain this vital structure without compromising its significant heritage value. There are hundreds of similar bridge structures throughout NSW and other states in Australia.

The solution proposed by SKM and Astute Surveying removed many of the risks that have been inherent in the practices to date. The approach from SKM and Astute Surveying to the requested services and project needs is a complete departure from what has been traditionally undertaken in previous surveys on these bridge structures. The proposed solution was up until recent years not even possible but typifies the rapid technical advances that are now a reality within the spatial industry. As early adopters of 3D laser scanning technology, especially MLS, SKM recognised that there are now different platforms (other than land-based methods) that can deliver data solutions when combined with other survey technologies, such as bathymetry and TLS, that were unthinkable as little as five years ago. The approach and acceptance by clients can change the paradigm of how the spatial industry can solve a multitude of technical challenges across multiple industry sectors. The project outlined in this paper is just one very small example.

ACKNOWLEDGEMENTS

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For Good Measure: The Story of the Adoption of Linear Standards of Measurement for Surveying Purposes in NSW

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ABSTRACT

This paper is part of an anthology designed specifically to provide a contemporary focus for candidates preparing for the assessment procedures conducted by the Board of Surveying and Spatial Information (BOSSI) leading to the awarding of a Certificate of Competency and accompanying registration as a Land Surveyor under the provisions of the Surveying and Spatial Information Act 2002. The purpose of this paper is to provide a retrospect outlining the circumstances leading to the adoption of a State Primary Standard and legal traceability to the national standard of measurement of length. The calibration of modern Electronic Distance Measurement (EDM) equipment and verification of Global Navigation Satellite System (GNSS) instrumentation are sufficiently described in Surveyor General's Direction No. 5 (Verification of Distance Measuring Equipment) and Surveyor General's Direction No. 9 (GNSS for Cadastral Surveys), therefore requiring only brief discussion.

KEYWORDS: *Standards of measurement, state primary standard, legal metrology, history, New South Wales.*

1 INTRODUCTION

By action of the Parliament of the United Kingdom, section 51(XV) of the Commonwealth of Australia Constitution Act (63 & 64 Vic. c. 12) gave legislative power to the Parliament of the Commonwealth to make laws in respect of weights and measures. The National Measurement Institute (NMI) is responsible for establishing and maintaining Australia's units and standards of measurement and for co-coordinating Australia's national measurement system. NMI was formed by bringing together the National Measurement Laboratory (CSIRO), the National Standards Commission (NSC) and the Australian Government Analytical Laboratories and continues their work.

The National Measurement Act 1960 (Act No. 645 of 1960 as amended), administered by NMI, establishes the legislative framework for a national system of standards and prescribes the legal measurement units for all physical quantities. The unit of greatest interest to surveyors is the standard measure of length. The Act defines the State primary standard of measurement as a standard of measurement that has been approved by the Chief Metrologist and that is maintained, or caused to be maintained, by a State or Territory and that has been verified under section 9 by means of, by reference to, by comparison with or by derivation from an Australian primary standard of measurement or an Australian secondary standard of measurement.

The office of the Surveyor General of New South Wales (NSW) has been appointed by NMI as a verifying authority under the provisions of Clause 73 of the National Measurement Regulations, 1999. Surveyor General's Direction No. 5 (Verification of Distance Measuring Equipment) outlines in considerable detail the facilities maintained by the Surveyor General for the verification of survey measuring bands and Electronic Distance Measurement (EDM) equipment (LPI, 2009). This paper provides a retrospect outlining the circumstances leading to the adoption of a State primary standard and legal traceability to the national standard of measurement of length. The calibration of modern EDM instruments and verification of Global Navigation Satellite System (GNSS) equipment is described elsewhere and requires only brief discussion in this paper.

2 EUROPEAN SETTLEMENT

When Augustus Alt arrived in New South Wales with the First Fleet in 1788 as the Surveyor of Lands, he would have carried with him a Gunter's chain. This particular item of equipment had been used extensively and exclusively for the measurement of farmlands in Britain since its invention by Welsh polymath Edmund Gunter around 1620 (Figure 1). The best quality chains were constructed of thick steel wire, consisting of 100 main links connected together by about 300 smaller links, and with constant use and wearing taking place on about 800 surfaces together with distortion of smaller links out of round it would be expected that the length of the chain changed considerably over time. The instrument was adequate for the period however, and the need for a precise determination of the length of the chain by verification against a known standard was unnecessary.

Figure 1: Gunter's Chain.

The imperial system of weights and measures was introduced into England by an Act of Parliament in 1824. The Weights and Measures Act, 1824 (5 Geo IV c. 74) provided a simplified measurement system that was nevertheless capable of meeting the demands of the industrial revolution in the United Kingdom. It was adopted rapidly throughout the British Empire, partly as a result of the requirements of imperial trade and partly because of encouragement and direction from the Colonial Office and the India Office in London.

At the founding of the colony, the standard linear measure in the imperial system was the statute mile, so named because it was defined by an English Act of Parliament in 1592, during the reign of Queen Elizabeth I. It was defined as being 1,760 yards or 5,280 feet. For surveying, the statute mile is divided into eight furlongs, each furlong into ten chains, each

chain into four rods (also known as poles or perches), and each rod into 25 links. The first attempt to standardise measures in England was during the reign of Edward I (1272-1307) when, although rod lengths from 12 to 24 feet were consistently used throughout the Anglo-Norman period, the statute English rod was set at 16½ feet and at the same time the statute acre was set at 160 square rods, measured with the statute rod of 16½ feet.

The provisions of the Weights and Measures Act 1824 did not extend to the British colonies. The colonial administration was initially content to rely on the lineal standard in force and in use in the United Kingdom, and it was some time before the Governor-in-Council introduced the Weights and Measures Act 1832 (3 Wm. IV, No. 4). The preamble of that Act recited that "…certain weights and measures of the standard now in force and in use in the United Kingdom … now deposited in the Colonial Treasury … are hereby declared to be the standard weights and measures of New South Wales." In the Act, no distinct or direct reference was made to measures of land, the standard measures of length being limited to the yard, the foot and the inch. It would appear that the Act was intended solely to regulate the buying and selling of merchandise such as is exchanged in warehouses, shops and marketplaces.

The wording in a despatch from Governor Bourke to the Secretary of State advising him of this proposed new legislation clearly confirms that a standard set of imperial weights and measures had previously been sent out to the colony by the Lord Commissioners of the Treasury and held in the office of the Commissariat (see Bourke to Goderich, Despatch No. 110, 30 October 1832, *Historical Records of Australia*, Series I, vol. 16, 1923, p. 782). These standards had been procured and transferred to the Office of the Colonial Treasurer. A 'standard yard' was obtained from the Office of the Surveyor General. This is also the first evidence sighted thus far to confirm that the Surveyor General was in possession of an established standard even though it was only three feet in length.

Beaver (1953) noted, however, that Parramatta Observatory was established by Sir Thomas Brisbane at his own expense and under the supervision of the Government Astronomer, Mr. Russell. In 1828, Mr. Rümker, the then Astronomer, took delivery of the "requisite rods and cylinders for the trigonometrical survey", the survey being in conjunction with the measurement of an arc of the meridian which Mr. Rümker had agreed to carry out. (The measurement of the arc of the meridian was never performed.) It should be noted that Christian Carl Ludwig Rümker arrived in Sydney in 1821 and worked at Governor Brisbane's private observatory at Parramatta. On 21 December 1827, Governor (Sir) Ralph Darling appointed him Government Astronomer – he was the first to hold that title in Australia.

The primary standards of weight and length in England were preserved at Westminster. When the Houses of Parliament burned down in 1834, these standards were destroyed and new primary standards had to be prepared. A commission established to resolve the matter was slow to act and by 1844 little had been achieved. Forty bars in total were cast in 1845 of which one was selected as the primary of the Imperial Standard Yard. The one which matched best the standard that had been destroyed in the fire became the new Imperial Standard Yard, and the next best bars were approved as Parliamentary Copies and sent to major cities in the United Kingdom and British colonies.

In 1855, Parliamentary Copies No. 18 and 34 were supplied to the New South Wales and Victorian Governments and became the primary standard of their respective colonies. They are constructed of metal developed by British astronomer Francis Baily, made up of 16 parts copper, 2½ parts tin and 1 part zinc. The yard is measured between fine lines marked on a

gold pin in the well at each end of the bar. Bar No.18 is currently on loan from the National Measurement Laboratory (NML), Sydney to Sydney University Museum and Bar No. 34 is in the permanent custody of Museum Victoria (Figure 2).

Figure 2: Parliamentary Copy No. 34 – Museum Victoria.

A circular issued by Deputy Surveyor General S.A. Perry to licensed surveyors on 10 April 1848, outlining existing practice of the Surveyor General's Office, included inter alia the following instruction for survey and measurement of portions: "… and measurement of the lengths of the several boundary lines with a Gunter's chain, *verified by comparison with the standard measure*..." It is reasonable to conclude that licensed surveyors had for some time had access to a standard baseline – very likely the one in the front of the old Lands Office later referred to and possibly laid down with the 'standard yard' in possession of the Surveyor General referred to by Governor Bourke in 1832.

The arrival of new sets of standard weight and measures duly verified and stamped at the Exchequer at Westminster prompted the enactment of the Weights and Measures Act 1849 (13 Vic. No. 25) necessary for the adoption of these new sets, as described in an annexed schedule, as the standard weights and measures of NSW in lieu of the weights and measures deposited in the Colonial Treasury in Sydney. The units of linear measures were itemised as "one imperial yard bed and rod" and "one 3 feet scale containing the yard foot and inch". Each item was engraved with the name of the Colony.

The Weights and Measures Act 1852 (16 Vic. No. 34), in similar fashion to the 1832 Act it repealed, failed to make any reference to measures of land, simply repeating the standard measures of length as the yard, the foot and the inch. The administration's focus, it seems, was firmly fixed on the value of standard weights and measures only in so far as it affected trade and commerce. A 10-foot Geodetic Standard Bar, Ordnance Intermediate No. 4 (OI4) was sent to Sydney for the Government of New South Wales in December 1858, and a second similar bar, with no distinguishing mark or inscription but made by Troughton and Simms in 1881, was sent to the Colony in March 1884. A third Geodetic Standard Bar, identified as OI6 was sent out in March 1862 to Melbourne for the Government of Victoria.

When official instructions for the measurement of the baseline at Lake George for the triangulation of NSW were issued by the Department of Lands to Government Astronomer George R. Smalley on 16 January 1867, the 10-foot standard bar of the Colony was placed in his charge at the observatory. In preparation for the baseline measurement some well-seasoned pine poles, originally the property of NSW, were recovered from the Lands Office in Melbourne and tested by reference to this iron bar. Mr. Smalley having died soon after starting the work, progress was interrupted until the latter end of 1870, when Mr. Adams (the new Surveyor General), undertook supervision of the operations (Chesterman, 1924). As a

means of ensuring accuracy, Adams transported the iron bar to Lake George where it was housed in a specially constructed underground vault. Daily comparisons of the pine measuring poles were made with the iron standard at night and in the morning. Under the system pursued, the iron standard was depended upon entirely, the measuring apparatus being trusted for only a few hours at a time.

In 1887, the NSW Department of Lands was in possession of Standard Bar OI4 when it was sent to London for re-verification by the Warden of the Standards, England (Lucas, 1889). Mr. J. Brooks, who in 1890 was in charge of the geodetic surveys in NSW, asserted "as far as I am aware these are the only 10 ft. standards in Australia" (Brooks, 1889).

The NSW Geodetic Standard Bar Ordnance Intermediate No. 4 (OI4), prepared under the direction of Sir Henry James of the Ordnance Survey of Great Britain, was made of wrought iron and had as its section the form of a girder with equal flanges above and below. The breadth was 2.3 inches and the depth 2.95 inches. A groove 1.4 inches in breadth and about a third of an inch deep was planed out through the whole length of the upper surface. In the centre of the breadth of this groove, seven holes were drilled about a tenth of an inch diameter at 0, 3, 6, 7, 8, 9 and 10 feet. Into these holes were screwed small, cylindrical plugs whose heads were then filed off level with the upper surface of the bar, but raised above the bottom of the groove. Small silver plugs were then inserted into these plugs. The upper surface of the bar was thus divided into yards and feet, which were marked by fine dots on the silver plugs. The bar rested upon two cradles, each cradle consisting of two pairs of rollers, and each pair rested on a subsidiary cradle which in turn rested on another roller. It was provided with three thermometers, the curved ends of which were let into wells in the centre of the bar. When in use, these wells were filled with mercury (Brooks, 1889).

Currently there are two 10-foot standard bars in the collection of the Powerhouse Museum, Sydney: object B754 is described as "one 10 ft long surveyors standard measurement bar, 7 camels for supporting bed of instrument and 1 microscopic stand and carriage (SB) – surveyors testing instrument from the Observatory (LC)" and object H9151 as "standard bar, 10 ft, Great Britain, c. 1865 (LC)". There is good reason to believe that B754 is Ordnance Intermediate No. 4 and H9151 is the bar manufactured by Troughton and Simms, and sent to the Colony in 1881.

The Regulations for the employment of licensed surveyors issued by the Surveyor General's Department in 1864 prescribed in a "list of instruments to be provided by each licensed surveyor and to be subject to the approval of the Surveyor General" inter alia "1 chain, to be kept as a standard, and never used in survey". It is not expressly stated but it is clearly implied that any such (Gunter's) chain was to be compared with the Surveyor General's standard described by Bayliss (1957) as "a standard of 100 links ... established by cutting marks in the stone flagging in front of the old Lands and Survey Office in Bridge Street, Sydney, which according to one authority, was probably correct to within half an inch or so". There appears to be some conjecture as to whether Bridge Street represented "the front of the old Lands and Survey Office", as it is known that at an earlier time the staff of the Department was housed in the Surveyor General's Office, a two-storey building occupying part of the present Lands Office site but located at the corner of Gresham Street and Bent Street.

Sandwiched between the latter regulations and the general instructions issued to salaried surveyors in 1884 was an event that was a momentous leap in a surveyor's ability to measure with enhanced accuracy. In 1872, F.B.W. Woolrych introduced surveyors to the steel riband.

In rapid time the Gunter's chain became all but obsolete in regards to land surveying. The Gunter's chain remained in the 1886 Surveyor General's regulations but in addition to a Gunter's chain and a light steel riband, not less than 500 links long, each surveyor was required to possess "two steel ribands, 66 feet long; one to be used for adjusting and testing the riband and chain used for measuring."

General instructions issued in 1884 to salaried surveyors of the Department of Lands made provision for a standard length to be maintained near the District Surveyors' offices as follows (Marshall, 1999):

146 In order to ensure accurate survey it is advisable that a standard length be marked in some suitable place near the District Surveyor's office, for comparing and adjusting chains and steel ribands used in the process of measurement.

147 For the mode of marking such standard length, see Appendix I.

It was clearly intended that these standard lengths be laid down using a steel band tested at the Sydney Observatory. Appendix I unambiguously makes reference to "…the standard riband … having been tested at the Sydney Observatory" (Figure 3). The steel riband was clearly seen as the way to the future.

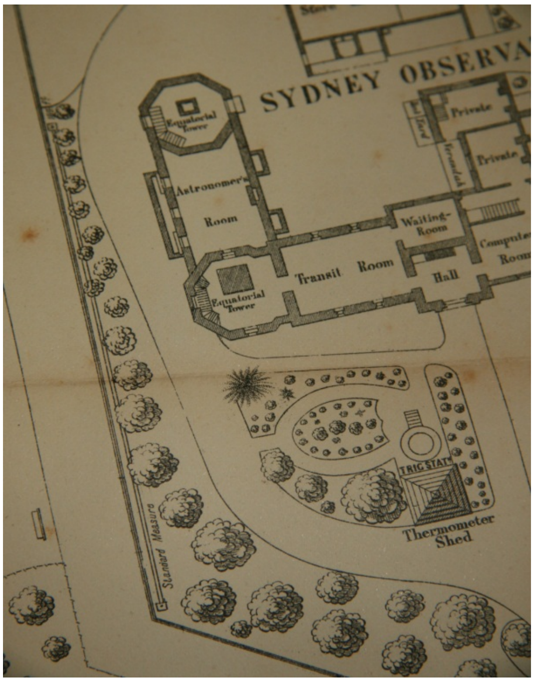

Figure 3: Sydney Observatory baseline.

Standards of 66 feet and 100 feet with stone terminals carrying the marks showing the distances had been laid down at Sydney Observatory around 1880 following the destruction of the one chain length in the pavement at the front of the Old Lands Office, Sydney. The pavement was destroyed to make way for the proposed new building. The image of Flagstaff Hill showing the location of the 'standard measure' in relation to the observatory depicted in Figure 3 is taken from a plan annexed to an 1881 publication by the Government Astronomer H.C. Russell entitled 'Results of Astronomical Observations made at Sydney Observatory – 1877 and 1878' and held at the Mitchell Library. Bayliss (1957) observed: "These standards were a distinct advance on the so-called standard in front of the old Survey Office, and proved to be of great service to surveyors generally. However, the observatory standards were apparently damaged by rough usage and were later found to be 0.04 inch short."

About this time, the newly formed NSW Association of Surveyors engaged in robust debate relating to the lack of satisfactory linear standards being available to the surveying profession. Herborn (1890) observed: "So far as I am aware, the only instruments or lengths used as standards are – the 10-feet Geodetic Bar, in the custody of the Survey Department; a 1-chain length laid down at the Observatory; a 1-chain length laid down at the Old Lands Office, and now destroyed; and the standard of Chesterman's tapes."

James Chesterman & Co. of Sheffield, England was noted for the manufacture of woven cloth tapes that incorporated strands of wire, and a process for heat treating long strips of steel patented in 1853, that led to the manufacture of steel tapes that remained unchanged for over 50 years. In particular, around the turn of the century, the company introduced tapes of steel alloy with very low coefficients of expansion. The tapes referred to by Herborn (1890) were later described by James Chesterman & Co. "…though correct for all practical purpose they are not made with the intention of being used as veritable standards … they are assumed to be correct at 62° Fahr" (Thomas, 1891).

The Association's deliberations resulted in (Sir) George Knibbs proposing on 11 March 1890 "that in the opinion of this Association it was desirable that the 10 feet geodetic standard bar OI. No. 4 be made the legal standard of the colony." The resolution passed at that meeting also provided for a request be made to the Surveyor General "that an accurate and convenient standard … be made available for the use of surveyors".

The Office of the Surveyor General continued to address the regulation of survey practice and in particular the integrity of measurement of surveys of land which was so crucial to the corresponding integrity of Torrens Title. Regulations for the employment of licensed surveyors issued in 1886 extended a concept first introduced in general instructions issued in September 1884 to government surveyors (Marshall, 1999). Regulation 53 prescribed that the accuracy of the survey of each portion should be determined by a method using latitude and departure, and provided a table showing the limit of allowable error in links, being the sums of the differences in latitude and departure, according to perimeter of the survey.

The accuracy of closure as provided for in this manner is not a statistically robust indication of the accuracy of a survey. In fact a loop survey in which all distances are measured with a 10% scale error will close perfectly, as would any loop survey in which all distances are measured with a consistent scale error. This concept was further developed over time providing surveyors with a simple but reasonable test of their field work. The technique used in boundary re-determination of maintaining angles and applying a determined scale factor to all lines between terminals established from marks found is wholly dependent on accurate closure of the original survey, a point obviously not lost on Phillip Francis Adams, who was Surveyor General at that time. Each surveyor however, as part of his instruments, was required to provide "two (2) steel ribands, 66 feet long; one to be used for adjusting and testing the riband and chain used for measurement".

3 THE INTERCOLONIAL CONFERENCE OF SURVEYORS, 1892

The first Intercolonial Conference of Surveyors in the southern hemisphere was convened in Melbourne on 31 October 1892. New South Wales was represented at the conference by Edward Twynam and R. McDonald, respectively Chief Surveyor and District Surveyor, Armidale, from the Lands Department, and G.H. Knibbs and T.F. Furber, President and

Secretary respectively of the Institution of Surveyors. It was a significant conference and possibly best remembered by the surveying profession for the establishment of the principle of reciprocal recognition by each jurisdiction of certificates of competency issued by the other jurisdictions. Besides reciprocity, there were a number of other principal objects the conference aimed at, including the adoption of uniform standard of length in each of the colonies.

Sir Augustus Charles Gregory, a prominent surveyor and politician representing Queensland, expressed an interesting opinion that English Statute law on the subject was in force in all the colonies. If any question arose as to the interpretation of weights and measures, the English law would prevail in the courts. Obviously confident in the protection afforded the matter by English Statute law, the conference resolved to recommend "that the measure of length used in all Australasian surveys being the English measure of length, as provided by English Statute law, standards 66 ft. and 100 ft. in length, in terms of such legal standard, should be established in the principal Australasian cities and adopted as the standard of surveys in all the colonies".

The Association's 1890 request that an accurate and convenient standard be made available, no doubt reinforced by the recommendation of the Melbourne conference, did not pass unheeded and upon completion of the Lands Office building, the baseline standard was restored to the Lands Office precinct but on this occasion it was laid down internally in the building. A 66-feet and a 100-feet standard were installed in the eastern corridor of the ground floor by cementing into the bedrock under the floor large blocks of trachyte (a form of volcanic rock) into which silver inserts had been embedded. The terminal plugs were protected by brass plates, which were removable to allow micrometer microscopes to be mounted over the terminals and a tension device to be set up.

In 1894, Edward Twynam, the Chief Surveyor of NSW, advised of a new acquisition by the Department of Lands (Lands, 1893): "An instrument named 'the comparator', designed by the late Surveyor General, has, under the supervision of the Government Astronomer, been completed at small cost; it is intended to facilitate the transfer of measure from the standard bar to a steel tape or other means of recording length, and it is found to operate in a satisfactory manner."

This newly-completed 'comparator' was used by D.M. Maitland in November 1894 to define on a steel band 66-feet and 100-feet lengths for laying down fixed standards in the Lands Office for adjusting surveying apparatus; these lengths were marked by very fine lines inscribed on silver bosses inserted in a steel band. The lengths were marked off by means of the 'comparator' from bar OI No. 4 (Lands, 1894). Having calibrated the steel tape, Maitland then proceeded to measure the distances between the terminal points established in the Lands Office corridor. The standard thereby created was known as the 'prime standard' and was very useful to surveyors but as it never made its way into legislation, it had no legal status.

Early in 1893, George Knibbs and D.M. Maitland gave important evidence in connection with making a legal standard of length for measuring land to a Board of Inquiry appointed to inquire into the administration of the Weights and Measures Act 1852. After a full inquiry into the operation of the existing Act, the Board recommended that a Bill be framed for submission to Parliament on the same lines as the United Kingdom legislation of 1878 and 1889 (Act 41 & 42, Vic. c. 49, and Act 52 & 53, Vic. c. 21 respectively) and that provision be made for the establishment in the colony of legal standards for land measurements (see

Report of Board of Inquiry appointed to inquire into the administration of the Weights and Measures Act, V.&P. Legislative Assembly, 1892-3, Vol. 8, p. 1051).

The 1878 imperial legislation referred to comprehensively provided for measurement of land by defining in section 11 not only the foot and inch, but also the rod, pole or perch, chain, furlong and mile, and in section 12 the rood and the acre. The resultant Weights and Measures Act 1898 (Act No. 19, 1898) contained no such provisions and simply perpetuated the "standard measures of length" as one yard, one foot and one inch.

4 POST FEDERATION

The Regulations for the Employment of Licensed Surveyors issued by the Department of Lands in 1901 and 1914 continued to make no specific instructions regarding the standardising of measuring tapes with the exception of the requirement that each surveyor was to provide a band "to be kept for adjusting and testing the chain used for measurements". The limits of "check closing and allowable error" were modified in the 1901 regulation and carried through to 1914.

The Weights and Measures Act 1915 (Act No. 10, 1915) further perpetuated the standard of the measurement of length as the yard but for the first time recognition was given to units used in the admeasurement of land. Clause 21 prescribed that "the units of weights and measure shall be those described in schedule C":

- The standard yard shall be the only unit or standard measure of extension, from which all other measures of extension, whether linear, superficial, or solid, shall be ascertained.
- One-third of the standard yard shall be the foot, and the twelfth part of such foot shall be an inch, and the rod, pole, or perch in length shall be five such yards and a half; and the chain shall contain twenty- two such yards, and the mile one thousand seven hundred and sixty such yards.
- The rood of land shall contain one thousand two hundred and ten square yards, according to the standard yard, and the acre shall contain four thousand eight hundred and forty such square yards being one hundred and sixty square rods, poles, or perches.

In July 1915, the Registrar General issued instructions specifically prepared for the information and guidance of surveyors specially licensed under the Real Property Act 1900. These instructions are recognised as the first attempt to regulate surveys carried out by private practicing surveyors. Regulation 41 required that "chains should be carefully adjusted to the standard at the Department of Lands", and Regulation 83, while retaining the principle of check closing and allowable error in the Lands Department's 1914 instructions, provided modified tables for limits of error not to be exceeded.

The Survey Practice Regulations 1933 under the Surveyors Act 1929 were gazetted on 12 May 1933 and applied to every survey made after that date. The Regulations for the Employment of Licensed Surveyors issued by the Department of Lands in 1914 continued in use as "the special requirements of the Department of Lands". In the absence of a State primary standard suitable for application to the surveying of land, recourse had to be had to the resources of the Office of the Surveyor General. Regulation 10 stated: "A surveyor shall make every survey … with a steel or invar band whose length is known in relation to the standard chain under the control of the Surveyor General."

Checking and accuracy of all measurements was provided for by a requirement of closure of latitudes and departures in Regulation 43, which prescribed that "a surveyor shall … check all measurements … by closure of the latitudes and departures of the lines … computed to two decimals of a foot if the survey is a city or suburban survey, or one place of decimals of a link if the survey is a country survey…" A table of the sums of the differences in latitude and departure that the perimeter could not exceed was provided and ranged from 1 link per mile crossing level country to 3 links per mile in mountainous country. This was amended in August 1934 so that the allowable misclose was expressed as a ratio, i.e. 1:8,000 for level country to 3:8,000 for mountainous country. Regulation 44 introduced the now familiar 'degree of accuracy' to survey practice by setting out a table of amounts of difference between the length of lines as measured and the correct length should not exceed. Allowable differences were identical to those stated in Regulation 43.

For operational reasons, it was decided by the Surveyor General in 1935 to install a new standard, known as the 'subsidiary standard', consisting of stainless steel plugs set in trachyte blocks. This new standard was marked and compared with the original 'prime standard' by means of an invar tape. A special invar tape, No. NPL 35A 58415, together with a Certificate of Examination issued by the National Physical Laboratory, Teddington was brought from England in 1936 but not used to verify the 'subsidiary standard'. Invar is a nickel-steel alloy invented by Swiss physicist and metrologist Charles Édouard Guillaume in 1896. It was named invar for its invariability under extremes of heat or cold; its coefficient of expansion is 15 times less than that of steel. He was awarded the Nobel Prize for Physics in 1920 "in recognition of the service he has rendered to precision measurements in physics by his discovery of anomalies in nickel steel alloys".

At a Council meeting of the Institution of Surveyors on 22 July 1938 "it was resolved to write to the Under Secretary for Lands asking that a standard be laid down on the southern face of the Showground boundary wall so that surveyors may test their long bands under working conditions, and that markings be placed at intervals of 100, 200, 300 and 500 links" (N.N., 1938). Surveyor General A. Max Allen responded on 20 December 1938 (N.N., 1939): "The provisions of a standard by this Department outside the precincts of its building cannot be favourably considered. Approval has been given to the laying down of a subsidiary standard in the basement of this building, which would be under proper and essential departmental supervision. Registered surveyors will be permitted to check their own chains, without charge, under such supervision as is deemed necessary – applications to be made to the Registrar, Surveyors' Board. If the Institute seriously considers that the provision of a standard in another location is necessary in the members' interests, the Institution should accept the responsibility to provide such standard and supervision at its own cost."

The special invar tape brought from England in 1836 was used to install this secondary or 'visual' standard intended for public use. Mr. Staff Surveyor F.C. Carr, who supervised the installation of this 'visual' standard, reported in 1939: "Unfortunately the pressure of work has been so great since the arrival of the special invar tape that there has been no opportunity to use it to check up on the soundness of our standards here, for which purpose the tape was procured. Because it is of invar which has a disposition to vary sometimes with age, even though not in use, I have felt obliged to accept the ascertained value of our standards, and, using the tape as a comparing medium, have deduced from that the values on the new (visual) standard." The intervals were measured as 66.00026 and 99.99961 feet and were accepted as 66.000 feet and 100.000 feet respectively for the special purposes of the 'visual' standard (Bayliss, 1957).

The decision to accept the public baseline as 66 feet and 100 feet respectively reflected a reasonable departmental view that the measurements were adequately expressed to satisfy the needs of the average practising land surveyors but not necessarily so for surveyors in the geodetic and mapping fields.

Section 51 of the Commonwealth of Australia Constitution Act 1900 (UK) deals with the legislative powers of the Commonwealth parliament (called 'specific powers'). These contain 'concurrent powers', in the sense that both the Commonwealth and States can legislate on these subjects, although federal law prevails in the case of inconsistency. Sub-section XV identifies 'weights and measures' as one of the matters subject to concurrent powers.

The National Mapping Council (NMC) was formed in 1945 and arose from the Commonwealth government's concern for the rehabilitation of various aspects of post-war Australia (Lines, 1992). It included representation from the Commonwealth and State Surveyors General and the Director of Army Survey. In July 1988, NMC was dissolved and replaced by the Inter-Governmental Advisory Committee on Surveying and Mapping (IGACSM). In 1991 it was enlarged to include a member from New Zealand, and this committee adopted a name change and became known as the Intergovernmental Committee on Surveying and Mapping (ICSM).

At the tenth meeting of the National Mapping Council held in April 1952, Resolution No. 94 was adopted and read as follows (NMC, 1952): "The Council recommends that as far as possible the States and Territories adopt uniform methods for the standardisation of survey tapes and to that end further recommends that the Commonwealth Scientific and Industrial Research Organisation be requested to investigate and advise on the most practicable method of setting up suitable working standards which will permit of certification of surveyor's (sic) tapes to an accuracy of 1 part in 500,000."

The Surveyor General (NSW), a party to that resolution, recommended appropriate changes be made to the Survey Practice Regulations 1933 and the Survey Co-ordination Regulations 1951. The amendments which accorded recognition to standards established by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) appeared in the Gazette of 4 February 1955.

It then became necessary to compare the existing Lands Department standards with those of the CSIRO and although the Certificate of Examination issued by the National Physical Laboratory, Teddington no longer had integrity, the special invar tape No. NPL 35A 58415 to which it belonged and brought from England in 1936 was selected for the comparison. In April 1956, the tape was compared against the 'subsidiary standard' and then forwarded to the National Standards Laboratory of the CSIRO for testing. The difference between the two standards was found to be approximately in the order of 1 part in 90,000 and a difference too great to be ignored. An extremely thorough investigation was then undertaken to eliminate any possible sources of error; among other changes made, new stainless steel caps were press-fitted over the existing terminal plugs. The marking of these new caps at precisely 66 feet and 100 feet was carried out by Mr. E. Esdaile Snr. of the highly regarded instrument firm of E. Esdaile & Sons Pty. Ltd. of Sydney. Subsequent measurements showed that the 100 feet base differed from standard by 1 part in 700,000 and the 66 feet standard by 1 part in 2,000,000.

Australia became a signatory to the Metre Convention in 1947, which made metric units legal for use in Australia. In June 1948, the Commonwealth government exercised its powers under

the Constitution to pass the Weights and Measures (National Standards) Act 1948 (No. 29 of 1948). It defined the roles of the National Standards Commission and CSIRO in Australia's system of weights and measures. In several respects, particularly in its flexibility, the Act was in advance of similar Acts in other jurisdictions around the world. It did not, for example, define any standards but gave power to the Government to make regulations under which standards could be defined, thereby permitting the changing of standards from time to time without changing the Act.

On 7 September 1984, the Commonwealth's Weights and Measures (National Standards) Act 1948 was replaced by the National Measurement Act 1960. "Australian primary standard of measurement" means a standard of measurement that is maintained, or caused to be maintained, by the Chief Metrologist as an Australian primary standard of measurement for the purposes of subsection 8(1) of the National Measurement Act 1960. This Act extends to all the Territories and consequently NSW was legally bound to accept the Australian primary standard of measurement as its primary standard.

In 1963, the Surveyor General of New South Wales was approved as a verifying authority under the Weights and Measures (National Standards) Act 1948 (Lands, 1963). This new authority of the Surveyor General was reflected in amendments to the Survey Practice Regulations on 19 June 1964 when Regulation 10 was substituted with a new regulation: "A surveyor shall make every survey … with a steel or invar band whose length is known in relation to a standard of measurement or a subsidiary standard of measurement established under the provisions of the Weights and Measures (National Standards) Act 1960, one such standard being under the control of the Surveyor General."

Regulation 43 was substituted by: "A surveyor shall ... check all measurements … by closure of the latitudes and departures of the lines … computed to two places of decimals of a foot if the survey is less than one, or at least one place of decimals of a link or foot if the survey comprises one acre or more." The tables of allowable misclose remained the same but a new requirement for calculating the misclose was introduced: "The misclose shall be determined as $\sqrt{(a^2 + b^2)}$, where a is the error in latitude and b is the error in departure." It will be readily perceived that the calculated misclose is the diagonal resulting from the application of a Pythagoras equation to the errors in each of the latitudes and departures. This practice has remained unchanged to the present day.

The tables in Regulation 44 were substituted with new values ranging from 1 part in 12,000 for level country and 1 part in 4,500 for mountainous country. The required accuracy of measure of length was thereby increased by 50% from the former values.

The Weights and Measures (Amendment) Act 1964 re-affirmed the Imperial Standard Yard as the predominant linear measure in the system but it did however finally give statutory recognition (by extension) to units of land measurement which had been in common usage in NSW since the proclamation of the colony in 1788. Recognition was also given inter alia to measures of length in the metric system.

Schedule C of the Act described the imperial system as follows:

- The imperial standard yard shall be the unit or standard measure of length from which all other imperial measures of extension, whether linear, superficial, or solid, shall be ascertained.

- One-third part of the standard yard shall be a foot; and the twelfth part of such foot shall be an inch.
- Five such yards and one-half shall be a rod, pole or perch; four such rods, poles or perches shall be a chain; ten such chains shall be a furlong; and eight such furlongs shall be a mile.
- One-hundredth part of such chain shall be a link.
- Ten square chains shall be an acre and one fourth part of such acre shall be a rood.

The metric system was described in Schedule C as:

- The standard metre shall be the unit or standard measure of length from which all other metric measures of extension whether linear, superficial, or solid, shall be ascertained.
- One thousand such metres shall be a kilometre; one hundred such metres shall be a hectometre; and ten such metres shall be a dekametre.
- One-tenth part of such metre shall be a decimetre, one-hundredth part of such metre shall be a centimetre; one-thousandth part of such a metre shall be a millimetre; and one-millionth part of such metre shall be a micron.
- For land measurement the square dekametre shall be an are; the square hectometre shall be a hectare; and the square metre shall be a centiare.

There were further amendments to the Weights and Measures Act in 1965, 1968, 1969, 1975 and 1980 but these amendments were all of a procedural nature and more particularly to recognise the dominant legislation of the Parliament of the Commonwealth of Australia.

In 1970 the Commonwealth's Metric Conversion Act 1970 (Act No. 16 of 1970) was passed. It was an Act to facilitate the adoption in Australia and in certain Territories of the metric system of measurement, and for that purpose to establish a Metric Conversion Board. The Metric Conversion Board was duly established and Australia proceeded down the path of change to metric units. On 1 July 1972, it became obligatory that plans for title purposes, intended to be lodged for registration at the Registrar General's Office, were required to show dimensions in metric units.

An amendment to the Survey Practice Regulations on 3 October 1970 heralded the arrival of technology of the modern era. Regulation 10 was extended with the additional words after the words 'Surveyor General': "or with electromagnetic distance measuring equipment properly calibrated by an authority recognised by the Board." The remaining amendments to the Survey Practice Regulations in 1972, 1973, 1975 and 1981 introduced no new principles regarding standards of measurement of surveys.

Finally, an amendment to section 3(1) of the National Measurement Act 1960 on 30 September 1984 provided a NSW primary standard suitable for adaptation to facilitate the surveying and measurement of land to a high degree of accuracy. The amendment states that "State primary standard of measurement" means a standard of measurement that has been approved by the Commission and that is maintained, or caused to be maintained, by a State or Territory and that has been verified under section 9 by means of, by reference to, by comparison with or by derivation from an Australian primary standard of measurement or an Australian secondary standard of measurement. On 25 March 2004 "the Chief Metrologist" was substituted in lieu of "the Commission" by the National Measurement Amendment Act 2004.

As a consequence of Surveyor General Don Grant's wide-ranging review of the survey systems of New South Wales in 1986, the Survey Practice Regulations were repealed and an

updated and a reorganised form was issued in 1990. The standard of accuracy of the measurement of length continued to be expressed as a proportion of measured distance relative to slope. The more widespread use of EDM equipment in survey practice was doubtless influence in the Surveyors (Practice) Regulation 1996 introducing "accuracy of length" being expressed as "6 mm + 30 ppm or better". The amendments in 2003 continued this practice but the Surveying and Spatial Information Regulation 2006 (formerly the Surveying Regulation 2006) introduced a paradigm shift that has continued into the current Surveying and Spatial Information Regulation 2012.

The current regulations are reliant for "accuracy of length measurements" on the Inter-Governmental Committee on Surveying and Mapping's (ICSM) publication Standards & Practices for Control Surveys (SP1) wherein "standards of class and order" are articulated in substantial detail. The maximum allowable error (r) is calculated using the following formula:

$$r = c\,(\,d + 0.2\,) \qquad (1)$$

where (in plain English):
r = maximum allowable error in millimetres.
c = a value assigned in Table 1 of the publication for the specific class of survey.
d = measured distance in kilometres.

The regulations simply state "length measurements must be made to an accuracy equal to or better than class C, for an urban survey, or class D, for a rural survey." The values of c assigned in the current publication for urban and rural surveys are 30 and 50 respectively.

5 CURRENT POSITION

The facility at the former Lands Office building in Bridge Street, Sydney now contains one departmental baseline for the exclusive use of the Surveyor General and one public baseline, each consisting of a zero terminal and successive terminals at:

- 20 metres.
- 1 chain (66 feet).
- 25 metres.
- 100 feet.

The two 20-metre baselines were the only intervals regularly verified by the Surveyor General in accordance with NMI requirements using a State primary standard. The primary standard used was a 6 mm wide stainless steel tape, which was verified in relation to the Australian primary standard of length every two years by the National Measurement Institute, Lindfield. As a consequence of modern surveying technologies such as EDM and satellite positioning replacing tape measures, Land and Property Information (LPI) has since discontinued maintaining and verifying these two baselines.

6 PRACTICAL APPLICATION OF TEST BASELINES

The 'statement of test' issued by the Surveyor General showed all information relating to the practising surveyor's tape such as nominal length, width, material, lengths tested and at what tension, conditions of support and test temperature. Recent practice was to provide printouts

of the various corrections to be applied under working conditions but in former times it was the surveyor's responsibility to compute the temperature at which the tape measures a standard length, the correction for catenary (or sag) and tension. The prudent surveyor has always taken sufficient steps to ensure that these calculations translate in practice by establishing test baselines and comparing the standardised tape adjusted by applying these calculated corrections. To this end, over time a number of test baselines were established. Some of the better known bases are described hereunder:

6.1 The Showground

This baseline was established on the Cook Road frontage of the Royal Agricultural Society showground by the eminent survey practice of Kent and Curdie about 1923 or 1924. It was Geoff Kent's and Jim Curdie's purpose to have a standard available to calibrate their working chains outside of normal Lands Department hours. The establishment method they adopted was for a one chain standard calibrated on the Lands Department baseline to be laid fully supported on the ground, corrections for tension and temperature applied and the terminals carefully marked. Then by means of a theodolite, those terminals were transferred to the adjacent wall at chest height and carefully marked. This then additionally enabled tension and sag corrections of a tape in catenary to be determined in a practical and accurate manner. The details of the baseline soon became shared knowledge and because of its convenience to Centennial Park for many years the scene of the Board of Surveyors' practical examination. Most candidates availed themselves of the opportunity of testing their tapes on this baseline before attending that examination.

As described earlier, the Institution of Surveyors unsuccessfully made representations to the Under Secretary for Lands in 1938 for the Department to establish a standard on the Showground's southern boundary wall to enable the testing of long bands under working conditions. Those representations resulted in a public baseline being laid down in the Lands Office building but it remained for the profession to establish and maintain any required working standards at no cost to the Department.

6.2 The Outer Domain

About 1950, the survey section of the Metropolitan Water Sewerage & Drainage Board (now known as Sydney Water) established a baseline on Mrs Macquarie's Point in the Sydney Outer Domain. It was on slightly undulating ground and about 400 feet long between the terminals which were marked with small brass triangles and pins in lead plugs set in sandstone bedrock. Broad arrows have been cut in the sandstone adjacent to these marks but the authority for its use is unknown. It was measured at 398.425 feet by the Board's Survey Branch and confirmed as 398.426 feet by Staff Surveyor L.H. Webber on 11 August 1953 with a first-order traverse specified in Regulation 12, Table 1, of the Survey Co-ordination Regulations 1951 (see Recorded Plan No. 55 in the Central Plan Register held in the offices of Survey Services Sydney at LPI). Webber's survey confirmed the integrity of the measurement made by the Board's survey staff; the baseline became very popular and was regularly used by public and private sector surveyors alike until the 1980s. The terminals remain in excellent condition and the base useable but the terminals themselves are no longer intervisible due to an increase in vegetation (Figure 4).

Figure 4: Southern terminal of the Outer Domain baseline (February 2013).

6.3 The University of New South Wales

The establishment of this 100-metre baseline located on the grounds of the University of New South Wales in 1969 is attributed in no small measure to the enthusiasm of Dr. George G. Bennett, former Head of the School of Surveying in the Faculty of Engineering, who was Senior Lecturer at the time. The baseline was established using a standard steel tape marked APT 3246 and calibrated in March 1969 at the National Standards Laboratory (CSIRO). It was considered that the baseline was accurate within plus or minus 1 part in 100,000. It was located on the retaining wall behind the Mechanical Engineering Workshop building. It was principally intended for use by students and staff of the University, however in due course its location became widely known and Bennett as Head of the School of Surveying found it necessary on 20 November 1979 to advise the broader profession of the implications associated with using the baseline (see Institution of Surveyors NSW Monthly Bulletin, January 1980): “Many surveyors use the above facility at Kensington for the standardisation of their surveying bands. However, it must be stressed that the results of these measurements have no legal standing and can only be used as a guide to standardisation characteristics.” The baseline was last used by students in 1986 and is no longer accessible.

6.4 Established Permanent Marks

By the 1980s the density of established permanent marks had increased and a plethora of test baselines became readily available to practising surveyors.

7 EDM CALIBRATION BASELINES

By the beginning of the third millennium, the emphasis had passed from effecting surveys with steel bands to measuring electronically. As indicated in the introduction, this paper does not intended to investigate the question of calibration of EDM instruments or validation of GNSS equipment. However, it is appropriate to mention that there are several EDM calibration baselines throughout New South Wales that are verified by the Surveyor General every two years.

8 GLOBAL NAVIGATION SATELLITE SYSTEMS

The use of the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS) for the measurement of land boundaries also emerged with the dawn of the

21st century. Based on precise time and orbital data signalled from rotating satellites and converted to positional coordinates with the help of ground tracking stations, it presented its own unique set of problems in terms of providing traceability to the national standard for Australian legal purposes. 'Position' was added to the list of physical quantities covered by the National Measurement Act 1960 and more than eighty precisely determined reference positions were established across the Australian continent, ten of these determined by multiple methods (Todd, 2004). In New South Wales, LPI's permanent GNSS network, known as CORSnet-NSW, provides fundamental positioning infrastructure across the State.

GNSS equipment must be validated against an approved GNSS test network. The Surveyor General has established a number of test networks, which may include pillars of existing EDM calibration baselines. However, GNSS equipment may be also validated over a local network of State survey control marks. Clause 14 of the Surveying and Spatial Information Regulation 2012 provides inter alia that any GNSS equipment to be used in making a survey must be verified against the State control survey by reference to at least three established survey marks with accurate Australian Height Datum (AHD) values on the basis that the State survey control network in itself has legal traceability.

There remains an element of uncertainty and whether the provisions of clause 14 are adequate to establish legal traceability, but this question will undoubtedly be resolved in due course, either by science or by a challenge in the courts.

9 CONCLUDING REMARKS

The landscape and settlement pattern of New South Wales bears testimony to the contribution made by members of the surveying profession. History has recorded a great many examples of the physical and mental difficulties they faced as they went about their allotted task. It was Surveyor General Major (Sir) Thomas Mitchell who in a circular to his survey staff in 1836 highlighted the importance of accuracy in the measurement of land surveys wherein he said (Marshall, 1999): "The measurements of the lands in question is altogether a different matter – the public being now purchasers at 1/- per acre from the Crown on whose faith they depend for the accuracy of the documents used in the progress of the sales – it is of the utmost importance that the most scrupulous exactness should obtain in these surveys."

For about the first 100 years or so, the legislature of New South Wales showed complete indifference to the circumstances that prevailed regarding not only the need for statutory recognition of units of measurement used in land surveying but also the provision of a suitable State primary standard of measurement capable of being physically extended to enable the measurement of land boundaries to be effected to a legally accepted standard of accuracy. In reaction, the surveying profession, in effect, became self-regulating and with the assistance and co-operation of the Office of the Surveyor General created a most adequate 'prime standard' on the ground floor of the Bridge Street Lands Office. The profession collectively and separately established test baselines throughout the metropolitan area and rural centres of the State. The aim, most responsibly motivated, was the pursuit of excellence in the measurement of property boundaries or in the words of Major Mitchell "the most scrupulous exactness".

The 'prime standard' was finally elevated to State secondary standard status in 1963 but the irony is that within two decades steel and invar tapes had all but been superseded by

electronic distance measuring devices. Technology has vastly improved since the 1980s and it is difficult to imagine a return to the use of steel or invar bands for the measurement of property boundaries.

The National Measurement Regulations 1999 define 'metre' as "the length of the path travelled by light in a vacuum during a time interval of 1/299 792 458 of a second". It has been scientifically determined that the most permanent and reproducible of all standards of length are not those made by etching fine lines on stable alloy bars, but those provided by nature herself in the form of the wave lengths of light emitted by excited atoms; from sources of light stationary with respect to the observer, these wave lengths, so far as is known, never vary.

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Getting Noticed for All the Wrong Reasons: BOSSI Investigations of Complaints Against Surveyors

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ABSTRACT

In New South Wales, land and mining surveyors are registered under the provisions of the Surveying and Spatial Information Act 2002 ('the Act'). The Act is administered by the Board of Surveying and Spatial Information (BOSSI) of NSW, a statutory authority created under the Act. Pursuant to section 28 of the Act, BOSSI's principal functions include the registration of land and mining surveyors and ongoing administration of the register, the investigation of complaints against registered land and mining surveyors, and the taking of disciplinary action which may arise as a result of the investigations. I have been a member of the Board of Surveying and Spatial Information of NSW since 2001. In 2002, I was appointed the Convenor of the BOSSI Professional Audit & Investigation Committee. The purpose of the Committee is to investigate complaints against registered surveyors. Since 2002, BOSSI has received about five complaints against surveyors per annum. One of these investigations resulted in the registered land surveyor being removed from the register, demonstrating that the consequences of a finding of professional incompetence or professional misconduct can be most severe. This presentation outlines some of the complaints that are lodged against registered land surveyors, the process that BOSSI employs to investigate them and the results of these investigations. The terms 'professional incompetence' and 'professional misconduct' are explained, as is the Board's interpretation of the difference between professional incompetence and an unfortunate mistake. A registered land surveyor's obligations under the Act in relation to the supervision of unregistered persons is also highlighted, as this is increasingly becoming a factor in errors made by surveyors that could be subject to a claim of professional incompetence. The presentation includes actual case studies.

KEYWORDS: *BOSSI, professional incompetence, professional misconduct, investigation, supervision.*

Contemporary Surveying Education and the Surveying Profession

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ABSTRACT

The authors recently prepared a report for the Council of Reciprocating Surveyors Boards of Australia and New Zealand (CRSBANZ), which concerned various matters relating to the surveying degrees whose graduates should be accepted for enrolment as candidates for registration with one of CRSBANZ's member boards. The more substantial part of the report involved a proposal for the minimum content of such a degree. As well, the report looked into some other issues associated with surveying education, including a consideration of the current viability of surveying degrees across Australasia. This paper explains the authors' logic in nominating the degree content and some of the more interesting aspects of the problem of nominating crucial degree content in the modern era, and then provides a short discussion of some of the more intriguing side issues, notably the current extent of the use of online material in education, the ambiguous mechanism of selecting cut-off scores for various courses, and the ultimate impact of surveying research on the education and the number of surveying graduates, assuming that the issues about university education may not be familiar to the surveying profession.

KEYWORDS: *University degrees, surveying education*.

1 INTRODUCTION

In late 2012, the authors prepared for the Council of Reciprocating Surveyors Boards of Australia and New Zealand (CRSBANZ) a report into various matters relating to those surveying degrees whose graduates would be accepted for enrolment as candidates for registration with one of its member boards. That report consisted of, primarily, a proposal for crucial university degree content, especially in the current era as technology changes and, secondly, comment on a number of other related educational issues which are seen to affect surveying education. The preparation of the report forced the authors to think seriously about various matters relating to current surveying education. Having gone through that process, it seemed worth sharing with the wider surveying community the authors' thoughts on some more interesting matters, especially as a number of the issues would be unfamiliar to people outside academic circles. More than that, the authors accept some responsibility to disclose and defend both their proposed course content and the logic used to prepare that list. The boards which have membership on CRSBANZ are those statutory organisations that register surveyors across all Australian states and territories and New Zealand, and this obviously includes the Board of Surveying and Spatial Information (BOSSI) in New South Wales.

The authors understand that at some time, CRSBANZ plans to disseminate the report among the surveying community. But the authors wish to make it clear that the contents of this particular paper does not necessarily reflect the content of the report to CRSBANZ, and CRSBANZ may or may not accept the authors' suggestions in that report. The issues in university surveying education which are raised here are not confidential, and are not relevant only to CRSBANZ.

2 DEFINING CURRENT DEGREE CONTENT

2.1 Why Define Surveying Degree Content?

Many surveyors will, of course, have an opinion about what should be in a university degree in surveying. Some high-level surveying material, such as aspects of geodesy or photogrammetry, or engineering design or Geographic Information Systems (GIS) can be contentious. The authors' choice of surveying degree content and also their approach to trying to make that selection might therefore be of interest, especially since the proposals have been passed on to CRSBANZ, who may at some stage base their assessment of degrees on the proposals. That list could be used to accept or reject degree programmes for entry into a profession, and may therefore influence students' entry into an employment avenue. The authors have therefore considered the matter carefully, as the account below should suggest.

It is necessary to begin by considering the fundamental question of what is being defined, and why. The universities themselves would have their own opinions as to what they fit into their degree programmes. It is apparent that statutory boards associated with CRSBANZ who have the responsibility to licence people to go into the community as 'registered surveyors', would need to ascertain whether degrees from universities in their domain meet registration requirements. Other groups associated with the surveying profession can also be interested in the content of a surveying degree. But perhaps the question only matters if there is such a thing as a surveyor. Does such a specific profession actually exist, and can a surveyor be exactly defined anyway?

The argument that there is not such a thing as a surveyor is based on the inverse notion: there is no definite educational content. Can graduates, nowadays, if they do not have the orthodox surveying education determine whether they would qualify as a surveyor? Consider a couple of interesting scenarios: Is it not possible to imagine a person who has a civil engineering degree, with extensive engineering design experience, and good TAFE qualifications in surveying and extensive work experience with GIS calling him/herself a surveyor? If that person applied for a position of surveyor, could someone not reasonably assess whether indeed that person is acceptable to do survey work – as a 'surveyor'. Can an organisation reject that person if it advertises for a surveyor, simply because the candidate lacks a familiar surveying degree? Indeed, if that person was rejected on that basis, might they not be able to seek the advice of their lawyer on that rejection? In the modern era, cannot a person 'cherry-pick' their own qualifications, but also cannot the person who employs or engages a surveyor decide whether that person's qualifications or experiences are suitable to them? If a person arrives from overseas with a surveying degree which, unlike most, does not include any photogrammetry, for example, can they not still regard themselves as a surveyor? So, to vary the question asked above: Is there really such a definable thing as a surveyor? And moreover, if it is difficult, does it matter whether the profession has or does not have a consistent view of what a surveyor is?

Although the answers to many of these questions are affirmative, it is also fairly obvious that certain groups – professional and industry organisations – do see certain people as surveyors. These organisations – and notably, in the case of CRSBANZ, those statutory bodies – may want to accredit or assess degrees. If so, then presumably there are times when the educational qualifications of those people need to be assessed to see whether they fit the model of what are regarded as surveyors, from a legal or community point of view. But, as well as that, it does seem that certain people, and only certain people, are regarded *by the profession and perhaps by other allied professions and even by the wider community* as surveyors (and by the Australian Tax Office when you put 'surveyor' as your occupation on your income tax form!). Other people who are not surveyors do not generally try to call themselves surveyors. If that is the case, it should be possible to isolate the common things that bring all surveyors under one umbrella, and excludes everybody else. What is it that makes certain people 'surveyors'? Once that is defined, the requisite university course material may be more apparent.

If people are to be regarded as surveyors, then what is crucial is a *minimum* list of things they must *all* know about in order to be regarded as a surveyor, not a total list of all things that they might like to know about. This is not a simple concept, as it involves deciding that some topics should be left out of the minimum list, but of course they can still be included by the educational institutions. Topics which people see as desirable, like engineering design or GIS expertise or business practices or even a good general knowledge may be excluded from a minimum list. Even so, the minimum list can be developed by recognising that certain people, and only certain people, are regarded by the profession and by the wider community as 'surveyors' because they are capable of doing the wide range of things that *all* surveyors can do. And *only* surveyors can do all those things. There is knowledge which is the province of the surveyor. Furthermore, surveyors should be recognised and be proud of that knowledge.

Engineering design or GIS expertise or business practices or even a good general knowledge are valuable – but they can be excluded from the list because, in the end, there are other professionals who do those tasks, and they are not crucial to enable surveyors to do what only they can do. It is helpful if a surveyor is a GIS expert, but if this is not covered in a person's qualifications, that person is still a surveyor. On the other hand, if that person cannot calibrate their Electronic Distance Measurement (EDM) instrument, that person is not a surveyor. It is the crucial or essential coverage that needs to be enumerated. It is therefore argued that a check list must contain *not* what is *desirable* for a degree, but what is *essential* for a surveyor's education. After that minimum coverage, a university programme – or a person's individual education – could cover more material, whether higher geodesy or useful land economics or the enlightening education – but the use of a minimum list must not exclude from the profession those who had what was crucial. The authors contend that that minimum content should fit the criterion that it would be included in a degree if, for some reason, it was decided to educate surveyors in minimum time or at minimum cost!

2.2 The Adopted Definition of a Surveyor

The most difficult part of the topic selection process is to define the surveyor which says what the community would expect all surveyors to be able to do. CRSBANZ (CRSBANZ, 2013) refers to the definition provided by the International Federation of Surveyors (FIG), which relates primarily to the 'functions' or 'activities' of the surveyor, which does not enumerate specific tasks.

But as well, the CRSBANZ website explains that "*land surveying is the definition of land boundaries by the application of survey procedures and exercise of judgement in accordance with precedent and statute law. It includes surveys for the layout of cities, sections, roads and streets; the disposition, subdivision, alienation, resumption, amendment of title and other dealings in land and interests in land. It also includes the collections of material facts and the giving of evidence for courts of law in cases of damage, title boundary disputes, the rectification of titles, etc., the preparation and giving of professional opinions, and interpretation of descriptions and other documents pertaining to land and interests therein…*" and "*…there are many other surveying disciplines*", which are listed.

Definition was also assisted by the outline by the Institution of Surveyors New South Wales (ISNSW) as it was seen as perhaps suggesting how surveyors see themselves: "*Surveyors carry out measurements both above and below ground and water, surveying by varying means to establish relative position and size of both natural and man-made objects*" (ISNSW, 2014).

Despite all the things that a surveyor might do, it was seen that, even in the modern era, and even with changes in technology and the ways that surveyors can do their work, the distinctive attribute of a professional surveyor in Australasia is still that of a professional measurer. All surveyors are able to undertake precise spatial positioning in a way that no other professional can, knowing the precision of the positioning and also whether it suits the purposes of the survey. All surveyors know about measuring the general topographic surface of the earth, and natural and constructed or cultural features on it, such as roads and buildings, and can measure a range of other objects, which may be from a few metres to some kilometres in size, particularly industrial objects, buildings and various other engineering structures, while operating if necessary in a wide variety of situations, including underground, on industrial sites and on the water. They know about setting-out points to define the location of objects to be constructed, to as high a precision as is required (and to a level which is higher than non-surveyors might), and converting the measurement data to spatial information of high accuracy, calculating in three dimensions and/or taking into account the curvature of the earth if necessary, while knowing the accuracy of the information they are providing, and presenting the results of the measurement as spatial information in a form required by a second party, while surveying safely, and communicating surveying results professionally with colleagues, clients and the public. Non-surveyors cannot be expected to do all this.

2.3 Crucial Surveying Educational Content and the Essential Surveyor

This list of tasks can then be seen as creating a special group of mandatory course topics, which, in line with the thinking above, are the province of surveyors. These topics 'belong' only to surveyors and belong to all surveyors. A classic case in the past was precise positional astronomy. No GIS expert or civil engineer, or accountant or politician could do it. The reasonable person in the street assumed surveyors could do it, and expected that nobody else could do it. But what else now fits into that core category of the province of surveyors? The nominated list includes professional field measurement, especially with total station and Global Navigation Satellite System (GNSS) technology, processing the measurements to deduce spatial information, the presentation of that spatial information, control surveys, and surveys for engineering, industrial, mining, tunnelling and hydrographic purposes, but also cadastral surveying, and even geodetic surveying.

After that, there are matters that people other than surveyors know, but some knowledge *about* them is *needed* by surveyors to enable them to execute the essential tasks listed above.

This can even include engineering, GIS, Computer-Aided Design (CAD), but also sciences and mathematics. These proposals are shown (but not detailed) in Table 1. Beyond that there is the material which is desirable but *not* mandatory, such as additional GIS, engineering, mathematics, sciences, economics and perhaps some general education.

Table 1: An outline of categories of surveying degree topics in terms of the proposed mandatory topics and desirable topics.

Category of Topics	**Summary of Coverage**
Mandatory matters seen as the province of the surveyor:	Field measurement, processing measurements to deduce spatial information, presentation of spatial information, control surveys, surveys for engineering, industrial, mining, tunnelling and hydrographic purposes, and cadastral surveying, geodetic surveying.
Mandatory knowledge, to support the crucial work of the surveyor:	GIS, CAD, sciences, mathematics and statistics, report writing, land development, water and geotechnical engineering, road and railway design, transportation management, town planning, property valuation, remote sensing, business management, work health and safety, ethical matters, social issues.
Material which is seen as useful and desirable, but which should not be mandatory:	Earth sciences: geophysics, geology; geography; computing skills, programming, economics, engineering design for land development (hydrological, hydraulic, geotechnical, transportation, structural); road and railway design, mining engineering, indigenous studies; positional astronomy theory and practice, higher geodetic surveying and geodetic science, higher photogrammetry.

2.4 The Underlying Characteristics of Surveyors

The interesting part of that selection of key surveyor's work seems not to be to detail course content so much as a recognition that there are a number of crucial characteristics of surveyors, the special group of course topics which are the province of surveyors, only surveyors but all surveyors. Identifying these matters may help create a surveyor's sense of identity and even of worth. After all, it seems to be arguable that too many times the surveyor is seen as a secondary profession. The engineer calls in the surveyor when some marks are wanted, like a chef calling in the kitchen hand to clean up the dishes while the chef decides what to cook next. It is the engineer who 'builds' the buildings – just as it is the chef who makes the cakes – while the surveyor never gets any credit. There exists a comment by Lemmens, from Delft University of Technology, that at the end of a day making observations at a construction site, surveyors leave and "*…perhaps some nails have been hammered into the asphalt. How can a profession be promoted without impressive products and appealing icons?*" (Lemmens, 2012).

However, there seems to be some benefit in recognising the surveyor's niche, if only for our own satisfaction. Users of GNSS to position, say, infrastructure around cites are often encountered. They know the GNSS jargon and the Map Grid of Australia (MGA) jargon – but when it comes to the hard questions about precise GNSS positioning and map projections, only surveyors can answer them. Surveyors who do not face geodetic issues on a daily basis may find they are a bit vague about some things, but somewhere the answer can be provided – by a surveyor. This list goes on: a surveyor is needed when expertise is required in adjustment of observations or photogrammetric theory or precision GNSS. Moreover, surveyors typically know more cadastral law than most lawyers, and only surveyors can execute cadastral surveys.

Historically, surveyors certainly had a distinctive role connected with land development and mapping. During the era of the Europeans' exploration of Australia and New Zealand, many explorers were surveyors. In subsequent eras, surveyors continued to be involved in mapping,

and were out and about on the land well before most other professions. Arthur Streeton's painting 'Surveyor's Camp', depicting a site near Richmond, NSW, in 1896, reveals how the surveyor was mapping, in the field, on the land, before perhaps any other professional worker. This connection with the land continued of course with the surveyor's crucial role in rural and urban land developments and the construction of all manner of infrastructure. It is a struggle to think of a historical painting that characterises, say, accountants or lawyers.

3 OTHER ISSUES IN UNIVERSITY EDUCATION OF SURVEYORS

The surveying industry's concerns about education often relate to the low numbers of surveyors being graduated. Surveyors, quite reasonably, can have views on what can be done about it, just as they have thoughts on surveying degree content. However, misunderstandings about how the higher education sector works – especially now, as compared with how it worked in the past – may occur. Some education issues are reviewed in this section.

3.1 Tertiary Entry Scores

The relevance of programme entry score requirements – now the Tertiary Entry Ranking (TER) across all of Australia – is a little complicated and often misunderstood. The principal use of the TER by university administrators is to regulate student numbers in a programme. Thus, the more *popular* programmes have higher TERs to constrain student numbers, and *vice versa*. However, the wider community – including prospective students and their parents – can assume, reasonably but quite incorrectly, that entry scores are based on academic assessment of course difficulty. This perception means in turn, that a low entry score is seen by the public to equate to an easy course. An easy course may seem attractive, but in fact it seems that an easy course implies a low status course, and one which is likely to lead to a lower income. It actually seems that many students want to study for a degree with a high TER cut-off, whether because it gives the course higher prestige, or because they expect a higher income! A vicious cycle can be created: a high prestige course can have high demand, hence a high TER, which creates further demand. What is important here is that surveying can have the reverse problem: it has a low demand (probably because it is relatively unknown as a profession), so the TER drops and the prestige and demand appeal is reduced even further. Of course, universities also have the option of setting a programme's TER artificially high, even for programmes with low numbers, to raise their status and hence their appeal. But the first point to recognise here is that surveying can lose out to other courses with a higher TER, and therefore with higher prestige, if its TER is allowed to drop.

The second important point may be to recognise that the academics (including those in surveying) may have no influence on the cut-off score which is typically set by university administrators. The decisions are often made at a level above even Faculty heads. The surveying profession therefore may have no means of influencing the TERs that they would like to see for surveyors who eventually proceed to registration.

3.2 Financial Priorities

While the community can regard the universities as educational institutions which are concerned primarily with educational issues relating to students, it has to be recognised that over the past couple of decades, as funding levels have dropped and funding formulae have become more complicated, the first challenge of university administrators has probably

become to balance their budgets. The business model seems to have taken precedence over the educational model. In particular, universities can be more responsive to student demand for programmes than community demand for graduates from their programmes. Surveying is not necessarily safe from closure simply because there is an argument about a shortage of surveyors and its impact on the community. There is a shortage of surveyors because there are few students taking up the degree programme, and that makes the programmes expensive and in danger. But what is important, following from a similar point made in in section 3.1, is that the surveying profession may have no means of influencing the maintenance of surveying degrees and hence influencing the number of surveyors.

3.3 Research and Programme Viability

The universities' attitude to research has often been misunderstood. As with the comments made in sections 3.1 and 3.2, it is seen that the community's belief and the universities' attitude may be completely different. The community probably once saw research as an optional side activity for staff who were so underworked that they would undertake interesting investigations, but that misunderstanding, like the assumption that universities close down outside teaching periods, is slowly dying. For universities, research is a very significant activity. They support research activity intensively, as a means of generating income through research grants, but perhaps just as importantly, research is seen to generate reputation and ranking which is used for publicity, to attract students (especially better students) and yield community esteem and hopefully benefactors. The homepages of university websites typically display research success, and perhaps even their world ranking, which is presumably influenced by research success.

Research activity is therefore generally expected of all academic staff. Staff appointments are normally influenced heavily by a candidate's research success, often measured by publications (not necessarily in journals read by practising members of the profession) and by their ability to secure research grants. For surveying, the viability of some undergraduate surveying programmes may be as much influenced by research profiles as by actual undergraduate numbers. The point is that it can be foolish to regard research as a distraction from surveying educational needs, but it would be beneficial to recognise that a lack of research in surveying can actually hamper programme viability. Admittedly, surveying research may not always be seen to benefit daily survey practice, but the surveying profession should not view academic research in matters which they do not immediately make use of as wasteful. It may be more helpful if the profession can do what it can to encourage research in certain specified directions which are useful to the profession.

3.4 Student Satisfaction

Despite the assertions made above that teaching concerns can take second priority to financial management and research success, it is possible to detect an increasing importance being attached by funding agencies, and hence in turn the universities themselves who want some of the funding, to student satisfaction. This is most obvious through a growing number of irritating and unwanted student questionnaires.

The Tertiary Education Quality and Standards Agency (TEQSA) website confirms this move, advising that "*TEQSA will undertake both compliance assessments and quality assessments. Compliance assessments involve auditing a particular provider's compliance against the threshold standards for registration as a higher education provider. Quality assessments can*

either be an assessment of the quality of an individual provider or a review of an issue across a number of providers (a thematic review)" (TEQSA, 2013).

The implication is that teaching may be regaining some priority, and this may balance the dominance of research and strictly budgetary priorities. But the danger may be that the student satisfaction surveys may pay more attention to education technique and student contentment – even student pampering – rather than to ensuring that students learn! In that regard, the profession can note that at least it can retain some influence on programmes through universities' programme advisory committees and also in procedures for professional accreditation.

3.5 The Revolution in Electronic Media

It is hardly surprising that in the current era there is pressure for an escalation of the availability of electronic materials for students. Students' expectation of electronic teaching material now includes routine provision of audio/visual presentations, such as PowerPoint presentations and YouTube video clips. But there is also university pressure and student expectation to provide online course materials such as video copies of lectures and copies of associated material. But it can be a concern that the modern student generation is so familiar with electronic media that it has a reasonable expectation of accessing online educational material instead of live attendance. With plenty of online material, attendance at university is seen to be a less important part of their daily routine, allowing students to change their daily timetable. It is noticeable that students spend less time on campus than in the past, their lives revolving more often around part-time work and their own social networks. It is occasionally reported in the media that for the current student generation, owning a car may not be as much a priority as an electronic social media device, and presumably also a computer. The availability of online material helps save extensive amounts of travel time and even the common hassles of car parking. But unfortunately, remoteness from university and from staff contact may detract from the learning experience, which is especially important in the case of practically oriented surveying.

Online capabilities allow not only students but the universities themselves to look at education in a new light. Remote learning can help resource saving in teaching and in the not-insignificant capital cost of lecture theatres, and other infrastructure, even the car parking mentioned earlier. Online learning is appealing to universities for large-scale teaching – even if teaching staff are concerned that it is less effective. Charles Darwin University claims to be the first Australian university to offer Bachelor and Masters level programmes in chemical engineering online (CDU, 2013). Universities are looking to engage in online education, sometimes as large-scale educational schemes with other cooperative institutions, as a means of both growth and survival. This new education (or perhaps business) model has been outlined by Professor Caroline McMillen, Vice-Chancellor of the University of Newcastle, who last year promoted the concept of offering course material online in the Newcastle Herald (McMillen, 2012). What was most interesting was the fact that the material would be offered free, but a student must enrol – and then pay a fee – if they want assessment. McMillen observed that such an online course in Circuits and Electronics, offered by Massachusetts Institute of Technology and Harvard together, attracted 155,000 enrolments – but with 7,000 students passing the course. It remains to be seen what impact these sorts of changes will have on surveying programmes and their practicability in coming years.

4 CONCLUDING REMARKS

The authors have taken seriously their proposal for enumerating crucial surveying degree content to CRSBANZ, and accordingly an outline is given here for the logic and the processes used to enumerate such a list. However, listing crucial material can provide a revelation that the surveyor has certain characteristics of which surveyors should be proud. Other issues in the changing education scene deserve to be recognised to ensure that the surveying profession keeps sight of how it can best face possible continuing low student numbers.

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The Role of ePlanning in the NSW Planning Reforms: Implications, Benefits and Opportunities for the Surveying Community

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ABSTRACT

A key objective of planning reform in NSW is to establish ePlanning services and tools that provide access to a digitised planning system, anytime anywhere. The introduction of the Department of Planning and Infrastructure's ePlanning program will improve access to land, property and planning information, provide a greater level of transparency, and offer online tools for transacting with the planning system. This paper sets out the rationale for the Department's ePlanning program, outlines the concept of ePlanning and how the use of electronic processes such as online lodgement and processing of development applications, the provision of web-based information (e.g. maps, regulations, state and local policies) will assist in the delivery of planning and development services. The challenges, impacts and benefits of ePlanning, and the critical role surveyors can have in the new planning system, are discussed. The implications of ePlanning for surveyors, in NSW in particular, are discussed with four key benefits identified: (1) Improved positional accuracy of the state-wide digital cadastre, (2) improved GIS positioning of land, property and planning information, (3) the creation of more spatial planning information that has positional accuracy, and (4) creating more planning information as 3D spatial data to facilitate realistic modelling of our natural and built environment. Improving the positional accuracy of the state-wide digital cadastre maintained by Land and Property Information (LPI) is of fundamental importance. To this end, LPI has been implementing a partnership program with local governments in NSW to improve the positional accuracy of what will be a first for NSW, i.e. the delivery of the state-wide online cadastre. This is a large undertaking, however it is anticipated that the introduction of ePlanning will draw focus back to the need for a state-wide cadastre that is accurate, reliable and accessible. This is crucial for the LPI program as it adapts to a greater reliance on online property information. The success of ePlanning in NSW will be accelerated when the full implementation and uptake of ePlanning services and tools takes place alongside the passing of the new planning legislation, which will give legal certainty to digital planning and property data. The role of surveyors in building and managing a reliable and accessible online digital cadastre will be a key building block to ensure this success.

KEYWORDS: *Planning reform, NSW, ePlanning.*

1 INTRODUCTION

A primary objective of surveying is to ensure the highest accuracy and reliability in the recording of property boundaries in order to build a digital cadastre that meets the expectations of residents, businesses and government agencies for land management. The role of surveyors in contributing to the development, establishment and maintenance of a digitised

cadastre for NSW planning will become increasingly essential as the delivery of planning and property information online becomes the principal means by which surveyors, planning professionals, businesses and residents interact with the NSW planning system. This paper outlines the concept of ePlanning and how a greater uptake of information and communication technology (ICT) in the management of planning and property data will improve business processes in state and local government and the private sector.

2 DEPARTMENT OF PLANNING & INFRASTRUCTURE EPLANNING PROGRAM

ePlanning can be thought of as the use of electronic services in the delivery of planning information and services online, anytime and anywhere, transitioning away from traditional paper-based and manual processes which constrain the current planning system. To date, there have been disjointed approaches to the delivery of online planning services through Commonwealth funded initiatives, i.e. the Regulation Reduction Incentive Fund (RRIF) and the Housing Affordability Fund (HAF). These approaches have created fragmented success at the local and state government level due to the limited co-production of delivering ePlanning services with the citizens' input. Government and stakeholders alike recognise the need for a holistic online planning system.

The Department of Planning and Infrastructure is implementing an ePlanning program to deliver citizen-centric planning services, in line with the emphasis on a coordinated uptake of technology in a new planning system for NSW (NSW Government, 2013). The program has been created as a direct result of the findings from the NSW planning system review. Stakeholders overwhelmingly confirmed the need for the state government to put the planning system online – and to provide a clear direction for online planning services for NSW.

The Program will look to deliver in the following areas:

- Standards and specifications: In a first for Australia, the ePlanning program will facilitate the creation of ePlanning data standards and technical specifications for ICT system compatibility. This approach will make it clear to planning professionals and technical financial investors in the NSW planning system what the stakeholders of NSW expect (i.e. transparency, accountability and accessibility).
- Planning portal: A centralised portal accessible in a web and mobile format to view planning information online, lodge, track and complete transactions, and engage with the planning system through comments/feedback and experiences on planning matters.
- Visualisation tools: 3D tools of houses and commercial/industrial buildings, along with 2D interactive maps of property and planning data, will bring new visual representations of planning controls to demonstrate to stakeholders what is and what is not possible based on a parcel of land to generate an understanding and an appreciation of the planning controls in order to deliver better planning outcomes.
- Transactional based services: The ability to search and discover planning information in order to lodge and track development applications online through a spatial viewer, application lodgement tool and tracking tool. This end-to-end service will make transacting with the planning system attractive and accessible to citizens and businesses alike.

ePlanning creates a number of critical benefits due to greater efficiencies in moving from a largely manual system to digital service delivery. The high-level benefits to the stakeholders of the NSW planning system include:

- Planning applicants (developers, planning/property professionals and community): Reduced time, cost and delays in investigating, preparing, submitting, tracking and having applications approved, and greater certainty of approval due to a better understanding of planning requirements.
- Communities: Reduced time to remain informed, and increased ability to be aware of, comment on and object to proposals.
- Councils: Reduced processing costs due to higher quality applications, improved productivity due to fewer general information requests and meetings, and reduced scanning costs longer term.
- Private certifiers: Greater understanding by applicants of requirements, leading to reduced complexity and improved efficiency.
- Agencies: Improved productivity due to single reference point for information, and greater certainty for decisions due to understanding of planning impacts.
- Department of Planning and Infrastructure: Improved productivity in maintaining a single database of planning information, and greater certainty for planning decisions and policy.

The delivery of ePlanning services will address (Figure 1):

- Transparency and accountability: Stakeholders demand a transparent and accountable planning system where services are made available online. Citizens are frustrated with limited access to planning information at the conceptual and assessment stage. The NSW Government is best placed to provide direction and assistance in this regard through the co-production of services and development of standards and specifications for existing systems and for new emerging systems.
- Time and cost savings: The ePlanning program takes direction from the NSW Government ICT strategy and the NSW open data policy and is focused on ensuring services become digital by default, significantly reducing costs and shortening waiting times, reducing red tape and transforming the way government engages with and empowers the community.
- Online usage: With 91.9% of Australians now having access to the internet and 71% on mobile phones (Nielson, 2013), there is a growing expectation for public services to be made available online. Citizens want to read and share information and conduct business online. The ePlanning program is one vehicle to deliver these expectations and contribute to the services of the modern public sector.
- Value in the public sector – International best practice: There is a proven emerging trend of international best practice examples for the delivery of public sector services where the citizen is placed at the heart of the service, e.g. the UK government's award-winning Government Digital Service (GDS). The GDS approach is to take existing content and work with content providers to think about the way the information is presented and consumed by the citizen. To date, 1,700 unnecessary websites have been deleted with information now accessed from one portal (https://gds.blog.gov.uk). NSW is able to learn from this approach and leverage their success, and has established a working relationship with GDS.

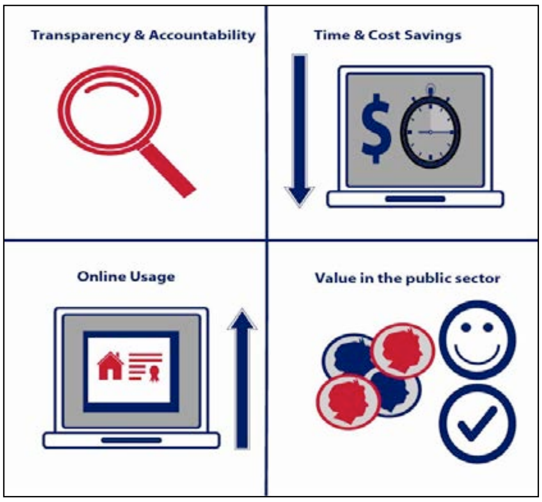

Figure 1: ePlanning benefits include increased transparency, time and cost savings for the community and planning professionals, meeting community expectations for greater online access to information and services, and streamlined interaction with (state) government.

3 EPLANNING SERVICES AND TOOLS

Improving the State's planning system is one of the NSW Government's top priorities. As part of this process, the NSW Government has commenced a 2-year ePlanning program as a way to enable many benefits identified across the planning reform. Key elements of the program are described below.

3.1 Planning Portal

The NSW planning portal will provide 24/7 access to NSW planning material in a central location. The portal will allow residents, businesses and state and local government agencies to access, transact and engage with each other and planning information via the various ePlanning services and tools. The portal will bring disparate systems and information at the local and state government level together for the first time and provide access to the other planning components, as discussed in this section, through a website. Therefore, the planning portal will encourage greater visibility, understanding and utility of planning information.

The portal will provide access to the following services:

- Spatial viewer: A planning viewer service that allows customers to visually identify property-based development standards and strategic plans in an interactive map viewer.
- Online lodgement: An application lodgement service that allows customers to lodge electronic applications where planning controls are embedded in the lodgement service.
- Online tracking: An application tracking service that enables customers to track the real-time status and receive SMS or email alerts related to their applications.
- Register of Consents: A register providing definitive data upon which industry and the community can rely for development decisions.
- Interactive house: A visual tool to assist with planning home renovations within the planning guidelines.
- Stakeholder consultation: Discussion threads and an outreach service for customers and practitioners. Users can access forums and planning news, with engagement via social media.
- Customer support service: Access to support services helping to interact with the portal.

The development of an online portal will enable residents, businesses, councils and government agencies to find planning information in order to assist with planning decisions. As all planning materials (e.g. plans, maps, policies, development approvals and datasets) are subsequently developed as digital assets, they will be stored and become searchable. Refinement of the portal will be based on user's feedback regarding functionality improvements. As shown in Figure 2, the planning portal allows users to access different ePlanning services and tools before a development gets approval.

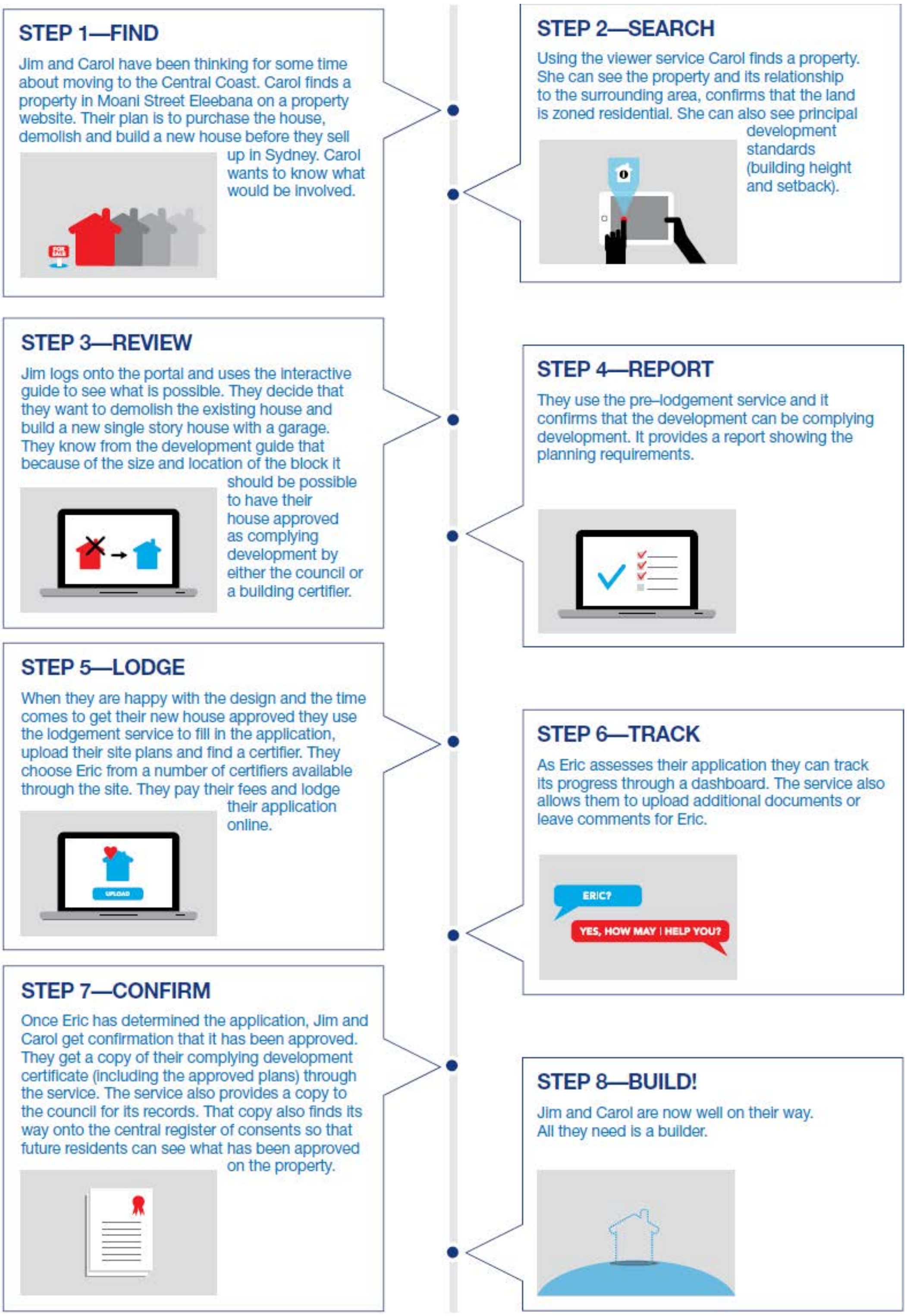

Figure 2: Flow diagram demonstrating the process of how ePlanning services and tools could be used.

3.2 Spatial Viewer

The spatial viewer is a 2D interactive mapping tool that allows surveyors along with members of the public and planning professionals to view information about zoning, height of buildings, floor space ratios and other planning controls in force across the State. The viewer will build on the work of LPI's NSW Globe (LPI, 2014) and bring a planning focus to online mapping by adding information sourced from NSW local environmental plans and other environmental planning instruments.

As illustrated in Figure 3, the spatial viewer allows various plans, planning information and controls to be turned on and off over a searchable area of interest. The coloured transparent sections in this prototype show land use zoning (red: medium density residential, yellow: infrastructure, green: public recreation etc.).

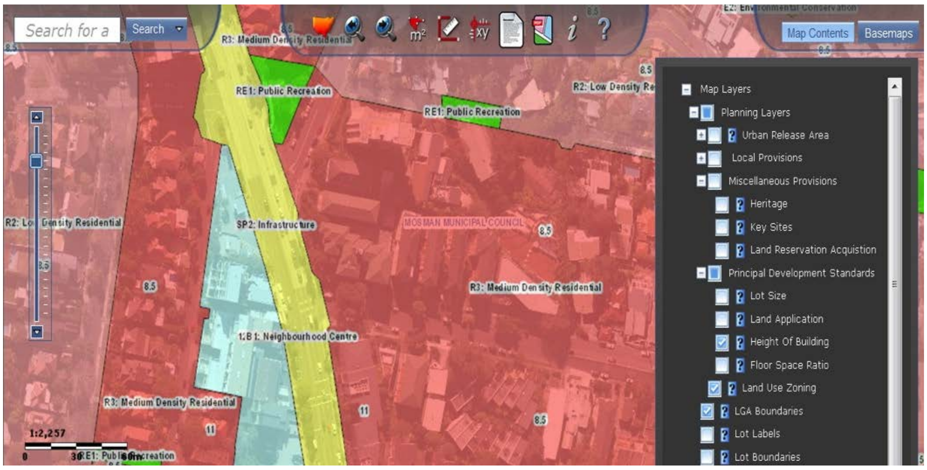

Figure 3: Example view from a proof-of-concept spatial viewer showing land use zoning, building heights and Local Government Area (LGA) boundaries.

The development of a spatial viewer will enable digital strategic, regional, sub-regional and local plans to be viewed seamlessly along with government base layers such as streets, cadastre, topography and aerial imagery. In addition, the integration with other functions, such as community consultation tools, will allow users to easily connect comments with specific information-layer combinations. The spatial viewer will provide residents, businesses and government agencies with a tool that can help make accurate planning decisions and improve people's understanding and confidence in the planning system.

3.3 Register of Consents

The Register of Consents will allow people to check and confirm if all relevant planning consents, construction and occupational certificates and building approvals applying to a particular parcel of land are present and have been followed.

The first steps in developing the Register of Consents are to fully understand and scope out:

- The extent of planning approval information available and staging of its capture and inclusion.
- Solutions to technical and legal issues associated with capturing this information electronically and then making it publically available through the Register of Consents.
- The mechanisms and processes for validating the information through a suitable quality management system.

The Register of Consents will be developed in stages to test and confirm that its operation and function is aligned with user requirements and expectations. Because the operation of the register relies on capturing electronic data, only those councils with suitable electronic data of an assured quality standard will be able to participate in the pilot project.

Once complete, the Register of Consents will benefit residents, businesses and government agencies by providing reliable data that could be used when making investment decisions based on previous approvals and to inform future policy.

3.4 Application Lodgement

Transitioning from a paper-based to an online application lodgement, assessment and tracking system is expected to provide the greatest reduction in processing times and access costs for participating councils, businesses and government agencies. The application lodgement and application tracking tools allow the user to upload all information relevant to a planning application. This allows councils to absorb information directly into an electronic work flow management system.

The data captured through the application lodgement process can then feed through to other planning tools. Consequently, the application lodgement process can greatly enhance the content and interactivity of the entire ePlanning system, such as visualising proposed development applications as a layer in the spatial viewer. Furthermore, the data captured creates an evidence base that allows performance monitoring and reporting to ensure that future planning policy and direction is informed.

The expansion of the existing state government online lodgement service, the Electronic Housing Code (EHC) to include more councils and the Commercial and Industrial Code, as well as the application lodgement tool will see the majority of planning applications being lodged online. This will assist residents and businesses in obtaining faster approvals and provide greater investment certainty.

4 IMPLICATIONS, CHALLENGES AND BENEFITS OF EPLANNING SERVICES FOR SURVEYORS

Currently the state-wide cadastre is described in the broader context of land and spatial information. This information is increasingly significant to making formal planning decisions. Improving the positional accuracy of the state-wide digital cadastre is of fundamental importance. ePlanning services and tools will be utilised as a way to refocus on the importance of the accuracy, reliability and accessibility of land, property and planning information. The successful implementation of ePlanning in NSW will provide legal certainty and electronic certification of planning spatial datasets, so that there is less reliance on paper maps. This means that all planning spatial datasets will be made electronically and publicly available through the planning portal. Furthermore, ePlanning services will facilitate the access to all government spatial datasets, such as heritage, environmental and planning data. Hence, the role of surveyors in the delivery of ePlanning will be critical in ensuring that digital data with legal recognition and ongoing integrity meets high quality standards for accuracy, currency and maintenance.

ePlanning services will address the textual component of a cadastral system, which involves identifying real property and land parcels and concentrating on those under ownership. Additionally, ePlanning services are able to acknowledge spatial components, such as cadastral maps showing land parcels graphically and corresponding to the registered title, to help determine land and subdivision locations and boundaries. Consequently, ePlanning responds to the demand for interaction of spatial data from the public and private sectors as well as businesses and residents. A summary of the challenges and benefits associated with the ePlanning services outlined in this paper is presented in Table 1.

Table 1: Summary of the challenges and benefits associated with each ePlanning service.

ePlanning Service	Challenge	Benefit
Spatial Viewer	As more data becomes available, there will be a challenge of accurately locating and marking property boundaries as well as improving and maintaining the state-wide digital cadastre for the purpose of allowing land, property and planning information to be made available in a geographical spatial context.	Improved positional accuracy of the state-wide digital cadastre.
	Cadastral surveying is concerned with defining the location and position of certain objects and land boundaries for the purposes of identifying ownership and/or the value of land parcels.	Improved positional accuracy of land information, property information and planning information defined and derived in a geographical spatial context.
Register of Consents	Development of common data standards and the copyright restrictions around the release of this information.	Planning approvals and consents that apply to an individual parcel of land can be accessed from a central online location.
Application Lodgement	Development of common data standards, storage, and testing mechanisms for DA tracking and online lodgement that will be applicable to all councils.	Enhanced data quality and consistency to enable better performance monitoring and reporting.
Planning Portal	Establishment and development of a pilot website accessible to the community.	More planning system-related information being created in a geographical spatial context with positional accuracy commensurate with the purpose.

5 CONCLUDING REMARKS

The importance of surveying and the surveyor to a planning, property, building and construction sector worth billions of dollars annually in NSW cannot be underestimated. ePlanning in NSW will be tasked with the role of supporting planning, property and industry professionals, including surveyors, in driving the push towards improvements in the collection, management, publication and access to digital planning and property data.

For surveyors, this will mean a renewed focus on the establishment, management and maintenance of a state-wide digital cadastre that is reliable and accurate. The Department of Planning and Infrastructure and LPI will continue to work towards seeing how technology can expand our horizons, open new areas in the surveying community and provide opportunities for collaboration across government and the private sector.

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ISNSW Cadastral Workshops: 2006 to 2014 and Beyond

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ABSTRACT

Currently there is a shortage of registered surveyors in NSW. A recent report by BIS Shrapnel entitled 'Determining the Future Demand, Supply and Skills Gap for Surveying and Geospatial Professionals' predicts that there will be an acute shortage of surveyors in NSW and Australia by 2019. The problem is twofold: the number of undergraduates in surveying is low and there are insufficient graduates continuing on to registration. The Board of Surveying and Spatial Information (BOSSI) has encouraged the Institution of Surveyors NSW (ISNSW) to offer programs and initiatives to assist graduate surveyors to become registered. ISNSW offers instructional and assessment cadastral workshops to financially enrolled BOSSI candidates undertaking registration. The Victorian and Queensland surveyors boards, in conjunction with professional surveying assocations in each state, are developing their own cadastral workshop models. The genesis of what they are developing is based on the ISNSW cadastral workshops. This paper presents a history of the development of the workshops that started with a letter of request in 2006 from the then NSW Surveyor General Warwick Watkins. Development and improvement of the workshops to the present are outlined along with a summary of the content of the Queensland and Victorian models. The paper concludes with an evaluation of the worth of these workshops.

KEYWORDS: *Cadastral, workshops, graduates, registered surveyors, ISNSW.*

1 INTRODUCTION: THE START OF CANDIDATE WORKSHOPS

Currently there is a shortage of registered surveyors in NSW. For instance, a recent report investigating future demand, supply and the skills gap for surveying and geospatial professionals predicts that there will be an acute shortage of surveyors in NSW and Australia by 2019 (BIS Shrapnel, 2013). The problem is twofold: the number of undergraduates in surveying is low and there are insufficient graduates continuing on to registration.

In NSW, the principal functions of the Board of Surveying and Spatial Information (BOSSI) are the registration of land and mining surveyors and ongoing administration of the register, the investigation of complaints against registered land and mining surveyors (and implementing disciplinary action which may arise as a result of these investigations), and the provision of advice to the Minister for Finance and Services on the practice of surveying, spatial information and all other matters in connection with the administration of the Surveying and Spatial Information Act 2002 (BOSSI, 2014).

In April 2006, the then NSW Surveyor General, Warwick Watkins, wrote to the Institution of Surveyors NSW (ISNSW) and suggested that ISNSW may like to provide seminars for graduates seeking registration. The seminars were to cover urban, strata and rural boundary definition and to be of an applied practical nature.

The Survey Practice & Legislative Committee of ISNSW undertook the task of organising these workshops. The first workshop was held in September 2006. It was an assessment workshop with 15 candidates presenting their cadastral BOSSI projects for a preliminary appraisal before going to the Board's assessments.

2 THE WORKSHOPS PROGESS

The first instructional workshop was held on 3 February 2007. Six presenters and four guest speakers presented 26 candidates with a range of urban, rural and strata information over one full day. Another plan checking assessment session was held prior to the March 2007 BOSSI examinations. This was also a one-day session.

Candidates were asked to provide a critique of the workshops. Their replies indicated that more in depth material was needed, particularly in regards to rural surveys. The next instructional workshop was held on two consecutive Saturdays and included expanded rural and urban material. In addition, a session on calibration of instruments and good drafting practice was included. For the first time, the mentors' presentations were made available to candidates via a CD ROM. The CD ROM also included a wide range of hard-to-find reference material including articles from professional surveying publications.

Feedback from BOSSI, the candidates and the mentors continued to be positive. Many candidates were travelling long distances to attend the workshops and as a result suggested a weekend format (rather than consecutive Saturdays) to assist in economy of travel. Further improvements were implemented as a result of this feedback.

3 THE WORKSHOPS NOW

3.1 Overview

The process has now evolved to the stage where an instructional workshop is held on a Saturday/Sunday weekend and an assessment workshop is held on a Saturday in the 6-week period preceding the BOSSI exams in March and September each year. Periodic briefings of 'pre-examiners' are held by BOSSI members to ensure that all assessors are on the same page. In addition, several pre-examiners have sat in as observers on BOSSI examinations. Board members do not participate in assessment workshops but do present at the instructional workshops.

3.2 Present Format of the Instructional Workshop

The instructional workshop is a 2-day workshop held over one weekend with up to 12 presentations on a range of cadastral and related topics. Some examples of presentations are listed in Table 1. Lunch, morning and afternoon teas and refreshments at the end of each day are provided. All presenters are volunteers, i.e. they are not paid. All presentations and additional reference material are now posted on Drop Box for easy access.

Table 1: Examples of presentations at instructional workshops.

Topic	Coverage
Land Ownership	Old system deeds - Torrens Title - Notations on Title - Qualified Title - Limited Title - Current Title Easements - types - creation - section 88B - transfer & grant leases
Rural Surveys Session 1	Natural boundaries - non-tidal streams - 'ad medium filum aquae' bank and bed of streams - doctrine of accretion & erosion - gradual and imperceptible - use of GNSS for rural cadastral purposes
Rural Surveys Session 2	Cadastral portions and town allotments Roads - Act 4 William IV, No 11-1833 - Public Roads Act 1902 Roads Act 1993 - Practical rural boundary definition
Rural Surveys Session 3	Presentation by a successful BOSSI candidate of a recently assessed rural survey project
Urban Surveys Session 1	City surveys - search - alignment/roads - obstructed boundaries old system deeds/conversions - survey the title not the plan
Urban Surveys Session 2	Identification surveys - procedures and many examples
Urban Surveys Session 3	Presentation by a successful BOSSI candidate of a recently assessed urban survey project
Equipment Calibration	Background - regulation & legislation – procedures including total station calibration over an EDM baseline
Community Title	An introduction to community schemes and plans
Plan Drawing	Good drafting practice - examples of bad drafting practice - how to deal with errors found on plans by others
Strata Title	An introduction to strata schemes and plans
The BOSSI Examination Process	Examples of both acceptable and unacceptable projects presented by a BOSSI examiner and details of what to bring on the day

3.3 Present Format of the Assessment Workshop

The assessment workshop is held over one day consisting of a 'pre-examination' of the candidates' cadastral projects, held approximately 3 weeks after the instructional workshop and 3 weeks before the BOSSI examinations. The candidates are assessed as they would be in the BOSSI examination by two registered surveyors with extensive specialist experience in the project being examined, be it rural, urban or strata. Each candidate is allocated a minimum of one hour for a review of each cadastral project. The candidate brings a draft plan, full search (i.e. adjoining plans and titles), calculations and field notes in electronic and/or hand-drawn format. Candidates are advised if more field work should be undertaken for their project. Candidates are welcome to sit in on another candidate's assessment, and many candidates take up this opportunity to learn from another candidate's experience. Occasionally, a candidate will realise that their project is not ready for assessment and consequently will withdraw from the upcoming BOSSI assessment.

4 WORKSHOPS IN OTHER AUSTRALIAN STATES

The Queensland and Victorian surveyors boards, in conjunction with professional surveying organisations in each state, are developing their own cadastral workshop models. The genesis of what they are developing is based on the ISNSW cadastral workshops outlined in section 3.

4.1 Queensland

Surveying graduates in Queensland become registered surveyors via a somewhat different process than in NSW. They register first as a surveying graduate, provide a postgraduate

training plan (PTP), provide a progressive assessment of competency via a series of Career Episode Reports (CERs) which demonstrate their exposure to and competence in the range of skills set out in the competency frameworks. The registered surveyor then applies for cadastral endorsement and provides another cadastral related set of CERs to satisfy a Cadastral Competency Framework.

The Queensland Surveyors Board (QSB) has appointed a training advocate and is implementing a series of surveying graduate training workshops. These workshops are free, have about eight delegates per workshop and address issues such as the process required to progress to registration as surveyor, interpretation of the competency framework for surveyors, assessors' expectations regarding amount of evidence to be provided and the format of the CERs.

The Surveying and Spatial Sciences Institute Queensland (SSSIQ) is introducing weekend seminars for graduate surveyors working towards registration as a surveyor or towards cadastral endorsement. These weekend residential-school style camps are aimed at providing graduates with the information and skills required to complete components of their registration that may not always be provided in the workplace. Targeted areas include titling, tenures, land administration, reinstatement and the use of Global Navigation Satellite System (GNSS) technologies. The seminars are supported by the QSB and include some practical sessions.

4.2 Victoria

Surveying graduates in Victoria become licensed via a Professional Training Agreement (PTA) that is registered with the Surveyors Registration Board of Victoria (SRBV). The PTA is structured to develop competencies in the categories of generic skills, boundary definition surveys, development planning, engineering surveying and professional practice management. The graduate surveyor is required to undertake and successfully complete an urban and a rural cadastral survey, a professional assessment project and the SRBV's cadastral law project.

The Surveying and Spatial Sciences Institute Victoria (SSSIV), the Institution of Surveyors Victoria (ISV) and the Association of Consulting Surveyors Victoria (ACSV) are collaborating to produce a PTA cadastral training professional development program. The initial workshop, to be held in June 2014, will be a one-day event involving an urban survey case study. A desktop assessment of plans, surveys and titles will be followed by a field session demonstrating urban surveying field methodology for the measurement of party wall and obstructed boundaries. A review of the essential components of field records, computations, plan drafting requirements and surveyors reports will complete the day.

It is proposed that future workshops will cover rural cadastral surveys, cadastral law and professional assessment projects. The development of the workshops is being supported by the SRBV.

5 HAVE THE ISNSW WORKSHOPS PROVED WORTHWHILE?

BOSSI answers yes. The better prepared candidates are presenting a higher standard of projects leading to increased pass rates and thus an increase in registrations.

ISNSW answers yes. There is continued interest and patronage from candidates, continued support from volunteer presenters, continued support from BOSSI and increased ISNSW membership as non-member candidates see a very tangible and valuable reason for being a member of a professional surveying institution.

Candidates answer yes. The instructional workshops provide well structured, relevant content. The assessment workshop's pre-examination procedures provide beneficial advice. Old friendships are renewed, new ones formed and valuable networks for the future are established.

6 LOOKING BEYOND 2014

ISNSW does not currently include worksite visits and practical sessions in their workshops. An evaluation of the success or otherwise of these components of the Queensland and Victorian models may lead to such visits and sessions in future ISNSW workshops.

Many countries have a similar system of registering surveyors to that in New South Wales. Those countries that require a candidate to have a degree in surveying, serve a period of practical experience after graduation, and sit for examinations conducted by a surveyors board, are being subjected to a desktop audit. The audit is seeking information regarding any initiatives that may be in place to assist graduates attain their professional surveyors licence. New Zealand, Canada, Malaysia, Singapore and the United States of America are being audited. As a result of the audit, further directions, innovations and ideas may be added to the ISNSW workshops to improve and enhance a proven worthwhile program.

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Port Botany Expansion Precision Monitoring Survey: Overcoming a Dynamic Environment

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ABSTRACT

In 2011, NSW Public Works' surveyors commenced a series of precision monitoring survey deployments at the newly established Port Botany Expansion site. With the site consisting of 72 hectares of reclaimed land, establishing high-order survey accuracy over the site presented several challenges. The project involved extending the primary survey control network throughout the site, and then undertaking the precise measurement of nearly 1,000 settlement points. NSW Public Works became involved with this project at a time when the site was effectively clear and free of obstructions, making the planned methodology for the initial survey relatively straightforward to execute. When the surveyors returned to undertake further epochs through 2011 and 2012, construction of the new port facility had gathered pace and the challenges associated with a large scale construction site forced a complete re-design of the earlier methodology. With many of the original sightlines now obstructed by construction activity, the initial survey control network was compromised to the point of being rendered obsolete. Despite the challenges this site presented, NSW Public Works has been able to successfully maintain the integrity of the survey control network and provide the client with accurate, reliable and repeatable results. This was achieved by capitalising on the availability and rigour of CORSnet-NSW, by utilising a wide range of instrumentation, employing robust field techniques, and by rigorous least squares analysis and network optimisation. This paper follows the development of this project over a 2-year period, explains the initial and re-designed methodology, and discusses the challenges that have been overcome to achieve a successful project outcome.

KEYWORDS: *Precise monitoring, NSW Public Works, least squares, CORSnet-NSW, optimisation.*

1 INTRODUCTION

The Port Botany Expansion (PBE) is a site consisting of over 72 hectares of reclaimed land adjacent to the existing Port Botany container terminal in Sydney. Once operational, this new terminal will provide more than double the capacity of container freight through the main Sydney shipping port. The site is approximately 1,200 m long by 600 m wide. The two main features of the site considered in this paper are the terminal surface and the crane rail beams.

For the purpose of this discussion, the port expansion project will be described as two distinct phases. The first phase of the project (Phase One) involved the reclamation and construction

of the terminal surface area, and then the subsequent construction of the surrounding crane beam pairs. Gantry cranes will run along rail slots within each crane beam, loading and unloading ships that will dock alongside the new terminal. This phase commenced in 2008 and was completed in mid-2011 (Figure 1a).

The next phase of the project (Phase Two) was to then develop the terminal surface into an operational port. This would involve stripping back the reclaimed land, re-compacting and re-laying the sub-grade, adding drainage, and then finishing the hardstand with asphalt and concrete along with the construction of other on-site port infrastructure such as buildings and automated container stackers. This stage commenced in mid-2012 and is currently in progress at the time of publication of this paper (Figure 1b).

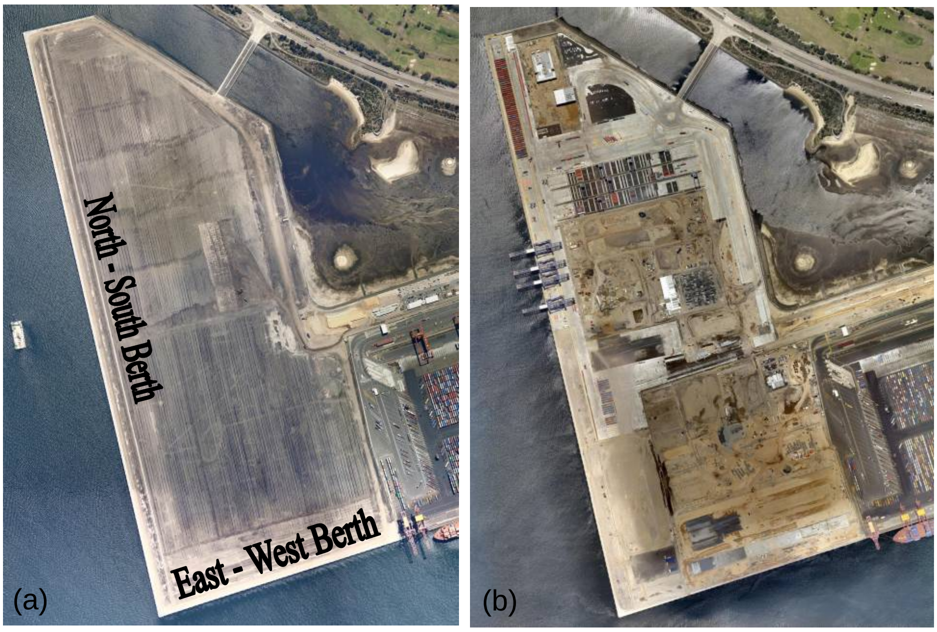

Figure 1: (a) Activity post Phase One construction and (b) during Phase Two construction.

2 PROJECT OBJECTIVES

As part of the contractual agreements between the port owner and the constructing contractor, on-going precise monitoring surveys of the terminal surface and the crane rail beams were required post construction. These survey results were required firstly to ensure that any faults in the construction were being identified as early as possible and secondly that the expected settlement of the terminal surface and the crane rail beams was within design tolerances. This survey information would then provide the basis for any claims against the contractor during the defects liability period.

The concrete crane rail beams consist of a pair of long concrete coping beams laid on top of a series of vertical piles cored into bedrock under the sea floor. A major risk identified with the crane rails was that any deformation in the concrete crane beams or the slots within the beams could make the gantry cranes work inefficiently or, worse, potentially jam the wheels of the cranes thus bringing the operation of the port to a standstill and costing untold sums in lost productivity. Accordingly, the crane rail beams were required to be monitored by precise survey both in the horizontal (X,Y) as well as the vertical (Z) dimensions as accurately as possible. The settling of the terminal surface, which consisted of reclaimed land, was assessed

as being not as critical a risk and as such was only required to be monitored in the vertical (Z) dimension.

In general, the surveys were designed to yield absolute horizontal positions to ±6 mm and vertical positions to ±2 mm. Clearly, relative accuracy between observed points is far higher than the absolute accuracy.

3 SURVEY INFRASTRUCTURE AND INSTRUMENTATION

3.1 Crane Rail Settlement Points

The pairs of crane rail beams run the entire length of both the western and southern sides of the terminal. In total, there are nearly two kilometres of parallel concrete rail beams set at approximately 35 m centres. Pairs of stainless steel pins were installed at 25 m intervals into each beam (Figure 2a). These pins were installed during construction as settlement pins for monitoring survey purposes. There are four settlement pins every 25 m along the western and southern docks, making a total of nearly 300 settlement pins that are required to be measured accurately in X,Y and Z dimensions.

For horizontal measurements, each settlement pin is radiated from two stations by high-precision total station to a prism with mini-pole and a stable mini-tripod specially fabricated for this project (Figure 2b). For this operation, a Leica TM30 precise robotic total station was deployed. This instrument is a 0.5" angular accuracy instrument with distance measurements accurate to ±(1 mm + 1 ppm). Kestrel weather stations were deployed to take meteorological observations at each end of the control sightlines. The vertical component of the monitoring was determined by precise levelling using an invar barcode staff, stabilising rods and a Leica DNA03 precise digital level.

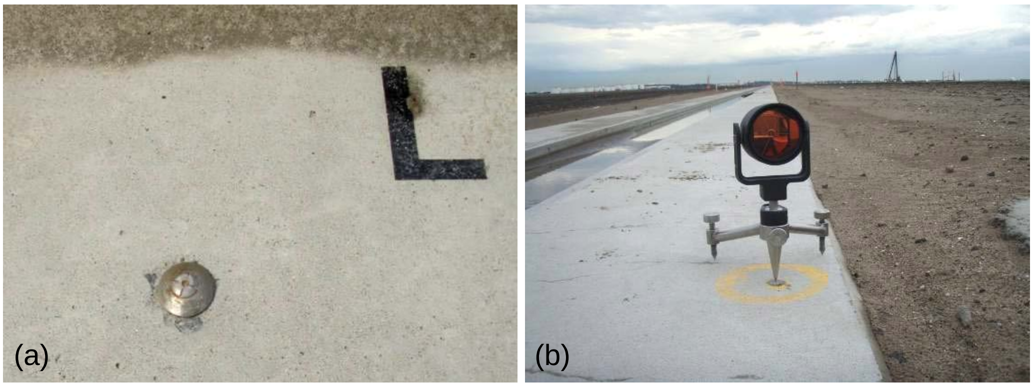

Figure 2: (a) Stainless steel settlement pin in crane rail and (b) prism set up on settlement pin using mini-tripod and mini-pole.

3.2 Terminal Surface Settlement Pins

Terminal surface settlement pins consist of a galvanised spike placed in a concrete pad in the surface. These marks were installed on a 50 m grid throughout the reclaimed land area. In addition, these marks were installed in groups between the crane rails. In total, there are approximately 600 terminal surface settlement pins covering the site. These marks were levelled only, initially using an invar barcode staff and stabilising rods, however in subsequent surveys the specifications were amended slightly to allow the use of a fibreglass

barcode staff. There are also additional marks outside of the main site that are included in the overall monitoring project, however the monitoring of those marks is not discussed in this paper.

3.3 Survey Control Pillars

Adjacent to the site and prior to NSW Public Works becoming involved in the project, three concrete plinths containing a State Survey Mark (SSM) had been installed along Foreshore Road. These marks formed the primary survey control infrastructure that had been used by the construction contractor's surveyor during the reclamation phase of the project. Once NSW Public Works became involved in the project in June 2011, and in partnership with the client, the plinths were upgraded to standard concrete survey pillars with pillar plates. Also, an additional three concrete survey pillars and ten removable steel pillars were installed. The removable steel pillars were installed along the dockside of the new terminal in the concrete crane rail beam. The primary motivation for the installation of these additional pillars (concrete and steel) was to improve the repeatability of the surveys by reducing centring errors associated with survey tripods set up over ground marks, ensure the same geometry was repeatedly observed, maximise on-site observation efficiency, and bring nominally stable levelling bench marks closer to site. Figure 3 shows the survey control infrastructure at various points in the project's development.

Figure 3: Survey pillars – yellow triangles indicate primary control.

4 SURVEY CONTROL DEVELOPMENT

4.1 Phase One Survey Control Network – Post Reclamation

The new survey control network that was designed to take the project forward following the initial stages of the construction and creation of the site had been installed by October 2011. As discussed, this control network consisted of a series of both concrete survey pillars and removable steel pillars.

The first survey using this control network was undertaken by NSW Public Works in September 2011 and is referred to as epoch 1. Where possible, the sightlines of this epoch 1

survey control network were observed for the following repeat surveys, i.e. epoch 2 in December 2011 and epoch 3 in June 2012. Epochs 1, 2 and 3 are referred to as part of the Phase One surveys. The observed sightlines between the concrete and steel pillars for each of these Phase One surveys is shown in Figure 4.

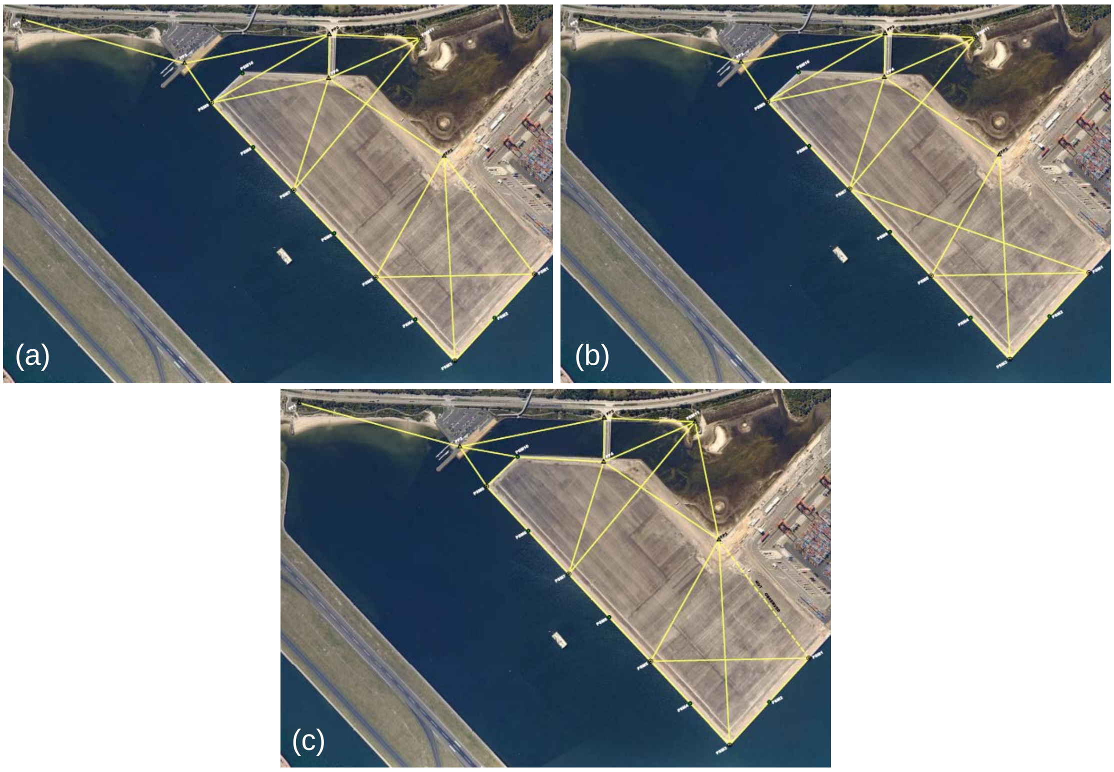

Figure 4: Survey control network for (a) epoch 1, (b) epoch 2 and (c) epoch 3.

4.2 Phase One Surveys – Results and Limitations

Epochs 1, 2 and 3 utilised the Phase One control network for the purpose of monitoring the crane rails and initial terminal surface settlement during a dormant period in the construction of the new port facility between the initial reclamation (Phase One) and the construction of the final hardstand and port facilities (Phase Two). While sightlines between the pillars where possible, the initial survey control network provided a reliable and reasonably robust geometric framework upon which to base the observations to the settlement pins. The network provided good results in terms of a least squares analysis, particularly where braced quadrilateral or triangular geometry was observable.

Despite using precise instrumentation and robust techniques, the overall geometry of the network was not ideal, and as a consequence optimum results could not be possible. Whilst the error ellipses derived from the least squares analysis were small and acceptable in the northern portion of the site (close to primary control), those in the southern portion of the site fell outside the preferred tolerances. The geometric strength of the network was limited by the nature of the site and the availability of additional control stations. Primarily the control for the survey was being propagated south over a long distance from the relatively short bas lines between the primary survey control concrete pillars along Foreshore Road (see Figure 3). Furthermore, the connection of the site ‘proper’ to Foreshore Road (across the Penrhyn Estuary) was based on a number of smaller triangles.

As the overall geometry, particularly in the east-west direction, was not strong, several options were considered to strengthen the network using total station observations of direction and distance between additional survey pillars and fixed prisms. One option considered was the installation of remote marks along the airport's third runway and the installation of pillars along the breakwall south of the current terminal. The aim of these potential improvements was to strengthen the connection of the site proper with the Foreshore Road baselines and reduce the likelihood of 'swings' in the network at its southern extremities. These options were eventually dismissed due to the likelihood that they were not viable or repeatable into the future.

Whilst the network had to date proven adequate for the task of monitoring the site in the dormant period between construction Phases One and Two, it was accepted that:

- The existing network was compromised with respect to redundancy, i.e. survey results are susceptible to yielding erroneous movements due to inconsistency in lines of sight observed.
- It had not been possible to observe a consistent set of lines of sight from one epoch to the next due to site obstructions, the loss of a single line of sight having a substantial impact on an already minimalist network.
- The existing network was reliant on the observation of lines of sight that cross the entire site, which where almost certainly not going to be clear during the construction and/or operational phases of the container terminal.

4.3 Phase Two Survey Control Network – Facilities Construction and Operational Port

By the time the epoch 4 survey was requested, the site had started to become a construction zone once again (Phase Two) with construction of the hardstand and port facilities having commenced (Figure 5). The increase in construction activity, including vehicle and plant movements, the creation of stockpiles and installation of site sheds, forced an immediate rethink into the methodology that had been previously employed. Many of the existing terminal surface settlement points were being progressively destroyed and some settlement pins on the crane beams were also obstructed by temporary stockpiles of equipment and materials including a jersey kerb that was placed half the length of the waterside dock. Multiple site inductions, inspections, medicals, discussions and safety briefings followed.

Figure 5: Dramatic change in site conditions from Phase One to Phase Two of construction.

A site inspection prior to the epoch 4 survey revealed that many of the total station sightlines available in earlier surveys were now not observable due to construction activity. NSW Public

Works carried out an assessment of the remaining lines of the network and found that of the 25 lines of sight which would ideally be observed in both directions (Figure 6), only the following could be observed at the time of epoch 4:

- 10 lines shown in green (observable in both directions).
- 1 line shown in yellow (observable in one direction only).
- 3 lines shown in red (observable in both directions but compromised by site obstructions).

The blue lines shown in Figure 6 could not be observed at all. As expected, the results of the network optimisation of the remaining observable lines of sight clearly demonstrated that the existing survey control network was completely compromised and that acceptable results could not be achieved using the original total station methodology.

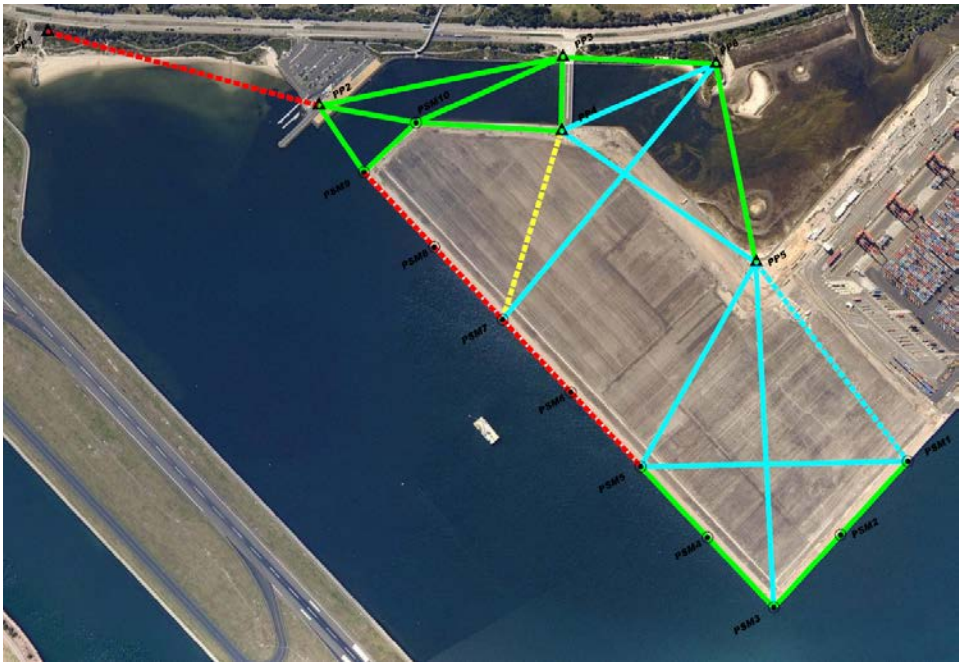

Figure 6: Phase One lines of sight at time of Epoch 4.

It was at this point that NSW Public Works advised the client that a new approach needed to be developed. An in-depth investigation into a new methodology that utilised a combination of the geometrically-sound braced-quadrilateral geometry and the CORSnet-NSW network of permanent Global Navigation Satellite System (GNSS) reference stations (Janssen et al., 2011; LPI, 2014) was commissioned.

4.3.1 Relative Position – Braced Quadrilateral Network

Whilst a variety of geometric configurations, including a single braced quad, had been used in the Phase One total station survey control network, once stockpiles started to grow and plant and materials arrived on site, the sightlines that crossed the site were now compromised. A variation to how the braced quads were implemented was developed. This involved a series of abutting braced quads that ran the length of the crane rail beams. However, the braced quads were now only the width of the two parallel crane rail beams, i.e. approximately 35 m wide. Sightlines were now limited to the relatively clear corridor afforded by the crane rail beams (see Figure 8). Consultation with the client and a review of proposed facilities plans indicated that these corridors would in fact remain relatively free of permanent obstruction, even when the port was operational.

Again, a network optimisation was run on this geometric configuration, and it was proven that this network was a strong and robust configuration best adapted to long narrow surveys (Anderson and Mikhail, 1998) that would support the monitoring of the settlement points into the future. From this network of braced quadrilaterals, the relative location of all crane rail settlement pins could be reliably measured using the total station methodology previously employed from the Phase One network. Whilst the network of braced quadrilaterals could effectively overcome the site obstructions, a total station-only propagation of control from the Foreshore Road baselines would still be plagued by the inherent weakness of a long network 'hanging' off a short baseline with a less than ideal connection across the Penrhyn Estuary. This connection was also to be further compromised by the erection of a continuous sound wall along the entire northern edge of the site proper. Consideration was thus given to the propagation of absolute control across the site using long-occupation GNSS techniques.

4.3.2 Absolute Position – Long-Occupation GNSS

Long-occupation GNSS, in particular utilising the CORSnet-NSW network of Continuously Operating Reference Stations (CORS), became a realistic consideration for the absolute positioning of the braced quadrilateral network. CORSnet-NSW would provide:

- A certified external reference frame for absolute positioning of the pillars within the Phase Two survey control network.
- A means of overcoming the geometrically weak link between the Foreshore Road control pillars and the site proper.

As the requirement for absolute position for this project was tight, the client was understandably cautious about adopting a GNSS methodology. A review of literature revealed that long-occupation GNSS had been successfully applied to similar monitoring activities previously, in particular:

- Eckl et al. (2001) estimated single baseline solutions of 12-hour observation sessions should yield accuracies of ±5.9 mm in Easting and ±4.8 mm in Northing. It should be noted that this evaluation used actual and not estimated satellite orbits.
- Wang (2011) reported accuracies of ±2.8 mm in Easting and ±5.1 mm in Northing under difficult conditions with a network of six reference stations, observing 6-hour sessions and processing a network adjustment, using actual and not estimated satellite orbits.

Furthermore, a review of available information on CORSnet-NSW (LPI, 2014) showed that observed daily coordinate differences for Port Botany CORS (PBOT) indicate a precision of approximately ±4 mm in both Easting and Northing.

While it is recognised that the precision of GNSS is dependent upon many factors, NSW Public Works could demonstrate to its client that several of these factors were under the control of NSW Public Works surveyors to ensure the highest possible precision:

- Session length and timing (day/night).
- Using a network adjustment methodology as opposed to single-baseline processing.
- Network geometry.
- Centring errors at survey stations.

NSW Public Works thus proposed that absolute horizontal control could be reliably propagated throughout the braced-quad network using long-occupation GNSS techniques and the CORSnet-NSW network as an external reference frame.

4.3.3 Observation of the Phase Two Network

Giving consideration to all of the site restrictions, availability of equipment, survey logistics, and a need to bench mark the proposed Phase Two methodology against the previously implemented Phase One methodology, the following survey specifications were developed and implemented for the observation of the GNSS component of the Phase Two network:

- Five CORSnet-NSW stations would be adopted as the external reference frame for absolute control: Villawood (VLWD), Chippendale (CHIP), University of NSW (UNSW), Port Botany (PBOT) and Waterfall (WFAL).
- 12-hour sessions at 30-second log rate continuous static observations.
  - ✓ Best balance between resolution of multipath, occupation time and survey logistics.
- Observations at night.
  - ✓ Best ionospheric conditions for GNSS observations.
- Two independent sessions.
  - ✓ Check on setup errors and detection of anomalies in GNSS that can occasionally occur and would be otherwise undetectable.
- GNSS observations at nine existing pillars with reasonably good prospects of clear sky in the future.
  - ✓ Distributed uniformly throughout the Phase Two survey network.
  - ✓ Some combinations of which would enable direct comparison of distances from both GNSS and total station between nominally stable pillars.
- All steps taken to reduce centring errors.
  - ✓ Same receiver at each pillar for each observational session.
  - ✓ Set up on precision carriages with trough bubbles and Leica adaptors.
  - ✓ All receivers to be orientated consistently.

Figure 7 illustrates the geometry of the CORSnet-NSW GNSS control network adopted for epoch 4 in relation to the Port Botany Expansion (PBE) site.

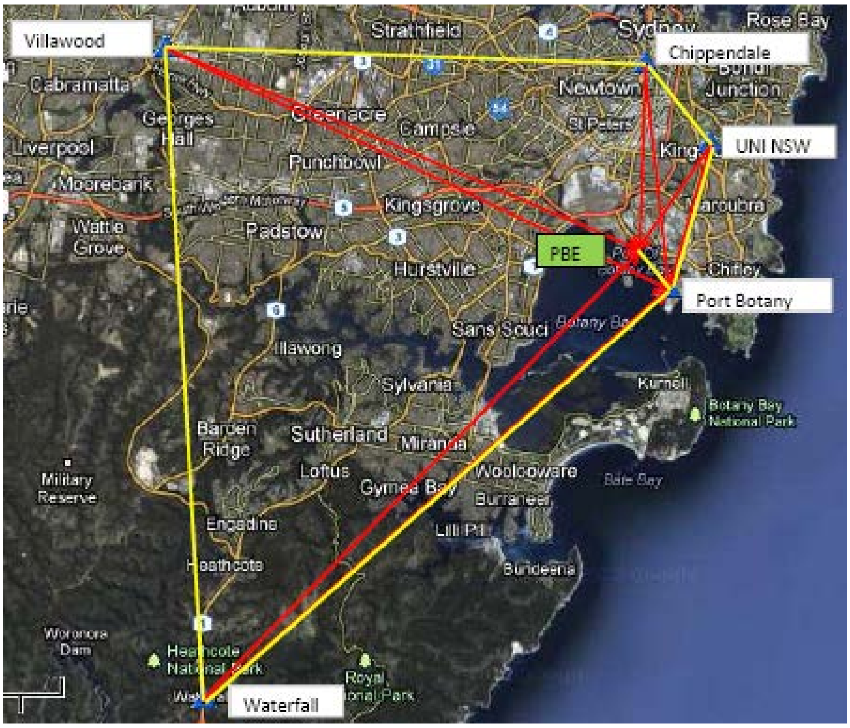

Figure 7: CORSnet-NSW GNSS survey control network adopted to establish control at PBE.

The distribution of GNSS stations throughout the braced quadrilateral network on site is shown in Figure 8. It can be seen that the north-south berth contained three main braced quad total station configurations, whilst the east-west berth contained one main braced quad, indicated by the yellow lines. GNSS receivers were placed at the stations denoted by blue circles.

Figure 8: Epoch 4 survey control network showing integrated GNSS and braced-quad configuration.

The braced-quad network for epoch 4 (January 2013) was observed from a selection of the removable steel pillars as well as temporary tripod stations which were set up on the inner crane rail beam. Being able to ensure that the observation of the survey control network could be repeated in the future was paramount when it came to the design of this new system. With construction activity to continue for the next two years, followed by the site being transformed into an operational port, it became necessary to develop a field methodology that was repeatable yet flexible enough to cope with unforeseeable obstructions that were undoubtedly going to emerge over time and yet still maintain the overall geometric integrity of the control network. The exact location of the temporary tripod stations can be varied to a degree (to accommodate temporary obstructions) without an adverse effect on the overall network geometry. The obstructions included cranes, container stacks and temporary site buildings. Maintaining the geometric integrity was essential to the accurate reporting of horizontal movements of the settlement pins. The additional temporary tripod stations also afforded much greater redundancy in sightlines should any settlement pins be unable to be radiated from the steel pillars only, as had previously been the case.

4.3.4 Processing Phase Two Observations

The processing methodology for the combined GNSS/braced-quad survey observations has a number of checks built into it to ensure the reliable reporting of settlement pin movements. The procedure developed for processing the observations for Phase Two was as follows:

1. GNSS field deployment and data collection, then:
   - A. Process all baselines in the GNSS network (approximately 90) using Trimble Business Centre (TBC) software.
   - B. Adjust GNSS network with four outer CORSnet-NSW reference stations held fixed and solving for PBOT.
     - ✓ Checks integrity of GNSS for that session.
     - ✓ Checks integrity of baselines between GNSS receivers on site that could otherwise distort the network.
   - C. Introduce PBOT into the network adjustment as fixed and solve for Map Grid of Australia (MGA) coordinates for the nine site pillars.
   - D. Compare and average results of two independently processed GNSS sessions.
   - E. Transform GNSS-derived MGA coordinates for all nine site pillars into Port Botany Plane Survey Grid (PBPSG). PBPSG is the datum within which all results are reported.

   Note that steps A, B and C are all done independently for each GNSS session.

2. Total station braced quadrilateral network field deployment and data collection, then:
   - A. Run a 'freenet' Compnet adjustment of control network observations.
     - ✓ Enables identification of any observational errors or compromised observations free of any distortion introduced by potentially noisy GNSS data.
   - B. Introduce PBPSG coordinates of pillars occupied with GNSS as 'weighted control' in Compnet adjustment of control network.
     - ✓ Yields PBPSG coordinates for all pillars and temporary tripod stations in the Phase Two network.

3. Total station radiations to settlement points:
   Adjust radiations from pillars and tripods to settlement points in Compnet adjustment with PBPSG coordinates for all pillars and temporary tripod stations in the Phase Two network (from 2B above) held fixed.
   - ✓ Extremely large number of observations with some potentially compromised to some degree, e.g. long shots low over concrete.
   - ✓ Ensures any compromised observations to individual settlement points do not distort the overall control network.

4. Presentation of results:
   Results of this processing and the comparison of each epoch to the previous epoch is presented to the client in Excel spreadsheet format, with full disclosure of control network survey repeatability, comments against potentially compromised measurements and high-quality plans to aid in the interpretation of the data by third party consultants.

5 RESULTS

Despite being situated in the early stages of a long-term monitoring effort, the initial results of the Phase Two network methodology are encouraging. This paper does not offer any public presentation or opinion of the movements detected in the settlement pins. That information is owned by the client and is not discussed here. However, it can be stated that importantly it was possible to migrate to the new methodology without any erroneous 'spikes' or noise in the monitoring data and as a result the client has retained a high level of confidence in the survey integrity despite numerous site challenges having to be overcome. Some of the more

significant challenges and notable outcomes of the most recent Phase Two monitoring surveys are detailed in this section.

5.1 Epoch 4 Results

An element of the epoch 4 (Phase Two) network was an ability to compare distances measured by GNSS directly against those measured by total station as a means of benchmarking the Phase Two methodology, and easing some of the client's concerns about the migration to the new methodology. Table 1 shows the comparison of distances measured between several pillars by both GNSS and total station. This comparison of distances yielded results that were within expectations, given the adopted survey and processing methodology.

Table 1: Comparison of distances measured by GNSS and total station.

Line	Distance (m)	Difference (mm)
PP2 → PP3	538.7	3.0
PP3 → PP4	160.4	2.7
PP2 → PSM9	174.8	1.2

As noted previously, the construction activities occurring on site required concrete safety barriers (jersey kerbs) to be placed along half the length of the north-south berth. These barriers were inadvertently placed almost directly under the lines of sight between the steel pillars in this part of the site, effectively reducing the ground clearance for some lines of sight. During processing it became evident that some of these lines were affected by refraction, with larger than normal residuals being observed. The impact upon the line of sight can be seen in Figure 9.

Figure 9: Jersey kerbs reducing effective ground clearance of total station observation.

However, and as expected, the redundancy afforded by the use of a network of braced quadrilaterals meant that in the instances where the observation between steel pillars was compromised by the jersey kerbs, it was relatively simple using Compnet to identify the offending observation and apply a statistical weighting that would effectively eliminate this observation from the dataset without any significant impact on the overall quality of the control network.

The use of CORSnet-NSW as an external reference frame also enabled not only the verification of the Foreshore Road baseline of pillars but it also enabled the detection of what appeared to be a small disconnect between the Foreshore Road control network and the site

proper in previous epochs. The GNSS network of baselines was both denser and geometrically better-conditioned than anything that could be observed previously with the total station. As a result, a small, unresolved anomaly in the propagation of control across the Penrhyn Estuary in previous epochs was able to be resolved in epoch 4.

5.2 Epoch 5 Field Deployment

In mid-2013, the request came for the next scheduled monitoring survey, epoch 5. This request now provided NSW Public Works with the opportunity to put the repeatability of the methodology to the test, with the nature of the site completely different again from the last deployment, epoch 4, in January 2013. Planning for epoch 5 began with a site inspection and another series of inductions and accreditations that were required to allow surveyors access to areas of the site now under the separate control of various operators and contractors. Epoch 5 has recently been completed, with the field deployment undertaken during November 2013. Prior to epoch 5, some of the gantry cranes had been delivered to the site, large areas of concrete pavement had been laid and 3 m high sound walls had been erected along the north-eastern perimeter of the expansion site (Figure 10).

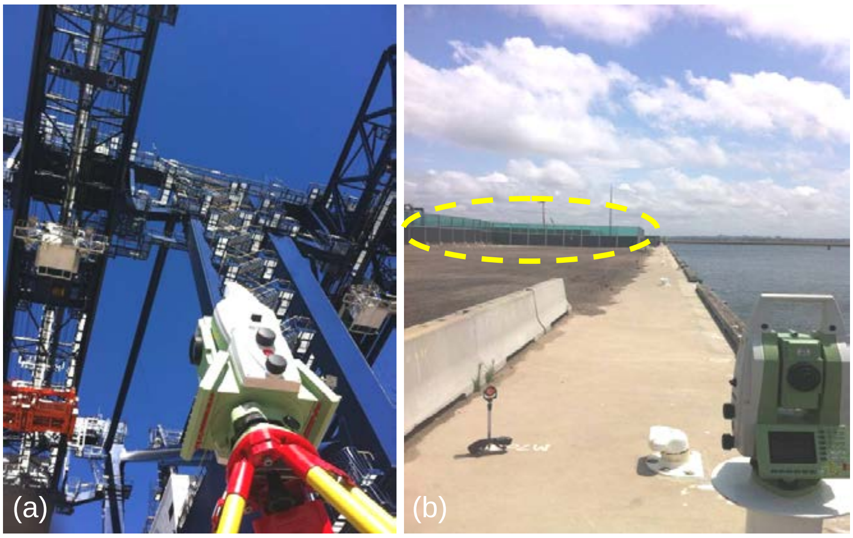

Figure 10: (a) Gantry crane and (b) sound wall in the background.

The erection of the sound wall in particular permanently 'broke' any total station-only connection of the site proper to the Foreshore Road control pillars. Although the site had changed appreciably in some ways, the survey methodology was surprisingly unaffected. This was due mainly to the in-built rigour and flexibility of the integrated GNSS/braced-quad system. Only some minor adjustments to the locations of the temporary tripod stations were required due to obstructions caused by the new cranes, temporary site sheds and items associated with the construction and commissioning of plant.

One change to the CORSnet-NSW GNSS control network between epoch 4 and epoch 5 was the omission of Chippendale CORS (recently decommissioned) and the subsequent inclusion of Fort Denison CORS. This change had little effect on the network geometry. At the PBE site, nine GNSS receivers were again deployed across the site, with some changes made to the stations that were occupied in the previous epoch 4 to better accommodate local sky obstructions.

Again, the integrated GNSS/braced-quad methodology was deployed across the site to obtain coordinates of both the control stations and the settlement pins to facilitate reporting on horizontal movements of the crane rail beam settlement pins. Vertically, precision levelling of all settlement pins continued in a manner similar to previous deployments.

5.3 Epoch 5 Results

Now that two repeat surveys have been completed with almost identical methodologies, it is prudent to look at the results obtained. The results have shown that excellent repeatability has been achieved between the epoch 4 and epoch 5 GNSS surveys, independent of the total station observations. Table 2 shows the variation in coordinates derived for the nominally stable control pillars that have been coordinated in epoch 5 when compared to epoch 4. Survey Pillar PP3 was also coordinated for another unrelated additional survey activity using essentially the same GNSS observation and processing strategy – the results of its comparison to epoch 4 are also shown in Table 2.

Table 2: Comparison of pillar coordinates against epoch 4 coordinates for nominally stable pillars.

	Additional Survey - PP3 Only (07/13)		Epoch 5 (11/13)	
Pillar	**ΔE (mm)**	**ΔN (mm)**	**ΔE (mm)**	**ΔN (mm)**
PP2			1	0
PP3	-2	-2	-1	-1
PSM9			0	-1
PSM5			-1	1

A truer indication of the repeatability of the entire methodology will only be realised after the completion of several more epochs of GNSS observations covering a wider variety of GNSS constellations and conditions such as ionospheric activity – given that the initial GNSS epoch was observed during a period of maximum solar activity (Janssen, 2012).

Also, if examining the braced quad network independently, the results comparing these surveys have also shown excellent repeatability. It is expected that the next repeat survey will be undertaken mid-2014, again deploying the outlined methodology with good results.

6 CONCLUDING REMARKS

Now that two repeat surveys have been completed under essentially the same conditions and using the same Phase Two methodology, NSW Public Works has been able to derive a number of conclusions over a range of topics. Foremostly, this project has been a good example of the rigour and reliability afforded by the CORSnet-NSW network. CORSnet-NSW has been used in a challenging and dynamic environment to provide precise absolute survey control across a site where construction activities tend to compromise lines of sight required by total station. The CORSnet-NSW network also has the benefit of being a legally traceable external reference frame, alleviating concerns about the stability or otherwise of primary control networks that may be potentially compromised by the very construction activities that they are intended to be used in the monitoring of.

In a geometric sense, it is important to highlight the flexibility afforded by the braced quadrilateral network which allowed NSW Public Works surveyors to effectively overcome the difficulties of a dynamic environment without compromising rigour and geometric

integrity. By its very nature, a monitoring survey demands a stable foundation for the survey control network. This site in particular is not stable: it is dynamic and currently affected by construction activity which brings many issues to the fore. Into the future, this site will be an operational port and it will therefore continue to be a dynamic environment that will present challenges for the execution of precise monitoring surveys, but the integrated CORSnet-NSW/braced-quad solution provides the stability, redundancy and flexibility that is required to achieve high-quality results that can be relied upon by the client now and into the future.

This project has shown that by applying lateral thinking and integrating a combination of reliable survey techniques and software, new methodologies can be developed to overcome dynamic and challenging environments to achieve high-quality precision results. With assistance from Land and Property Information (LPI) colleagues, NSW Public Works surveyors have been able to research and develop alternative methodologies that provide reliable and high-quality results to the client in order to help them meet their obligations by the most efficient and accurate means.

ACKNOWLEDGEMENTS

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- Michael Waud – Senior Registered Surveyor, NSW Public Works.
- Jarad Cannings – Registered Surveyor, NSW Public Works.
- Gary Batman – Manager Survey Services, Sydney Ports Corporation.
- Tony Navaratne – Manager Port Planning, Sydney Ports Corporation.

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Quality of Quantity: L1 Norm Residuals in Geodetic Networks

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ABSTRACT

The task of 'cleaning' a large network of archived Global Navigation Satellite System (GNSS) vectors such that the confidence of truth can be assured is complicated by the nature of traditional methods of outlier detection. Least squares techniques that test the hypothesis of the presence of a single outlier in a minimally constrained model are known to sometimes fail in the presence of several outliers, in particular the obfuscation of gross error 'localisation' to a single measurement. An alternative to least squares is the minimisation of absolute residuals (L_1 norm residuals), which assesses measurement quality against a 'best candidate' minimum set of measurements. One aspect of an L_1 adjustment is the improved ability to identify measurements that do not fit the geodetic network model. The successful application of a fast linear programming technique to minimise L_1 residuals enables this technique to be used as a pre-processing step before a least squares adjustment and also allowed the evaluation of a comparison between least squares and L_1 residuals on large geodetic networks with incomplete metadata.

KEYWORDS: *Least squares, L_1, residuals, outliers, data cleaning.*

When is a Rock not a Rock?

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ABSTRACT

Environmental legislation today is very rigorous with respect to working around, on or near any environmental heritage site. No longer can ignorance of the fact or unintentional impact be used as a defence. Over the last few years, the Roads and Maritime Services (RMS) surveying section has been involved in two environmental incidents on aboriginal heritage sites and one incident involving a rare or threatened species. This presentation outlines lessons learnt and subsequent system improvements that have been implemented for RMS staff and contractors performing surveys for RMS.

KEYWORDS: *Environment, incident, aboriginal heritage.*

Discussion Forum: Impact of the New SP1 Version 2.0 on Surveyors in Practice

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ABSTRACT

An updated version of SP1, released in November 2013, has been developed by the Intergovernmental Committee on Surveying and Mapping's (ICSM's) Permanent Committee on Geodesy (PCG) after lengthy consultation with the broad spatial community and technical experts. SP1 version 2.0, along with six associated guidelines, now provides an outcomes-based framework, aligned to international standards to support in the delivery and maintenance of Australia's survey control mark network. As a consequence, this standard is less prescriptive with respect to methodology, but still provides recommended practices to achieve outcomes appropriate for Australian control surveys. SP1 version 2.0 will supersede some of the best practice guidelines outlined in SP1 version 1.7. This version of the standard completes the transition from class and order to uncertainty (survey, relative and absolute) as the basis for evaluating and expressing the quality of measurements and positions. ICSM recognises that for many organisations the transition from previous versions of SP1 will take some time. An official review process is in place to carefully examine feedback provided, especially in the first year after publication. This forum provides the opportunity for discussion and feedback regarding this new standard, so please carefully consider the implications for your organisation and come along to voice your views!

KEYWORDS: *SP1, standard, control surveys.*

List of Attendees
(at 24 February 2014)

Surname	First	Organisation
Addison	Rob	Eurobodalla Shire Council
Ahearn	Daniel	Wyong Shire Council
Anderson	Cheryl	Mepstead and Associates Pty Ltd
Armstrong	Michael	Roads & Maritime Services
Arnison	Chris	Roads & Maritime Services
Avery	Mark	Ausgrid
Baitch	George	Retired - formerly LPI
Begg	Donald	Tattersall Lander Pty Ltd
Bennett	Neil	Office of Environment and Heritage
Berrett	Anthony	Usher & Company Pty Ltd
Berrisford	Simon	Usher & Company Pty Ltd
Bolte	Mark	Roads & Maritime Services
Brown	Sam	Roads & Maritime Services
Brown	David	ASA
Burke	David	Roads & Maritime Services
Burns	Graham	Land Dynamics Australia
Burrows	Allan	Conway Burrows & Hancock
Burton	David	Aspect Development & Survey Pty Ltd
Butler	Mark	Parsons Brinckerhoff
Carter	Trevor	ADW Johnson
Casey	Thomas	Casey Surveying
Catzikiris	Jamie	Upper Hunter Shire Council
Connolly	Paul	Roads & Maritime Services
Conway	Chris	Conway Burrows & Hancock
Cookson	Michael	Positive Survey Solutions
Cornish	Peter	Cardno Hard & Forester
Corry	Paul	City of Sydney Council
Cosentino	Joseph	Land & Property Information
Davidson	Colin	Defence Material Organisation
Davies	Laurence	Land & Property Information
de Belin	Fred	City of Ryde Council
de Witt	Bernie	de Witt Consulting
Dearsley	Mark	Meadows Consulting
Delbridge	Michael	ADW Johnson
Delfs	Nigel	Delfs Lascelles Consulting Surveyors
Denny	Tony	Newton Denny Chapelle
Dickson	Greg	Land & Property Information
Doyle	Greg	Wyong Shire Council
Eckels	Rod	McMullen Nolan Group
Edwards	Murray	ADW Johnson PTY LTD
Edwards	Joel	Land & Property Information
Ellis	Dick	Retired - formerly LPI
Evans	Gavin	ACT Environmt & Sustainable Developmt
Evans	John	Port Stephens Council
Fenwick	Wayne	Crown Lands
Filocamo	John	Primary Industries - Cemetery Reform
Finlay	Ian	Sinclair Knight Merz
Gardner	Les	Land & Property Information
Gilmour	Ray	Roads & Maritime Services
Gordon	Mark	Roads & Maritime Services
Gowans	Nicholas	Land & Property Information
Gregory	Thompson	Leslie & Thompson
Griffiths	Bob	Consult Survey GRA Pty Ltd
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Sussanna	Vittorio	Land & Property Information
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Taylor	Gavin	McMullen Nolan Group
Thompson	Kevin	Crown Lands
Turner	David	ADW Johnson
Usher	Andrew	Usher & Company Pty Ltd
Wadley	Scott	LCPL
Ward	Michael	King & Campbell Pty Ltd
Ward	Ruth	Port Macquarie-Hastings Council
Webb	David	Transgrid
Wells	Phil	City of Newcastle
Wharton	Chris	ADW Johnson
White	Adrian	Land & Property Information
Whitty	Mark	University of New South Wales
Wilkinson	Paul	Sydney Trains
Wilson	John	de Witt Consulting
Wood	Keith Henry	Keith H. Wood - Surveyor
Wormald	Geoff	Land & Property Information
Wyers	Greg	Map & Survey
Zhou	Xuebo	Sydney Catchment Authority