Capitalising on our Position

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Editorial

These proceedings contain the papers presented at the Association of Public Authority Surveyors Conference (APAS2013), held in Canberra, ACT, Australia, on 12-14 March 2013. Papers were not peer-reviewed but have been subject to changes made by the Editor.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:

Ellis D., Janssen V. and Lock R. (2013) Improving survey infrastructure in NSW: Construction of the Eglinton EDM baseline, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 187-201.

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The Transit of Venus and 18th Century Positioning and Navigation

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ABSTRACT

This paper outlines the significance of the Transit of Venus observations, as viewed through the eyes of a surveyor. Did the Nautical Almanac tables of contemporaries of First Fleet astronomer William Dawes incorporate any of the new information resulting from the transit observations of that century? The author presents an overview of the state of celestial mechanics of the 18th century and the exciting mathematical developments that were taking place at the time. A closer look is taken at how the predicting of the eclipses of the satellites of Jupiter and the development of lunar theory was affected by the gaining of an understanding of the size of our solar system. Hand in hand with this were the technological improvements in the optics of instruments like telescopes that took place in Great Britain, and the progress in the cataloguing of star positions for navigation. On the continent, vast theoretical development in celestial mechanics took place in response to prizes offered by the French Academy of Science. The understanding of the way a gravity field looked in the presence of three orbiting attracting bodies not only influenced the understanding of the irregularities in the motions of the Moon, but also the understanding of the resonance of the motions of the satellites of Jupiter. In the case of the Jovian satellites, the observations of the apparent satellite eclipse times could only be understood in a mechanical sense after the proper light-time corrections could be made, and the data cleaned of this effect. The observing of the Transit of Venus played its role to bring this about.

KEYWORDS: *Solar parallax, celestial mechanics, Transit of Venus, satellites of Jupiter, history of navigation.*

1 INTRODUCTION

The two recent Transit of Venus events, in 2004 and 2012, have been of interest to surveyors, trained as they are in the principles of positioning and navigation. During the 18th and 19th centuries, the use of field astronomy was a common technique for a surveyor engaged in positioning, as it was right up to 30 years ago. Earlier Transit of Venus events have had an interesting history. Transits presented an opportunity to calculate the size of the solar system, as a global effort. At an inferior conjunction, Venus passes between the Earth and the Sun. These conjunctions of Venus can line up with alternate nodes of the planet's orbit and transits of Venus across the Sun then occur in an 8-year pair at each node, about a century apart.

For today's surveyors, the early Transit of Venus efforts can evoke the following question: How soon did the new solar system parameters resulting from the Transit of Venus observations of 1761 and 1769 influence the then state-of-the-art of our industry of positioning? This question unfolds into various other questions, as certain astronomical tables

were necessary for positioning and navigation. How good were these tables at the time? How much did the transit results improve the tables for immersions of satellites of Jupiter, by the end of the 18th century? (When a Jovian satellite moves into the shadow of Jupiter, the word immersion is used.) What improvements in celestial mechanics were happening at the time? Did the tables of lunar distances benefit from any advances in this? The accuracy of navigation depended directly on the accuracy of these tables. The author has reviewed such advances made and checked some of the relevant navigational tables of this period.

2 THE IMMERSIONS OF THE SATELLITES OF JUPITER

Let us set the scene with a summary of a letter written to the Royal Society of London by James Hodgson in the first quarter of 1735 about immersions of Jovian satellites (Figure 1).

IV. *An Account of ſome Obſervations of the* Eclipſes *of the* Firſt Satellite *of* Jupiter, *compared with the Tables, by the ſame.*

James Hodgson

Phil. Trans. 1735-1736 **39**, 15-16

Figure 1: Title of James Hodgson's letter to the Society, and a portrait of 'Jacobus Hodgsonus' (engraved by George White, MacDonnell Collection).

James Hodgson, who lived from 1672 to 1755, was master of the Royal Mathematical School in Christ's Hospital in London, and was a member of the Royal Society. Hodgson wrote to the Royal Society in 1735 that he had reviewed half a century of Jovian satellite observations covering a period from 1677 to 1731 (Hodgson, 1735). Immersion tables of these 'Galilean' satellites were used for determining longitude on land after 1650. Immersion predictions in these tables were shown to the second (the French showed them to the minute). Hodgson said that he compared the reported observations of immersions of the satellites of Jupiter with the Flamsteedian tables from which the catalogue of immersion predictions was deduced. He found that the 244 Jovian eclipses observed in that time slot could be categorised as follows:

- 74 observations differed by less than 1 minute with the tabulated times,
- 53 differed between 1 and 2 minutes,
- 54 differed between 2 and 3 minutes,
- 33 differed between 3 and 4 minutes,
- and another 30 observations differed between 4 and 5.5 minutes from the published tables.

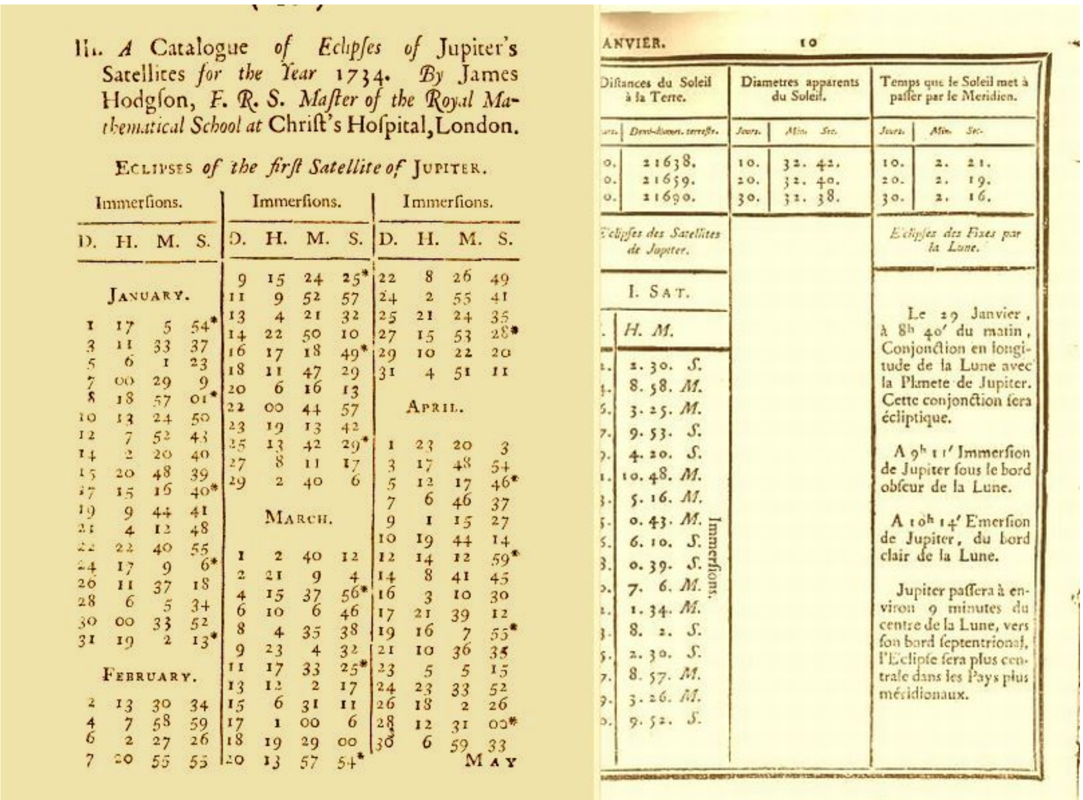
Hodgson used the generalised word 'eclipses'. An error of a minute of time will result in an error of about 25 km in longitude at the equator. The worst difference between observed and predicted immersion events, by 1735, shown by James Hodgson, is 5.5 minutes of time. This is equivalent to a remaining 2/3 Astronomical Unit (AU) light-time correction, unaccounted for, if this would be the reason for the difference. Not having sufficient knowledge of the orientation of the line of apsides of Jupiter's orbit (apsides are the points of greatest or least distance of the orbit of a celestial body from a centre of attraction) could also explain quite a proportion of this difference, as in Jupiter's case the eccentricity is 4.8% of 5.2 AU. Today the speed of light is known, as is the size of the solar system. It was 1676 when Ole Roemer (1644-1710) saw the need for a light-time correction because not allowing for a finite speed

of light had an accumulative effect. Roemer estimated that light took 11 minutes to cross one AU; now the accepted value is 8 minutes. The Jovian satellite Io makes 17 revolutions around Jupiter per month for example, so even an error of half a minute per revolution was going to compound. The interval between immersions appeared to decrease when Earth approached Jupiter, complicating the issue.

The errors in the tables were small enough though, so that someone could observe the immersion at about the right time. The trick would have been to start observing about half an hour early. If the same immersion were also observed simultaneously in another place with known longitude, it would be very useful to bring the observations together. This would allow longitude to be produced through post-processing by differencing. This cancels the effect of the accumulative prediction error. Thus, a multitude of Jovian satellite immersion observations in the British Empire was routinely sent off to Greenwich after reduction.

In the example of Figure 2, it is evident that the British Jovian satellite table of 1734 was in the old Julian calendric system; Britain's changeover to the Gregorian calendar was not until 1752. Here it should be noticed that:

- Hodgson's January 1 is Godin's January 12.
- The Greenwich times will be 9 minutes less than the Paris ones, to allow for the different meridians used.
- The Greenwich Mean Time (GMT) day started at noon (Hodgson's table), while the Parisian day starts at midnight.
- The 1st of January at 17h 05m 54s in Hodgson's table is the 13th of January 05h 16m 'matin' in Godin's table.


II. *A* Catalogue *of Eclipses of* Jupiter's Satellites *for the Year* 1734. *By* James Hodgson, *F. R. S. Master of the Royal Mathematical School at* Christ's Hospital, London.

ECLIPSES *of the first Satellite of* JUPITER.

Immersions.

D.	H.	M.	S.
JANUARY.			
1	17	5	54*
3	11	33	37
5	6	1	23
7	00	29	9
8	18	57	01*
10	13	24	50
12	7	52	43
14	2	20	40
15	20	48	39
17	15	16	40*
19	9	44	41
21	4	12	48
22	22	40	55
24	17	9	6*
26	11	37	18
28	6	5	34
30	00	33	52
31	19	2	13*
FEBRUARY.			
2	13	30	34
4	7	58	59
6	2	27	26
7	20	55	53

Immersions.

D.	H.	M.	S.
9	15	24	25*
11	9	52	57
13	4	21	32
14	22	50	10
16	17	18	49*
18	11	47	29
20	6	16	13
22	00	44	57
23	19	13	42
25	13	42	29*
27	8	11	17
29	2	40	6
MARCH.			
1	2	40	12
2	21	9	4
4	15	37	56*
6	10	6	46
8	4	35	38
9	23	4	32
11	17	33	25*
13	12	2	17
15	6	31	11
17	1	00	6
18	19	29	00
20	13	57	54*

Immersions.

D.	H.	M.	S.
22	8	26	49
24	2	55	41
25	21	24	35
27	15	53	28*
29	10	22	20
31	4	51	11
APRIL.			
1	23	20	3
3	17	48	54
5	12	17	46*
7	6	46	37
9	1	15	27
10	19	44	14
12	14	12	59*
14	8	41	45
16	3	10	30
17	21	39	12
19	16	7	55*
21	10	36	35
23	5	5	15
24	23	33	52
26	18	2	26
28	12	31	00*
30	6	59	33

MAY

ANVIER. 10

Distances du Soleil à la Terre.		Diametres apparents du Soleil.		Temps que le Soleil met à passer par le Meridien.	
	Demi-diamet. terrestr.	Jours.	Min. Sec.	Jours.	Min. Sec.
0.	21638.	10.	32. 42.	10.	2. 21.
0.	21659.	20.	32. 40.	20.	2. 19.
0.	21690.	30.	32. 38.	30.	2. 16.

Eclipses des Satellites de Jupiter.

I. SAT.

Immersions.

	H. M.
1.	2. 30. *S.*
4.	8. 58. *M.*
6.	3. 25. *M.*
7.	9. 53. *S.*
9.	4. 20. *S.*
1.	10. 48. *M.*
3.	5. 16. *M.*
5.	0. 43. *M.*
6.	6. 10. *S.*
8.	0. 39. *S.*
0.	7. 6. *M.*
2.	1. 34. *M.*
3.	8. 2. *S.*
5.	2. 30. *S.*
7.	8. 57. *M.*
9.	3. 26. *M.*
0.	9. 52. *S.*

Eclipses des Fixes par la Lune.

Le 29 Janvier, à 8h 40′ du matin, Conjonction en longitude de la Lune avec la Planete de Jupiter. Cette conjonction sera écliptique.

A 9h 11′ Immersion de Jupiter sous le bord obscur de la Lune.

A 10h 14′ Emersion de Jupiter, du bord clair de la Lune.

Jupiter passera à environ 9 minutes du centre de la Lune, vers son bord septentrional, l'Eclipse sera plus centrale dans les Pays plus méridionaux.

Figure 2: Example of a tabulation of Jovian satellite immersions for the meridian of Greenwich, for the satellite Io, by Hodgson, with at the right a January page from 'Connaissance des Temps' for the meridian of Paris, by Godin (M=matin, S=soir). The French page uses the Gregorian calendar, as adopted in 1582. Hodgson's dates are in the old Julian calendar, before the now 11-day adjustment to the Gregorian one.

Elizabeth I had been convinced by her scientists to go along with the changeover to the Gregorian calendar in 1582, but the English had an issue with the number of days to be intercalated. The English wanted to intercalate 11 days in 1582; Pope Gregory XIII's papal bull had proposed adjusting the calendar by 10 days, the excess of leap days since the Council of Nicaea. As a more sensitive matter, the Spanish attempted an invasion of England in 1588 with support from the next pope, of all things. This put an end to the matter of course, and Britain stayed with the Julian calendar for another 170 years (Duncan, 1999).

Giovanni Cassini (see section 6.1) and Jean Picard already struggled around 1671 with the question of Jovian satellite immersion prediction errors, but could not explain it. General acceptance of Ole Roemer's explanation regarding the finite speed of light took until 1727, when Astronomer Royal James Bradley (1693-1762) made his measurements of stellar aberration and also determined that the mean Sun to Earth light-time distance of one AU was 493 seconds (the currently accepted value is about 498 seconds). The French 'Connaissance de Temps' almanac of 1734 carried the suggestion to observe one immersion and apply the prediction error to the next tabulated values. So how good were the nautical almanacs that came after 1765, after Nevil Maskelyne became Astronomer Royal, almost a century after Ole Roemer's discovery (Figure 3, left portrait)? What was still lacking in the celestial mechanics (also called astrodynamics) of that age, to enable improvement of the almanacs?

The above questions are addressed in the timeframe of the latter half of the 18th century, in the context of how well the tables served Australia's First Fleet astronomer William Dawes in Sydney. This organises the investigation by anchoring it somewhere in time. Dawes regularly observed immersions of Jovian satellites. The nautical almanacs of the 1780s were used for the lunar distance method of determining longitude at sea; and for longitude on land one used the tabulations of the times of the immersions of Jovian satellites, tabulated to the second in GMT. Dawes was issued with the nautical almanacs covering the years 1787 to 1792, so they were obviously printed 5 or 6 years ahead of the current date. This means the 1787 almanac was probably printed before or in 1781, and only reflected the knowledge of the 1770s.

In order to generate these Jovian satellite tables today, one needs a good understanding of the celestial mechanics involved in the mutual orbital resonance of these bodies, while embedded in the gravity field of each other and of Jupiter as well as of the Sun and planets. This is at least a three-body gravity problem, or even a 'four-or-more-body' gravity problem. Once one allows for a light-time correction, the phenomena can be time-tagged better and it becomes possible to separate this effect from the observed data. Only then, a theoretical framework of celestial mechanics can start emerging, with accuracy.

In the case of the Jovian satellites, other forces of disturbance were due to Jupiter's flattening and both Saturn's and the Sun's gravity. The interplay of the Jovian satellites could only be calculated by differencing and fitting polynomia to observed events, similarly as was done with the Moon. Pehr Wargentin (1717-1783) from Stockholm Observatory (Figure 3, right portrait) generated Jovian satellite eclipse predictions quite successfully in this way, but this also still had an incomplete theoretical framework. Wargentin published his first paper on the Jovian satellites in 1741 in the Transactions (Acta) of the Royal Society of Sciences in Sweden. Wargentin's tables were published by J. De Lalande in 'Connaissance des Temps', and after 1765 Nevil Maskelyne inserted these into his nautical almanacs. In the tables after 1746, Wargentin, who was now adjunct professor of astronomy at the University of Uppsala, did allow for what was called 'the great inequality' of the second Jovian satellite of 437.6

days (a periodicity found by differencing of differences). He attributed the effect to the mutual gravitational attraction of the satellites but did not have an analytical derivation for this (De Sitter, 1931). Through analysis of the multiple three-body problems, the satellite interactions are understood as orbital resonance today. When one moon gets ahead of schedule, another one seems to pull it back.

Figure 3: Ole Roemer, left (Frederiksborg Museum), and Pehr Wargentin, right (Svenska Familj-Journalen).

3 THE ORBIT OF THE MOON

In order to generate lunar distance tables, a good understanding is required of the celestial mechanics involved in the lunar motion and the rate of variation of its orbital elements while subject to the gravity field of the Sun and planets. This is a three-body gravity problem and even a more multiple body gravity problem when the other planets are included. A light-time correction is hardly relevant here as it amounts to only one second. The biggest questions for the development of a theoretical framework of the lunar motion involved the bothersome and little understood change in the variations of the orbital elements of the lunar orbit.

Apart from agreeing only approximately with the two-body Newtonian equations, the Moon's longitude was affected by phenomena like lunar evection and lunar variation. Evection means the eccentricity of the lunar orbit changes depending upon the orientation of the line of apsides with respect to the Sun. Although Ptolemy (90-168 AD) coped with evection via his epicycles and deferents, what lacked was a means to deal with this in a new mathematical sense, using celestial mechanics. What Ptolemy did was equivalent to performing a polynomial fit to observed data, without a theoretical framework. Later, Tycho Brahe (1546-1601) observed (actually rediscovered) the lunar variation in 1590, another lunar longitude effect eventually explained later by Lagrange as also caused by the Sun's gravity acting as a disturbance force on the lunar motion around the Earth. This leads to apparent accelerations and decelerations of the lunar motion, separate from the well-known difference between true and mean anomaly resulting from the elliptic orbit. Newton did treat the three-body problem in his 'Philosophiæ Naturalis Principia Mathematica' (the 'Principia'), but without giving the solutions to the 8th order equations. A rather complicated gravity field landscape had unfolded here that was not properly dealt with yet. This had to wait until the three-body gravity problem was sufficiently developed analytically.

When the Moon's perigee is at quadrature to the line from the Earth to the Sun, the direction of the rate of rotation of the line of apsides (which contains the perigee and apogee) becomes opposite compared to the direction of the rate of rotation of the line of apsides when the Moon's perigee lines up with the line from the Earth to the Sun. Therefore, it lurches each

way, yet on average the Moon's line of apsides rotates a little in excess of 40° per year in an anti-clockwise direction, relative to the line from the Earth to the Sun. An explanation for these variations was still awaited (a first tentative solution only came in 1749). Exacerbating this, the line of nodes (which contains the ascending and descending nodes) rotates clockwise by a little over 19° per year, but irregularities in its rate of motion also occur when the line of nodes is oriented at quadrature to the line from the Earth to the Sun. This rotation of a little over 19° per year explains the lunar cycle of 18.6 years, known to the ancients. These issues were important for predictions for the lunar distance method.

Therefore, in the context of the transits, at least three important things were happening in 18th century astronomy. One was the development of insight in the finite speed of light and the acceptance of this. The second was the use of the solar parallax in order to get an accompanying insight into the real size of the solar system. The third was the development of a better analytical or numerical understanding of celestial mechanics. It should be noted that the latter was influenced by the first two.

4 IMPROVEMENTS OF THE MEASUREMENT TOOLS

In order to make these developments possible, the measurement tools had to be improved. Christiaan Huygens (see section 6.1) solved the problem of chromatic aberration (Gribbin, 2003) in 1662, but this created more spherical aberration (Watson, 2004). The Dollonds found solutions perfecting the observing instruments and they could reproduce these in quantity, e.g. the John Dollond double object glass achromatic telescopes made in 1758 (Figure 4) and his son Peter Dollond's even better treble object glass (apochromatic) telescopes made in 1763 (Figure 5). These were also good for observing the moons of Jupiter.

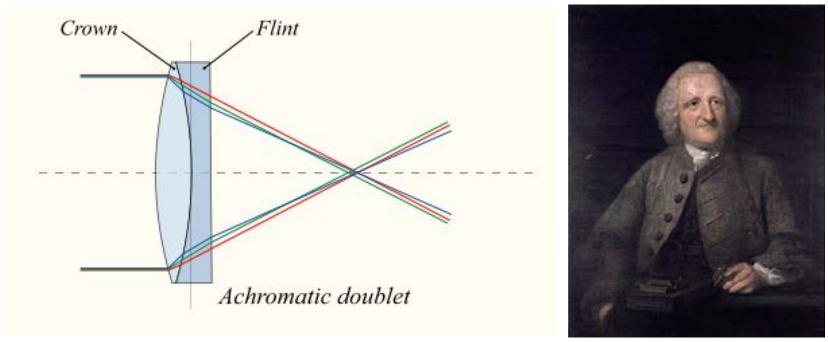


Figure 4: Achromatic doublet lens (left) and John Dollond (Royal Museums Greenwich) (right).

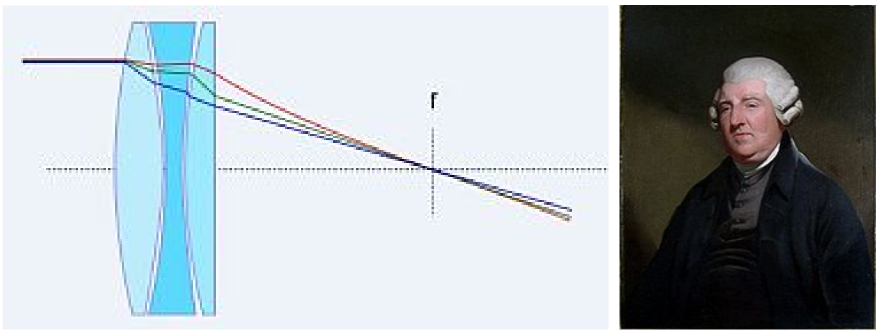


Figure 5: Triple achromatic (or apochromatic) lens (left) and Peter Dollond (Royal Museums Greenwich) (right).

The other development was the improving of the catalogue of star positions, especially in a

12° band centred on the ecliptic, for measurement of lunar distances. Of interest is that William Dawes was issued with the double object glass achromatic telescope. He requested the treble object glass one, owned by the Board of Longitude, but his request was unsuccessful as that was Nevil Maskelyne's favourite instrument.

Methods of observing and equipment specifications were also important. In 1773, Jean-Sylvain Bailly (1736-1793), a French astronomer and mathematician from Paris, showed the influence of aperture on the timing of an immersion. He had masked the aperture of his telescope down to a smaller aperture (17 Parisian lignes or 38.3 mm) when observing a Jovian satellite immersion. With this reduced aperture, he observed a Jovian satellite lose all its intensity and disappear. Taking away the aperture mask, he could again see the satellite for another two or more minutes through the full and larger aperture (of 24 Parisian lignes or 54.1 mm). The significance here is that when Jupiter is 40% further away than before, e.g. nearer conjunction rather than opposition, the light intensity of the Jovian moons will be 1.4 x 1.4 less than before, as intensity relates to the square of the inverse distance. Just this intensity effect will already cause a difference between observed and predicted time.

In addition, if the immersion times observed in various places are compared in order to deduce longitude differences, it would be of advantage to have similar apertures, or one has to make use of an aperture-dependent correction value. Bailly reasoned that if two telescopes with different apertures would be observing the time of the satellite immersion, the telescope with the smaller aperture would appear to see the immersion happen a couple of minutes too early, as the telescope with the larger aperture would continue to see the uneclipsed moon even minutes later. The necessary aperture correction value would use a calculation of the actual part of the satellite disc that could still be uneclipsed at the instant when the light intensity drops below the threshold of the telescope of a certain aperture. Bailly thought it useful if everyone recorded this limiting aperture during their observation.

It is worth mentioning some of the developments with micrometers. The first fixed micrometer with an invariable scale was credited to Christiaan Huygens (see section 6.1). Giovanni Cassini invented the reticulum, the oblique wire micrometer, for measuring differences in right ascension and declination, this micrometer was later improved by James Bradley. Ole Roemer had suggested a double image micrometer in 1675, but the idea was lost. Servington Savary independently developed one in 1743, by introduction of a split element into the optical path, producing a double image. In 1753, John Dollond combined Savary's divided object glass with a new method of measurement by Bouguer and came up with the divided object glass micrometer.

5 THE SOLAR PARALLAX

The parallax effect is what makes our eyes perceive distance. The use of parallax for astronomy was understood more than 2,200 years ago. It is said that Aristarchus of Samos (310-250 BC) noticed on a sundial that when it was exactly first quarter of the Moon, the Moon was not at 90° to the Sun. He estimated the angle to be 1/30 smaller than 90° and realised the Sun was at least 20 times as far as the Moon (Dreyer, 1953). He actually wrote a book 'On the Dimensions and Distances of the Sun and Moon' although he did not pursue the subject much further. Hipparchus of Nicaea (190-120 BC), famous for his discovery of precession of the equinoxes, became aware that the March 14 solar eclipse of 189 BC had looked different to observers in widely separated places (Hirshfeld, 2001). This is a parallax

effect. The eclipse was total in the Dardanelles (the Hellespont) but the Moon was seen as only covering the Sun by four fifths in Alexandria. Knowing the latitudes of these places, Hipparchus, after Eratosthenes' work regarding the Earth's circumference, figured the Moon to be 35 to 40 earth diameters away from Earth. We now know the correct value is 30.

Parallax measurements are still an important tool today. One example illustrates a transit method of the 1970s. When the first artificial satellites were orbiting Earth after 1957, it was soon realised that the parallax effect was not only a way to track the satellites but also a very efficient way to do transcontinental triangulation of European observatories. The idea of a bundle adjustment comes to mind. The satellite was photographed simultaneously from different observatories against the backdrop of stars (Figure 6, top). Time tags were inserted into the satellite track being photographed, using a louvre shutter action on the telescope that was timed to milliseconds, which created repeated mid-exposure dot-like gaps in the satellite trace. The right ascension and declination of these gaps in the trace were measured in a comparator, in relation to the nearby star images. This produced time tagged satellite locations. It should be noted that the stars are regarded as being an infinite distance away.

When all the photographs of the different observatories were measured and the data centrally collected, one could solve for corrections to the numerically integrated predicted satellite state vector and corrections to the initial positions of the observatories. This way one could triangulate in giant strides across the continent and across the British channel, to about 5 parts per million (ppm), using the principle of parallax by way of satellites. The 30 m diameter aluminium coated Mylar balloon PAGEOS, launched in 1966 to an orbit between 3,000 and 5,000 km altitude, and the similar balloons GEOS-2, Echo-2 etc. where used in this way. In 1970, the author participated at one of the observatories and measured its photo plates.

Halley had pointed out that the Transit of Venus presented an opportunity to measure the size of the solar system. In 8 years (bar 2.4 days) Venus orbits the Sun almost exactly 13 times, so it would have overtaken the Earth 5 times. The positions along Earth's orbit where this overtaking occurs are neatly spaced at 72° intervals along the zodiac, one fifth of 360°. At these points a line-up of the Sun, Venus and the Earth occurs, familiar to us as the points where Venus disappears as an evening star and emerges as a morning star. These 5 overtaking points form a 5-spoke wheel of what we call inferior conjunctions. This wheel of conjunctions slowly rotates along the zodiac in a clockwise direction by a little less than 2.4° per 8 years, due to the small 2.4-day mismatch mentioned above. With slow regularity, one of the positions of inferior conjunctions occasionally lines up with one of the nodes of the orbit of Venus. This is where Venus' orbit intersects the plane of the Earth's orbit, the ecliptic plane. If we have an inferior conjunction at one of these places near the node, a transit can occur.

Behind the scenes, something else is happening at the other node: When a transit happens at one node, the opposite node of Venus' orbit will be exactly halfway between 2 of the other 5 spokes, halfway one of the 5 sectors of 72° and thus about 36° away from one of the inferior conjunction spokes. This means after about 15 sequences of 8 years (15 movements of 2.4° in 121.5 years) one will see a position of inferior conjunction again line up with a node, this time the opposite node. The window near the nodes is just wide enough to accommodate two transits, especially if the line-up with the node is not perfect. When this happens a transit can take place just before the node, 8 years early, and as the last transit at the other node was the second transit in the 8-year two-transit sequence and thus a little past the node, the gap between the transits is at times 105.5 years. The next transit double event is then 121.5 years away to complete the 243-year periodicity, with again a change of nodes. This also means the

transits occur about once a century as a double event at the node near the June part of Earth's orbit, alternating with a double event at the node near the December part of Earth's orbit.

Projecting the planet Venus onto the body of the Sun (Figure 6, bottom) from widely separated points on Earth, and measuring its parallax is no more complicated than the above satellite example, in concept. In practice, it is different as the Transit of Venus happens in the daytime, so the measurements have to be made against the undulating edge of the body of the Sun (Figure 7).

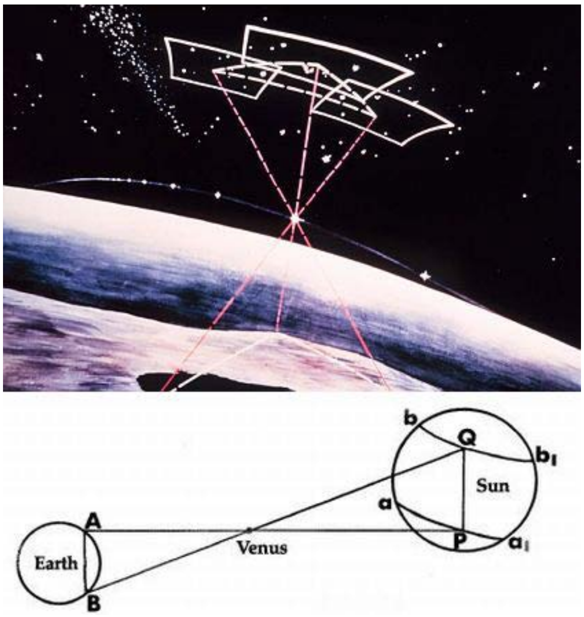


Figure 6: The principle of parallax applied to a 1960s satellite (NOAA Photo Library) (top) and parallax applied to Venus after Howse (1969) (bottom).

In this case, the Sun is at a finite distance, which has to be solved for. This undulation complication, still valid for modern observers today, was expressed by Pehr Wargentin (who observed the 1761 transit) by reporting to the Royal Society, in Latin (Wargentin, 1761): "*Venus jam aliqua sui parte discum Solis occupaverat. Propter vehementem marginum Solis undulationem, primum contactum exteriorem accuratius notare non potui.*" Freely translated this equates to "Part of Venus itself was already to some extent covering the solar disc [when I timed it]. Because of vigorous undulation of the solar margin, I could not accurately record the first exterior contact."

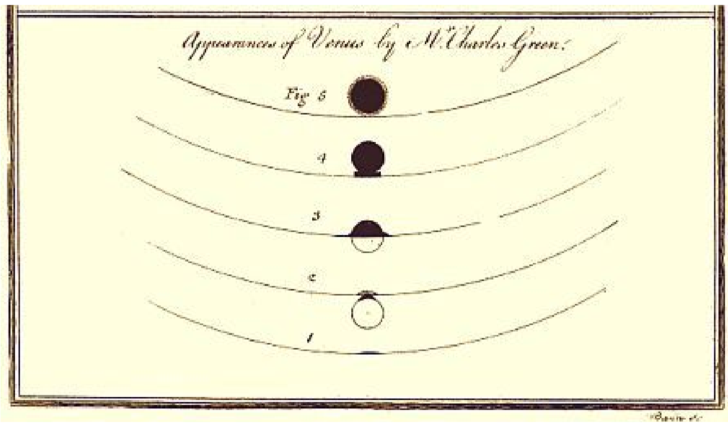


Figure 7: Drawing of the exterior contact (1) and interior contact (5) at the 1769 ingress (Green, 1771).

It is worth noting that this was also exactly the author's experience when timing the ingress of the 2004 Transit of Venus at a re-enactment at Woodford NSW. Gary Hovey from Mt Stromlo observatory was present, who supplied the UTC 1-second time pips with an early breadboard version of the VNG users' consortium GPS time receiver, after the VNG radio time signal broadcast ceased to operate in 2002 (Hovey and Herald, 2005). The interior contact was a lot easier to observe, when compared with the exterior contact.

In 1763, the solar parallax (the angle subtended at the Sun by the Earth's mean radius) from the 1761 Transit of Venus based on 53 observatories had been determined as 8.56", but it was acknowledged that there was disagreement between various methods, some even resulting in 10.5". In 1771, Thomas Hornsby produced a summary of the next solar parallax results (from the 1769 transit) in a letter to the Royal Society. At the end of the letter he showed a table that listed the Astronomical Unit as having a length of 93,726,900 English miles (Table 1). The metric equivalent is 150.8 million kilometres, which is within 1% of the currently accepted value of 149.5 million kilometres and 100 years after Cassini had first used the parallax of Mars for this. Hornsby (1733-1810) was a mathematician and astronomer, and a fellow of the Royal Society. After 1763, he occupied the Savilian Chair of Astronomy at Oxford. Thomas Hornsby observed the 1761 Transit of Venus in Oxfordshire.

Table 1: Solar system dimensions in English miles, calculated by Hornsby (1771).

	Relative diſtance.	Abſolute diſtance.
Mercury,	387,10	36,281,700
Venus,	723,33	67,795,500
Earth,	1000,00	93,726,900
Mars,	1523,69	142,818,000
Jupiter,	5200,98	487,472,000
Saturn,	9540,07	894,162,000

Oxford, Dec. 17, 1771.

6 DEVELOPMENTS IN CELESTIAL MECHANICS

The Paris Royal Academy of Sciences has played a prominent role on the continent towards encouraging the development of the necessary mathematics for orbital mechanics. In 1788, Sir Henry Charles Englefield (1752-1822), an English scientist who was elected a Fellow of the Royal Society in 1788 at the age of 26, wrote a lamenting passage in an introduction to his book (Englefield, 1788) 'Tables of the apparent places of the comet of 1661, whose return is expected in 1789' (yes, that is William Dawes' comet). He said that since the death of Edmund Halley in 1742, practically nobody in England had written anything substantial on the science of orbits. Although this passage was written in the context of comets, he points to the work done in Germany, France and Russia by people like Lambert, Clairaut, Lagrange, Laplace and Euler, who all also played a wider role in other aspects of celestial mechanics.

6.1 The Founding of the Paris Royal Academy of Sciences

The early development of solutions for the equations of triple-body and multiple-body celestial mechanics owes a lot to the Paris Academy of Sciences. Jean-Baptiste Colbert (the French First Minister, Minister of Finances, later the Secretary of State of the navy) had suggested the value of royal patronage for science to King Louis XIV. Colbert had already

gathered a group of eminent scholars, which also happened to include the 'géomètre' Christiaan Huygens (1629-1695). Christiaan was a Dutchman educated at the University of Leiden, who later corresponded with contemporary scientists like Isaac Newton and played a role in the formulation of Newton's second law of motion.

Huygens was from a family that had held down the post of Secretary of State of the Stadholders of the Dutch Republic for three generations (Jardine, 2009). Christiaan's brother Constantine Huygens became the Secretary of State, just as his father and grandfather had been. The Huygens family saw to it that their sons were given the necessary wide-ranging, cultural and penta-lingual tertiary education, and also included in the character formation of their sons such useful things as training in classics, horsemanship, etiquette, diplomacy, music, song, poetry, politeness, composure and even posture, so they could move with confidence in international circles and courts (Stoffele, 2006). The Huygens brothers were trained in their teens to write polite letters in diplomatic language to each other, when they had to solve mundane domestic disagreements amongst themselves. Christiaan eventually showed a preference towards the sciences, after travelling for a brief period as a diplomat.

Aged 28, he published a book on probability theory in 1657. In the following years he formulated the centripetal force concept, became adept in the grinding of lenses, discovered in 1657 that Saturn had rings and explained them, showed that Saturn was not a contact triple planet as Galileo had described, discovered Saturn's moon Titan, derived the famous pendulum equation and was the first to measure precise gravity with this. He later contributed to the development of the 'moment of inertia' concept.

Christiaan already became a Fellow of the Royal Society of London in 1663, and was in Paris in 1666 when he saw that the French wanted to set up their own Académie Royale. The proposed members had not organised themselves yet, apart from some limited get-togethers of some of them in Jean-Baptiste Colbert's library. As he was a senior figure of the Parisian Montmor Academy and the only foreign scholar selected for the Royal Paris Academy by Colbert, Christiaan Huygens was perfectly suited to take on temporary leadership and initiate the 1666 inaugural meeting of the Paris Academy of Sciences. This was because he was not part of the competing vested interests. He was fluent in French and well trained for this formal function. Christiaan Huygens had a good relationship with the French King, was already in receipt of a pension of 1,200 livres from the King thanks to Colbert in 1663, and had earlier received the King's privilege in 1665 with respect to distribution in France of his pendulum clock (somewhat like a patent). Therefore, the Paris Royal Academy of Sciences was born in 1666. For the next three decades, it was referred to as L'Assemblée (Figure 8).

There are no minutes of the first meetings but some accounts are accessible (Sturdy, 1995). These show that Cassini (who joined three years after the inaugural meeting) and Huygens received a generous annual pension of about four times the size of what the other scientists received, reflecting Huygens' and Cassini's prestige. In the list of founding members of the Academy, Huygens is identified as a 'géomètre', the French word also used for surveyor, although he is mostly known as a mathematician, physicist, horologist and astronomer. Huygens left the Academy in 1682 and his extensive library of thousands of books, including a plethora of books on surveying among 300-odd mathematical books, was auctioned after his death in 1695. The Paris Royal Society also included Johannes Hevelius as one of its members. Eventually, it was for the return of one of the comets sighted by Hevelius in 1661 that William Dawes was sent to Australia more than a century later. It was 80 years after the inaugural meeting that certain biannual prizes offered by the Paris Academy became the

catalyst for further important developments in celestial mechanics.

Figure 8: Colbert presenting the members of the French Royal Academy of Sciences to Louis XIV in 1667. Detail of a 1672 painting by Henri Testelin (Palace de Versailles).

6.2 Celestial Mechanics Prizes Offered by the Paris Academy

Celestial mechanics had intrigued people throughout the ages. Thales of Miletus (640-516 BC), who rejected mythological explanations of phenomena (and this became fundamental to the scientific revolution), had taught the sphericity of the Earth after being instructed in Egypt. Pythagoras (569-470 BC) taught that the Earth rotates and revolves. Aristotle (384-322 BC) maintained that the Earth was round. Aristarchus of Samos (see section 5) had championed the idea of a heliocentric solar system, but his idea did not gain acceptance as the conventional wisdom although his contemporaries such as the 20 years younger Archimedes (287-212 BC) were aware of his heliocentric view and are known to have discussed it. Even 300-odd years later, there was still awareness of the view of Aristarchus. Plutarch (46-120 AD), in ‘On the face in the disc of the moon’, says someone held that Aristarchus supposed “that the heavens stand still and the Earth moves in an oblique circle at the same time as it turns around its axis” (Dreyer, 1953). One generation later, Ptolemy did not adopt the heliocentric system. Another millennium went by.

It took until Copernicus’ posthumous publication in 1543 about the heliocentric circles for planetary orbits, for the issue to regain a wider audience. The publication was posthumous in order to escape raised eyebrows from the Church.

Further insight was gained by Johannes Kepler (1571-1630), who benefited from being able to use the set of accurate observational data of his mentor Tycho Brahe. Kepler’s laws of planetary motion of 1609 and 1619, which assumed elliptical orbits, allowed some analytical understanding of these motions. The planets apparently obeyed some very precise laws. These were later given physical substance by Newton’s equations of mutually attracting masses, published in his ‘Principia’ in 1687. However, these solutions for planetary motion generally treated everything first as a two-body problem. The reality of the solar system, with a bit of exaggeration, is more comparable with half a dozen children jumping on a single trampoline, together with one very obese one, and all of them affecting the balance of the others (Figure 9). Newton did study the three-body problem, but his treatment awaited someone who could solve the complicated set of 8th order equations. Parts of Newton’s unpublished work, like that about precession of the lunar perigee, were not discovered until 1872.

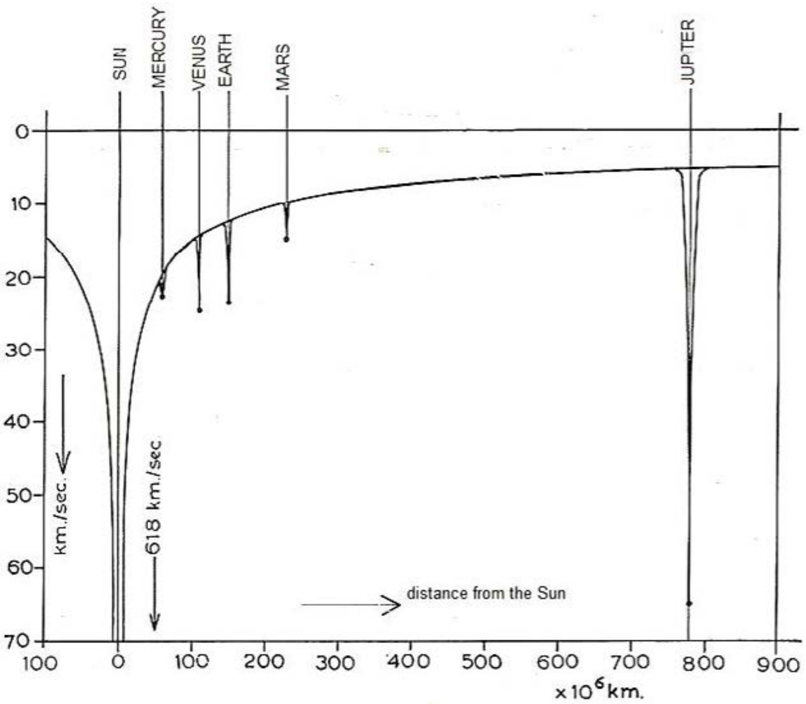


Figure 9: Escape velocity minus circular velocity, after Vertregt (1959), showing the interplay of multiple body gravity fields.

Some of the observed celestial phenomena did not conform to the conventional and usual two-body theory of gravity. These were called 'inequalities' of the phenomena. The inequalities of planetary and lunar motion led the Paris Academy of Sciences to propose that the solving of certain analytical problems should be subject to a competition. Those competitions led to important developments in celestial mechanics. In the period under consideration, Joseph-Louis Lagrange (1736-1813) played a prominent role among others like Leonhard Euler (1707-1783), Alexis Clairaut (1713-1765) and Jean-Baptiste le Rond d'Alembert (1717-1783), shown in Figure 10.

Figure 10: Leonhard Euler (by J.E. Handmann), Joseph-Louis Lagrange (wiki), Alexis Clairaut (by L.J. Cathelin) and Jean-Baptiste le Rond d'Alembert (The Louvre).

Only the Academy's competitions relevant to this story will be mentioned in this paper. Although Pierre-Simon Laplace has also been very important in this field, he was only born in 1749 and his influence covers a slightly later period. He published on Jupiter-Saturn perturbations in 1784-1786, and on lunar acceleration in 1787. The first part of his 'Méchanique céleste' was not published until 1799.

6.3 Lunar Theory and the Three-Body Problem

The demand for lunar tables was high due to their importance for navigation. Various learned societies offered substantial prizes for lunar tables that could be proved to agree with observations within narrow limits. Euler, a Swiss scientist, set the scene by publishing a set of lunar tables in 1746, but these were rather imperfect.

While Newton had a geometric approach in his perturbation theory, with respect to lunar motion, Clairaut and d'Alembert, two Parisians, made their advances through integration of differential equations. They sent memoirs on lunar theory to the Paris Academy in 1747, but still could not properly explain the rather irregular motions of the lunar perigee. Clairaut won a prize in 1752 set by the St Petersburg Academy, with 'Théory de la lune'.

Euler published more on lunar theory in 1753, and Tobias Maier (1723-1762) of Göttingen, Germany, compared this with observations. He saw that the eight unknowns which Euler was solving were sensitive to the choice of observations held in the eight simultaneous equations and systematically optimised the solution by combining equations and adding occultations of the star Aldebaran by the Moon. So successful were Maier's corrections to Euler's theory, that the English government offered Euler and Maier a payment of £3,000. The lunar theory had become accurate to one arc minute and became the basis of the nautical almanac of 1767 and later (Bradley and Sandifer, 2007).

In 1762, the Paris Academy established a competition for 1764 to explain why the Moon always shows the same face to the Earth (a tidal resonance effect) and whether it undergoes precession and nutation. Lagrange responded with his successful 'Recherches sur la libration de la lune' but failed to explain the strange motion of the line of lunar apsides and that of the line of lunar nodes.

In 1763, values for the size of the solar system were published, resulting from the 1761 Transit of Venus. This was followed in 1771 with results from the 1769 transit. It was then that the three-body problem became a subject of the competition in 1772. This resulted in Lagrange producing his groundbreaking 'Essai sur la problème des trois corps' in reference to the Moon. This later led to his development in 1788 of Lagrangian mechanics. One can imagine this as based on the analogy that water finds that path downhill that minimises the action that is required. In the same way, a body in a complicated gravity landscape (Figure 11) will find that path of least resistance or the least required action. In fact, in an elliptical trajectory, there is an energy balance where no energy needs to be added and no energy is withdrawn in order to continue the motion. If the potential energy increases, the kinetic energy decreases to measure. Without this energy balance approach, one would have to calculate the effect of gravity between each possible pair in three bodies at every single point along their path in order to determine that path. Lagrange shared this prize with Euler, who had already made a submission on the same subject with his 'Nouvelles recherches sur le vrai mouvement de la lune'.

In 1774, the Paris Academy sought an explanation for the secular equation of the Moon and whether that involved the gravity fields of all celestial bodies or whether the non-sphericity of Earth and Moon played a role herein. Lagrange's 'Sur l'équation séculaire de la lune' won the prize.

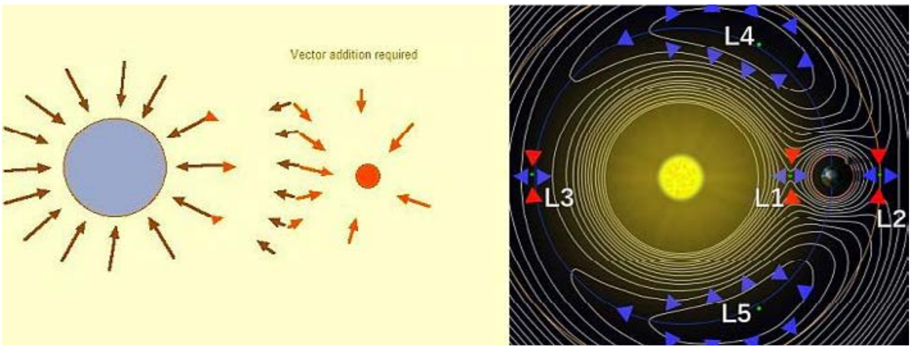


Figure 11: Addition of the gravity vectors of the two bodies are required, resulting in an interesting gravity landscape for a third body, like our Moon, to move through. This led to the discovery of the Lagrangian points.

When the mathematician William Rowan Hamilton (1805-1865) later developed his Hamiltonian mechanics in 1833, he acknowledged his debt to Lagrange's energy balance approach. No new solutions to the three-body problem were found until George William Hill (1838-1914) developed his lunar theory in 1878. Hill's solutions were of a substantially greater practical value than those of Lagrange. Hill's work was not surpassed until Henri Poincaré (1854-1912) took it further again in 1892 with a groundbreaking and more profound approach published in 'Les méthodes nouvelles de la mécanique céleste' (Moulton, 1970). He had also shown that the equations for the secular terms of lunar (and planetary) motion diverged rather than converged and this had consequences for the stability of the solar system. Poincaré's work later led to chaos theory and the Lyapunov exponent, which play a role in celestial mechanics.

6.4 Motions of Jupiter and its Satellites

Euler first had derived the differential equations for perturbations in general, and submitted this work to the Berlin Academy in 1747. Then Euler wrote a memoir, also in 1747, with the derivation of the perturbations upon Saturn by the action of Jupiter, and submitted it for the prize set by the Paris Academy of Sciences for 1748. Euler won the 1748 prize.

For 1766, the Paris Academy had put forward the question of what inequalities should be observed in the motions of the four Jovian satellites as a result of their mutual attractions. D'Alembert had earlier objected to the wording of this question, as it appeared to ignore the gravity of the Sun. Lagrange won the prize with 'Recherches sur les inégalités des satellites de Jupiter'. Euler followed in 1769 with 'Recherches sur les inégalités de Jupiter et de Saturne'.

After Lagrange's work in 1772 on the three-body problem with regards to the lunar motion, it became possible to derive analytically why satellite III will be at quadrature when the Jovian satellites I and II line up with Jupiter, and that satellite I will be in opposition when satellites II and III line up with Jupiter. Similarly, when satellites I and III line up, satellite II will be in opposition or in two other places of always the same fixed azimuth. Although this interplay of the satellites is a temporary resonance that unwinds in the long term because the equations of motion do not converge, it has lasted for centuries.

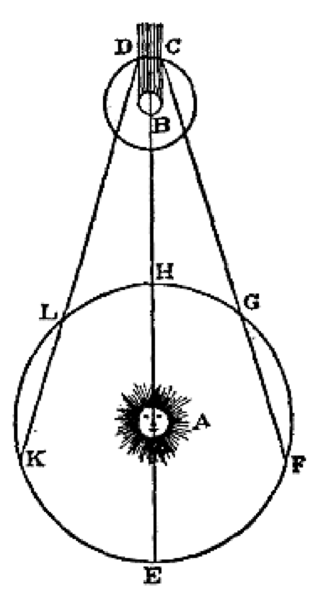
Lagrange's 1772 work on the three-body problem and the later 1788 development into Lagrangian mechanics still had to become widely known, understood and accepted, before it could start to affect the elaborate calculations for the nautical almanacs for Jovian satellite immersions.

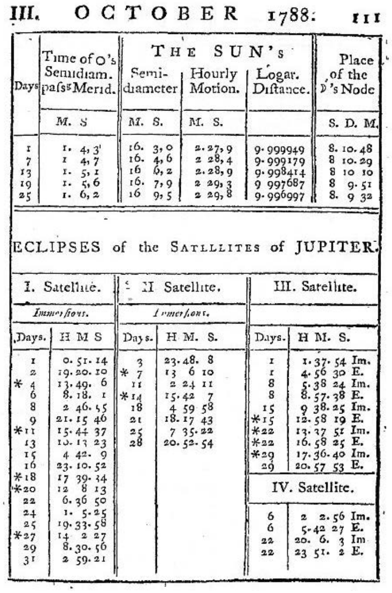
7 COMPARISONS OF TABLES OF JOVIAN SATELLITE IMMERSIONS

The 1787-1792 nautical almanacs carried by William Dawes were each printed half a decade or more in advance. There would be a small chance that some of the advances made in celestial mechanics just before 1781 would have found their way into those almanacs, but the lead-time involved in the required effort of calculation and preparation of the tables was enormous. In order to spot-check the quality of the Jovian satellite immersion tabulations, some comparisons will be made of those in the 1788 nautical almanac, with Jovian satellite phenomena generated by modern astronomical software.

From William Dawes' correspondence with Nevil Maskelyne (Morrison and Barko, 2009) it is known that Dawes observed the immersions of the Jovian satellite Io on 15 October, 7 November and 7 December 1788, for longitude. The October observation, by sheer coincidence, can be illustrated with a drawing by Ole Roemer, which shows a casual selection of points of the orbit of the Earth from which an immersion of a satellite of Jupiter is viewed (Figure 12). As the distance from Earth to Jupiter on 15 October 1788 was 5.2 AU, it can be compared with a point say 10° further than the point marked F, in an anti-clockwise direction on Earth's orbit. As seen from the Sun, the angle between the Earth and Jupiter was only a little more than a right angle. Three months earlier the distance to Jupiter was 6.2 AU (i.e. near E), and three months after October the distance was 4.3 AU (i.e. near H).

Of these Jovian satellite observations made in October, November and December 1788 the quality of the predicted times can be evaluated (Figure 12 shows October). A comparison can be made between tabulated values out of Dawes' 1788 nautical almanac and retrospective predictions from modern professional astronomical software like SkyMap Pro. When using SkyMap Pro 10 to check events that occurred in the past, like Charles Green's Jovian satellite immersion events in 1769 (Green, 1771) during his Transit of Venus observations, agreement is found within a few minutes of the 1769 immersion predictions. By applying this procedure to Dawes' observations from 1788, the results shown in Table 2 are obtained.





III. OCTOBER 1788: 111

Days	Time of ☉'s Semidiam. pass⁸ Merid.	THE SUN's Semi-diameter	THE SUN's Hourly Motion.	THE SUN's Logar. Distance.	Place of the ☽'s Node
	M. S	M. S.	M. S.		S. D. M.
1	1. 4, 3	16. 3, 0	2. 27, 9	9·999949	8. 10. 48
7	1 4, 7	16. 4, 6	2 28, 4	9·999179	8 10. 29
13	1. 5, 1	16 6, 2	2. 28, 9	9·998414	8 10 10
19	1. 5, 6	16. 7, 9	2 29, 3	9 997687	8 9. 51
25	1. 6, 2	16 9, 5	2 29, 8	9·996997	8. 9 32

ECLIPSES of the SATELLITES of JUPITER.

I. Satellite. Immersions. Days	H M S	II Satellite. Immersions. Days.	H M. S.	III. Satellite. Days.	H M. S.
1	0. 51. 14	3	23. 48. 8	1	1. 37. 54 Im.
2	19. 20. 10	* 7	13 6 10	1	4. 56 30 E.
* 4	13. 49. 6	11	2 24 11	8	5. 38 24 Im.
6	8. 18. 1	*14	15. 42 7	8	8. 57. 38 E.
8	2 46. 55	18	4 59 58	15	9 38. 25 Im.
9	21. 15 46	21	18. 17 43	*15	12. 58 19 E.
*11	15. 44 37	25	7 35. 22	*22	13. 37 51 Im.
13	10. 13 23	28	20. 52. 54	*22	16. 58 25 E.
15	4 42. 9			*29	17. 36. 40 Im.
16	23. 10. 52			29	20. 57 53 E.
*18	17 39. 34			IV. Satellite.	
*20	12 8 13			6	2 2. 56 Im.
22	6. 36 50			6	5. 42 27 E.
24	1. 5. 25			22	20. 6. 3 Im
25	19. 33. 58			22	23 51. 2 E.
*27	14 2 27				
29	8. 30. 56				
31	2 59. 21				

Figure 12: Jovian satellite immersions viewed from Earth on different months, after Ole Roemer (left) and the October predictions for Jovian satellite immersions in the 1788 nautical almanac (right).

Table 2: Jovian satellite immersion predictions of 1788, compared with modern astronomical software results.

Satellite immersion observed	Date	1788 Almanac	SkyMap Pro 10	1788 Almanac Offset	Distance to Earth
Io	15 Oct 1788	04h 42m GMT_{old} (16h 42m UT)	16h 26m UT	16m later	5.23 AU
Io	7 Nov 1788	04h 53m GMT_{old} (16h 53m UT)	16h 35m UT	18m later	4.87 AU
Io	7 Dec 1788	06h 46m GMT_{old} (18h 47m UT)	18h 37m UT	10m later	4.48 AU

The Earth had been travelling towards Jupiter from about 1 July 1788, so this makes the intervals between the Jovian satellite immersions for the next 6 months appear up to a quarter of a minute shorter per revolution than average as seen from the Earth. This apparent rotation period deficit is accumulative and makes the tabulated values appear late. It distorts the real times by a maximum accumulative 4 minutes per month after which it accumulates at a decreasing rate through a cosine factor. It appears that the difference already had accumulated to 16 minutes by October and was coming some way back towards the average by December. Some of this can be explained by the non-application of a light-time correction, and the balance obviously has something to do with unknowns remaining in other orbital variations like in the 'equation of the centre' of Jupiter, also known as the orbital eccentricity. The author finds that no light-time corrections appear to have been made to the Jovian satellite tables at that time, in the 1788 nautical almanac, more than a century after Ole Roemer's explanation that light travelled at a finite speed.

8 CONCLUDING REMARKS

At the start of this paper, a few questions were asked about the possible early influence of the Transit of Venus results of 1761 and 1769. In answer to these questions, one can say that the Transit of Venus results did not yet improve the calculation of the values for the astronomical tables by the last decade of the 18th century. The tables for lunar distances were already of good quality at the time through inclusion of occultations of Aldebaran results into the calculations, but the increased knowledge about the variations in planetary orbital elements through understanding of the three-body problem came later. The tables of immersions of satellites of Jupiter appear not to have improved until the 19th century.

It can be concluded that tremendous improvements in celestial mechanics were happening during the 18th century, which have added a lot to our understanding of the mathematics and dynamics of orbital motion, in both the short term and the long term. Before the light-time correction was applied, anomalies still appeared to be present in the data as late as almost the 1790s. Of course, the data could be cleaned of this effect in the future. The main influence of the 1761 and 1769 Transit of Venus results during the 18th century was to give the eminent mathematicians some better 'ground truth' to check their theoretical derivations against while they were developing the theory, as such enabling their great advances at the time. The nautical almanac tables for the practitioners were not corrected until later.

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Surveys at the Sydney Cricket Ground 1999-2013

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ABSTRACT

Many people are surprised when told that the author does survey work at the Sydney Cricket Ground (SCG). A common response is "What do they need you for? Isn't it just a piece of grass that people play sport on?" It seems to be a common misconception that the hallowed field of the SCG is something set in stone, never to be altered. However, during the author's involvement with the ground it has been modified a number of times. Between times, there is survey input into various maintenance tasks. A comprehensive as-built survey of buried services is of increasing value. This paper outlines several surveys undertaken over the years, including determination of the horizontal and vertical geometry of the SCG field, its reconstruction in 2000, sporting field set-outs, the building of the Trumper Stand in 2008, the field renovation in 2010 and the current Stage 2 development.

KEYWORDS: *Sporting fields, cricket, construction, machine control, design, as-built surveys.*

1 INTRODUCTION

Sporting fields were traditionally built using local soil formed into a domed cross-section intended to allow rainwater to drain across the surface to the sides of the field. The gradient was necessarily slight and the soil retained moisture. When a match was held after heavy rain the combination of saturated material and many sprigged boots typically resulted in one of the 'mud baths' of fond memory (Figure 1).

Figure 1: Mud-caked footballers of the Australian and English national rugby league teams walking off the Sydney Cricket Ground after a test match on 12 June 1950.

The Sydney Cricket Ground (SCG) originally opened in 1886. For many decades, it has been famous for cricket and being the home ground of the Sydney Swans AFL team. However, it has also hosted other sports in the past. Around 1900, it included a concrete cycling track on which Australia's first motor race was held in 1901. In 1914, the New York Giants played the Chicago White Sox – the only U.S. Major League Baseball (MLB) game ever to be played in Australia. In 1938, the Empire Games were held at the SCG. Tennis matches have also been staged, as well as many concerts.

On 25 January 1998, a one-day international cricket match between Australia and South Africa at the SCG was washed out when heavy rain fell overnight and in the morning. Initially it was thought that conditions would improve and the gates were opened. The crowd, including the author, waited several hours in the stands and watched as the ground staff attempted to dry out the ground. This was unsuccessful and the patient fans were sent home and told to come back the next day.

Subsequently, it was decided to rebuild the playing field and incorporate a modern sub-surface drainage system under the outfield (Figure 2). Water now falls onto the surface and works down through porous sand and gravel layers to an impervious subgrade. This subgrade is designed to direct water across it towards the fence. It is transected by a herring-bone network of trenches filled with gravel and slotted pipes. Water flows across the subgrade and into the trenches where it is picked up by the pipes and directed into the main drainage network. The sand and gravel dry out the surface quickly and the subgrade and piping take the water away. At the SCG, the outlet from the field is below the drainage system outside the ground. Water is directed into a holding tank under the Churchill Stand concourse and then pumped out to the street.

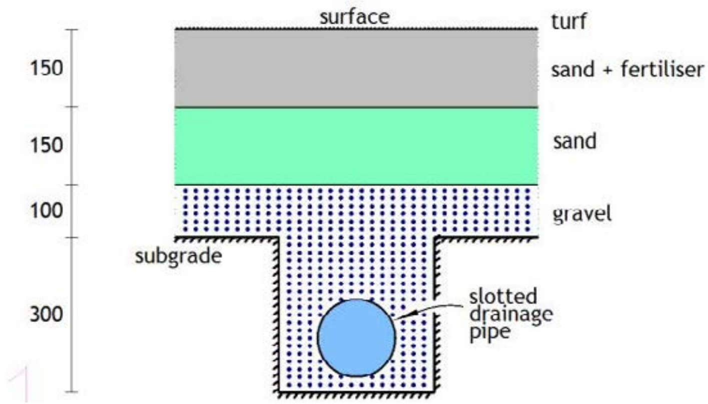


Figure 2: Typical cross-section of the rebuilt outfield (dimensions in millimetres).

The author commenced his professional connection with the SCG during the reconstruction project in 2000 and has continued work at the ground since. This paper describes the SCG field and some of the surveys undertaken.

2 SCG PLAYING FIELD GEOMETRY

2.1 Horizontal Geometry

The SCG started life in the 1850s as the Garrison Ground, built for English troops based at Victoria Barracks. The field is an irregular shape, neither circular nor elliptical. It has been

created over a long period by numerous local re-alignments of the fence. Residuals from best-fit solutions show the deviations as long shallow slivers (Figure 3). The wicket square consists of 9 pitches and is the focus of the centre of the field. It is oriented towards Magnetic North.

Harvey (2010) has used 36 points around the drain as a student least squares ellipse-fitting exercise. His best-fit north-south aligned ellipse has a semi-major length of about 80.8 m and a semi-minor length of about 72.6 m. Offsets from the calculated ellipse are up to about 2 m.

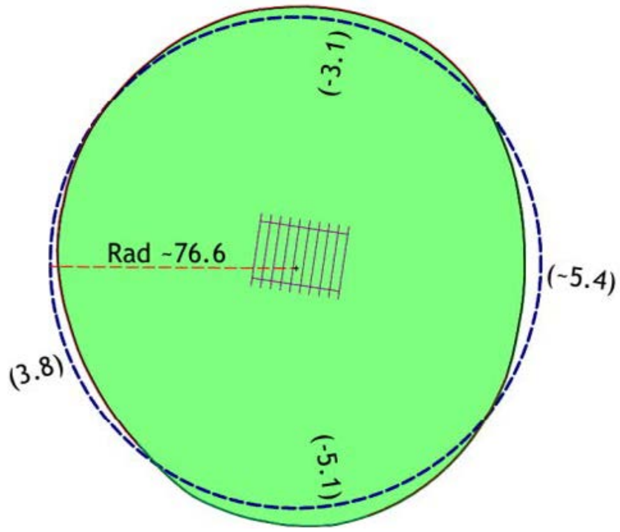


Figure 3: Residuals from a typical best-fit circle. Field shown is post construction of the Trumper Stand in 2008.

2.2 Vertical Geometry

A concrete drain at the edge of the field (Figure 4) is intended to capture water from the concourse seating immediately behind the fence. The grassed area inside the drain is 1.84 ha, or a little over 4½ acres. A long section along the drain shows that the vertical alignment of the field boundary is also far from regular (Figure 5).

Figure 4: concrete edge drain.

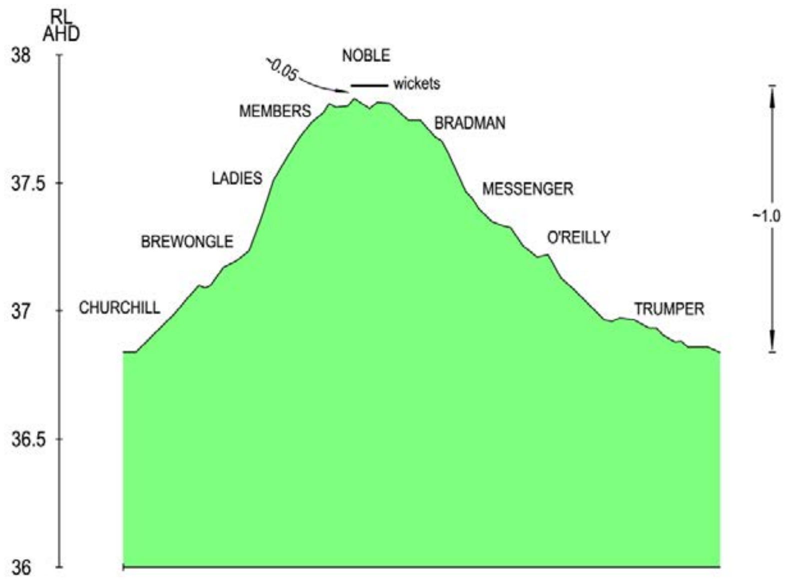


Figure 5: long section along edge drain (all values in metres).

The surface of the field is also highly irregular. In the 1990s it was graded in 8 segments with a laser level. The 2000 reconstruction adopted smoothed contours that roughly approximated the pre-existing shape (Figure 6). The 2010 renovation will be dealt with in section 5.

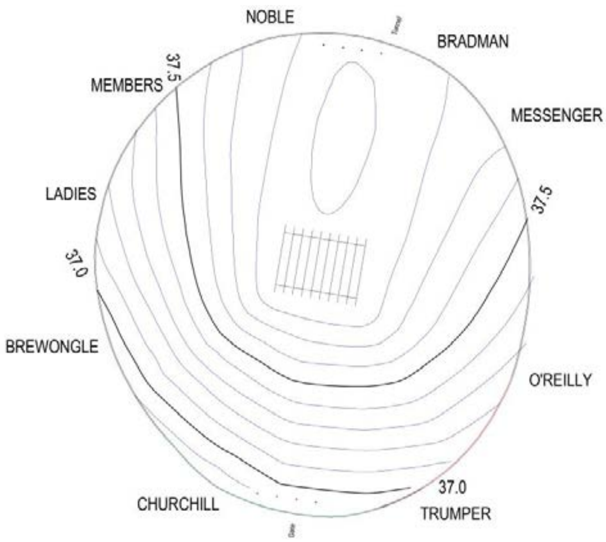


Figure 6: 2000 reconstruction design contours with post 2008 field.

3 THE 2000 RECONSTRUCTION

3.1 Description

The 2000 reconstruction of the SCG was a $2M project, which is unimpressive compared to the almost $200M currently being spent on the new Northern Stand. About 400 mm of material was removed and later replaced in layers after trimming of subgrade and installation of complete new drainage and irrigation systems and other services.

Two Leica robotic total stations were used. Grading of the layers by machine control methods was considered but the final trimming was done manually. Backpacker labourers were trained

to set up the instrument and operate the 'DTM Setout' program, which gives a cut or fill to design level.

3.2 As-Built Survey

The two instruments were also used for the set-out and as-built surveys. Files were reduced daily and integrated into the main Liscad file. The as-built survey of underground services can be a stressful operation – contractors are not happy waiting. The surveyor must be available as work is completed. It is very helpful if the surveyor is on-site full time, observing progress and pre-planning windows of opportunity for survey work. The final plan fitted onto a B1 sheet at 1:250 scale (Figure 7). The survey has been updated since as services are altered or added and has proven its usefulness on many occasions. The sprinklers form a very useful network of on-field control points, and it is often possible to mark locations by simply intersecting calculated distances from them.

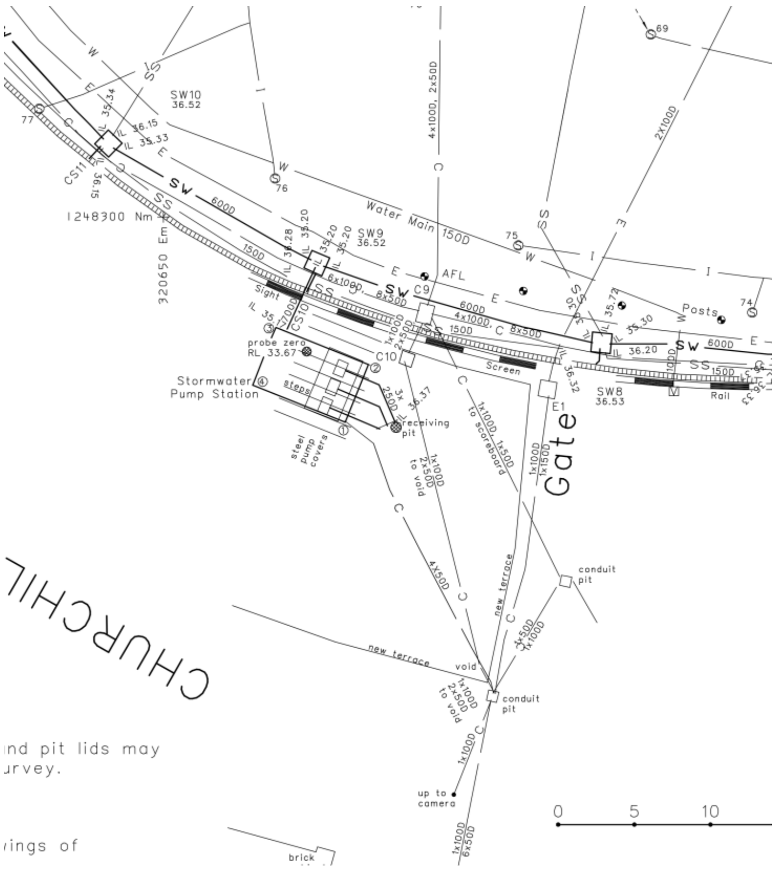


Figure 7: 2001 as-built plan, detail showing drainage to storage tank for pump out to street system.

4 SPORTING FIELD SET-OUTS

4.1 Description

Apart from cricket in the summer, the SCG is the home ground of the Sydney Swans AFL team during the winter. 'Heritage' rugby matches are also played every season but a soccer field sees little use (Figure 8). Sleeves buried in concrete allow rapid installation of goal posts. The positioning of these sleeves to avoid existing services is an example of the use of

the as-built survey. An interesting feature of the Trumper Stand development in 2008 was the lengthening of the field by about 2 metres. An important reason for this was to ensure that the 50 m arcs of the AFL field would not touch the centre square.

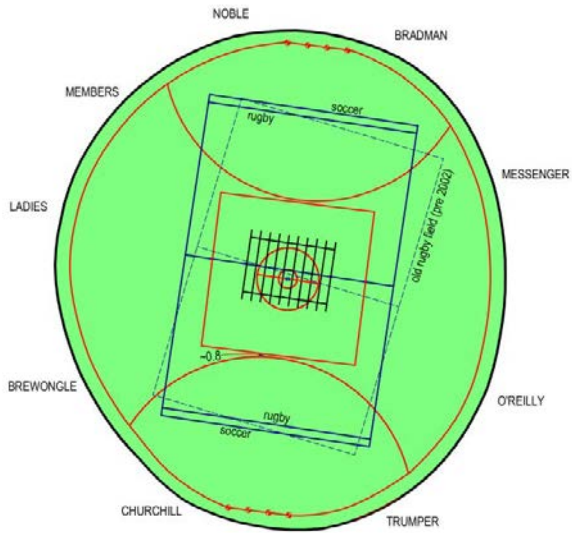
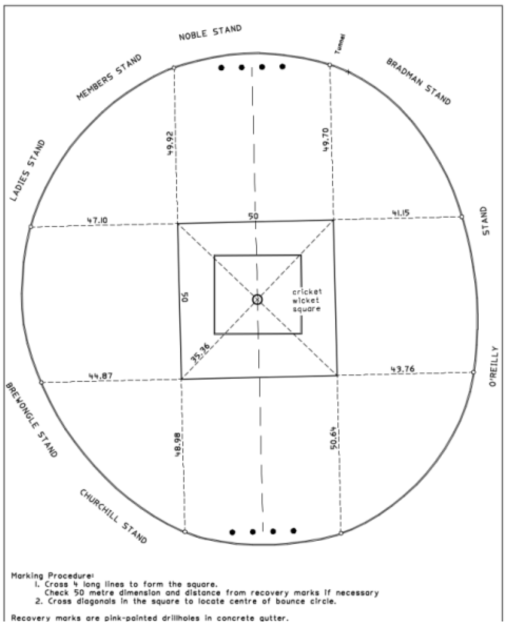


Figure 8: SCG sports field layouts – post 2008 field shown.

4.2 Field Marking

Drillhole recovery marks are placed in the concrete edge drain for each field. By mutual agreement these are colour coded for easy identification, e.g. the AFL marks are painted red and white in honour of the Swans. Ground staff have very long ‘stringlines’ that are actually light cord, and a 100 m nylon-coated steel tape. A plan for each field explains how to mark it using these tools (Figure 9). Another drawing shows the position of the wickets and a table of distances from the centre of each pitch to the boundaries (Figure 10).



Marking Procedure:
1. Cross 4 long lines to form the square.
Check 50 metre dimension and distance from recovery marks if necessary
2. Cross diagonals in the square to locate centre of bounce circle.

Figure 9: AFL field set-out plan 2006 and detail of set-out instructions.

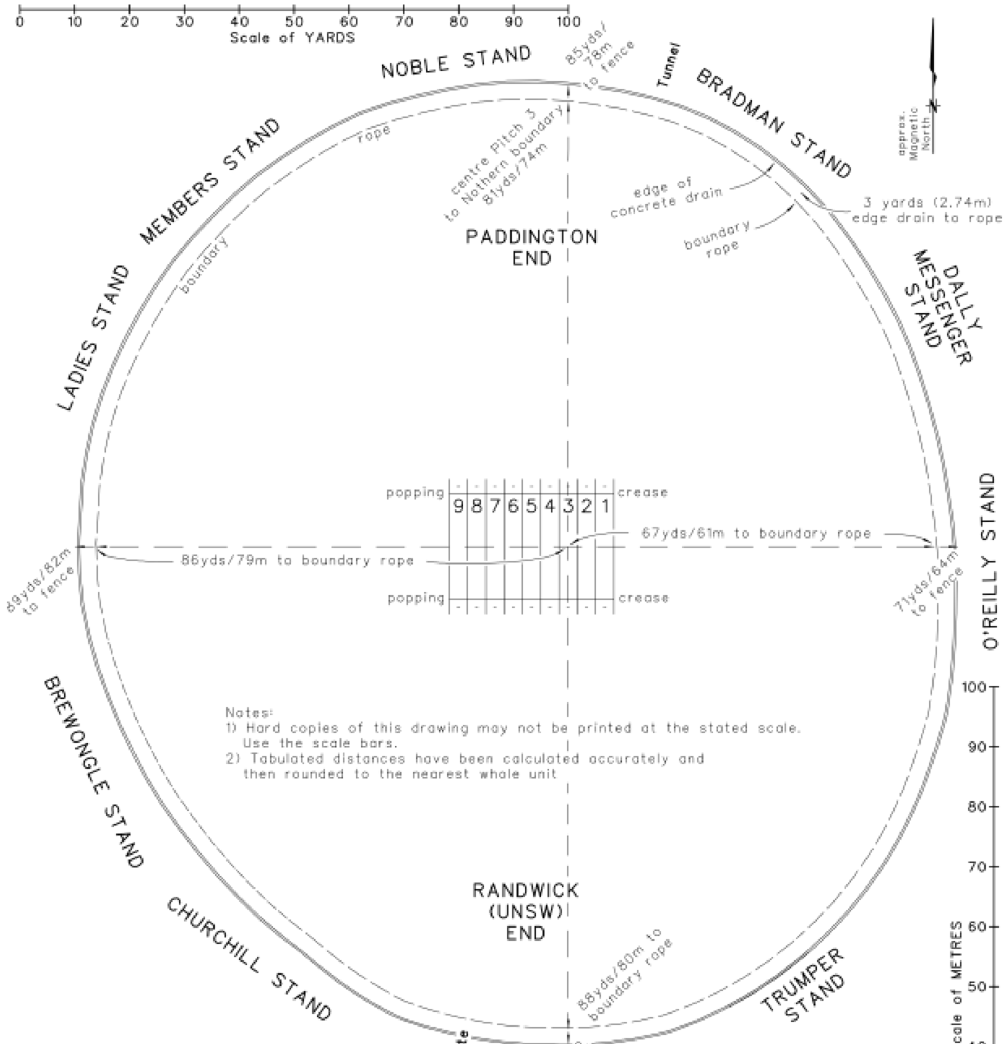


TABLE OF BOUNDARY DISTANCES
Distances are from the centre of each pitch as shown on the plan

PITCH	9		8		7		6		5		4		3		2		1	
	yds	/m	yds	/m	yds	/m	yds	/m	yds	/m	yds	/m	yds	/m	yds	/m	yds	/m
N boundary	81	74	81	74	81	74	82	75	82	75	82	75	81	74	81	74	80	74
E boundary	87	80	84	77	81	74	77	71	74	68	71	64	67	61	64	58	61	55
S boundary	86	78	87	79	87	80	88	80	88	80	88	80	88	80	88	80	87	80
W boundary	66	60	69	63	73	66	76	70	79	73	83	76	86	79	89	82	93	85
N fence	84	77	85	77	85	78	85	78	85	78	85	78	85	78	84	77	84	77
E fence	91	83	87	80	84	77	81	74	77	71	74	68	71	64	67	61	64	58
S fence	89	82	90	82	90	83	91	83	91	83	91	83	91	83	91	83	91	83
W fence	69	63	73	66	76	70	79	73	83	76	86	79	89	82	93	85	96	88

Figure 10: Cricket boundary distances.

5 THE 2010 RENOVATION

5.1 Description

After a few years, the new drainage system was not working as well as it first had, especially in the flatter area in front of the Noble Stand. After heavy rain, water was pooling on the surface and only slowly escaping down to the subgrade. The cause was the build-up of a skin of grass clippings ('thatching') and other material. The solution is occasional renovation of the playing surface. There had also been some uneven settlement over the field and the surface was becoming somewhat bumpy.

It was decided to remove about 50 mm of grass and sand, regrade the surface and lay new turf. This time the grading was to be done by machine control methods and the surface was to be redesigned. The very simple brief was to produce a smooth, even fall from the wicket to the boundary. Any irregularities were to be adjusted out near the fence.

An initial Digital Terrain Model (DTM) was created by fixing only the wicket and the edge drain (Figure 11, left graph). It was immediately apparent that some finessing was required. The cricket field boundary rope was surveyed. It is about 3 m from the edge drain. Design levels along the rope were determined by manual, graphical methods (Figure 11, right graph). Contours were updated automatically as these levels were entered into the Liscad model. The slight rise north of the wickets was retained, producing a final DTM design (Figure 12).

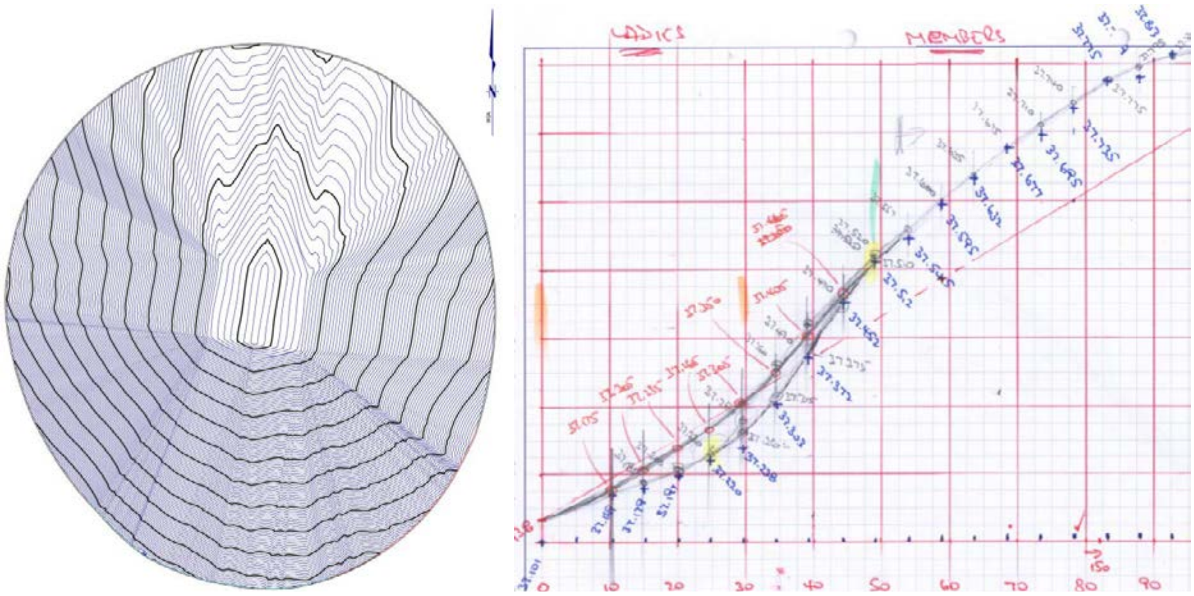


Figure 11: Initial DTM design (left) and manual working sheet (right).

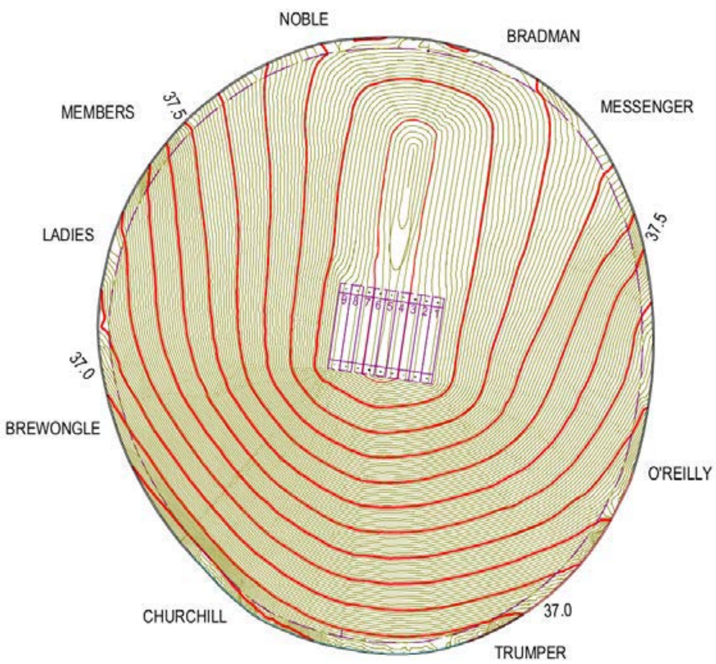


Figure 12: Final DTM design (August 2010).

The entire grading process, both bulk and final trim, was completed in 2 or 3 days. Random check surveys gave results generally within 5 mm. The finished product was much smoother than the 2000 manual grading, and the process was many times faster. In addition, it will be possible to restore future renovations, whether complete or partial, to this design profile.

6 CONCLUDING REMARKS

This paper has described the SCG field and some of the surveys undertaken. Topics not covered in this paper include work at the Sydney Football Stadium (SFS), the AFL and Rugby League practice pitches in Moore Park and the cricket practice nets. Cadastral surveys have also not been mentioned.

At the time of writing (January 2013) the Noble, Bradman and Messenger Stands have been demolished, and work on the vast new Northern Stand is at basement level. The first major event after construction will be the Ashes Test in January 2014. The main impact of the development on the playing field will be a further lengthening, this time by about 7 m.

New and not-so-new uses for the ground can be expected in the future. For instance, published reports state that MLB games may be played at the SCG in 2014.

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Sustainable Development, Subdivision, Surveyors and Sun Angles II

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ABSTRACT

This paper reviews the principles of the comfort zone for human habitation, passive solar house design theory with a view to provide more sustainable development, sun angles as they change daily and seasonally by location, and annual temperature variation. It provides a summary of observations based on years of surveying in private practice, related to the traditions of construction and orientation of dwellings erected on modern subdivisions, and how these traditions are often at odds with passive solar house design. If these principles are put together with the preferred orientation of the subdivision road and lot layout, the overall energy usage of the housing estates can be optimised or minimised by the layout of various development types. Modelling has shown potential energy savings of 30% through adoption of the ideas behind this paper. A case study of a recently zoned area of land under the NSW Local Environmental Planning template is also presented along with predictions of high and low energy requirements as a result of the design of subdivision layout which is apparently fixed by the 'planning system'. This paper is a follow-up to a presentation given at the APAS2002 conference over a decade ago.

KEYWORDS: *Sustainable development, subdivision, surveyors, sun angles.*

1 INTRODUCTION

The theme of this conference is 'Capitalising on our Position'. How can we benefit from where we are? Our Position as surveyors, particularly registered surveyors, is that we must be involved, by virtue of legislation, in any subdivision of land parcels into two or more lots. Surveyors lay out the basis for living spaces of human habitation, the lots, roads and byways. When we do this, we create the building footprints for the end user, the households.

This paper combines the observations of 35 years of experience as a surveyor and family man with an interest in the principles of comfortable living and passive solar house design to provide an insight into superior low energy input subdivision orientation. Incorporating these insights into future subdivision design using the models demonstrated in this paper along with the surveyor's own local knowledge can lead to significant reduction in energy usage and more sustainable, comfortable housing estates.

Why do a follow-up paper to one given at the APAS2002 conference (Calvin, 2002) over a decade ago? Design ideas tend to follow three Fs: functional, fashionable and forgotten. Following up on forgotten ideas can bring back useable design and function based on reliable logical concepts. The 'pelmet' for example was originally functional. Pelmets reduce heat loss and gain by cutting off air circulation around curtains where exchange of heat through the glass occurs. Pelmets then became fashionable. Interior designers hid the lights behind the

pelmet and removed the top so that reflected light bounced off the ceiling and provided lighting ambiance. The original function of the pelmet was lost. Today, pelmets are forgotten even as a lighting treatment and are seldom seen in any modern construction.

Similarly, Australia's wide eaves and verandas seem to have lost their appeal. In the quest for larger floor space in modern small-lot developments, verandas and eaves that perform the function of shading the walls of houses appear to have been forgotten and have been replaced with costly, energy-consuming reverse-cycle air conditioners.

This paper makes the connection between the subdivision lots and the housing built thereon. It provides preferred orientations of road and lots for use by surveyors and planners in development. This paper chronologically reviews Australian housing and climate research that forms the basis for low energy housing and how it links to road and lot orientations. The objective is to provide surveyors with information and logical argument that can assist surveyors and planners in creating better, more effective and efficient living spaces.

2 SUSTAINABLE DEVELOPMENT

Sustainable development became fashionable in the 1990s – that is doing something that you can keep on doing, ad-infinitum. Yet the idea for providing a sustainable framework for today and future generations has been around for much longer. Bill Mollison, a forward thinker, put the ideal of sustainable living and permanent culture into his design theories into his book *Permaculture 1* (1978) which is still used as a model for sustainable low-energy input, high-yielding agriculture today. Permanent culture has been shown throughout history to be very difficult to achieve. Many past civilisations have proved to be unsustainable for a variety of reasons. The legacies of old cities remain in the road layout and basis for land parcels conceived by their surveyors.

An Australian surveyor may have to work with road layout created anytime since 1788. In Europe, surveyors may work with the framework created by ancient Romans. Thus, it must be recognised that the work designed today provides the framework and living spaces for many generations to come. A small change in design orientation could create a notable advantage for future society.

2.1 Are We Doing It Right?

Traditional views are probably the greatest things to overcome in promotion of energy efficient housing to the public. These views have come about due to convention, building industry trends and people's increasing removal from the natural environment:

- Most houses are designed to 'face the road'. This often means that the largest area of glass will commonly face the street. This was traditionally designed to show your wealth and is a pattern especially hard to break.
- The front wall of houses is generally fixed at the front by the 'building line', an imaginary offset from the street boundary set by the local Council, in front of which the house cannot be built. This is often solely to save costs by minimising the length of the driveway.
- The building will often be placed at the minimum side boundary offset for either the main wall or the eave and gutter, depending on the width of the eave. This is done to maximise the available building footprint. Side boundary setbacks of 675 mm to the eave and 900 mm to the wall were, and remain, common.

- When the lot is not square, the building is usually aligned parallel to a side boundary rather than the road boundary.
- Many houses seem to be built where the garages have become a feature of the northern wall.

With these conventions, it can be seen that the orientation of the street can and will directly affect the layout of the building on the allotment. The trick is to orientate the roads to provide building spaces where the warming winter sun can be included and incorporated into the living spaces of the house and the hot blast of the summer sun can be excluded.

3 OPTIMUM ROAD AND LOT LAYOUTS

3.1 East-West Road Alignment

East-west is the optimum orientation for roads designed for single detached housing. Houses on east-west roads tend to naturally provide warmth in winter and cool in summer. They have uninterrupted solar access to their northern wall and are often protected from the summer sun by their neighbouring buildings. In preparing layout plans, one must consider yield and building concepts like utilising the maximum footprint available. In addition, it should be considered making the allotments shallower and wider to allow optimum solar access on the northern wall (Figure 1).

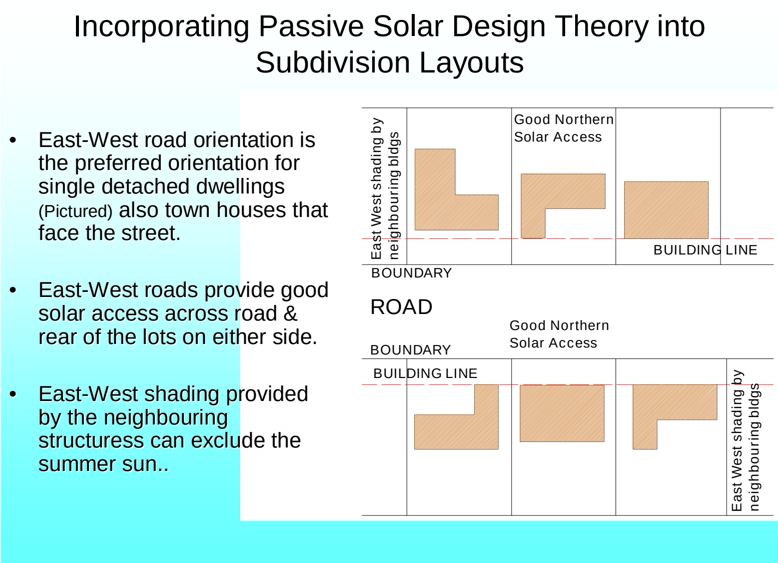


Figure 1: Preferred orientation along east-west roads.

3.2 North-South Road Alignment

Obviously, some north-south roads will be needed. However, much consideration of the solar access on these north-south roads is required. Detached housing on north-south road alignments tend to be hot in summer and cold in winter. This is because the important northern wall is often overshadowed in winter by the neighbouring buildings and the eastern and western walls are generally un-protected from the summer sun. Thus, external energy for heating and cooling may be required for comfort.

On north-south road alignments, the lots need to be significantly wider than normal in order to account for the winter overshadowing. This is particularly difficult in areas where the popular

2-storey McMansions are prevalent. They cast a long shadow in winter, almost twice as long as the building is high and detrimentally affect the solar access of the southern neighbour as shown on the western side of Figure 2. Recent modelling of energy usage and road orientation indicates that houses on north-south roads may require up to 30% more energy than houses on east-west roads to stay comfortable (A. Gentle, 2011 – email communication).

North-south road orientation is the best for multi-unit developments where the units tend to be arrayed behind each other along the block as shown on the eastern side of Figure 2. Surveyors should consider shaping allotments designed for multi-unit developments where a north-south road orientation is required.

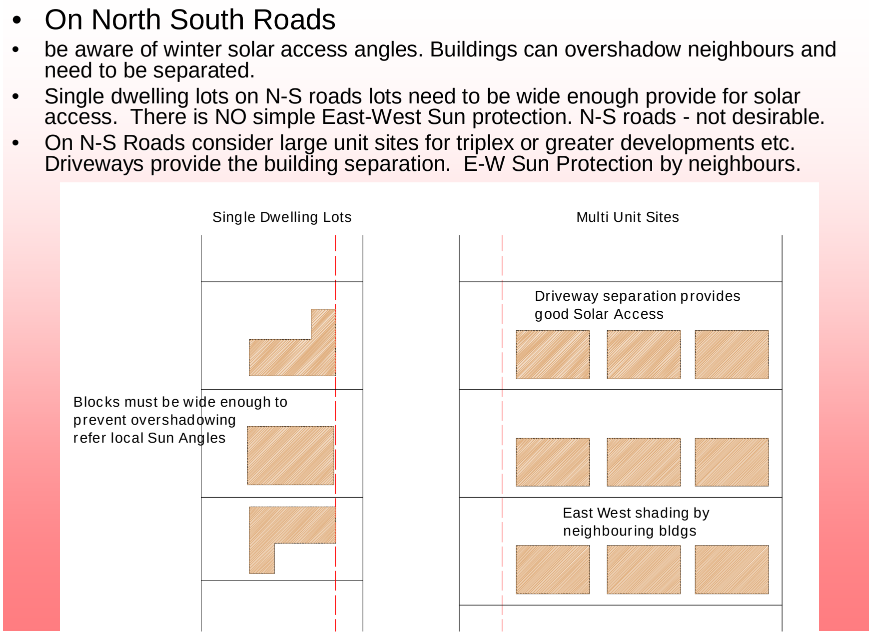


Figure 2: Considerations for houses along north-south roads.

3.3 Skew Lots

Lots skewed to the cardinal directions are probably the most difficult to consider. No walls can effectively control the input or exclusion of the sun's energy. All walls are open to the summer sun and can only effectively receive 70% of the northern sun's energy in winter. Some suburbs like Cundletown, near Taree, are seemingly entirely oriented on the 45° axis due to being aligned with the adjacent river (Figure 3).

Figure 3: Cundletown aligned parallel to the Manning River.

To promote effective solar orientation of the dwellings, it should be considered aligning the side boundaries north-south to create well-oriented building envelopes (Figure 4). This method also sets up an interesting streetscape with buildings being stepped along the street, which can also provide cross-ventilation. This methodology departs from the traditional survey that seeks to provide symmetrically square allotments and is a very difficult tradition to break. The arguments that follow provide the basis for making the change.

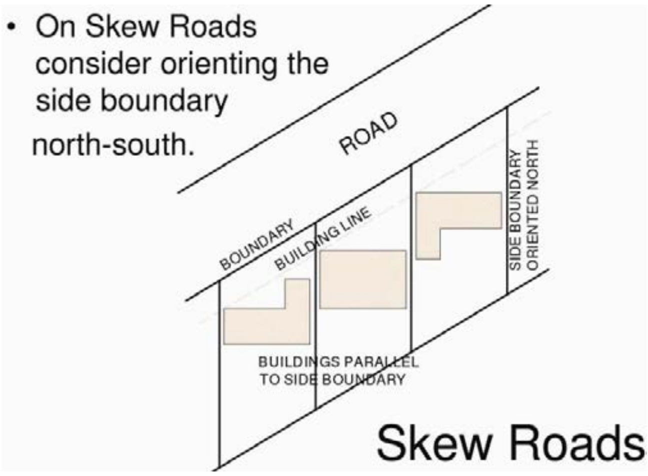


Figure 4: Orientation of lot boundaries on skew roads.

3.4 Road, Lot and Building Orientation

The tradition and compunction to comply with standard building and lot orientation (i.e. how the building aligns with the boundaries and addresses the street) appears to be too great for most people to vary. Changing the building orientation on lots of varying alignments has been promoted and documented numerous times by many individuals, architects and authorities.

One example is shown in Figure 5, taken from a brochure *Housing Western Australia* (June 1989), which provides an architectural solution to solar orienting houses on lots of varying street alignments. The same figure has been copied into any number of energy-smart Development Control Plans (DCPs), including Newcastle City Council's and Wagga Wagga's DCP 13. The reality is that building designers unerringly resort to the standard orientation of building on lots (as noted above) regardless of the alignment of the street, and the ideals depicted in this diagram seldom occur.

The ideal suggested by this paper is for the surveying and planning professions to provide lots with orientation and shapes that result in the traditional building and lot layout providing optimum solar alignment.

Occasionally, people do align their house on the block to attain optimum passive solar orientation. One case recently occurred in Wallabi Point near Taree, where the developer noted how other home/lot owners in the estate had pilloried the crazy lady who built her house crooked on the block, raising concerns that in doing so she had ruined the look of the subdivision and potentially had a negative effect on the value of the properties (A. Hook, developer – personal communication).

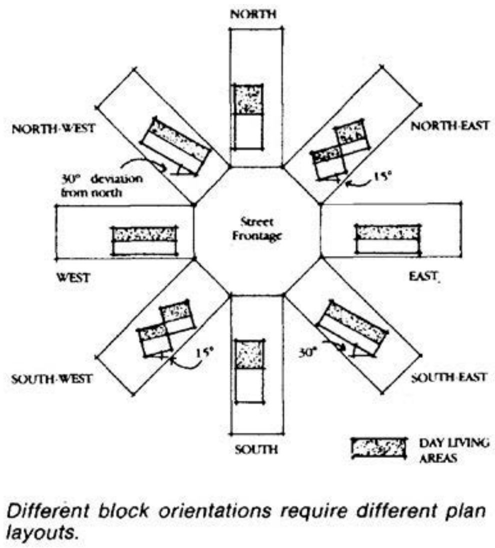


Figure 5: Architectural ideal for lots of varying orientation (Housing Western Australia brochure, June 1989).

An astute person may see this situation quite differently. Only one of the hundred odd houses in the estate actually got it right! The 1% of the houses in this development oriented to the sun rather than controlled by the lot layout are probably well above the norm. The percentage of non-conformists who actually overcome the lot orientation in development of their houses is in all probability much, much less. This can be seen in almost every urban development across Australia and can be confirmed with a quick 'google map' of any urban area.

4 STAYING COMFORTABLE

4.1 Temperature Range

Humans naturally desire a safe and comfortable habitat. We depend on several variables including air temperature, humidity and air movement. The temperature range or comfort zone has been variously described as being between 15C° and 25°C, between 20ºC and 25ºC and 18ºC and 28ºC, with relative humidity between 30% and 70% based on various documents. The other variables include:

- Air movement: 0 to 1.5 m/s
- Radiant temperature: within 3°C of air temperature
- Maximum temperature variation: 1.5ºC per hour
- Clothing: light

Maintaining our living spaces within the comfort zone commonly needs intervention in most Australian climates. Essentially, we need to be warmed in winter and cooled in summer. However, rather than thinking about designing our houses to minimise potential energy consumption, we seem to be more and more reliant on costly energy-consuming reverse-cycle air conditioners.

The average temperature of Campbelltown (Figure 6) fluctuates with the seasons. In order to stay comfortable, this requires heating in April to October and cooling (or exclusion of energy) may be required in November to March. This temperature chart is typical of much of temperate NSW. The record maximum and minimum temperature (also shown in Figure 6) indicate that the average temperatures can spike significantly.

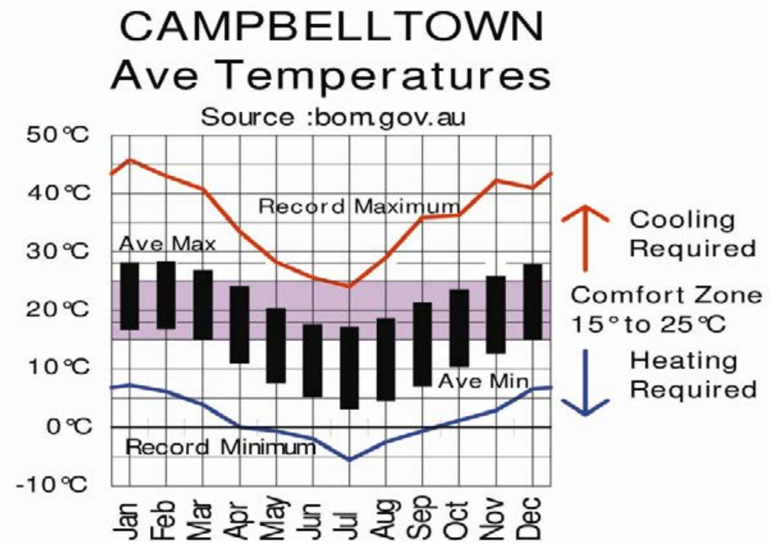


Figure 6: Campbelltown temperature chart.

4.2 Domestic Energy Use

Table 1 shows the typical energy use for households in 1992 and 2012. The major difference between the two is in the energy used for cooling, which appears to have significantly increased. A similar increase from 1.2% to 8% is believed to be occurring in Australia due to the increase in the number and use of reverse-cycle air conditioners over the last 20 years.

Table 1: Typical household energy usage comparison between Australia (1992) and the U.S. (2005) (Ballinger et al., 1992; US Energy Information Administration, 2011).

Domestic Energy Use in AUS	1992
Heating	41.5%
Water heating	26.6%
Cooking	9.8%
Appliances	8.8%
Refrigeration	8.7%
Lighting	3.4%
Cooling	1.2%

Domestic Energy Use in USA	2005
Space heating	41%
Electronics lighting & appliances	26%
Water heating	20%
Air conditioning	8%
Refrigeration	5%

The energy requirement for heating and cooling our living and working environments can be significantly lowered by effectively utilising the sun's energy in winter and by excluding the sun's energy from our living space in summer.

5 SUN ANGLES

According to the University of Technology Sydney's Earth Building website, the Australian Commonwealth Experimental Building Station (EBS) was formed in 1944 in order to produce standards for more efficient buildings with improved thermal comfort. Most of the basic principles of passive solar design date back to the work of these scientists (UTS, 2007).

The EBS produced and disseminated information from their research. Technical Study No. 23 (1948) became *Sunshine and Shade in Australasia* (EBS Bulletin 8, 1963) and described the apparent motion of the sun in our region. EBS 8 published sun charts for a variety of latitudes and described how energy from the sun may be may be controlled through orientation and

shading devices (Phillips, 1977). Sun charts reduce the sun's location at any season and time to simple azimuth angle (bearing) and altitude angle (Figure 7).

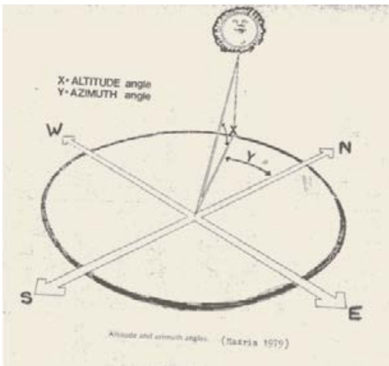
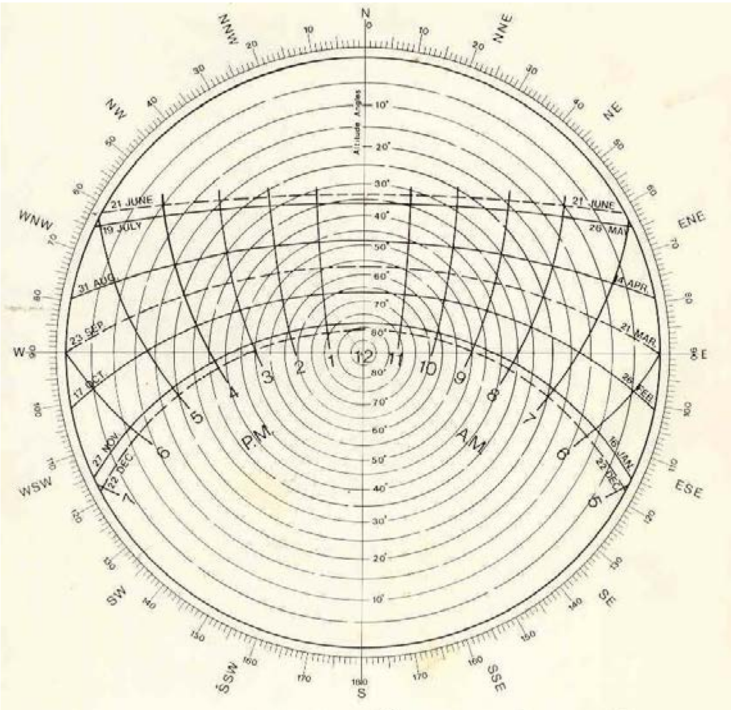


Figure 7: Altitude and azimuth angles (Mazria, 1979).

Figure 8 shows the seasonal sun paths, which are labelled with dates:

- Time lines (sun time) curve through these sun paths labelled 5 am through 7 pm.
- The azimuth angle of the sun is read off the protractor as a bearing.
- The altitude angle of the sun is read off the concentric rings.

Diagrams from EBS 8 are useful and understood by surveyors in a format they are used to. Displayed as sun time, these charts are correct for all points along any given latitude.



Latitude 32½° south

Fig. 26

The centre of the diagram represents the observer's position. The heavy curved lines represent the sun's path for selected dates and latitudes, and are crossed by lines indicating hours. To find the sun's position for the required conditions, select the point where the appropriate lines intersect. The sun's altitude (in degrees above the horizontal plane) is shown by the relation of this point to the concentric circular lines within the diagram. The direction of the sun's rays is shown by a line drawn through this point from the outer graduated circle towards the centre.

Figure 8: Solar chart for 32° latitude, approximating Newcastle (EBS 8).

Some people, unfamiliar with working with bearings, found this style difficult to understand. To overcome this, sun charts have been modified, updated and now come in a variety of shapes (Figures 9 & 10). The time lines have been elaborated to be correct for specific locations (longitudes) with variation from the central meridian and the equation of time. This is shown in the more complex Figure 10. Not surprisingly, the charts shown in Figures 8-10 all show the same results.

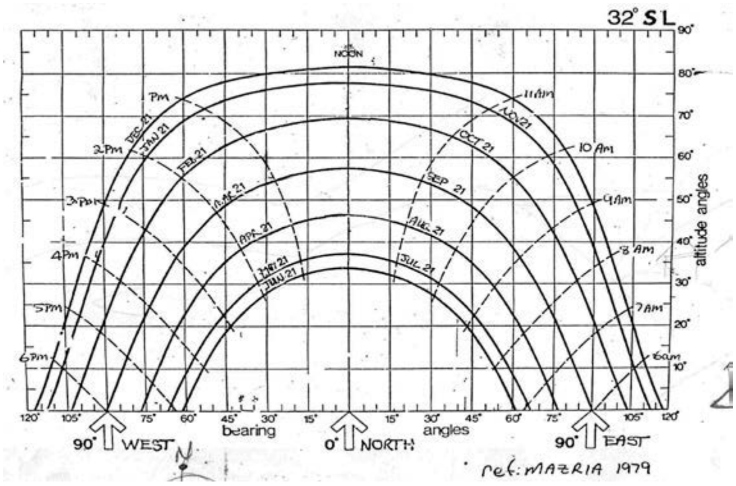


Figure 9: Sun chart (Mazria, 1979).

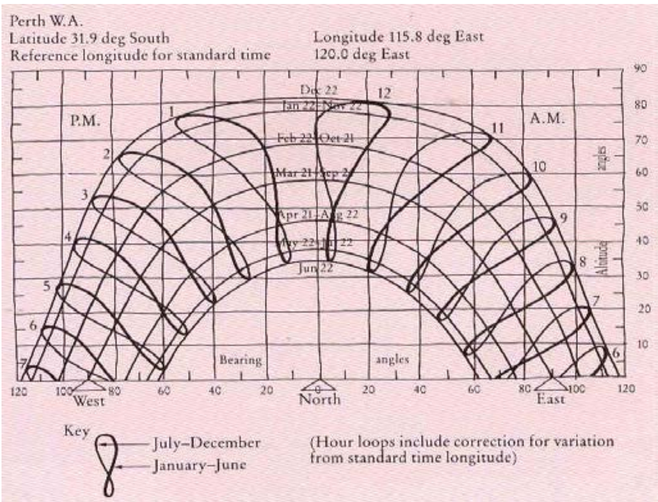


Figure 10: Sun chart (Ballinger et al., 1992).

Most people are surprised that the sun only rises east and sets west twice a year at the equinox (21 March and 21 September). During the rest of the year, it rises and sets off the cardinals up to 27° at the solstice (21 June and 21 December).

Major positions on the sun angle calendar are the noon altitude angles for:

- Equinox noon altitude = 90° – latitude 58°
- Summer solstice noon altitude = 90° – (latitude – 23.5°) 81.5°
- Winter solstice noon altitude = 90° – (latitude + 23.5°) 34.5°

These seasonal changes can be effectively utilised in providing passive solar house design for dwellings that will be built on properties subdivided by the surveyor.

5.1 Understanding and Utilising Sun Angles

Surveyors should be aware of the sun angles and climate factors in the locality of their developments. This includes the prevailing breezes that may be positive or negative depending on the season. All of the sun charts shown above are appropriate for 32°S latitude (Taree, NSW), though the time lines in Figure 9 may vary due to the longitude and variance from the central meridian of the time zone.

Combining the temperature chart (Figure 6) and the sun angle charts (Figures 8-10) one can see that the sun angles can be used to effectively control the sun's energy input and exclusion on the northern wall by simply utilising the correct eave width.

5.2 Sunshine on East-West Walls

Phillips (1977) describes how difficult it was to shade the eastern and western walls. Figure 11 shows how the rising and setting sun affects these walls. Protecting the east and west walls from the sun is difficult even with a wide eave. When a building is positioned skew to the cardinal bearings, impact of the rising and setting sun occurs partially on all sides of the building.

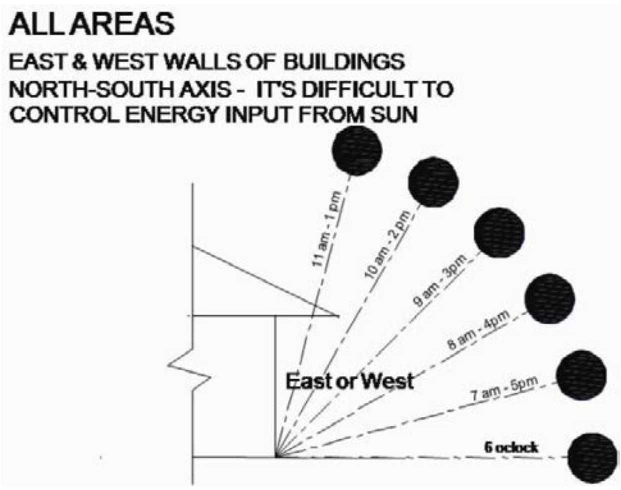


Figure 11: Sun angles for eastern and western walls.

The azimuth angle of the sun at sunrise and 9am on the eastern end of buildings skew and square to the cardinal bearings is shown in plan in Figure 12. The effect on the western wall is similar and it should be recognised that the eastern sun provides the same radiant energy as the western sun. The fact that the air has heated by the afternoon gives the impression that the afternoon sun is hotter.

The azimuth angles show the angle of incidence with the wall, which controls the impact the sun's energy has on the walls and windows of a building. When set square to the cardinal bearing, the important northern wall is virtually shaded solely by its orientation for a significant part of the day in summer while receiving significant solar benefit in winter. These benefits are not available to the walls of a building set skew to the cardinal bearings.

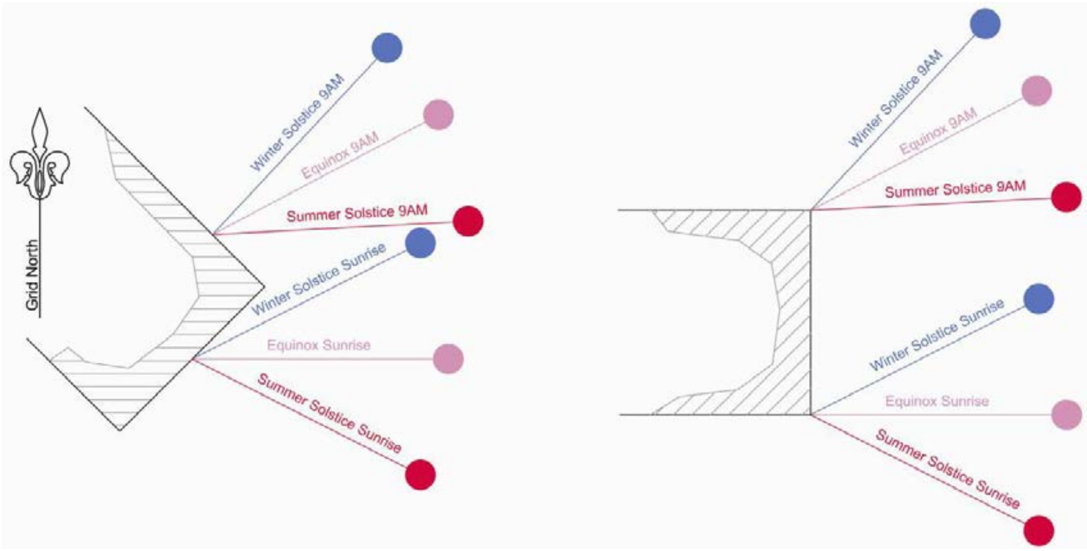


Figure 12: Changing seasonal angle of incidence sun on eastern walls.

Phillips (1977) also describes how seasonal movement of the sun provides the means to effectively control the sun's energy on the northern wall through variation in the eave width. In this way, one can choose which months the sun's energy is to be excluded from the northern wall. Around Taree at 32° S latitude, we have satisfactorily used the equinox sun angle of 57° to define eave lengths on northern walls. Eave widths set to about half the drop to the windowsill will gain sun penetration through northern wall windows starting around equinox in March. Sun penetration increases until the winter solstice and then reduces until exclusion after the spring equinox in September – really quite simple. At higher elevations or latitudes, where it is cooler, earlier sun penetration may be warranted.

6 PASSIVE SOLAR HOUSE DESIGN

6.1 Recent History of Knowledge

Sunshine and Shade in Australasia (1948) was followed up with further research and the publication of *Designing Houses for Australian Climates* (EBS Bulletin No. 6) in 1952 (Drysdale, 1977). This gave a scientific insight into design and construction practices in Australia. The original ideas in this publication were often simple but effective. It seems that each point of the original text has been studied and expanded upon in the ensuing years:

- *Sunshine and Shade in Australasia* (EBS 8) (1948) is a booklet of only 38 pages.
- *Designing Houses for Australian Climates* (EBS 6) (1952) a booklet of 50 pages.
- *Energy Efficient Australian Housing* (1992) is a book of 280 pages.
- *Your Home* (2010) is a manual of 353 pages (Commonwealth of Australia, 2010).
- A Google search of 'passive solar design' brings up 3,820,000 results.

The implications and ideas contained in the original 50-year-old-documents are still being expanded and incorporated into government policies today. For example, many of the underlying principles of the BASIX system used in NSW have a direct input lineage from these documents. There is a mass of information available but perhaps so much that the basics have been forgotten. For those in the market for a new home, or wishing to renovate their existing home, seeking and gathering this information to assist with the design or purchase

decision is strongly advised. Surveyors who understand this information stand a better chance of creating better and more sustainable developments.

The caption to Figure 19 on page 34 of EBS 8 succinctly summarises some passive housing principles: "*Orient to admit cooling breezes, exclude cold winds, admit sunshine in winter, exclude sunshine in summer. Buildings sited with their long axis east-west simplify the shading problem.*" Aligning the long axis east-west promotes the important northern wall, which can seasonally control and exclude energy input from the sun. Eastern and western walls cannot control the sun's energy and need to be protected.

In relation to breezes, EBS 8 provides wind roses that depict the breezes you might expect in most climatic regions of Australia. For example, on the Mid North Coast of NSW, the most prevalent cooling summer breeze is the nor-easter. Less prevalent but also cooling in summer is the southerly-buster, and less prevalent again but scorching in summer is the westerly wind. In the cooler months, the westerly can be quite cold as it comes down off the mountains, the southerly is also cold but the common nor-easter is milder as it comes off the warm ocean. From these few observations, it can be seen that the nor-easter is the breeze to be admitted and the westerlies are to be excluded. Southerly winds remain an each-way bet. Surveyors are often local and will therefore intuitively know this information in regards to their area. When working remotely, the local breezes should be recognised and incorporated into any designs if possible.

6.2 Energy Free from the Sun

At NSW latitudes, the sun's radiation at the earth's surface is equivalent to about 1,100-1,200 watts/m^2 in summer and about 800-1,000 watts/m^2 in winter. These measurements are taken square to the path of radiation and the actual energy received on the wall of a building related to the angle of incidence of the sun's rays.

The original graph from EBS 6 provides the basis for Figure 13 and shows the energy in kW that passes through a 2 m^2 window. Kilowatts, a measure of energy, are foreign to most people. A one-bar radiator, however, is more familiar – it is equivalent to about 1 kW and has been depicted as an energy unit. Similarly, many people have trouble visualising a 2 m^2 window but most are familiar with a double-glass sliding door with an area of about 4 m^2.

Imagine every day in summer turning on two one-bar radiators and running them for four hours in your kitchen (or whatever room has an unprotected double-glass door facing east or west). You would not do it, but that is exactly what the design and window placement of many houses does. Eastern and western windows collect solar radiation and heat (8 kWhr) in summer when it is desired to keep it out, and in winter the same window provides very little energy input (about 3 kWhr). The same double-glass sliding door on the northern wall receives significant energy, equivalent to two one-bar radiators running for over six hours (>13 kWhr) in winter when it is needed. On the other hand, it receives very little energy in summer.

As noted earlier, skew walls cannot be simply protected through the seasonal change in sun angles. One should be wary of real estate agents who espouse the fantastic attributes of the 'north-east aspect of a building'.

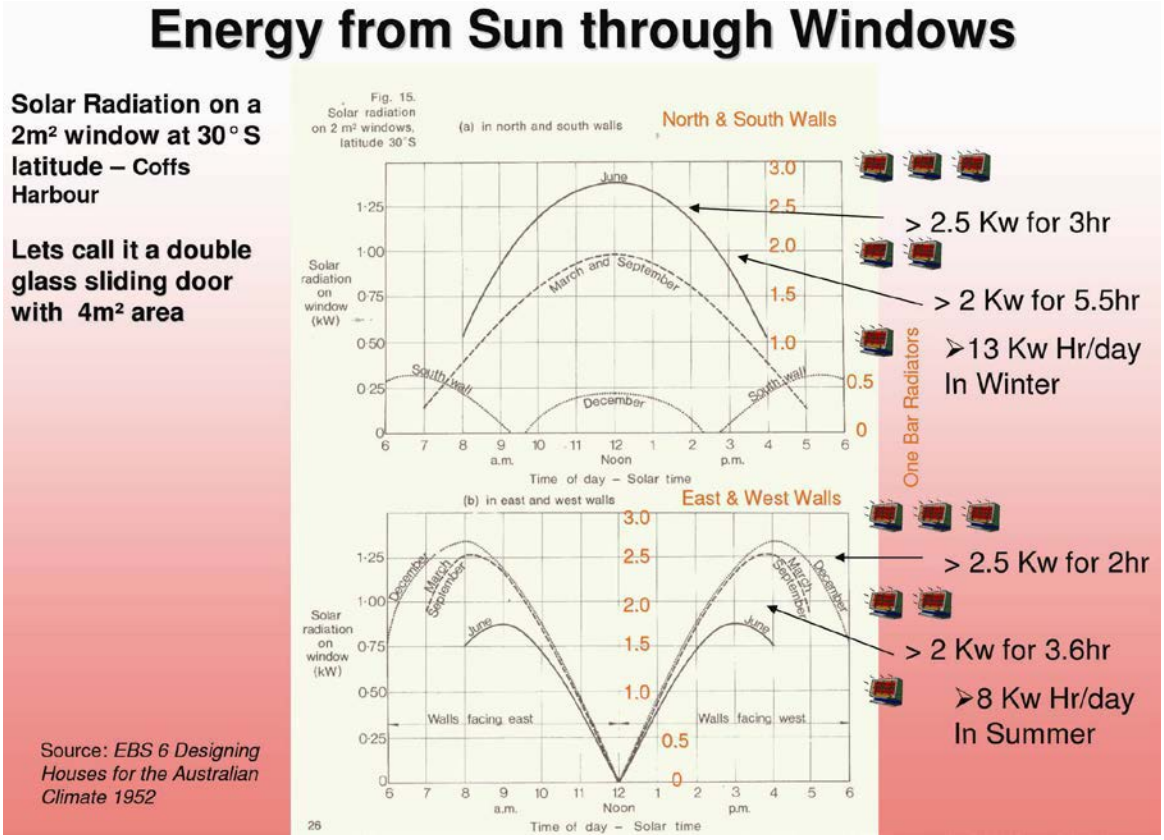


Figure 13: Energy through windows on various walls.

A plethora of information describes what and how to build an energy efficient house. For example, refer to Chapter 4 in Ballinger et al. (1992): "*Thermodynamics and heat flow; density, specific heat and time lag; black body radiation and surface properties; thermal conductance; thermal resistance; thermal transmittance; transparent materials; opaque materials*". However, this is beyond the scope of this paper.

It is sufficient to say that a well-oriented building can be designed to be thermally efficient if well researched and documented. The importance of solar access for the northern wall and protection from solar gain on the eastern and western walls is well documented. This, in turn, relates to energy savings in winter where heating of the dwelling is simply by effectively utilising the sun's radiation and in summer when the energy from the sun is excluded as much as possible.

The majority of the passive solar house design information is aimed at individual houses. The layout of the roads and subdivision of the lots is what combines the individual houses and promotes the requisite solar access to be able to effectively utilise the sun's energy. In NSW, the BASIX system is designed to promote energy efficient buildings. However, it does not effectively consider the surrounding environment.

As surveyors, we must consider holistically the developments we are involved in. This goes well beyond servicing the lots with roads, water sewer and phone. When the subdivision orientation promotes good solar access, energy efficient housing can eventuate and be designed to a certain degree. When the subdivision orientation promotes shading of the neighbour's northern wall, then the passive energy provided by the sun is denied and additional external energy inputs are required. Recent modelling of energy usage and street

orientation indicate that up to 30% more energy may be required on north-south street alignment (A. Gentle, 2011 – email communication).

6.3 Sunshine by Lot Orientation: East-West Road Alignment

Ideally, the houses to be built on all allotments will be able to be constructed with passive solar design principles providing a comfortable, low-energy lifestyle. A shadow diagram of a typical single and double storey house set on an east-west road at the latitude of Canberra is shown in Figure 14.

Figure 14: Shadow diagram for east-west road alignment at the latitude of Canberra.

Clearly, the solar access for the northern walls on the neighbouring allotments is preserved. On the southern side of the road, it is preserved by the road and the building line. On the northern side of the road, it is preserved by rear yards and rear boundary setbacks (which often include sewer and drainage easements). Neighbouring buildings are also protected from the morning and afternoon sun by virtue of the adjoining structures. Only the houses at either end of the street need to cater for the eastern and western sun angles as described in section 5.1. Lots on east-west road alignments have the capacity to build energy efficient buildings with the potential to live a low-energy lifestyle. Solar access is available to all without the need for easements and other restrictions being imposed upon the lots.

6.4 Shading by Lot Orientation: North-South Road Alignment

On north-south road alignments, standard suburban lots are typically not wide enough to provide unfettered solar access for the majority of lots. This is exacerbated when a 2-storey dwelling is erected on the north side. The shadow diagram (Figure 15) shows how a typical single and double storey house in Canberra overshadows the adjoining lots on a north-south road. Clearly, where 2-storey dwellings are prevalent a standard subdivision layout on a north-south road would block solar access on all but the northern most property of the street.

As noted in section 4.2, the greatest energy consumption is for heating of homes. The loss of solar access in this way has a multiplier effect. Because natural heating is not available, the building is cooler and more additional external energy input is required for comfort. A home designed under the BASIX system that is purported to ensure energy-efficient housing in NSW will be cold in winter when subject to the shadowing seen in Figure 15. In addition, it will more than likely be hot in summer as it addresses the street in the traditional manner. Buildings on north-south roads often need higher external energy inputs for comfort.

Figure 15: Shadow diagram for north-south road alignment at the latitude of Canberra.

If a north-south road alignment is unavoidable then consideration should be given to the separation available to the buildings that will eventually be constructed on the properties. The separation required to maintain solar access increases at high latitudes. The two examples shown in Figure 16 are for Campbelltown, a western suburb of Sydney (34°S), and Christchurch, New Zealand (43.5°S). While a building separation of over 5 m is required around Sydney (4.7 m from wall to eave shown), further south in Christchurch a separation of well over 7 m is required to maintain solar access for a neighbouring building on the south side.

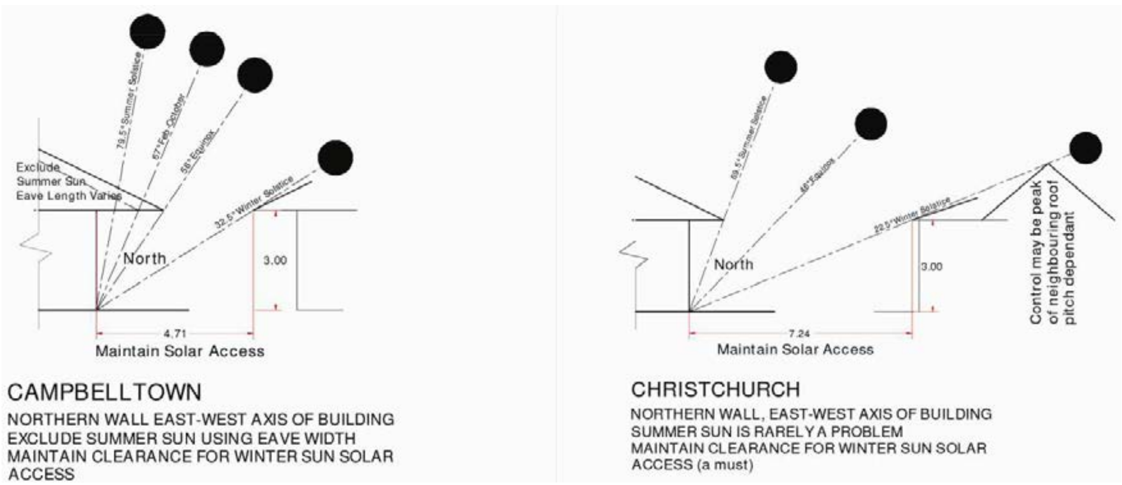


Figure 16: Separation of buildings on north-south aligned roads.

The separation of buildings shown in Figure 16 is based on buildings with heights of 3 m on flat ground; 2-storey buildings will require twice this distance. Sloping ground also has its problems. South-sloping ground requires a greater separation than a north-sloping block. Clearly, the old standard side boundary offsets of 675 mm to the eave and 900 mm to the wall will not protect the neighbouring building from poor orientation and maintain solar access. Easements for solar access are therefore desirable, but may be a complex and limiting burden to place on developers and buyers.

Terrace houses on north-south roads are surely the epitome of this situation. The only solar access comes from the east and west. This often translates to the inhabitants being hot in summer and cold in winter. People in the market for a ‘cute little terrace’ to live in should be thoroughly aware of the street orientation. The ongoing energy costs just to maintain comfort may end up being formidable.

7 OLD BAR: A CASE STUDY IN ORIENTATION

Old Bar is a coastal village on the NSW Mid North Coast within the Greater Taree City Council LGA. It is typical of many coastal villages built behind the dunal system adjacent to a river entrance. The road layout of this village has been elongated north-south and contains a number of long north-south oriented roads. The older areas are typified by grid-pattern streets. Later development of the 1970s and 1980s are curvilinear in pattern.

Figure 17 shows a few of the dwellings that can be found in Sheppard Street, one of the typical north-south street alignments in Old Bar. While Old Bar typically receives a cooling nor-easterly sea breeze in summer, certainly some of the residents feel the heat of the afternoon sun. On the north-south streets, a large number of owners have endeavoured to protect the western wall of their houses with external screens, shutters and the like, presenting an unusual streetscape.

Figure 17: Typical western aspect window treatments.

7.1 Case Study: Old Bar North (Precinct 2B)

A rezoning application (RA) for Old Bar North was lodged with the Greater Taree City Council in October 1998. It included a plan endorsed by the 67 landowners and described, in part, with the following statement: "*With a glance at the proposed road layout you can see that the roads are arranged generally along the north/south and east/west cardinal directions where the higher proportion of roads are aligned east/west. As a result, a majority of lots are provided with the optimum solar alignment. In turn, orienting the houses to take advantage of the winter sun reduces the necessity to provide excessive power to maintain comfort in those dwellings, lowers the consumption of fossil fuels and minimises the ongoing effects on global warming and climate change.*"

Greater Taree City Council planning staff took over the rezoning process and, through the major developer Mirvac Pty Ltd, who had taken up purchase options, hired Mirvac's fully owned subsidiary HPA Planners to prepare the 'master plan' (Figure 18). This plan is now part of Greater Taree City Councils Development Control Plan (DCP) 2010.

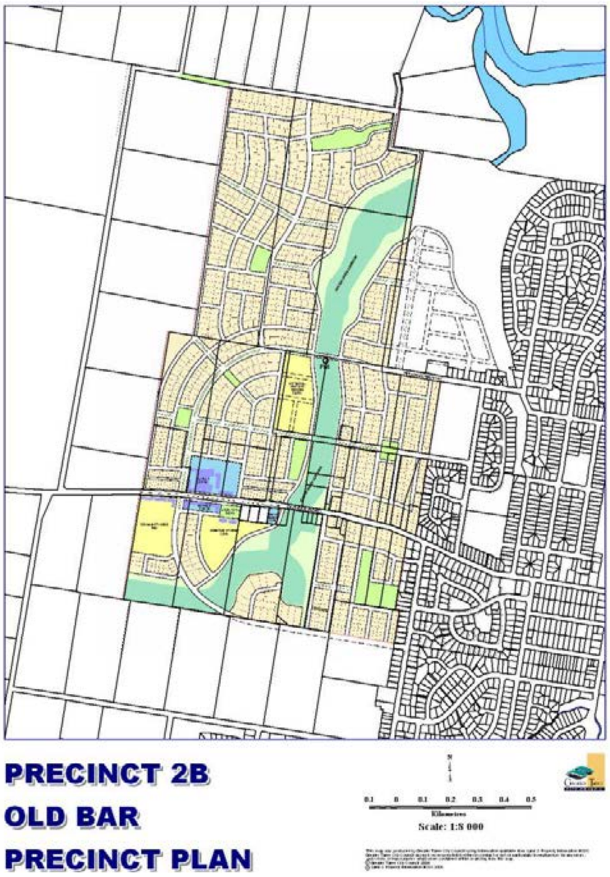


Figure 18: Master plan for Old Bar North (Precinct 2B).

The grid pattern of the plan reflects the typically rectilinear pattern of the older sections of the village to the east. The predominance of east-west roads of the rezoning application plan has been replaced with a predominance of north-south roads. Public submissions raising concerns about the poor orientation were answered by Council stating that the HPA planner had noted "how the north-south roads though unorthodox, allow for sufficient solar access to dwellings."

As shown in this paper, the north-south roads in reality have the opposite effect. The photographs of dwellings in the existing village clearly indicate that these orientations are not optimum at Old Bar and the stated aim of the DCP providing sites where “homes can easily achieve effective solar access” has not been achieved. The resultant is a village expansion that will contain a high percentage of high-energy consuming allotments. As noted earlier, modelling suggests as much as 30% more energy will be required by houses on north-south roads than comparable lots on east-west road alignments.

In order to gauge the effect, allotments on north-south roads have been highlighted on Council’s DCP 2010 master plan (Figure 17). It shows that a significant percentage of proposed lots are likely to be high-energy consuming lots. In this age of increasing energy costs, awareness of ‘greenhouse gases’, concerns about ‘anthropogenic climate change’ and ‘global warming’, this is not a good result. This precinct plan is a long way from the best practice outcome claims in the text of Council’s DCP 2010.

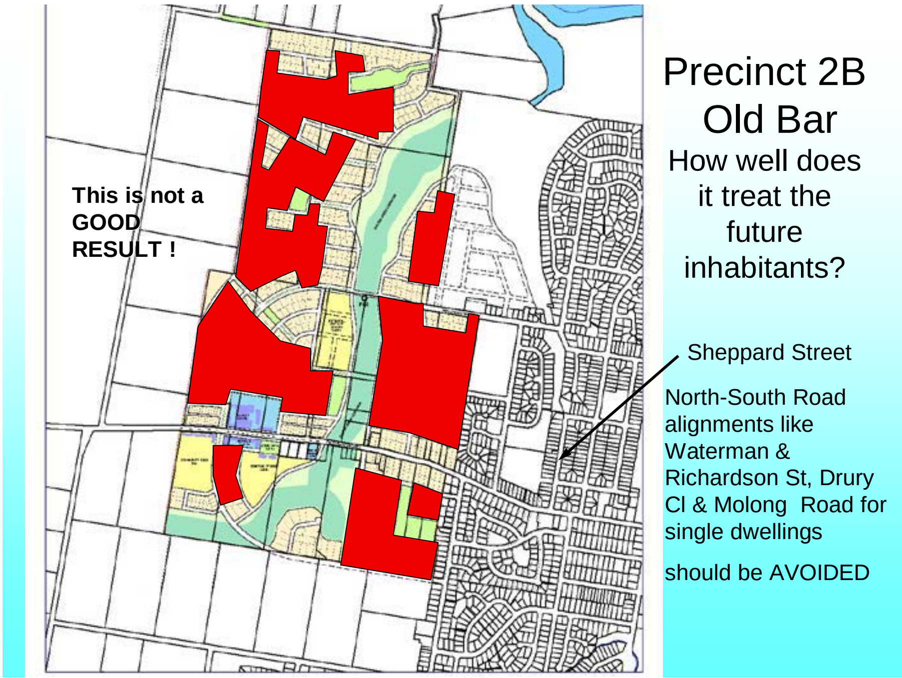


Figure 19: Master plan for Old Bar North (Precinct 2B), highlighting allotments on north-south roads.

Council’s DCP for this precinct requires that future developers ‘justify’ any changes proposed to be made to the layout of the adopted plan. The most likely outcome is that developers will simply avoid confrontation and additional costs, adopt the plan and provide a large proportion of high-energy consuming lots as depicted in Figures 18 & 19.

7.2 Case Study: Old Bar South (Precinct 3)

Rezoning in the adjacent Old Bar South precinct was undertaken at the same time. The rezoning was gazetted without the requirement for a pre-prepared ‘master plan’. Figure 20 shows part of the draft layout plan proposed as the development blueprint. The plan was prepared by a local survey firm, Lidbury Summers & Whiteman of Forster.

It can be seen that:

- There is a pre-dominance of east-west roadways for single lots, and larger wider lots are proposed on north-south roadways to promote/accommodate unit sites.

- The existing land parcels have been recognised, and the plan is prepared to allow for potential discrete development on the separate parcels.
- The existing dwellings have been located and recognised as part of the existing infrastructure, and the lots have been designed to cater for them.

This is a most pleasing result from one of our local surveyors. Consequently, the Old Bar South precinct is likely to have a much lower energy requirement than the corresponding Old Bar North precinct. This is considered to be a far better, more sustainable result.

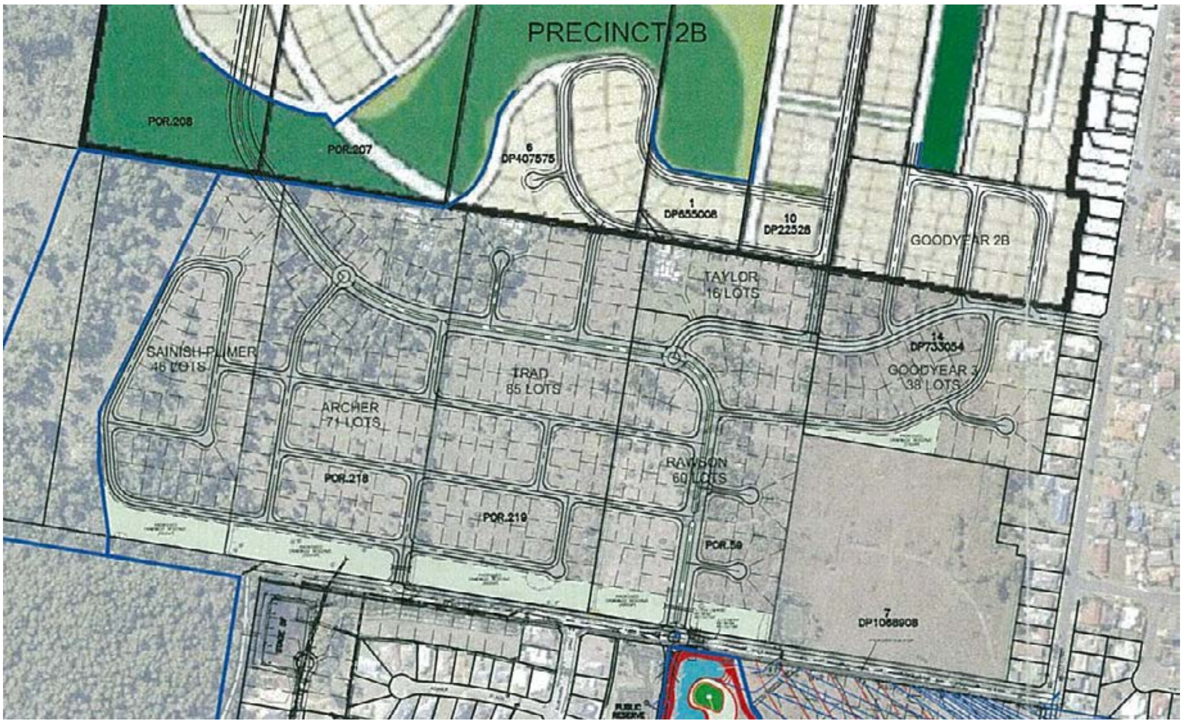


Figure 20: Part of the master plan for Old Bar South (Precinct 3).

8 CONCLUDING REMARKS

This paper has provided a nexus between the orientation of subdivision roads and the principles of passive solar house design. It has provided surveyors with detailed knowledge in order to discuss with land developers the preferred orientation of road layout. The aim is to minimise the energy footprint of future housing estates and provide a practical way in which the surveying profession can contribute towards a sustainable future, both in Australia and well beyond. Examples of development principle plans have been analysed to ascertain how energy consumption may vary as a result of the layout design and orientation.

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Flexible Learning in Vocational Education and Training for Surveying: Approaches, Lessons, and Directions

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ABSTRACT

This paper's objective is to review emerging training delivery methods for surveyors in the Vocational Education and Training (VET) sector. The introduction of flexible learning as a method of training delivery in the VET sector has resulted in a shift in the student patterns at the Illawarra Institute TAFENSW. Two major cohorts have been identified in the flexible delivery mode. The first are former TAFE students wanting to complete previously attempted qualifications, while the second are relatively recent entrants to the industry who are being encouraged by their employers to become qualified. Methods used to manage these two different groups reflect issues relating to flexible learning. The main issues are ones of self-paced learning, mentoring, recognition of prior learning, and authenticity of evidence. Although some of these issues are the same as those found with traditional 'correspondence' courses, there is the added complexity that web-based learning brings. This paper describes approaches taken at the Illawarra Institute, reviews the lessons learnt from our experiences so far, and presents the directions in which we intend to head. Results are based on experiences in training students in the flexible delivery mode for the past three years. This paper will be of interest to those who have students currently enrolled in flexible learning, or considering staff for such a course.

KEYWORDS: *Surveying, training, flexible, web-based, VET.*

1 INTRODUCTION

The objective of this paper is to review emerging flexible training delivery methods for surveying in the Vocational Education and Training (VET) sector. The education of surveyors in Australia has been a point of recent discussion. While much of the discussion revolves around university education of surveyors (e.g. Hannah, 2012), vocational technical training by TAFE has also been identified as has having an important role (Roberts, 2011).

The surveying profession is experiencing a skills shortage with surveyors included on the 2011-2012 New South Wales skill shortage list (Australian Government, 2012). What has become apparent over the last five years is the demand for flexible delivery in the area of vocational surveying training. The industry driver for flexible delivery options has been supported by the Federal Government's creation of the 'Australian Flexible Learning Framework', an organisation that supports e-learning opportunities with funding, tools and standards. In the case of surveying in NSW, the Consulting Surveyors Association deemed this training method of such importance that it provided funds to support the development of e-learning resources. Additionally, the International Federation of Surveyors' (FIG) Professional Education commission has a 'Learning and Teaching Methodology' working group that has as one of its aims to make recommendations on distance learning. This paper

reviews the approaches and presents lessons learnt and future directions from the flexible delivery program at Illawarra TAFENSW.

Reviewing this emerging delivery method is important because its implementation has resulted in shifts in student patterns in the surveying training area. The mix of learners has changed, the difference in delivery methods has influenced content and assessment, and new design and management methods have had to be developed. This paper includes a background to VET and outlines the flexible surveying programs the Illawarra Institute TAFENSW delivers. The survey methods used to review the Illawarra Institute's program are outlined. The results of the review are presented and discussed, with the major points of interest including the identification of different student cohorts, the differences between length of experience and breadth of experience, foundation skills (numeracy and literacy), and issues of evidence authenticity. Future directions and improvements based of the results of the review are also discussed.

2 BACKGROUND

2.1 VET Training in Australia for the Surveying and Spatial Industry

VET training in Australia uses training packages as their framework. These training packages are nationally endorsed standards and qualifications that are used to define assessment requirements. Training packages are developed by industry and then delivered by Registered Training Organisations (RTOs). Although training packages include descriptions of the competencies, the training and assessment strategies are developed by the RTOs that deliver and assess the qualifications. The training packages include a description of the knowledge and skills that must be demonstrated, the units of competency required for the qualifications, employability skills, and assessment guidelines.

The relevant training package for the surveying industry is Property Services (CPP07). The Construction and Property Services Industry Skills Council is responsible for its development. The Council has a steering committee for the Spatial Information Services sector that provides advice about qualifications related to surveying. The official national register of information on the training packages, qualifications, courses, units, and the RTOs is http://training.gov.au/. This VET database is a joint initiative of Australian State and Territory Governments.

2.2 Surveying and Spatial Qualifications

The following qualifications from the Property Services training package are relevant to the surveying and spatial information industry:

- Certificate II in Surveying and Spatial Information Services
- Certificate III in Surveying and Spatial Information Services
- Certificate IV in Spatial Information Services
- Certificate IV in Surveying
- Diploma of Spatial Information Services
- Diploma of Surveying
- Advanced Diploma of Spatial Information Services
- Advanced Diploma of Surveying

The Illawarra Institute currently runs the following three qualifications:
- Certificate III in Surveying and Spatial Information Services
- Certificate IV in Surveying
- Diploma of Surveying

At present only the Certificate III and Certificate IV are offered in the flexible delivery mode, with the Certificate IV flexible offering suspended for Semester 1, 2013. In addition to qualifications delivered as part of the training package, the Illawarra Institute also delivers two graduate qualifications. These are the Vocational Graduate Certificate in Applied Geographic Information Science and the Vocational Graduate Diploma in Applied Geographic Information Science. These two graduate courses are also delivered by flexible methods, but will not be discussed in this paper. The Certificate III in Surveying and Spatial Information Services course currently has the largest student numbers, and results from its delivery will form the majority of the discussion in this paper.

2.3 Qualification Levels

In Australia, there is a national system of qualifications called the Australian Qualification Framework (AQF). Each qualification is allocated an AQF level. For example, the Certificate IV in Surveying is rated at AQF 4, while the Vocational Graduate Certificate is rated at AQF 8. This framework regulates qualifications by describing learning outcomes for each level. The outcomes include standards and expectations for knowledge, skills, application and volume of learning (time taken to complete the qualification).

For levels 3-5, which cover the surveying qualifications delivered at the Illawarra Institute, the following outcomes are described:
- Knowledge: Factual, technical, procedural, theoretical, specialist knowledge, in specific or broad fields of work.
- Skills: Cognitive, creative, technical and communication skills in methods, tools, materials, problem solving and transmitting information.
- Application: Autonomy, judgement and responsibility.

Employability skills are also incorporated into the training packages and include broad advice on industry expectations at each qualification level – and for each unit of competency. These are more industry specific than AQF descriptions. Themes incorporated into the employability skills include communication, teamwork, problem solving, initiative and enterprise, planning and organising, self-management, learning and technology.

2.4 Qualification Design

Each qualification is made up of the qualification requirements, a list of units of competency, and an employability skills qualification summary. The qualification requirements contain the ‘packaging rules’ for the qualification, which state the number and type of core and elective units required to complete the qualification.

Each unit of competency is broken into sections that must be understood to ensure that teaching and assessment strategies developed by the RTO meet assessment standards. These competency unit sections include:
- The unit descriptor.
- Elements and performance criteria.

- Evidence guide.
- Required skills and knowledge.
- Range statements.
- Employability skills and information.

2.5 Illawarra Institute Approach to Flexible Learning

What is generally meant by the term ‘flexible’ today is a range of delivery methods that might include distance learning, e-learning, recognition of prior learning, on-the-job training, skills tests and portfolios. At the Illawarra Institute, each qualification incorporates different flexible learning elements based on expected student cohorts and industry needs. For all flexible courses, students must be working full time in the surveying industry. This requirement means that workplace experience is gained and mentoring is possible. The requirement for a minimum of six months fulltime work in the surveying industry, with a preference for one year, is expected to allow the learner to reflect on their experiences as part of the training and assessment process. The structure of the units and the assessment required depends on the focus of the unit in question. For example, field surveying units rely on work-based experiences, while computationally based units are more likely to rely on skills testing. The current pathway for the learner is to begin at the Cert III, which is mostly assessment only, continue into the Cert IV, which is a mix of assessment, training, and recognition of prior learning (RPL). The next qualification is the Diploma, which is still in the design phase. At the time of writing, both the 2013 Cert IV and Diploma flexible courses are suspended pending the outcome of the ongoing TAFENSW budget review process.

3 METHOD

The primary method used to review the flexible training program is based on semi-structured interviews with students, teachers and employers. For the period under consideration here (2010 to mid 2012), 53 students enrolled in the course. Student details, such as current position and years of experience, were collated from the surveys conducted as part of the course application process. Opportunistic feedback was used in addition to 12 targeted interviews. The completion rates of each unit were assessed to ascertain areas for improvement and review. The qualification completion rates of students were analysed in an attempt to identify issues of delivery and content. A group of six students was interviewed from a group who indicated they were not intending to complete the course in order to collect targeted information about their experiences with the training. Four teachers were interviewed to provide their feedback on the course, and five employers were contacted to ask specific questions related to the course. The review themes were based on e-learning research methods (Misko et al., 2004). Themes used during interviews included delivery, assessment, quality, and improving arrangements. The review themes were discussed in terms of key features of success, continuing challenges, and suggestions for improvements.

4 RESULTS AND DISCUSSION

4.1 Results Overview

The successes of the flexible training program will not be dealt with in detail. They were generally as expected and are not a main contributor when identifying areas of improvements

for the course. In summary, the identified successes were access to training, opportunities for promotion, and the validation of experience, skills and knowledge via formal qualifications.

The main challenges and improvements that were identified from the review included understanding the cohort groups and their varying requirements, the gaps in foundation skills, the authenticity of evidence and the role of mentoring. Each of these issues is discussed in more detail in the following sections.

4.2 Who Wants Flexible Training?

Students in the flexible program ranged from workers with over 25 years experience working in the industry to those that had recently left school and had been working for less than one year. The reasons given for lack of qualifications by surveyors with considerable experience were also varied and included:

- Starting formal training but not completing a qualification.
- Starting work without qualifications and relying on experience for future positions.
- Difficulties in accessing training with work pressures.
- Difficulties in accessing training due to remote location.

The reasons why flexible training was sought included:

- To apply for a position in a different organisation.
- To move to a higher-level position.
- Address identified missing skills and knowledge in specific areas.
- Wanting staff to be qualified to prove commitment to quality.
- Wanting staff to be qualified to be eligible for tenders.
- Wanting to improve staff morale and provide training opportunities.
- Expected minimised disruption to earnings.

Students, and enquiries for the course, came from both within and outside NSW. Employers included multinational construction firms, mining companies, government departments, local councils and private surveying companies. The need to formalise experience was a clear driver for companies that worked on large infrastructure projects. This appeared to coincide with the tightening of regulation as part of quality assurance programs, not pressure from the surveying industry.

4.3 Differences Between Surveyors

Given the diversity of student experience and background, it was not surprising that designing a specific course was challenging, and that a flexible course would differ significantly from the full-time course run on campus (where knowledge or skills were not presumed). The challenge was how to identify and match experience to the skills and knowledge required for the qualification. The length of experience indicated the amount of time that the student had been working in the industry, while the breadth of experience indicated the amount of exposure to the different aspects of the surveying industry. Some flexible learners had a broad range of experiences within the surveying industry, while others had only worked in a single sub-discipline area. Generally, a greater breadth of experience translated into a student having more skills and knowledge in a greater range of units compared with those with fewer experiences to drawn on. The amount of experience students had mostly reflected their years in the industry, and sometimes their position in the organisation.

The problematic student was the one with experience in terms of length in the industry but not in terms of breadth. This situation seemed to be most prevalent when a student had worked in only one position in the same organisation, doing only a narrow group of survey activities repeatedly. In these cases, students were generally well skilled in selected instruments, and selected survey tasks, but had limited underpinning knowledge of surveying concepts.

A student's industry experiences and their level of experience influenced their approach to flexible learning. This in turn affected our ability to deliver relevant and efficient training. A more experienced surveyor often had greater expectations in regards to a quick completion of the course, while a less experienced surveyor was more likely to be unsure of learning expectations.

Two main cohorts emerged from the review: (1) experienced but not qualified and (2) recent entrants to the industry. The first group was likely to have considerable years of experience, mostly in senior roles. This group was identified as needing a skills gap analysis, and was keen to explore opportunities for RPL. The second group relied heavily on mentoring and needed more support with the self-paced learning process, in particular in the areas of maths and Computer-Aided Design (CAD). A more detailed course entry form has the potential to improve student information data. Capturing both experiences and experience before the commencement of study could help to improve the identification of students that might require extra support, skills gap analysis, mentoring, extra experiences or fast-track options.

4.4 Numeracy and Literacy

Maths was identified as a key concern for both the students and teachers. Students started courses with varying levels of maths, sometimes lacking basic learning skills. The problem with maths reflects the path that some students took into the surveying industry. The role of maths was discussed amongst the teachers with reference back to the qualification's employability skills. This resulted in some maths concepts being moved into the higher Cert IV qualification to reflect the learning outcomes. Flexible learners that did not complete past year 10 would need supplementary studies to meet learning outcomes for the Cert IV and Diploma qualifications.

Literacy was identified as another key concern. Many students selected surveying as an area to work because it does not focus on writing skills. Most flexible students are able to reach the Cert III level based on their current work experience. However, analysis revealed that there would be a problem moving some of the students into Cert IV and the Diploma without extra support as higher levels of literacy are expected for these qualifications.

4.5 CAD

Computer-Aided Design (CAD) was also identified as an area of weakness for some students. Analysis indicated that this in part was due to some students being mostly field based with limited access to office work. Possible solutions to improve this situation included a redesign of self-paced learning resources and increased mentoring in office-based activities. The issue of CAD experience raised questions about the future role of the surveyor. Some students noted that they visited the office rarely, using a laptop and wireless connection in the work truck to send results and download data files. The question then needs to go back to industry, i.e. how important are CAD skills for a surveyor? Is it a matter of which qualification level is required? Maybe CAD is not essential for the Cert III, but expected at levels higher than this?

Is it just a reflection of the different company structure and surveying activities? Is this a reflection of technology?

4.6 Changes in Work Practice

The surveying industry has a history of changing work methods based on the emergence of new technologies, and this brings interesting problems to education and training (Frank, 2008). As new work practices emerge, older ones are dropped. Deciding when to drop the older equipment and methods requires careful consideration as generalisation across the industry cannot be made. Calculators are a good example. Many surveyors do not take a calculator in the field as some instruments have powerful calculating capabilities. So when assessing a student's fieldwork practices, should the use of the calculator be required? The use of an automatic level is another example. In some cases, mentors have had to run special exercises to introduce a student to the automatic level. The issue is easy when face-to-face learning is employed as this type of level is used to introduce levelling concepts. However, it is not easy to decide when assessment is based on the student's work experience. This is another question for industry to answer. Does industry expect knowledge of the automatic level as standard knowledge for a Cert III graduate? The answer could depend on whom you ask in industry. The development of a 'surveying body of knowledge' by the American Congress on Surveying and Mapping in conjunction with FIG and the National Society of Professional Surveyors' (USA) national technician certification process may provide useful guidelines in how to move forward in this area (e.g. Greenfield, 2012).

4.7 Authenticity of Evidence

Authenticity of evidence concerns all distance educators who do not 'see' the student. The units of competency developed by industry for surveying are largely open for interpretation and are considered by some teachers to be vague, thereby making assessment design difficult. Students also generally lack the ability to interpret unit requirements, usually using the title of unit to determine its meaning. This problem with unit interpretation sets up an expectation of RPL without full comprehension of the underlying skills and knowledge that make up that unit. Suggestions for improving authenticity of evidence include the development of detailed assessment guides, video-based assessment, assessment days and workplace visits using evidence checklists.

4.8 Role of the Mentor

The review found that students benefited when mentors were genuinely engaged in the process. This was particularly true of students who were relatively new to the industry. In these cases, mentors were able to give advice, pass on experience and organise internal training sessions. Mentors were sometimes unsure of their role and unfamiliar with the qualification structure. This suggests that mentors need to be engaged earlier in the process and provided with more supporting information to help make their involvement effective. In some cases, the identification of a mentor was difficult if a student was working at a senior level. In these cases, the mentoring role was more likely to involve the verification of experience, skills and knowledge, rather than learning support.

5 CONCLUDING REMARKS

This paper has presented a review of flexible training delivery for training in surveying. Through a review of the program at the Illawarra Institute of TAFE, successes and areas for improvement have been identified. Recommended is the development of streams of assessment to match skill and experience levels to help increase completion rates and, where appropriate, reduce course completion times.

The review has also provided a view of technical surveyors working in this industry. The experience and skill levels of people working in this industry are varied – and this is reflected in the difficulties faced when designing distance-learning programs. The results also highlight the changing nature of the industry and the role that technology is playing in changing work practices. The role of mentoring was identified as an important component of the training program, and one that should be strengthened to help improve the student experience and completion rates.

ACKNOWLEDGEMENTS

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The Tomago to Stroud 132 kV Transmission Line: A Surveying Mixed Bag

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ABSTRACT

The 66 km Tomago to Stroud 132 kV transmission line project undertaken by TransGrid was a good opportunity for its survey group to showcase their spatial skills and knowledge and apply them to many facets of the project. Using numerous sources of survey and spatial data, the survey group delivered a homogenous, quality product that provided stakeholders with the information they needed whilst staying within critical time and cost constraints. The TransGrid survey group analysed and overlayed spatial data from many sources such as Airborne Laser Scanning (ALS), the Digital Cadastral Database (DCDB), aerial photography, SCIMS and field surveys to provide relevant accurate information to designers, land economists, land valuers and project managers. Based on this information a design was handed back, and the TransGrid survey group created route plans and set out the proposed structures, in effect 'testing' the design. This was an iterative process that refined the design to the 'for construction' stage. To protect this piece of infrastructure and to ensure the project progressed in a timely manner, easements had to be surveyed and created prior to construction. The survey of easements proved to be both interesting and testing from a boundary definition perspective with the new transmission line crossing through many old portions of limited title and definition. The TransGrid survey group took a 'whole of project' approach when tasked with the planning, investigation and delivery of spatial data services. In doing so, efficiencies in time and cost were achieved. Risks were mitigated through careful planning and understanding the internal clients' needs and requirements. The project was an excellent example of how diverse the surveying and spatial information profession is and highlighted the ever-evolving role of surveyors as the custodians of spatially accurate data and the increasing synergies with other professions reliant on this information. The TransGrid survey group exceeded client expectations by providing the expertise to deliver the project in a timely, cost-effective manner while improving survey infrastructure and cadastral definition in the project area.

KEYWORDS: *TransGrid, Airborne Laser Scanning, easements, infrastructure, boundary definition.*

1 INTRODUCTION

TransGrid has a long history in the power business (TransGrid, 2013). Since 1950, as part of the Electricity Commission, it has transmitted electricity throughout the State to give the people of New South Wales (NSW) a reliable, world-class power system. The Electricity Commission went on to become Pacific Power. Under Pacific Power, transmission and specialist engineering services were performed until 30 June 1994. On 1 July 1994, PacificGrid was formed as a wholly owned subsidiary of Pacific Power.

TransGrid, as we are now known, was formed as a Statutory Authority on 1 February 1995, under the Electricity Transmission Authority Act 1994. On 7 May 1996, under the Electricity Supply Act 1995, TransGrid developed and operated the State's electricity market and played a key role in facilitating the transition to the National Electricity Market (NEM). This role was handed over to the National Electricity Market Management Company (NEMMCO) when the National Electricity Market commenced on 12 December 1998. After further industry reform, TransGrid became a corporatised entity under the State Owned Corporations Act 1989 on 14 December 1998.

Demand for electricity on the NSW Mid North Coast has been steadily increasing for many years due to population growth and industry expansion. Analysis of the electricity transmission network has shown that, coupled with limitations in the capacity of the existing network (due to thermal overloads), the reliability and quality of electricity supply from TransGrid's network will be reduced as the demand continues to increase.

In order to maintain a reliable electricity supply to the Lower Mid North Coast, TransGrid, and electricity distributors AusGrid (formerly Energy Australia) and Essential Energy (formerly Country Energy), have proposed to increase the region's existing network capacity through a series of co-ordinated reinforcement projects.

2 PROJECT BRIEF

For TransGrid, the proposal involved the establishment of a 66 km long 132 kV transmission line between Tomago and Stroud (Figure 1). The new transmission line will run parallel to an existing 66 kV line where possible, with some deviations occurring where terrain and property constraints dictate. This project will serve to improve supply reliability across the Lower Mid North Coast network and provide support for other projects being completed by the distributors such as the Brandy Hill substation.

The need for the supply reinforcement, and the proposed network solution, underwent review and consultation within the National Electricity Market (through a 'Request For Proposals' process), to identify any feasible alternative and non-network solutions. No feasible alternative solutions have been proposed. The proposed transmission line reinforcement is considered the best long-term solution to meet the current and forecast supply demands on the Lower Mid North Coast.

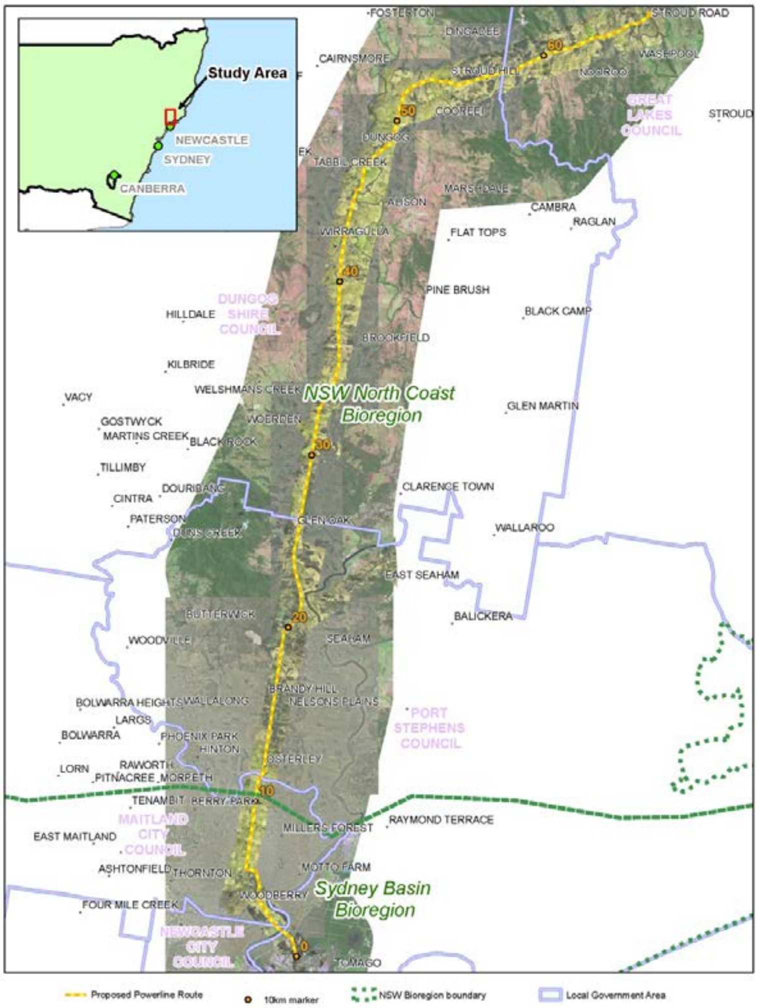

Figure 1: Project area.

3 SURVEY ELEMENTS

The TransGrid survey group were asked to provide the project team with the spatial products and services necessary to progress the project from the feasibility stage to completion. Many facets of the surveying and spatial information profession were utilised to deliver accurate data in a timely and cost-efficient manner. These products and services included:

- Airborne Laser Scanning (ALS)
- Aerial imagery
- GPS control survey
- Cadastral surveying
- Constraint mapping
- Route selection
- Production of route plans
- Manipulation of spatial data
- Converting between different data formats
- Structure setout
- Internal consultation
- Public consultation

3.1 Airborne Laser Scanning and Aerial Photography

Based on the results of the Environmental Assessment and community consultation, a final corridor was chosen as the preferred option. In order to aid centreline location, concept design and final design, a survey accurate 3D model was required. The model was to contain sufficient data to aid identification of ground constraints such as buildings, creeks, roads and railways as well as non-ground constraints such as vegetation and existing powerlines. Due to the length of the project and its time constraints, it was not feasible to create a 3D model by traditional survey methods. Based on past project experiences, it was decided that Aerial Laser Scanning (ALS) was the best-suited technology and method for the acquisition of the ground and non-ground data along with aerial photography.

TransGrid developed comprehensive ALS and aerial photography specifications to ensure that the data received by contractors was of a quality and format that would satisfy the end users' requirements as well as ensure consistency with previously acquired data. A shape file was provided to Terranean Mapping Technologies showing the proposed corridor as well as a buffer where data was to be captured but not processed. This was contingency planning for deviations that invariably happen in these types of projects. Terranean provided a thinned point cloud, which was classified into ground and non-ground ALS layers using specific filtering routines and delivered in a format suitable for import into PLS-CADD transmission line design software.

The ground data was triangulated to create a Digital Terrain Model (DTM). This model was verified by ground survey of well-defined points such as edges of roads and fencing. The 3D data was further verified by checking the ground model against actual ground heights obtained during the setout stage of the project. Figure 2 shows a frequency histogram of the differences in height measured between the ALS model and those obtained by the GPS survey during setout. It is expected that the 'bell-shaped curve' be centred about zero, however in this case it is centred about +0.19 m. Some argue that the pegs were not 'flush' and sticking out of the ground by 0.19 m, but the offset is actually due to the difference between locally derived Australian Height Datum (AHD71, see Roelse et al., 1971) values and those used by the ALS flight.

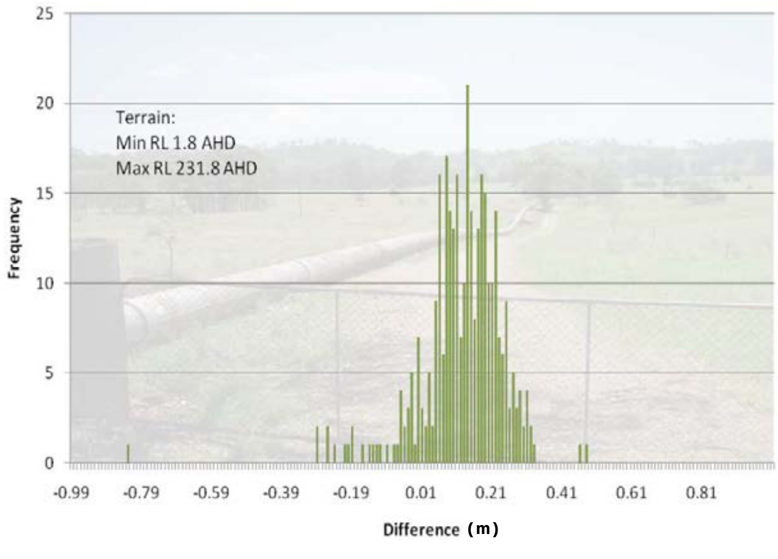

Figure 2: Frequency histogram of differences between reduced levels (RLs) from the GPS survey and ALS.

The aerial photography was captured at the same time as the ALS. The images were ortho-rectified and geo-referenced to enable the digitalisation and mapping of features such as roads, railways, buildings and watercourses. The aerial photography was then imported as an image overlay ECW in PLS-CADD along with the mapping delivered as a 3D DXF file. This allowed the generation of a photo-realistic 3D model as a base layer for the transmission line design (Figure 3). It also had the added benefit of providing instant conceptualisation of the proposed design for relevant stakeholders.

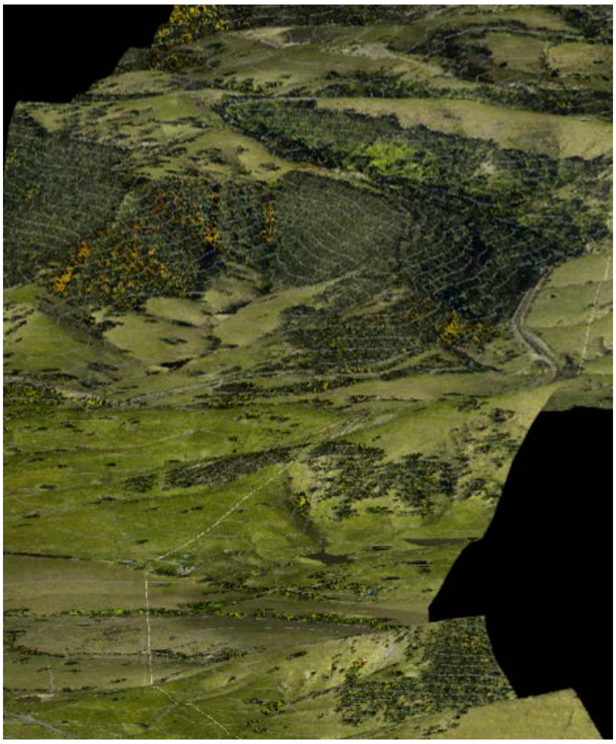

Figure 3: 3D view within PLS-CADD.

3.2 Control Survey

Once the transmission line corridor was locked in, it was time to plan how the surveys to follow would be controlled. A review of SCIMS (LPI, 2013a) revealed that sufficient control for Real Time Kinematic (RTK) based survey tasks (e.g. easement and setout surveys) was not available throughout the length of the proposed line. At that point in time (January 2010), CORSnet-NSW (Janssen et al., 2011) did not cover the area of interest and as such was not an option. In fact, the implementation of the CORSnet-NSW network seemed to follow us around the state, usually with a CORS being installed about four weeks after we had finished a project! It was decided that the fastest and most relatively accurate method of establishing a control network over the 66 km project area would be a static GPS control survey (Figure 4). The control survey tied non-established marks to geodetic stations of higher class and order as well as tied into newly placed permanent marks at locations suitable for RTK base stations (Figure 5).

The control survey was undertaken using the principles of the ICSM guidelines set out in the Standards and Practices for Control Surveys (SP1) document (ICSM, 2007). The method of survey was rapid static, post-processed GPS observations using four simultaneous units. This meant that each session was a geometrically braced quad. Over a period of two weeks of

fieldwork, 36 marks were surveyed, including seven new marks that were placed during the survey in accordance with Surveyor General's Direction No. 1 (LPI, 2009).

Figure 4: Big sky country – the Tomago-Stroud project had an abundance of 'sky', making GPS extremely effective.

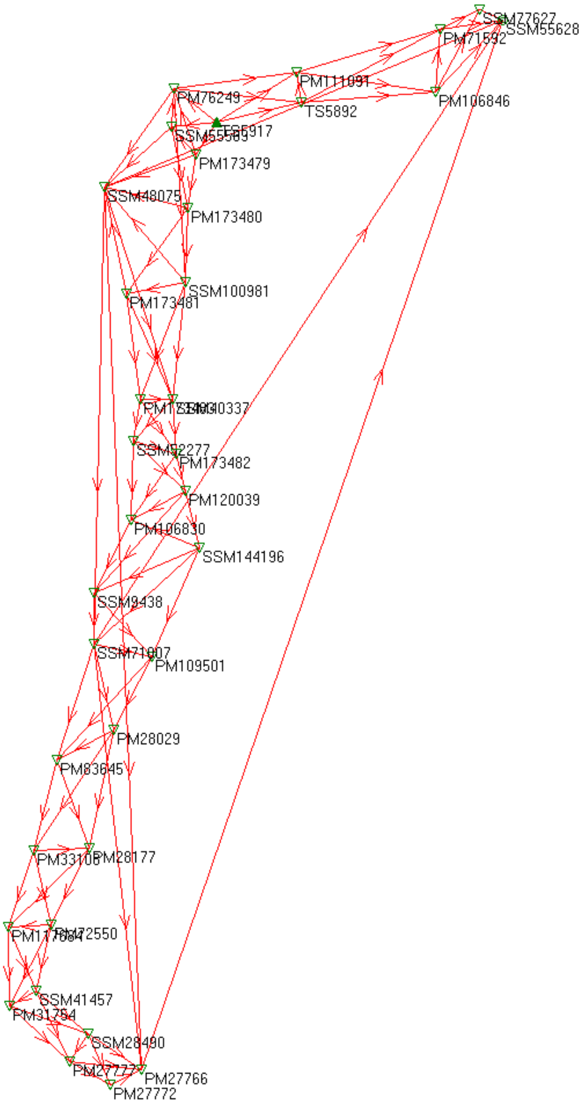

Figure 5: Static GPS control network comprising a system of braced quadrilaterals from Tomago to Stroud Road.

In addition to TransGrid's processing, the baseline data was also sent to Land and Property Information (LPI) for processing, adjustment and upload to SCIMS for public use in accordance with Surveyor General's Direction No. 12 (LPI, 2012). The marks previously not established were updated to Class B Order 2, providing the area with a much more robust level of horizontal and vertical control.

3.3 Centreline Alignment Selection

With the control network adjusted and entered into SCIMS, and an approximate location of the centreline known, it was time to lock in the angle locations. Approximate locations were derived using aerial photography and ALS data. These were then staked in the field with RTK to see how it fitted with current occupations and land uses (Figure 6). This gave landowners an opportunity to visualise the proposed location and make comments. In most cases, the angles were tweaked and re-measured in a seemingly ongoing iterative process.

Figure 6: Needle in the haystack – a proposed angle location.

At this stage, it was important to start considering impacts on the cadastre. In some instances the boundaries dictated where the centreline was to be located due to various reasons such as landowner requests or avoiding certain holdings altogether (e.g. national parks, state forest or disgruntled locals). Once the angles were agreed on, the coordinates were entered into PLS-CADD to define the design centreline.

3.4 Cadastral Survey

In the past, TransGrid acquired easements for transmission lines after the line was constructed. This enabled us to use the existing line of poles or towers to define the centreline and a set easement width was taken according to the design voltage (Figure 7). This process had the advantage that if there were any design changes, it had no adverse impacts on the easement.

The current procedure is to aim to acquire the easement before the construction commences. This negates the need for access agreements for construction and ensures all landowners are compensated before their land is affected. It is a far more transparent approach that gets all of the issues onto the table before the project advances to a final stage.

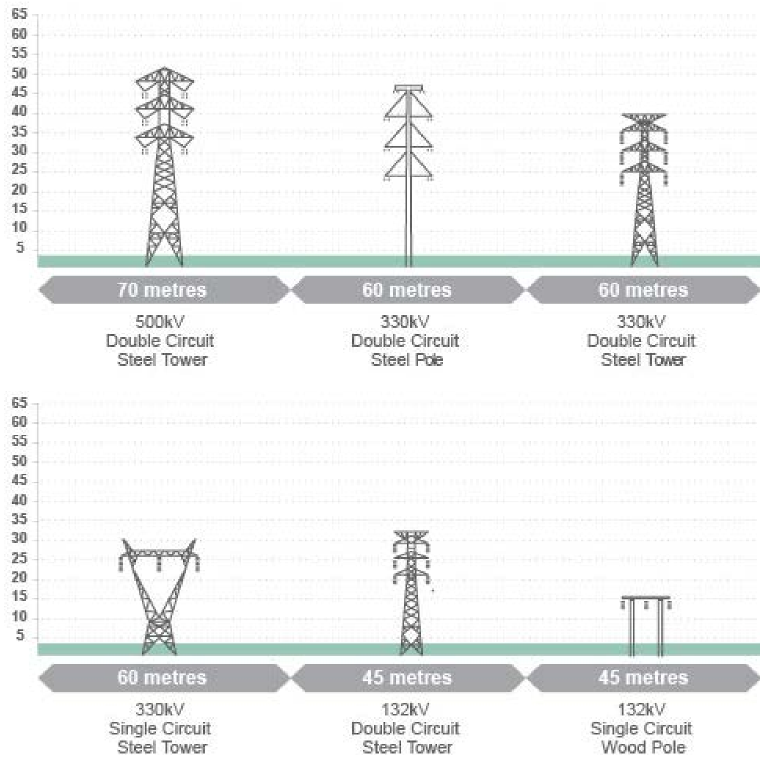

Figure 7: Easement widths as a function of operating voltage.

Easement surveys for TransGrid assets are undertaken using the Registrar General's Directions for Deposited Plans – Easements for electricity supply purposes over an existing line of poles or underground cables (LPI, 2013b).

The Registrar General's Directions state: "*An easement intended to be created for the purpose of the supply of electricity from an electricity supply authority by means of overhead or underground power lines affecting rural or suburban land can be identified by centreline traverse. The centreline should be defined by survey, however, a compiled plan will be accepted provided it complies with the requirements set out below.*

The easement may be created by:

- *A dealing registered under the Real Property Act 1900 based on either:*
    - *a plan of survey or compilation registered as a deposited plan, or*
    - *a compiled plan annexed to the dealing.*
- *A section 88B instrument lodged for registration with a new deposited plan, or*
- *A deed registered in the General Registry of Deeds (Old System) based on either:*
    - *a plan of survey or compilation registered as a deposited plan, or*
    - *a compiled plan annexed to the deed.*"

For this project, full plans of survey were needed covering the entire proposed line. Preparing easement plans by centreline traverse negates the marking of the edges of the easement as well as showing bearings and distances on the plan around the easement site. Cuts are shown along intersecting boundaries to the centreline and conversely along the centreline to cutting boundaries (Figures 8 & 9). This approach has the great advantage of increasing plan readability without adverse effects on cadastral or easement definition.

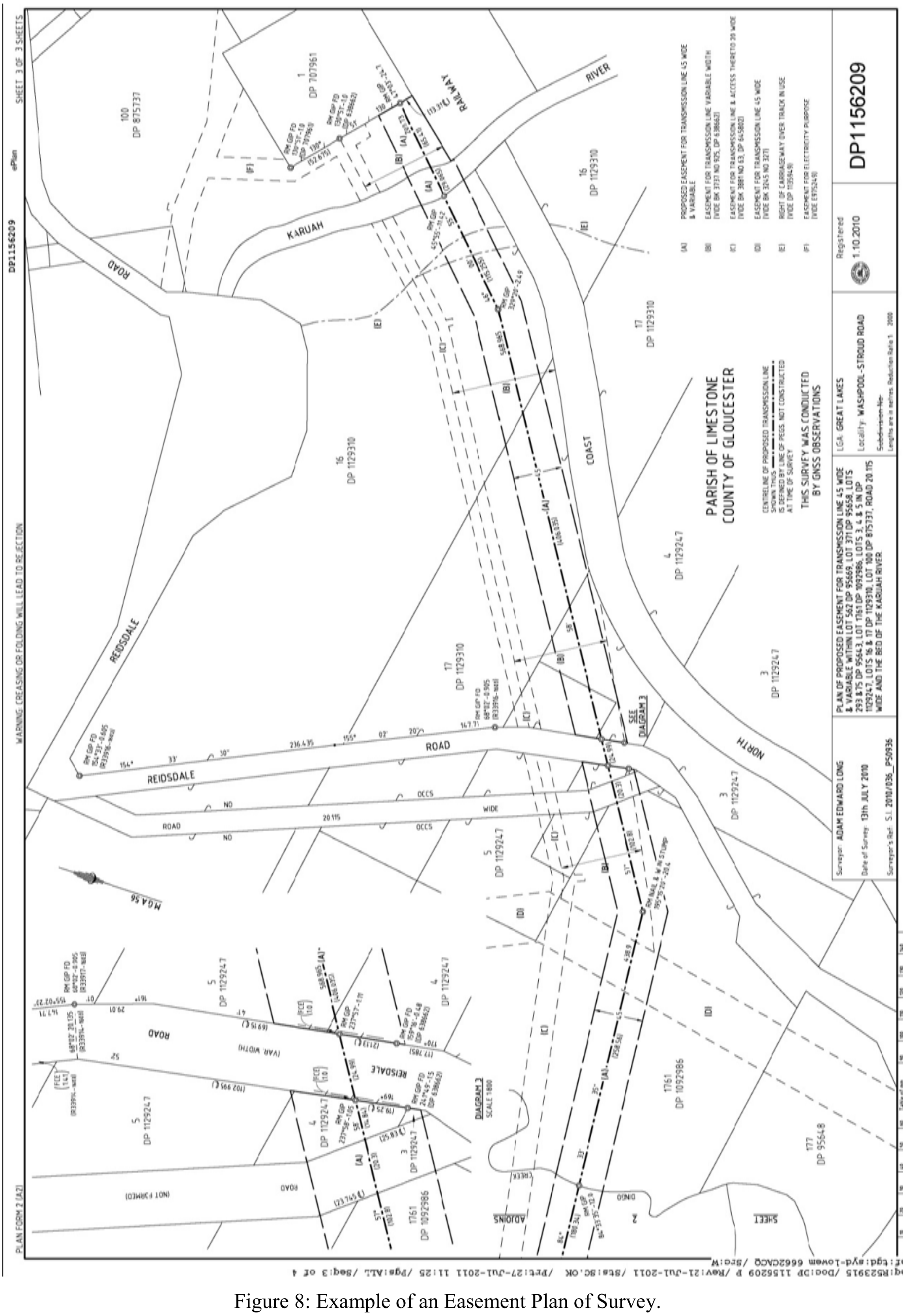

Figure 8: Example of an Easement Plan of Survey.

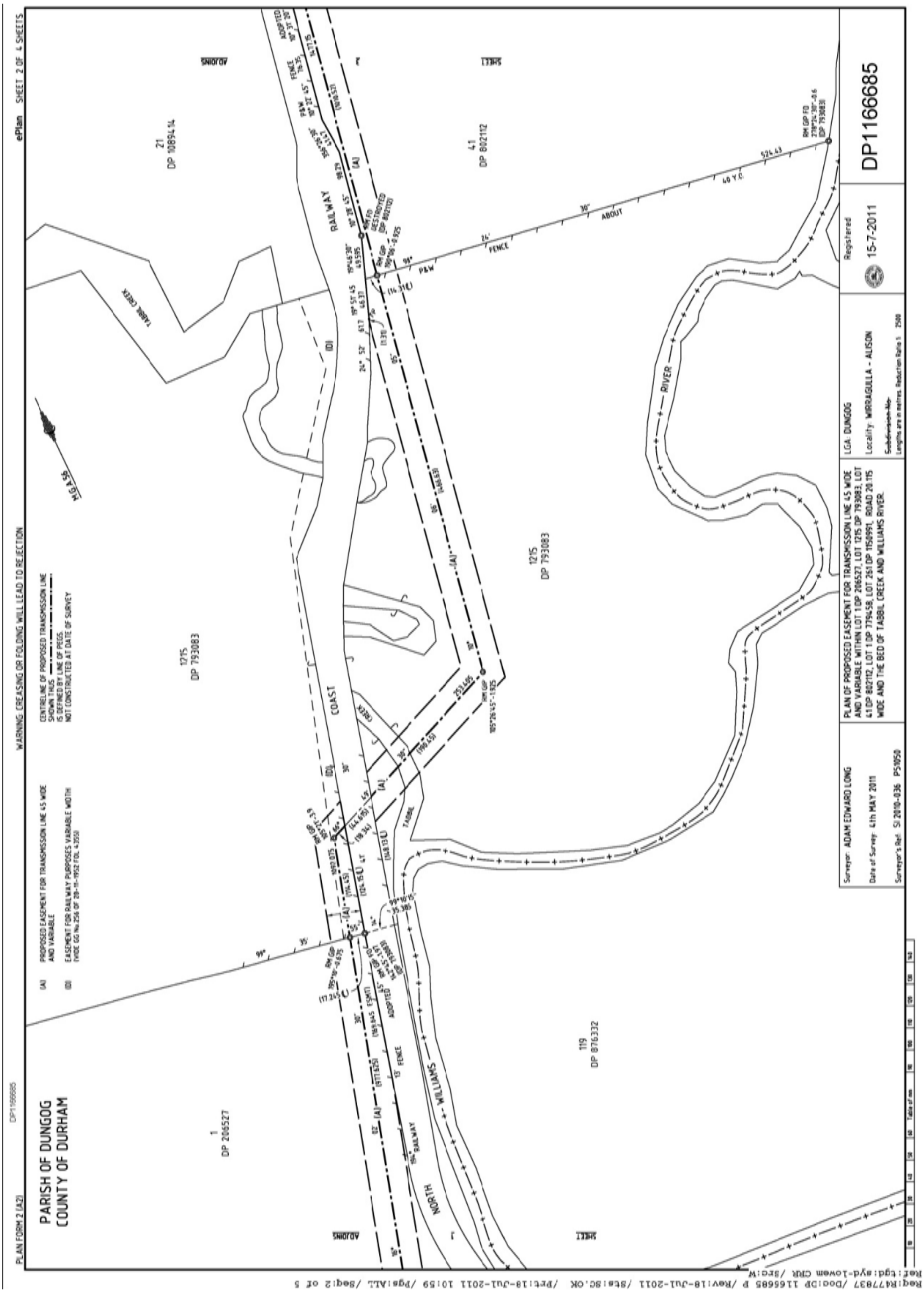

Figure 9: Example of an Easement Plan of Survey abutting railway land.

A total of 20 Deposited Plans were surveyed by TransGrid surveyors, covering 51 km of transmission line easement. In addition, one plan covering some 15 km was prepared by Rennie Golledge Pty Ltd.

The survey of easements proved to be both interesting and testing at times from a boundary definition perspective with the new transmission line crossing through many old portions of limited title and definition. Most sections crossed through land that had previously been surveyed in the 1960s, most notably by Andrew Clark whose plans were a pleasure to work with. However, some sections, such as around Duckenfield, had very little cadastral information. At one stage, boundary definition was relying on information in DP197 created in 1838. In this situation, the location of cadastral boundaries was aligned with existing occupations such as old fencing or walls (Figure 10).

Figure 10: A lot of boundary definition relied on occupations such as this.

Parts of the Hunter Water pipeline (Figure 11), which the centreline criss-crossed, had very little reliable survey information to work with as most of the plans were compiled. The centreline also crossed at very acute angles making the showing of ‘cuts’ very difficult at times. There were also railway boundaries, original Crown grants, farm plans and Australian Agricultural Company lease issues to deal with – a real ‘mixed bag’ of cadastral challenges.

There is now 70 km worth of cadastral survey on MGA94 orientation, which should make future boundary surveys in the project area a little easier. The easement plans progressed from south to north, each plan covering about 6 km over four sheets. As boundaries continued to be defined by survey, the cadastral layer for the whole project was adjusted and updated for inclusion on the Route Plans.

Figure 11: The Hunter Water pipeline weaves its way under the proposed line on its way to Chichester Dam.

3.5 Route Plans

Route plans combine all of the collected spatial data to form a homogenous plan of the project (Figure 12). The rout plant is an information-rich product generated by the survey group to aid many different end users. It includes the following information:

- Aerial imagery
- Cadastral boundaries from DCDB 'tweaked by survey'
- Local government area, parish and county boundaries
- Landowner and title details
- Roads, railways and pipelines
- Access tracks
- Edges of vegetation
- Creeks, rivers, streams and dams
- Control marks
- Low voltage crossings
- Proposed centreline, structures and span distances

The route plan is used at many stages of the project, e.g. to help analyse impact on land holdings and/or environmental impact, initiate discussions with landowners, complement design profile drawings as a plan view attachment, and determine access strategies for construction and maintenance.

Figure 12: Example of a route plan.

3.6 Structure Marking

The design was completed by Brisbane based company PLD Consulting using the PLS-CADD model created from ALS. The aerial imagery was used to map constraints that told PLS-CADD where structures could not be placed, i.e. in areas near dams, roads, railways and watercourses. Using certain design criteria inputs such as design voltage, pole types, statutory clearances and maximum span distances, PLS-CADD created the design in a fairly automated process (Figure 13). For this reason, it is crucial that the design be setout in the field to confirm that the design can work and that all constraints have been considered.

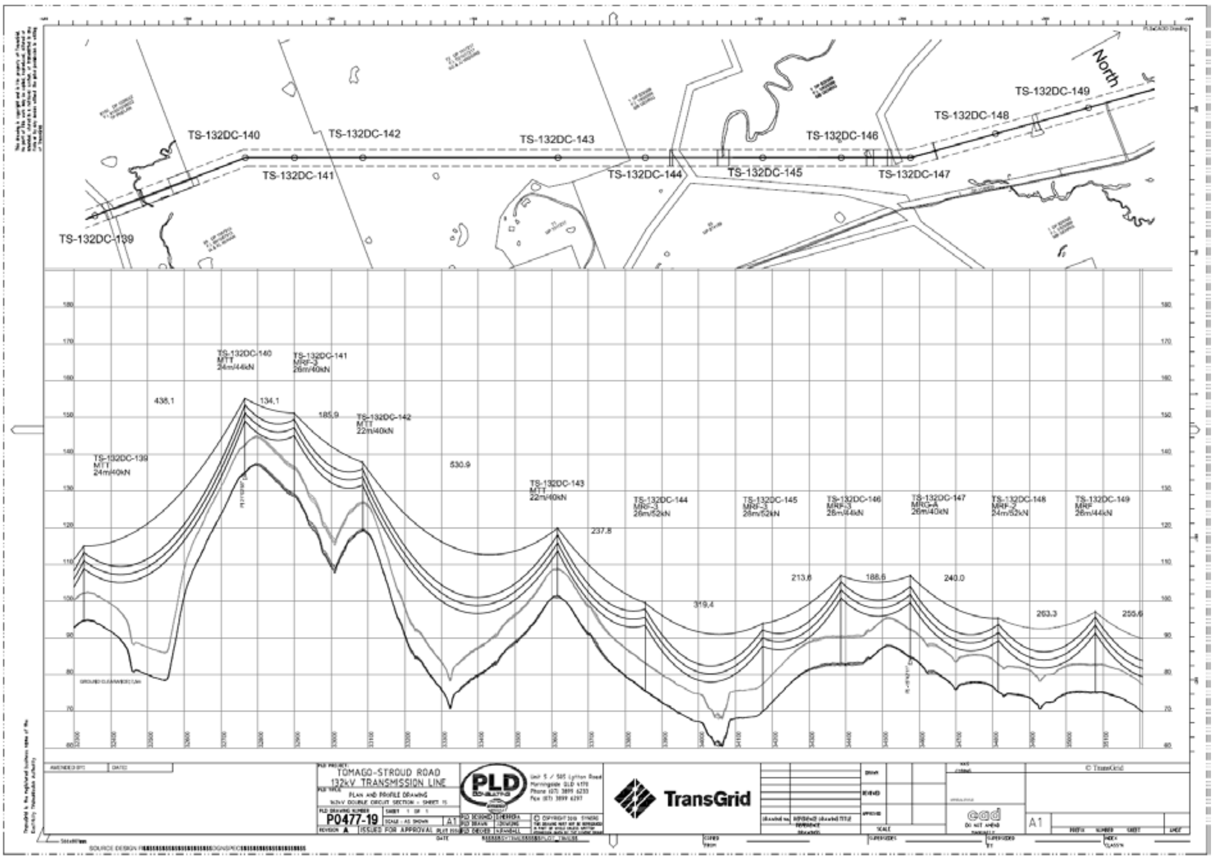

Figure 13: Example of a design profile.

PLS-CADD outputs each structure and guy location as Easting and Northing on MGA94 and AHD 71 heights suitable for setout by RTK GPS survey using either CORSnet-NSW or local base stations (Figure 14). As each structure is setout, the surveyor checks that the proposed structure location does not affect visible services, access ways or watercourses. As problems are found, structures can be moved on the ground to a more suitable location and input back into the design. This process is very iterative with a lot of communication required between ground staff and designers.

Figure 14: TS Dungog and TS Coorei – the use of RTK GPS had great benefits throughout the project.

4 CONSTRUCTION

Construction on the project began in May 2012. So far, 85% of access tracks have been completed and more than 5 km of the new transmission line, including 70 of the planned 300 concrete pole structures, have been installed (Figure 15). Recently the southern section of the transmission line at Brandy Hill had been connected to Ausgrid's new Brandy Hill substation, reinforcing electricity supply to communities in this expanding region of the Hunter Valley. Work is now progressing with the stringing of the new transmission line north of Brandy Hill to the Martins Creek Tee. Construction is due to be completed by the end of 2013.

Figure 15: Section of newly constructed line heading towards Brandy Hill and example of power pole type.

5 CONCLUDING REMARKS

The Tomago to Stroud 132 kV transmission line project certainly put TransGrid's surveying capability to the test. Throughout the design phase of the project, quality spatial products and services were delivered that provided stakeholders with the information they needed whilst staying within critical time and cost constraints. Overall, this project was an excellent

example of surveyors proving that they are the experts when it comes to analysing and manipulating spatial data, and providing survey accurate plans, drawings and 3D models.

It was evident that technical skills alone are not sufficient in this type of environment. The project highlighted that exemplary communication skills with all stakeholders were essential for progressing the project from feasibility to 'for construction'. The project confirmed that TransGrid's survey group has the experience, skills and drive to deliver on large-scale infrastructure projects for the benefit of the state of NSW.

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Locata: A Positioning System for Indoor and Outdoor Applications Where GNSS Does Not Work

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ABSTRACT

The Global Positioning System (GPS) is a reliable, versatile, generally available and comparatively accurate positioning technology, able to operate anywhere across the globe. In the coming decade, a number of other Global Navigation Satellite Systems (GNSS) and regional systems will be launched. Nevertheless, the most severe limitation of GPS performance will still remain – the accuracy of positioning deteriorates very rapidly when the user receiver loses direct view of the satellites, which typically occurs indoors or in severely obstructed urban environments. In such environments, the majority of receivers do not function at all, and even the high-sensitivity receivers have difficulty in providing coordinates with sub-decametre level accuracies. A new terrestrial radio frequency (RF)-based distance measurement technology, known as 'Locata', has now overcome the technical challenges required to create "a localised autonomous terrestrial replica of GPS". This paper describes some of the technical aspects of this Australian technology and discusses the possible role Locata can play as part of the National Positioning Infrastructure. Locata can complement, and even replace, GNSS for difficult signal environments. For example, a recent news release (September 2012) by Leica Geosystems has announced a combined GNSS+Locata positioning capability – the first commercial product that integrates GNSS and Locata capabilities into a single high-accuracy and high-availability positioning device for open-cut mine machine automation applications. Accurate indoor positioning is required for a variety of commercial applications, including warehouse automation, asset tracking, emergency first-responders, robotics, and others. GNSS is not suitable for high-accuracy indoor positioning. Locata has developed a new type of antenna which allows industrial-grade, centimetre-level positioning indoors by mitigating multipath by forming and pointing tight beams at the Locata transmitters, significantly reducing the effects of multipath corruption of the direct positioning signal. This paper briefly describes Locata tests conducted in a number of conditions, including indoors, at an open-cut mine, airborne flight testing, and on Sydney Harbour.

KEYWORDS: *Locata, GNSS, indoor positioning, location.*

1 INTRODUCTION

The Global Positioning System (GPS) is a reliable, versatile, generally available and comparatively accurate positioning technology, able to operate anywhere across the globe. GPS can address a wide variety of applications: air, sea, land, and space navigation; precise timing; geodesy; surveying and mapping; machine guidance/control; military and emergency services operations; hiking and other leisure activities; personal location; and location-based services. These varied applications use different and appropriate receiver instrumentation, operational procedures, and data processing techniques. However, all require signal

availability from a minimum of four GPS satellites for 3-dimensional fixes.

GPS and the Russian Federations' GLONASS are currently the only fully operational Global Navigation Satellite Systems (GNSSs). However, the European Union's Galileo may be operational by 2016-18, and China's BeiDou will join the 'GNSS Club' by 2020 (by 2012 it had deployed a Regional Navigation Satellite System, or RNSS). Together with dozens more satellites from other countries and agencies in the form of augmentation satellite or regional systems, it is likely that the number of GNSS satellites useful for high-accuracy positioning will increase to almost 150 – with perhaps six times the number of broadcast signals on which carrier phase and pseudorange measurements can be made. However, the most severe limitation of GNSS performance will still remain; the accuracy of positioning deteriorates very rapidly when the user receiver loses direct view of the satellites, which typically occurs indoors, or in severely obstructed urban environments, steep terrain and in deep open-cut mines.

Locata's positioning technology solution is a possible option to either augment GNSS with extra terrestrial signals (as in the case where there is insufficient sky view for accurate and reliable GNSS positioning), or to replace GNSS (e.g. for indoor applications) (Locata, 2013). Locata relies on a network of synchronised ground-based transceivers (LocataLites) that transmit positioning signals that can be tracked by suitably equipped user receivers. These transceivers form a network (LocataNet) that can operate in combination with GNSS, or entirely independent of GNSS – to support positioning, navigation and timing (PNT). This permits considerable flexibility in system design due to there being complete control over both the signal transmitters and the user receivers. One special property of the LocataNet that should be emphasised is that it is time-synchronous, allowing point positioning with cm-level accuracy using carrier phase measurements. This paper describes some technical aspects of this technology, and summaries several recent tests that demonstrate a variety of high accuracy 'GNSS-challenged' applications of Locata technology.

2 FROM PSEUDOLITES TO LOCATALITES

2.1 Background

Pseudolites are ground-based transmitters of GPS-like signals (i.e. 'pseudo-satellites') which, in principle, can significantly enhance the satellite geometry, and even replace the GPS satellite constellation in some situations. Most pseudolites that have been developed to date transmit signals at the GPS frequency bands (L1: 1575.42 MHz and/or L2: 1227.60 MHz). Both pseudorange and carrier phase measurements can be made on the pseudolite signals. The use of pseudolites can be traced back to the early stages of GPS development in the late 1970s, at the Army Yuma Proving Ground in Arizona, where the pseudolites in fact were used to validate the GPS concept before launch of the first GPS satellites.

With the development of the pseudolite techniques and GPS user equipment during the last two decades, the claim has been made that pseudolites can be used to enhance the availability, reliability, integrity and accuracy in many applications, such as aircraft approach and landing, deformation monitoring applications, Mars exploration, and others. However, extensive research and testing has concluded that pseudolites have fundamental technical problems that, even in a controlled or lab environment, are extremely difficult to overcome. The challenges of optimally siting pseudolites, controlling transmission power levels, overcoming 'near-far'

problems, trying to ensure extremely high levels of time synchronisation, configuring special antennas, and designing the 'field of operations' such that GNSS and pseudolites can work together (or at least not interfere with each other) have been largely insurmountable in the real world. Yet over the years a number prototype systems have been developed and many papers have been written dealing with this technology.

Pseudolite research at the University of New South Wales (UNSW) commenced in 2000. UNSW researchers have experimented with them in the unsynchronised mode, using the GPS L1 frequency, on their own or integrated with GPS and Inertial Navigation Systems, for a variety of applications. The reader is referred to SAGE (2013) for a full list of pseudolite-related papers by UNSW researchers. However, Locata is not a pseudolite-based positioning system.

2.2 Locata Technology

In 2003, Locata Corporation took the first steps in overcoming the technical challenges required to create "a localised autonomous terrestrial replica of GNSS". The resulting Locata positioning technology was designed to overcome the limitations of GNSS and other pseudolite-based positioning systems by using a time-synchronised transceiver called a LocataLite (Figiure 1a). A network of LocataLites forms a LocataNet, which transmits signals that have the potential to allow carrier phase point positioning with cm-level accuracy for a mobile unit (a Locata – Figure 1b). In effect, the LocataNet is a new constellation of signals, analogous to GNSS but with some unique features, such as having no base station data requirement, requiring no wireless data link from base to mobile receiver, and no requirement for measurement double-differencing.

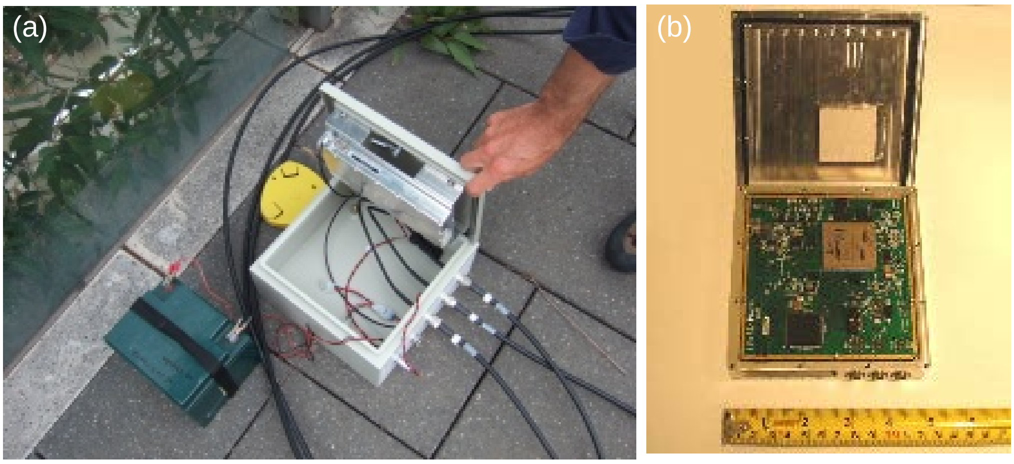


Figure 1: (a) LocataLite inside box with cabling to antennas, and (b) Locata receiver box.

The first generation Locata system transmitted using the same L1 C/A code signal structure as GPS. However, using the GPS frequency for signal transmissions has significant limitations for several reasons. The rules for transmitting on L1 vary throughout the world, but there is no doubt that a licence for wide deployment of a ground-based system on L1 would be extremely difficult (if not impossible) to obtain. If a licence was granted, ensuring there was no GPS signal degradation or interoperability issues would be of paramount importance. As a result this would limit the LocataLite's capability in terms of transmitter power – and therefore operating range – and penetration into buildings. It would also place a practical limit on the number of LocataLites in a LocataNet to ensure that no interference or degradation of the GPS signal quality occurred.

In 2005, a fundamental change was made to the first generation Locata design that affirms its claim to not being a pseudolite. Locata's new design incorporates a proprietary signal transmission structure that operates in the Industry Scientific and Medical (ISM) band (2.4-2.4835 GHz). Within the ISM band the LocataLite design allows for the transmission of two frequencies, each modulated with two spatially-diverse Pseudo Random Noise (PRN) codes.

This new signal structure was beneficial in a number of respects in comparison to Locata's first generation system – or pseudolite-based systems in general – transmitting on the GPS frequency bands L1 and/or L2, including:

1. Interoperability with GPS and other GNSS.
2. No licensing requirement.
3. Capability for on-the-fly ambiguity resolution using dual-frequency measurements.
4. Better multipath mitigation on pseudorange measurements due to the higher 10 MHz chipping rate, and less carrier phase multipath than GPS/GNSS due to the higher frequency used.
5. Transmit power of up to 1 watt giving line-of-sight range of the order of 10 km or so.
6. Time synchronisation of all LocataLites at a level to support single point positioning with cm-level accuracy.

3 LOCATA APPLICATIONS

Since 2005 the Locata technology has been refined through tests carried out at Locata Corporation's Numeralla Test Facility (NTF) outside Canberra (Australia), at the UNSW campus (Australia), at the University of Nottingham campus (U.K.), at the Ohio State University campus (USA), at the U.S. Air Force (USAF)'s Holloman Air Force Base (AFB), and at several real-world test sites including several bridges, in road tests, at two open-cut mines, a dam site, and on Sydney Harbour. From the beginning, the driver for the Locata technology was to develop a centimetre-level accuracy positioning system that could complement, or replace, conventional Real Time Kinematic (RTK)-GPS in classically difficult GNSS environments such as open-cut mines, deep valleys, heavily forested areas, urban and even indoor locations. Some of these test results are described below.

3.1 Kinematic Positioning

Figure 2 shows a Locata receiver together with two GPS receivers/antennas (to provide 'ground truth') fitted to a truck. Extensive tests over many years have confirmed few centimetre-level positioning accuracy for truck trajectories. During first flight trials conducted in May 2011, a UNSW test aircraft locked onto signals from a Locata network at distances from 3-49 km at around 7,000 feet, producing metre-level accuracy pseudo-range and decimetre-level accuracy carrier-phase solutions.

The Locata technology's potential was confirmed in a September 2010 announcement that Locata Corporation had been awarded a contract by the USAF 746th Test Squadron (746TS) to deliver a system able to provide an independent high-accuracy positioning (sub-decimetre-level) capability over almost 6,500 square kilometres of the White Sands Missile Range whenever GPS is undergoing jamming tests (see Figure 3 for one of the LocataLite installations). Locata was used on several types of aircraft. Craig and Locata Corp. (2012) reported on the extensive tests results. The USAF awarded Locata Corporation the contract

for the delivery of technology for the High Accuracy Reference System through to the year 2025. The 746TS described Locata as "the new 'gold standard truth system' for the increasingly demanding test and evaluation of future navigation and navigation warfare systems for the U.S. Department of Defense".

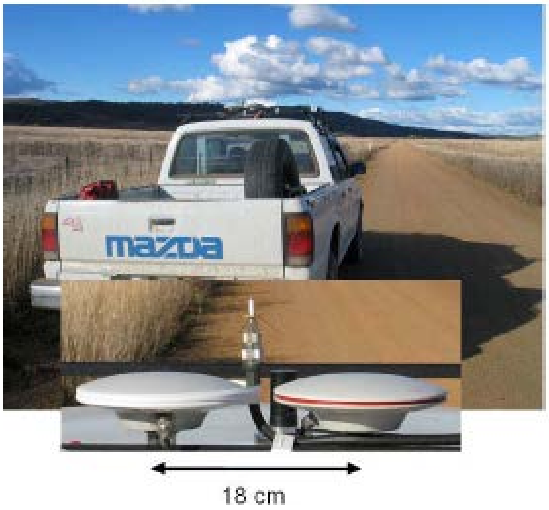


Figure 2: NTF kinematic test set-up, Locata antenna between two antennas of the Leica RTK-GPS ground truth system.

Figure 3: One LocataLite installed on a mountaintop at White Sands Missile Range.

3.2 Deformation Monitoring

Another important application of Locata (on its own or in combination with GPS) is deformation monitoring of structures such as buildings, bridges or dams. Early Locata testing was conducted in Sydney and in Nottingham (U.K.) and demonstrated the benefit of augmenting GPS with Locata signals in order to improve availability, and consequently improve the horizontal accuracy. Recently Locata-only tests were conducted on a dam structure, the Tumut Pond Dam (Figure 4). Comparison with 3D coordinates derived from a robotic total station confirmed sub-cm level repeatability, as well as sub-cm accuracy (under the assumption there was no dam wall movement).

Figure 4: (a) Tumut Pond Dam (total view), and (b) LocataLite and receiver installation.

3.3 Locata/GPS/INS Integration

The determination of the position and orientation of a device (or platform to which it is attached), to high accuracy, in all outdoor environments, using reliable and cost-effective technologies is something of a ‘holy grail’ quest for navigation researchers and engineers. Two classes of applications that place stringent demands on the positioning/orientation device are: (a) portable mapping and imaging systems that operate in a range of difficult urban and rural environments, often used for the detection of underground utility assets (e.g. pipelines, cables and conduits), unexploded ordnances and buried objects, and (b) the guidance/control of construction or mining equipment in environments where good sky view is not guaranteed. The solution to this positioning/orientation problem is increasingly seen as being based on an integration of several technologies. Researchers from UNSW and the Ohio State University (OSU), Columbus (USA) assembled a working prototype of a hybrid system based on GPS, inertial navigation, and Locata receiver technology (Figure 5), and have reported the results in a number of papers (see SAGE, 2013).

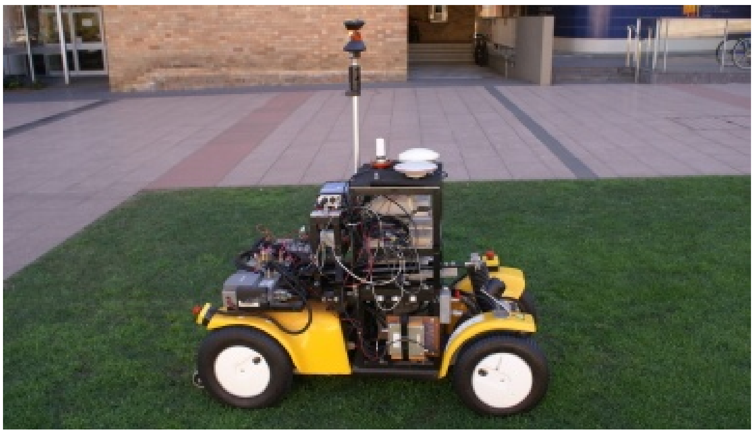


Figure 5: Integrated GPS+INS+Locata test car on UNSW campus.

3.4 Open-Cut Mining

Many of the ‘new paradigms in mining’ have at their core the requirement for reliable, continuous centimetre-level positioning accuracy to enable increased automation of mining operations. The deployment of precision systems for navigating, controlling and monitoring machinery such as drills, dozers, draglines and shovels with real time position information increase their operational efficiency, and reduce the need for humans to be exposed to hazardous conditions. GNSS cannot satisfy the high accuracy positioning requirements for

many applications in mine surveying, and mine machine guidance and control. The reason is that increasingly open-cut mines are getting deeper, resulting in a reduction of the sky view necessary for GNSS systems to operate satisfactorily.

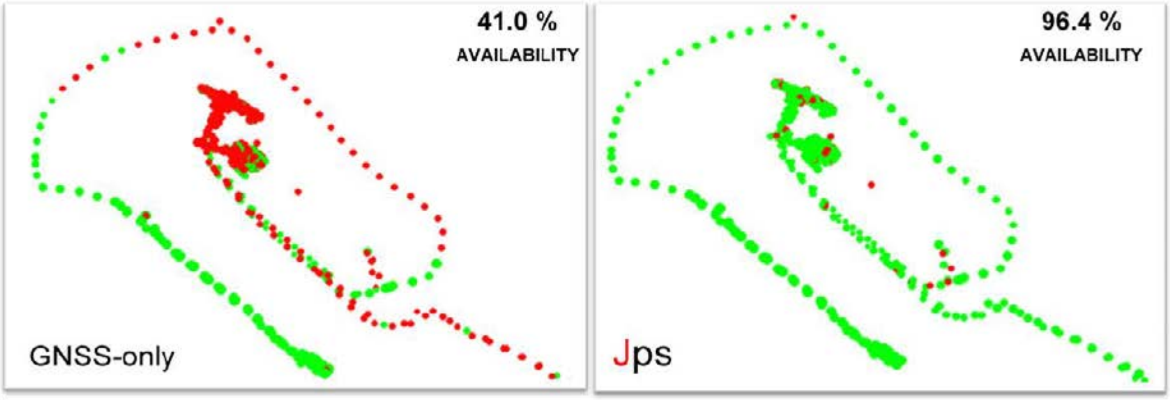
In the last week of September 2012, Leica Geosystems capped off five years of product development with the global launch at the huge MINExpo Convention in Las Vegas of the world's first "Powered by Locata" network for mining fleet management. Leica revealed they had already installed the first operational LocataNet at one of the world's biggest gold mines – Newmont Mining's Boddington Gold Mine in Western Australia. This open-pit mine (like most others) experiences severe machine control GPS outages as the mine gets deeper and visibility to sufficient satellites for a position solution is reduced. The efficiency of the mine suffers significantly during GPS outages, as machine control reverts to manually positioning machinery.

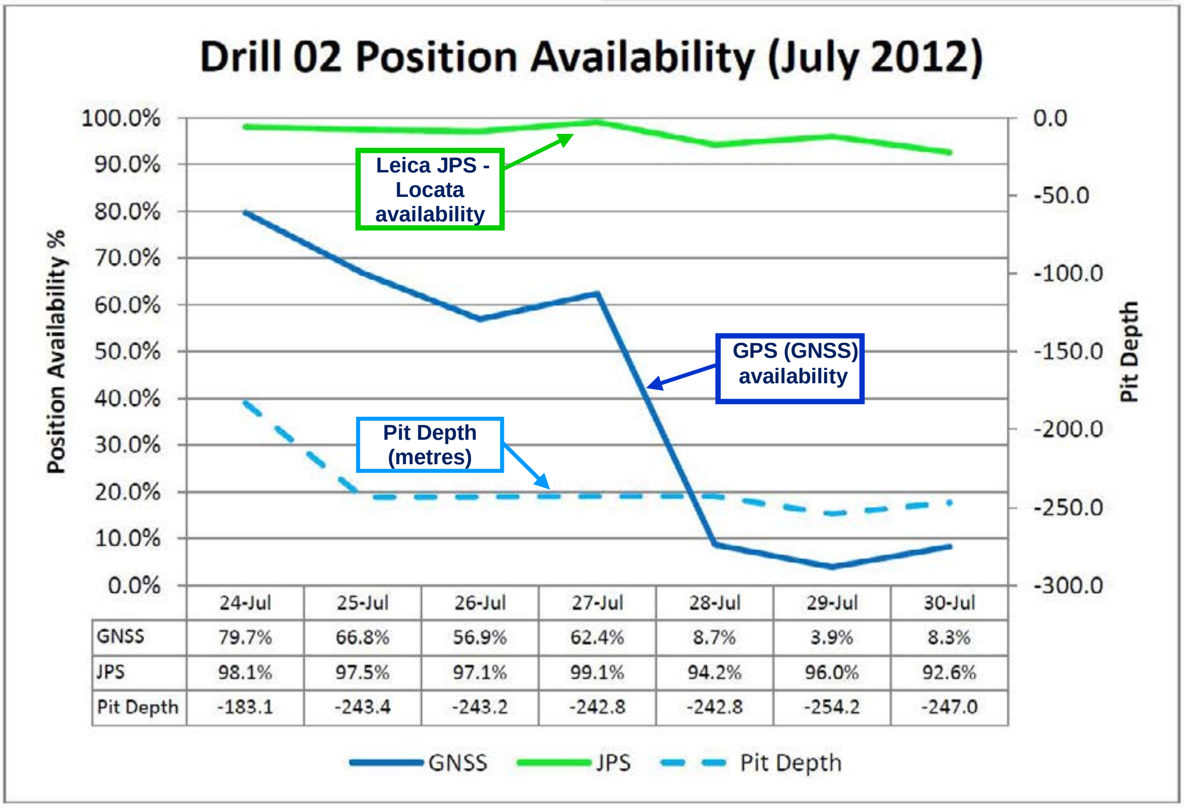
The results since the first Leica LocataNet became operational in May 2012 have been spectacular, both in terms of efficiency gains and financial return to the owners. Over a 2-month period, two Locata-enabled drill rigs in the pits worked an extra 4.7 days compared to the non-Locata drills – at a cost of over $1,000 per machine per hour, this represented over $112,700 of efficiency gains for those two drills alone. A comparison of availability of GPS-only versus Locata is shown in Figure 6. As of October 2012, the mine had installed the first of Leica's integrated GNSS+Locata receiver units on 10 drill rigs. Not only was the signal availability of the LocataNet an impressive achievement, but comparison measurements showed that these drills are being positioned to an accuracy of about 1.2 cm across the mine – an exceptional performance by any measure in such difficult physical environments.

3.5 Indoor Positioning

In April 2004, the first indoor tests were conducted at BlueScope Steel, one of BHP Billiton's steel producing companies located in Wollongong, south of Sydney (Australia), to assess the performance of the prototype Locata technology for tracking a large crane in a harsh multipath environment. A total station was used to provide independent 'ground truth'. The results demonstrated cm-level accuracy. However, no further public demonstration of indoor positioning was conducted until 2010, at which time a radically new Locata indoor antenna design (trademarked as a small TimeTenna) was tested for the first time at the NTF.

The 2010 indoor experiments were conducted inside a large metal shed, approximately 30 m long and 15 m wide (Figure 7). Such an environment guarantees severe multipath disturbance. A LocataNet consisting of five LocataLites was installed inside the shed. The Locata receiver was placed on a small trolley. The TimeTenna was mounted on a pole attached to the trolley and was connected to the receiver. In order to compare reported receiver positions with the true position, a Robotic Total Station (RTS) was setup near the test area. A surveying prism was placed vertically above the phase centre of the TimeTenna. The RTS was programmed to track the location of the prism as it was moving and log the data internally for subsequent processing. The experimental set-up is shown in Figure 7.





	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul	30-Jul
GNSS	79.7%	66.8%	56.9%	62.4%	8.7%	3.9%	8.3%
JPS	98.1%	97.5%	97.1%	99.1%	94.2%	96.0%	92.6%
Pit Depth	-183.1	-243.4	-243.2	-242.8	-242.8	-254.2	-247.0

Figure 7: Indoor test site, Locata receiver on trolley and RTS set-up.

Static (Locata receiver placed over nine known points marked on the ground) and kinematic tests were conducted. Apart from some initial convergence challenges, all static coordinates were determined to cm-level accuracy. The kinematic tests indicated that the trajectory was in almost all cases less than 3 cm from that derived using the RTS. (Note that the pole was not perfectly vertical, and that there was movement of the prism relative to the TimeTenna.) Nevertheless, impressive first results were obtained from this new multipath-mitigating antenna technology. TimeTenna consists of an array of antenna elements that take advantage of Locata's proprietary signal structure and time synchronisation features to track only the direct line-of-sight signals – opening up opportunities to many new location-based applications that were not possible previously. More tests have since been conducted.

3.6 Urban Positioning: Sydney Harbour Tests

In October 2012, a Locata test-bed for positioning in the Sydney Harbour area was set-up with the assistance of NSW Land and Property Information (LPI) and Sydney Ports. A LocataNet was deployed to service the area of Farm Cove (Figures 8 & 9), and the Locata receiver was deployed on a Sydney Ports vessel (Figure 10). Preliminary results were shown by Paul Harcombe (Chief Surveyor and Director of Location Policy, LPI) at the spatial@gov Conference in Canberra in November 2012, in a presentation titled "Sydney satellites – towards ubiquitous positioning infrastructure". A comparison with GPS-only positioning showed that the Locata-only solutions were different by about 4.4 cm. This was the first demonstration of Locata positioning using signals across water, and the first trial of Locata in an urban-like environment.

Figure 8: LocataNet established for 10 October 2012 Sydney Harbour tests.

Figure 9: (a) LocataLite atop Sydney Harbour Bridge, and (b) LocataLite near seawall of Botanical Gardens.

Figure 10: Locata receiver and GPS antennas on Sydney Ports vessel.

It is hoped that a permanent Locata test-bed will be established in the city of Sydney in 2013. This would be a first step to demonstrating that the network of signal transmitters to support Locata-based positioning could be included within a plan for deploying National Positioning Infrastructure (NPI). It would go part of the way to addressing the shortcomings of GNSS-based positioning for urban and other difficult GNSS signal environments.

4 CONCLUDING REMARKS

Locata can be considered a new type of localised ‘constellation’, able to provide high-accuracy positioning coverage where GNSS fails. This paper introduced some of the technical aspects of this technology, summarised the R&D highlights over the last decade or so, and described a variety of applications for Locata technology, including some recent results of high-accuracy outdoor and indoor positioning. Over the coming years several commercial positioning systems will be developed that incorporate the ability to track Locata signals in addition to GNSS. Locata is a technological solution to high-accuracy indoor and outdoor

positioning where GNSS cannot on its own provide the requisite positioning capability. It is a terrestrial augmentation to GNSS where sky visibility is restricted due to high walls in open-cut mines, as indicated by recent news announcements by Leica Geosystems.

There are no 'GNSS equivalent' systems for indoor positioning, hence one cannot speak of Locata as an 'augmentation' in such senarios. Locata is the only high-accuracy RF-based system that does not have serious range restrictions, and can be used over distances of 100s of metres. However, many more tests will be necessary to investigate the operational issues associated with deploying a LocataNet and developing user solutions based on the Locata technology.

Finally, the issue of Locata infrastructure, within the context of an NPI must be addressed. It is necessary to study how a LocataNet could be deployed and operated across an urban area, to support critical high-accuracy and high-availability positioning applications (which cannot be satisfied using GNSS-only solutions). Only very early trials have been conducted. Many more are needed, and could be undertaken using a permanent test-bed in a downtown urban area.

Locata is an Australian invention, it is here, and it is working now. Locata technology represents an unprecedented opportunity for Australia to become a world leader in positioning, one of the most important hi-tech markets of the future. It's not every day that a completely new, game-changing technology is invented in Australia. Opportunity knocks. Let's embrace it.

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A Next Generation Datum for Australia

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ABSTRACT

Within the coming decade it is anticipated that Global Navigation Satellite System (GNSS) technology will be capable of providing pseudorange-based positioning services with an uncertainty (1-sigma) of 3 cm (open sky) and 15 cm (tree covered) while carrier-phase positioning services supported by GNSS ground networks with an inter-station spacing of 100-200 km should achieve uncertainties of 1-2 cm in real time. These capabilities will improve business processes and national productivity but are also likely to encourage spatial-data collection by a broad community of users, including those without strong spatial expertise. From a spatial-data management perspective, a challenge will emerge in that these new global services will support positioning in the International Terrestrial Reference Frame (ITRF), which is a dynamic and time dependent coordinate system, and not directly in any individual national datum, including the Geocentric Datum of Australia 1994 (GDA94). GDA94, established in the 1990s, has relatively poor internal accuracy, weak linkages to the ITRF, and is held static at an epoch date nearly two decades ago. Recognising that GDA94 will be incompatible with these future positioning capabilities and that the national datum will need to directly serve a wider community of users, the Intergovernmental Committee on Surveying and Mapping (ICSM) - Permanent Committee for Geodesy (PCG) in collaboration with the Cooperative Research Centre for Spatial Information (CRCSI) is currently examining options for revision of the datum. This presentation gives an overview of the drivers for further developing Australia's datum, initial concepts and indicative timeframes for implementation.

KEYWORDS: *Datum, geocentric, Australia, ITRF, GDA94.*

Data-Mining in NSW: Working Towards a New and Improved Australian Datum

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ABSTRACT

Advances in positioning technologies in the last decades have given a large range of user-groups access to positioning at ever-increasing accuracies and improved spatial and temporal resolution. In this context, the limitations of our current Australian datum(s) are becoming apparent. For example, while the Geocentric Datum of Australia 1994 (GDA94) was cutting-edge when it was adopted 13 years ago, it has since been shown to have limited internal accuracy and indirect linkages to the current global reference frame, the International Terrestrial Reference Frame 2008 (ITRF2008). Since GDA94 was 'frozen' at the epoch of 1994.0, Australia has moved (and rotated) by up to 1.3 metres. The spatial community is currently discussing the best way forward to a next-generation datum, here hypothetically termed 'GDA201x'. In preparation for this new datum, each state and territory is harvesting all available observations from their archives. New computing technologies mean that state-wide and even nationwide adjustments are now routinely possible with a theoretically unlimited number of observations. In the context of New South Wales (NSW), this paper discusses the process of 'dusting-off' the observations originally used to compute GDA94, and the 'data-mining' of our archives for all new GNSS observations which have contributed to the densification of the datum since its adoption. These observations are combined, cleaned and adjusted using the phased-adjustment software 'DynaNet' and other in-house software, and constrained by the CORSnet-NSW network and several hundred AUSPOS results. It is demonstrated that by increasing the number of fiducial stations in NSW (from 13 Australian National Network stations to 113 CORS), and by increasing the number and quality of observations across NSW (from 4,000 GNSS observation to more than 62,000), we can significantly improve the accuracy of the datum across and between the states. Rigorous Positional Uncertainty (PU) can be computed from this first ever state-wide simultaneous adjustment, and with the current preliminary constraints the majority of stations have a horizontal PU of better than 20 mm, up to an order of magnitude better than in GDA94.

KEYWORDS: *GDA94, GDA201x, CORSnet-NSW, datum, data mining, phased adjustment.*

1 INTRODUCTION

Imagine that a surveyor decided to have another look inside all of those yellow project folders that are squirreled away in their office, in order to make one big list of all the observations

that they had ever taken. This includes the current folders that are hiding under the phone and coffee cups, the folders from recent years filed in the compactors, and even the historical folders in the garage/offsite archive that were inherited when the practice was purchased. If they have managed to 'go digital' in the last two decades, all the better, but what about those aging CD-ROMs (or floppy discs?) that were eagerly burned years ago with that brand-new '386' computer or AppleIIc. Now consider the different file formats and programs that have probably been used over the years, and the need to find (or write) converters to translate each observation into the same format.

The task described above seems unthinkable and almost insurmountable; why would anyone do such a thing? Well, if the surveyor's new job is to provide control station coordinates over their whole area of operations, and results are expected to join seamlessly with neighbouring surveyors, then the benefits of consolidating these observations become more apparent. In a perfect world, all of this data would end up in a searchable database and be visualised in a GIS. This would serve as a good record of where observations are plentiful, and more importantly, highlight gaps in the coverage and areas in need of new control. Since the most expensive part of any survey is putting boots on the ground, existing data could be reused, where appropriate, to minimise the time spent gathering new observations (although making appropriate checks of previous work remains best practice).

Individual jobs could be amalgamated to take advantage of new computing power, which can solve for the coordinates of *all* stations in a single least squares adjustment, instead of job by job. The beauty of this approach is that existing data would be used to highlight any errors in new observations, and vice-versa. As measurement technologies improve, any new higher-precision observations would serve to make the resulting control network stronger and more accurate. Consider the pros and cons in terms of precision, distance and speed of observations when comparing the steel band vs. Electronic Distance Measurement (EDM) vs. Global Navigation Satellite Systems (GNSS). In addition, combining jobs observed at different times will give a good idea of where the land (or the monuments) might be moving.

NSW Land and Property Information (LPI) is undertaking just such a task. In this paper, it is argued that the coordinates of our control stations (the realisation of the datum) actually need to be periodically re-examined and refreshed in order to provide a backbone of suitable accuracy against which all new technologies, observations and spatial data are applied. In order to facilitate investigations into a possible datum update, the Intergovernmental Committee on Surveying and Mapping (ICSM) has mandated that each state and territory prepare a primary network of geodetic data for testing a nationwide adjustment in 2013. To this end, LPI is undertaking a project to collate and clean all available GNSS vectors in its archives and to test the first ever state-wide simultaneous adjustment of these observations.

This paper briefly outlines some of the salient features of some of the previous datums in Australia, reviews some of the drivers of datum change and introduces the use of DynaNet for large-scale simultaneous adjustments. It then describes the lessons learned, and some of the tools created during the harvesting, cleaning and adjustment of nearly a quarter of a million GNSS vectors, collected over the last 20 years, from the digital archives at LPI.

1.1 Recent History of Australian Datums

Featherstone (2013) provides a good history of recent geodetic datums in Australia. Prior to 1966, a variety of datums and ellipsoids were used for mapping and charting in Australia,

leading inevitably to coordinate discrepancies and confusion. In the1960s, the Australian Geodetic Datum (AGD66), and its UTM projection – the Australian Map Grid 1966 (AMG66) – were introduced Australia-wide to remove the heterogeneity and make use of all available geodetic observations (Bomford, 1967). AGD66 was realised with the Australian National Spheroid (ANS) and coordinates adopted for the Johnston origin based on 275 astro-geodetic stations distributed over most of Australia (ICSM, 2006).

In the 1980s, new technology (notably satellite-derived geodetic data) soon highlighted deficiencies in the AGD66 coordinates (Lambert, 1981). A readjustment produced the Geodetic Model of Australia (GMA) 1982, which was subsequently adopted as the Australian Geodetic Datum 1984 (AGD84) along with its UTM projection (AMG84) again based on the ANS and Johnston origin. Differences between AGD66 and AGD84 of up to 6 metres (up to 1 metre in NSW) were noted (Allman and Veenstra, 1984). Even as AGD84 was adopted, the National Mapping Council (NMC, 1986) "*recognised the need for Australia to eventually adopt a geocentric datum*" in order to be directly compatible with emerging and global satellite technologies. AGD84 was only the first of two steps towards datum modernisation. With this in mind, many states and territories decided to hold off until the change to a geocentric datum. Only Western Australia, South Australia and Queensland adopted AGD84, resulting once again in heterogeneous coordinate datums across Australia.

In the 1990s, the ICSM resolved to adopt the Geocentric Datum of Australia (GDA94), based on a new ellipsoid (GRS80), and recommended that the implementation of this datum be completed Australia-wide by 1 January 2000 (GA, 2012a; ICSM, 2013a). GDA94 was realised in 1995 by the 3-dimensional coordinates of 8 Australian Fiducial Network (AFN) stations determined simultaneously, using GPS in the most rigorous datum available, the International Terrestrial Reference Frame (ITRF) 1992, at epoch 1994.0 (Manning and Harvey, 1992; ICSM, 2006). Through the ITRF, and for all practical purposes, GDA94 was fully compatible with GPS in terms of spheroid and datum *at the time of implementation of GDA94* (Malays and Slater, 1994; ICSM, 2006). By 2012, the GDA94 coordinates of the AFN could no longer be realised to better than 30 mm (horizontal) and 50 mm (vertical) (95% confidence – Dawson and Woods, 2010). Since 1995, these AFN stations have been re-gazetted twice, with more stations (now 21 AFN stations) and improved coordinate precision (now 7 mm horizontal, 15 mm vertical), to allow an improved realisation of the datum (Australian Government, 1998, 2012; GA, pers. comm.).

In addition, 78 national stations (13 in NSW), known as the Australian National Network (ANN), were observed with GPS and adjusted together with the AFN in a single solution to create a framework for GDA94 at 500 km intervals, with an estimated accuracy of 50 mm (95% confidence – ICSM, 2006) or 0.1 ppm (ICSM, 2006; Watson, 2006). Further adjustments were computed in a hierarchy where coordinates of higher order control were held fixed and assumed to be perfectly known in each subsequent adjustment. For example, a densification of horizontal geodetic control using approximately 71,000 terrestrial and GPS observations (Table 1) was undertaken in 12 sections of less than 1,000 stations each (computing power limiting the size of each section) to propagate the datum (ICSM, 2013b; Figure 1). This last adjustment, containing the 3,000 NSW stations commonly referred to as the 'spine' network was officially accepted by ICSM in June 1997. The majority of horizontal coordinates in the NSW spine network were estimated to be better than 250 mm (95% confidence – Watson, 2006) and were given Class '2A' and Order '0'.

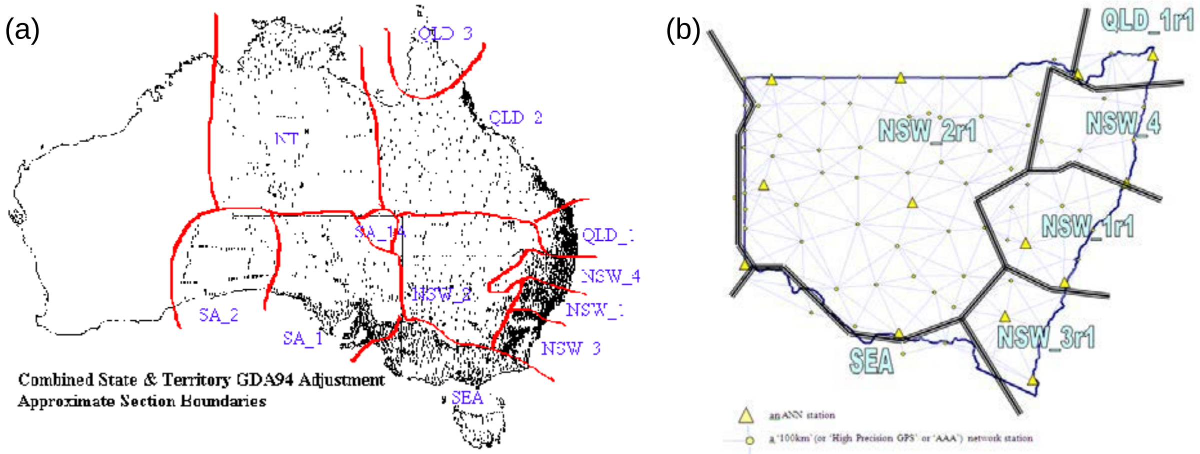

Figure 1: Datum adjustment sections for GDA94 – (a) Australia (ICSM, 2013b), and (b) NSW (Watson, 2006).

GDA94 was adopted by all states and territories, with only NSW and South Australia passing related legislation (e.g. LPI, 2013a). Any remaining stations would be transformed from AGD66 to GDA94 and then re-adjusted as more observations become available, a task which is still ongoing. Distortions across state borders were too large to allow a single national transformation model to be developed, so instead a national NTv2 grid was adopted (ICSM, 2006; LPI, 2013b).

This brief history demonstrates four main drivers of datum improvement: (1) technology changes such as terrestrial vs. satellite surveying techniques, (2) the desire for a single standard (homogenous) nationwide coordinate datum, (3) the inclusion of up-to-date geodetic observations and increased precision to smooth out distortions, and (4) the need to provide a denser realisation of the datum. The approximate numbers of stations and observations in recent Australian datums are shown in Table 1. Note that NSW contributed almost half of the stations and more than half of the observations included in the national GDA94 adjustment.

Table 1: Numbers of stations and observations in recent Australian datum definitions (Watson, 2006).

(values rounded to nearest 100)	AGD84 (NSW)	AGD84 (National)	GDA94 (NSW)	GDA94 (National)
Stations	~1,100	1,700	3,000	7,700
Directions		14,300	32,200	46,400
Distances		3,900	6,100	13,700
Azimuths		~200	~200	1,200
GPS Baselines			2,900	4,000
GPS Clusters				6,100
All Observations		18,400	41,400	71,400

1.2 Current Drivers for Datum Update

Since the adoption of GDA94 more than 13 years ago, the four drivers of datum change described above have still been in operation. Over time, and for more and more users, our world-class datum is beginning to shows its age. The motivation for datum change has once again become significant enough to cause us to carefully consider the best way forward. At the same time, it is necessary to carefully review the impacts and minimise any negative consequences associated with datum change. It is not in the scope of this paper to suggest the best format for any new datum, but it is instructive to consider some of the major issues and new drivers of datum change.

Since the last official datum update, GDA94, a significant amount of additional data has been gathered. Figure 2a, for example, shows a large number of new GNSS baselines (approximately 60,000, in blue) overlying the network of GPS observations that were used in the previous GDA94 adjustment in NSW (green). Currently in NSW, these new observations are used to provide coordinates for additional local ground control, but are not allowed to modify the coordinates of the higher order 'spine' stations. New, higher precision observations are often forced to fit the distortions in the original GDA94 adjustment.

Systematic distortions of up to 200 mm (horizontally) and 300 mm (vertically) have been demonstrated in the current datum in NSW (Figure 2b; Haasdyk et al., 2010). Positioning services such as CORSnet-NSW (Janssen et al., 2011; LPI, 2013c) and AUSPOS (GA, 2012b) provide precise coordinates in GDA94, without any reference to local ground control. As a result, an ad hoc, more homogenous realisation of the datum, dubbed GDA94(2010), has been created for use in NSW based on the direct connections of the CORS network to the AFN stations (Janssen and McElroy, 2010). CORSnet-NSW provides a backbone for positioning in NSW, of much higher density and precision than the original ANN. Removing these distortions between local control in the original GDA94(1997) and coordinates in GDA94(2010) would require a re-adjustment of the entire NSW network, without a hierarchy of fixed control, which is the subject of this paper. In the interim, a site transformation (Haasdyk and Janssen, 2012) is required to agree with the local (and legally accepted) ground control available in NSW via SCIMS (LPI, 2013d).

Soon, any internet-capable device will be able to determine an accurate position in the latest ITRF, with or without direct reference to GDA94, by directly accessing International GNSS Service (IGS) products in real time (Caissy et al., 2012). However, while GDA94 coordinates remain unchanged over time, the ITRF recognises that the Australian tectonic plate is moving at up to 7 cm/yr (~6 cm/yr in NSW) (Figure 2d; Dawson and Woods, 2010) and therefore GDA94 and ITRF diverge over time. This motion, equivalent to 1.3 metres since 1994.0 must be taken into account in order to transform these results into GDA94.

The Australian plate is not simply moving, but also rotating slightly, and deforming in places (Dawson and Woods, 2010). Significant errors can be introduced between observations taken at different epochs unless this rotation and deformation is accounted for. Stanaway et al. (2012) show that errors of up to 7 mm are introduced for baselines of only 30 km (Figure 2e) over the life of GDA94. These errors might not impact cadastral surveys directly, but engineering surveys and the provision of accurate control coordinates are definitely affected at these scales. Deformation, e.g. due to earthquakes, underground mining or water extraction, is less predictable, less systematic and occurs over a variety of time and distance scales.

Finally, creating a truly 3-dimensional datum which is coordinated across Australia is important for delivering the "*optimum benefits [of precise positioning] to the nation as soon as possible*" (ANZLIC, 2010). Figure 2c demonstrates jurisdictional boundaries where coordinate jumps are often introduced by the running of separate adjustments using different methods. In contrast, a nationwide simultaneous adjustment of all geodetic observations would result in a truly national and homogenous datum. Such an adjustment, without a fixed hierarchy of control, would allow the long-awaited introduction of Positional Uncertainty (PU – ICSM, 2007) at all stations and yield a dense network of ellipsoidal heights.

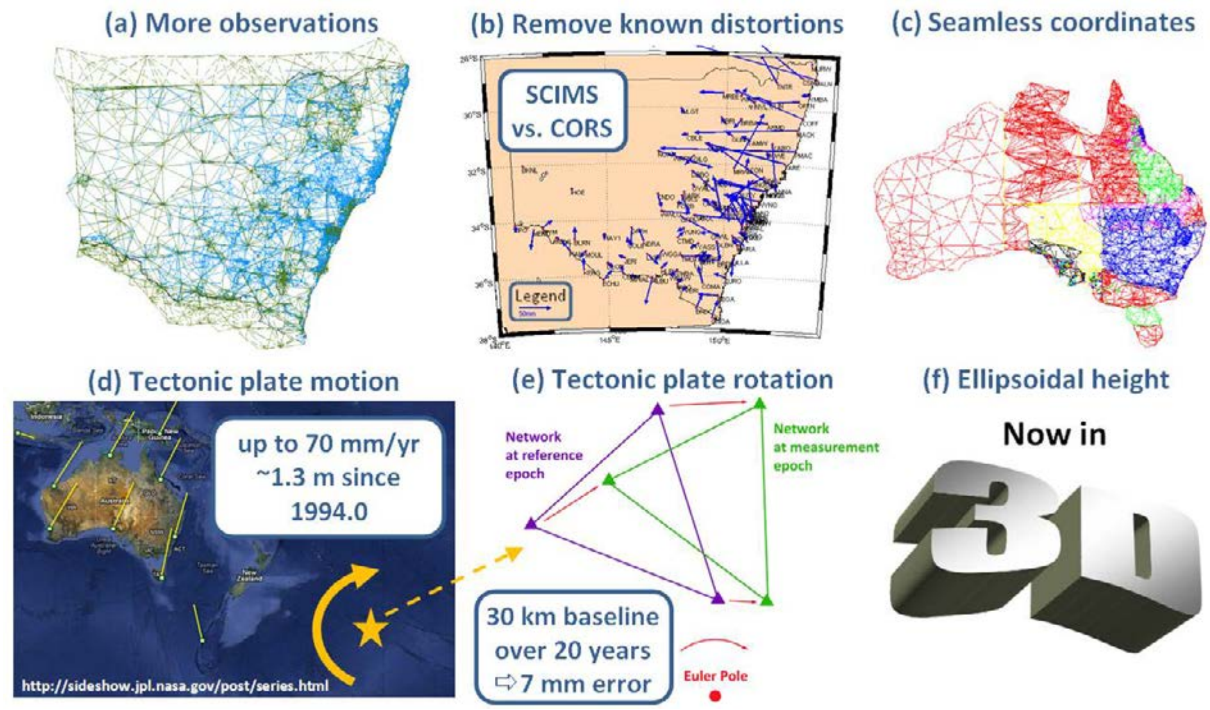

Figure 2: Some current drivers of datum change.

1.3 Dynamic Phased-Adjustment Least Squares Methodology and DynaNet

In the past, computing power has been a limiting factor in the simultaneous adjustment of large survey networks. Instead, large networks such as the most recent Australian national GDA94 adjustment (ICSM, 2013b, Figure 1) had to be segmented into ‘sections’ of ‘adjustable size’, which were treated individually and later recombined. This can lead to discrepancies across section boundaries, and also results in the loss of any relationships between stations in different sections.

However, least squares methodologies that are *not* limited by the number of stations or observations are possible, and have been recently re-examined. Leahy and Collier (1998) describe a ‘dynamic phased-adjustment’ that can perform a rigorous adjustment on a network of any size, and return a rigorous assessment of the quality of the adjusted station coordinates and observations. This allows the computation of absolute Positional Uncertainty (PU) as well as relative uncertainties across the entire network (ICSM, 2007). DyanNet, a program that can perform this dynamic network adjustment, is currently under development by the ICSM, building on the original work of the Department of Geomatics at the University of Melbourne. DynaNet can be implemented on a desktop computer, with adjustments of similar size to the GDA94 adjustment running in a matter of hours.

1.4 Challenging Paradigms

There is no doubt that the suggested adjustment ‘en-masse’ of all available observations challenges many paradigms. Survey and geodetic control networks are generally regarded as being static to provide control for lower order networks, but in a simultaneous adjustment, all stations and observations stand on their own merits (according to the weighting supplied), and any new observation should improve the adjustment accordingly. In this way, there is a 2-way interaction between all layers of control, in which ‘higher order’ control can influence ‘lower order’ control *and vice versa*.

Another implication of a simultaneous adjustment of all data is that new observations can be incorporated into the adjustment immediately after they are available and validated. A 'dynamic adjustment' allows for the regular or even continual upgrading of coordinate values. While modifying control values with any frequency might seem unpalatable at first, artificially constraining network stations and forcing new observations to fit the existing control will introduce distortions and tensions in the network as discussed above.

The result of increasing the frequency of adjustment would be increased homogeneity and reliability of all survey control coordinates. To date, the coordinates of the NSW spine network '2A0' control as determined in 1997 have been regarded as untouchable. While new observations and adjustments are allowed to affect the coordinates of subsidiary control as required, only exceptional circumstances will result in the change of spine coordinates. This is the reason why any distortions present during the initial densification of the datum in 1997 are still present today and being highlighted by new observations of better precision.

Other surveying maxims that are being challenged are the dismissal of the 'purpose of survey' (all observations are included in this adjustment out of context) and the neglect of network design (in terms of geography and repetition of observations). The implication of these paradigm changes should certainly receive proper attention and discussion in other forums.

1.5 A Comparison of Existing and Proposed Datum Methodologies

In light of the above discussions, Table 2 summarises the differences described between the existing and proposed datum definitions.

Table 2: A comparison between existing and proposed datum definitions.

	GDA94 as defined in 1997 ***(as applied in NSW)***	**GDA201x** ***(as applied in NSW)***
Primary Control	8 AFN *(1 in ACT/NSW)* 78 ANN *(13 in ACT/NSW)*	150+ CORS at final CORSnet-NSW network
Dimensions	3D with Ellipsoidal Height *(but 3D to ANN only within NSW)* AHD71 separate	3D with Ellipsoidal Height AHD71 remains separate
Observation Type (and Number)	GPS (*~ 3,000*) Terrestrial (*~38,000*)	GNSS (*60,000+*) No terrestrial at this time
Density	1st order spine control *(~3,000 stations)*	All control (*~20,000 stations and counting*)
Sectioning	YES: *(6 sections used to adjust NSW control, see Figure 1b)*	NO: Simultaneous adjustment of all control
Positional Uncertainty (95%)	Estimated: *(majority of NSW spine control at better than 250 mm)*	Computed for all control: Majority at better than 20 mm
Relative Uncertainty	Within individual adjustments	Between all control Full VCV computed
Update Frequency	Frozen *(at NSW spine control),* ad hoc local infill	Live / as required
Tectonic Plate Motion/Rotation	Ignored	Applied
Deformation	Limited application (only current coordinates available)	Monitored / applied

2 METHOD

The methodology for gathering, adjusting, testing and cleaning all GNSS vector data at LPI appears relatively straightforward (Figure 3). However, actually accomplishing the few steps required to collate and clean this data in a single adjustment was extremely time consuming, and indeed is still ongoing. Perhaps an initial aversion to opening all those 'big yellow folders' and piecing together a single adjustment for all the observations was well founded. The sheer number of observations precluded manual data mining and analysis. New software tools had to be developed for data and metadata gathering, for translation of the data, for adjustment, and for assessment of an adjustment of unprecedented size.

Not surprisingly, many of the same issues that were discussed during the original GDA94 adjustment were encountered here again, but on a significantly larger scale. These include stations with standpoint errors, non-standard names and archives in a multitude of data formats. For this study, only GNSS data has been collected; terrestrial data such as directions, distances and levelling is currently excluded.

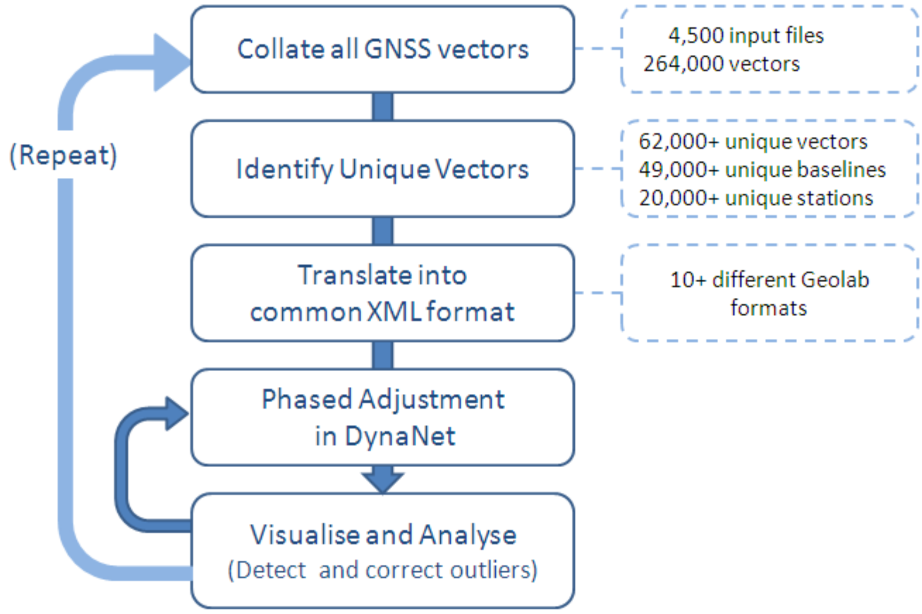

Figure 3: Flowchart of GNSS vector acquisition and cleaning

2.1 Data Sourcing (GNSS Vectors)

Historically, GPS observations and adjustments have been stored digitally within job-specific folders in the archives of LPI, and held uniquely at several offices around NSW. The large number of folders and significant repetition of information precluded manual investigation of these archives. Instead, a number of software 'spiders' were written to automatically scour every directory and file in these digital archives in search of GNSS observations.

The GNSS observations in these files were collated, compared and characterised according to the following criteria:

- Retain only one copy of each unique 3D vector (by spatial distance and station names).
- Adopt the weighting as per the most recent adjustment that employed this vector.
- Retain only vectors involving standard SCIMS naming (i.e. TS, PM, SS, MM).
- Exclude vectors that were flagged in the original adjustment (unless investigated).

More than 10 distinct GeoLab input formats were encountered. For instance, combinations of ΔXYZ, ΔNEH, ΔPLH, correlation matrices, covariance matrices, with and without SIGM weighting records, etc. were used variously at different times, and outliers were flagged in slightly different ways. Different weighting strategies have been employed as our understanding of GNSS processing has developed and matured over the decades. This made it difficult to combine and analyse the data. Ultimately, all formats discovered are automatically converted (by novel software) to a single format, an XML input in ΔXYZ with VCV matrices, suitable for use with DynaNet. As part of another ICSM project, a universal geodetic XML is currently under development for the future transfer of geodetic data between jurisdictions (Donnelly et al., 2013).

First in February 2012, and subsequently in August 2012, the LPI archives were data-mined and more than 264,000 GNSS vectors were located and characterised. Approximately 62,000 vectors were found to be unique, comprised of more than 49,000 unique baselines covering more than 20,000 stations (Figure 3 and Table 3). Interestingly, more than 80% of these baselines were found to have been observed on a single occasion. The most common GNSS vector length was approximately 600 m. In total, there were 21 times as many GNSS baselines as in the initial GDA94 adjustment.

Table 3: Numbers of stations and observations in GDA94 (Watson, 2006) vs. current adjustment.

(values rounded to nearest 100)	**GDA94 (NSW)**	**All GNSS Vectors (NSW)**	**Increase**
Stations	3,000	20,000+	6.8 x
GPS/GNSS Baselines	2,900	62,000+	21 x

2.2 Adjustment Constraints

Discussions with Geoscience Australia indicate that any new national adjustment would be constrained to CORS stations contributing to the Asia-Pacific Reference Frame (APREF – GA, 2012c) and also to AUSPOS solutions of significant duration. In this way, the CORS essentially become the new primary control and offer very high precision and ongoing monitoring of the stability of our datum at a density much greater than the ANN stations of GDA94.

The NSW network of GNSS observations is strongly linked to this CORS backbone by virtue of the 'local tie surveys' which provide connections between each CORSnet-NSW station and the local ground control in the area (Gowans and Grinter, 2013). At the time of the data mining, about 60% of the CORSnet-NSW stations had been explicitly connected to the surrounding control. As more of these connections are observed (and/or data-mined), the constraint supplied by the CORS will further improve the positional uncertainty across the network.

For the purposes of data-cleaning and initial testing, the GNSS vectors collated above are constrained by the Regulation 13 certification coordinates (GA, 2012d) of the CORSnet-NSW stations (115 in operation at the time of writing), and also 500+ AUSPOS solutions of greater than 4 hours at various stations across the state (Figure 4). The GNSS CORS are constrained to 10 mm in each X,Y,Z component, and the AUSPOS stations to 20 mm in each component, These constraints will be reviewed closely for use in any final datum product.

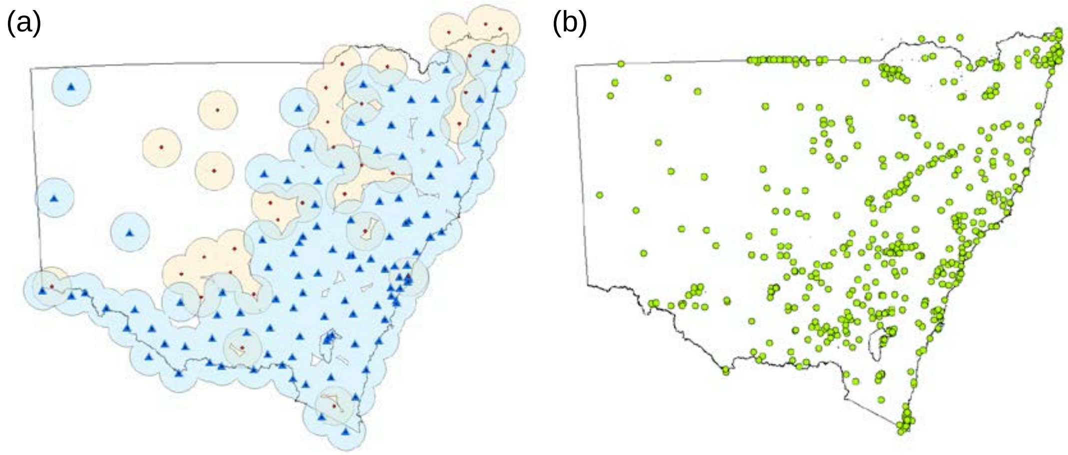

Figure 4: Datum constraining stations – (a) CORSnet-NSW stations (operational in blue and proposed in beige) with nominal 50 km operational radius, and (b) AUSPOS observations of more than 4 hours (green circles).

2.3 Adjustment and Ongoing Analysis

The simultaneous adjustment of all observations using DynaNet and the analysis of the results is an ongoing task. The large array of output information is being visually and numerically assessed using new software tools developed in house, to identify gross errors and outliers. These analyses included sorting the data before and/or after adjustment by 'observed minus expected' comparisons, observation residuals (raw and normalised), observation corrections, coordinate corrections, and vertical and horizontal Positional Uncertainty to name a few.

As expected, by combining adjustments that were previously been kept in isolation, the adjustment was initially plagued with issues relating to station naming and standpoint identification. These gross errors are generally detected by visual inspection, or identification of the 'worst' performing station or measurement. For this purpose, the display of the data geographically in ArcMap (see Figures 4-9) is invaluable for detecting patterns and outliers in the data. For example, if 'local' stations in an adjustment are labeled generically as 'PM1' in their original adjustments, then they would appear as very long and grossly incorrect vectors ending on the Far North Coast, where the true PM1 actually resides (Figure 5a). The common practice of naming a temporary station 'STN99' is fine in context, but no one ever considered the implications of combining multiple adjustments each with a STN99!

Additionally, since observations that span several decades are combined, different naming of the same station will result in two (or more) stations adjusting to coordinates in very close proximity (Figure 5b). For example, the station named 'TS5458' was re-named 'TS12033-3' when the original trigonometric station was replaced, but both names are present in the collated vectors. Of course, the inevitable typo or two were also flagged as significant outliers and easily fixed after reference to the original field notes. Note that these issues are normally detected by the quality control preceding a normal SCIMS update, but the current study has circumvented these procedures by gathering the raw vector data from the archives.

At the time of writing, the majority of these simple issues have been cleaned up, but the adjustment still continues to undergo additional cleaning. Smaller and more subtle errors are being detected through their effects on the surrounding adjustment as described in the sections below.

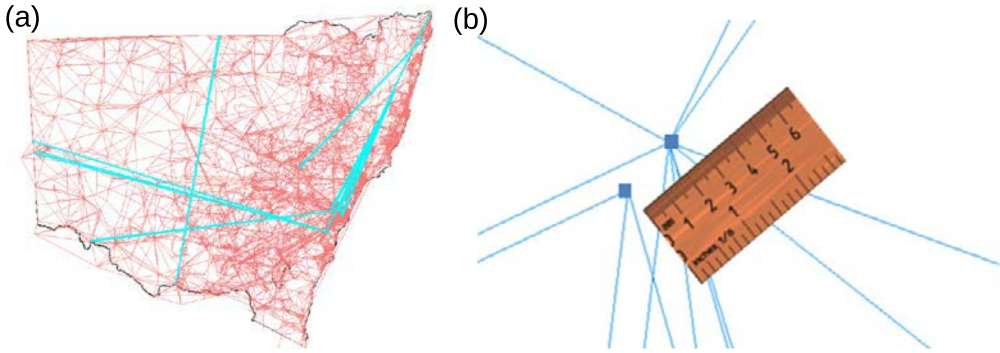

Figure 5: Incorrect station labels resulting in (a) erroneous baselines or (b) station duplication.

It is worth noting that the preparation for GDA94 involved a dedicated team of up to a dozen people working manually to collate and assess the data and the adjustment. In contrast, the current preparation of NSW data for GDA201x involves the part-time labours of two LPI staff who are primarily developing a suite of automated tools for the collation of the data, and where possible the automated detection and mitigation of errors. Most of the tools that have been developed are novel for this project, but will aid the organisation by allowing greater visualisation and interrogation of our existing dataset.

2.4 Adjustment Results

At the time of writing, only a handful of issues remain in the simultaneous adjustment of all GNSS vectors in LPI's archive. These have been flagged as orange or red vectors (Figure 6), with normalised residuals (NR) greater than 3 or 10 respectively. Recall that 99.7% of the NR values are expected to fall within ±3 (and ~95% within ±2 etc.). Therefore, a NR of ±3 was deemed a good cut-off value for the initial detection of outliers. The larger the NR, the less well the observation (and its weighting) fits the adjustment. Most (> 95%) of the observations fit well in this test dataset and the remaining outliers are generally being pushed around by a few vectors with very poor fit (see section 3).

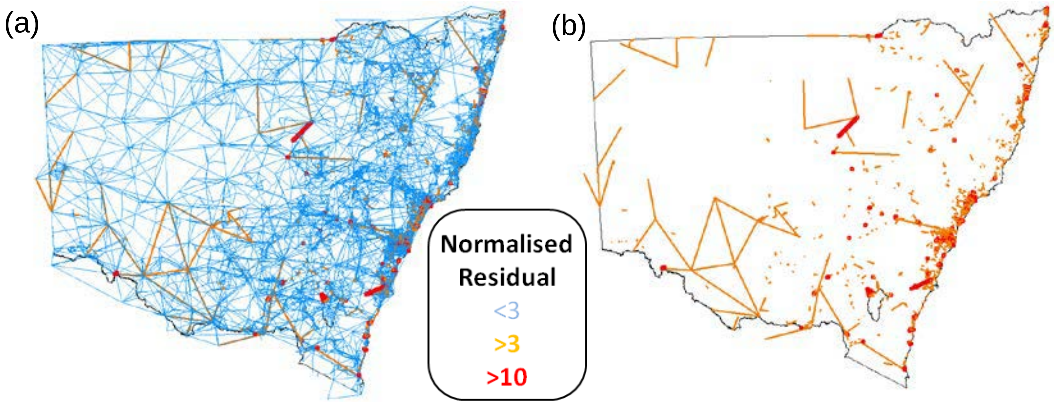

Figure 6: All GNSS baselines post DynaNet adjustment, validated observations in blue, flagged outliers in orange and red – (a) all GNSS baselines, and (b) outlier observations with NR > 3 only.

From this simultaneous adjustment, an initial assessment of PU (95% confidence) of all stations can be made. With the current CORS and AUSPOS constraints, the majority of stations have a computed horizontal PU of better than 20 mm, i.e. *more than an order of magnitude better than the estimated horizontal PU for GDA94*. As expected, stations in the western portion of NSW have higher PU (up to 100 mm), due to the relative scarcity of observations (see Figure 6).

2.5 GDA94(1997) SCIMS vs. GD94(2010) State-Wide Adjustment

By constraining the adjustment to the CORSnet-NSW Regulation 13 coordinates and AUSPOS solutions, the adjustment returns coordinates in GDA94(2010). As discussed in section 2.2, any national adjustment would be constrained in a similar way. Figure 7 shows a preliminary sample of the amount and direction by which existing SCIMS coordinates are expected to change after a new state-wide (or nationwide) adjustment. As expected, these changes mirror distortions highlighted previously by the CORSnet-NSW network (Haasdyk et al., 2010), i.e. up to 250 mm at the North Coast, and generally 100 mm or less in the Newcastle, Sydney, Wollongong, South Coast and inland areas. In some areas, this GNSS dataset is insufficient to determine these distortions.

Figure 7 demonstrates visually why a site transformation is restricted to a 'local' area where such changes from GDA94(1997) to GDA94(2010) are quite consistent (Haasdyk and Janssen, 2012). Obviously a complex transformation such as the NTv2 grid method employed between AGD66/84 and GDA94 would be required for datasets spanning larger areas.

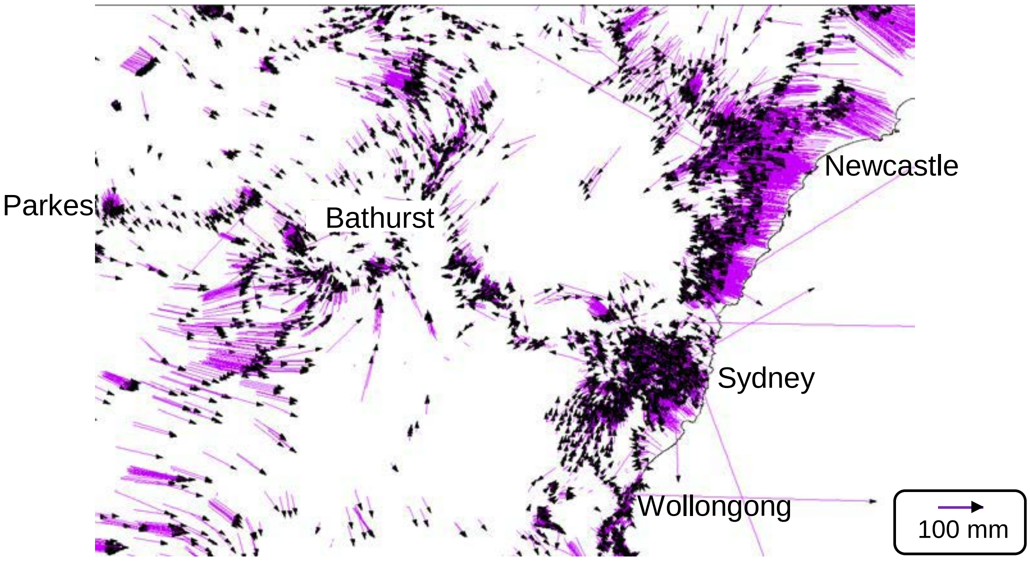

Figure 7: Expected change from GDA94(1997) SCIMS coordinates to a new adjustment in GDA94(2010) shown as purple vectors with black arrow heads. Some black arrow heads are omitted on shorter vectors for display purposes. Only established stations are included (Class C or better). Note that some large coordinate changes are present, indicating gross movement of individual stations.

3 THE NEXT STEPS

Despite the progress made thus far, there is still a lot of work to do before this dataset is free from gross errors and appropriately weighted for a simultaneous adjustment. The sections below describe the next steps for this project, and the methods by which the dataset is still being actively cleaned before submission (in whole or part) to Geoscience Australia by the middle of this year.

3.1 Identification and Elimination of Remaining Gross Errors

The task of eliminating the remaining gross errors is still ongoing, purely because it requires significant manual interaction. It is well known that the least squares method spreads errors across an adjustment, which can make the identification of offending observation(s) difficult

and time consuming. Every tool that is developed in-house highlights a new class of issues and sparks additional adjustments and/or debugging of the collation and translation software.

As an example, a region on the South Coast of NSW suggested that a 2-metre shift between SCIMS coordinates and the new adjustment may be expected (Figure 8). Upon investigation, it was found that this region of the network has suffered from a single standpoint error, i.e. the GNSS vector from the archive suggested that a certain trigonometric station was occupied, but investigation of the field notes revealed that the real occupation was of an eccentric mark, 2 metres away. Correcting this gross error improves the adjustment in this region significantly by removing the erroneous stress from the network.

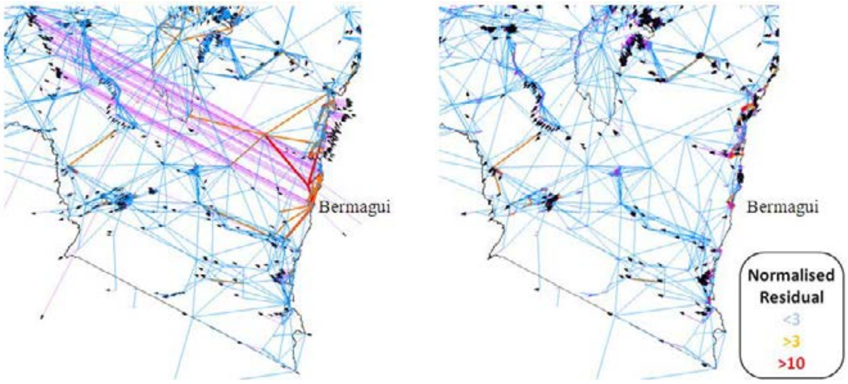

Figure 8: DynaNet adjustment before and after gross error elimination with validated observations in blue, flagged outliers in orange and red. Purple vectors with black arrow heads indicate expected change in coordinates of approximately 2 metres.

Finally, after the dataset is considered clean, it will be instructive to re-introduce known errors of various magnitudes in order to determine the smallest error that can be detected in the existing dataset via least squares, or other error detection methodologies.

3.2 Investigation of Station Movement

Investigations into the remaining outliers suggest that a number of our trigonometric stations are subject to significant land subsidence and/or movements of the monuments. For example, TS5551 Milbrodale (southwest of Singleton) has been known to move both horizontally and vertically due to nearby mining. If the adjustment assumes that this station has constant coordinates over time, observations taken at various epochs will significantly disagree with each other (Figure 9a). When this station's coordinates are solved separately for each campaign, then the outliers in the adjustment disappear (Figure 9b). TS5551 is shown to have moved more than 0.6 m horizontally and 1.6 m vertically between 2002 and 2009!

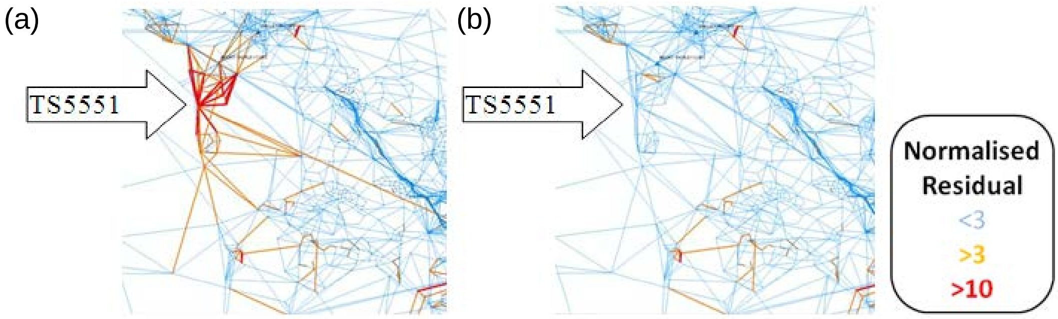

Figure 9: Effect of land subsidence on measurement residuals for observations spanning many years – (a) TS5551 assumed to be constant over time, and (b) TS5551 solved separately at each campaign observed.

It remains to be determined which other stations are subject to movement, but it is quite obvious that stations on silos, water reservoirs and other tall buildings will need to receive special attention, as well as stations near known mining and subsidence areas (Figure 10).

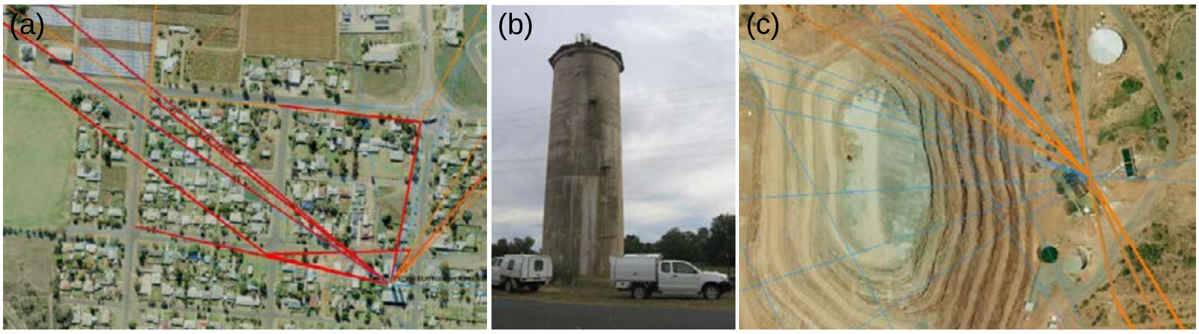

Figure 10: (a) TS7350 Euston showing significant measurement residuals, (b) TS1619 Coonamble on top a water reservoir, and (c) TS6697 Robinson, a concrete pillar on a building, next to significant 'earthworks'.

3.3 Inclusion of Additional Stations

As noted above, this analysis was limited to stations already issued with SCIMS coordinates and therefore following standard SCIMS naming conventions (i.e. TS, PM, SS, MM). Additional vectors have been identified with stations that served as standpoints in a GPS network but were never intended for inclusion in SCIMS, such as various GI pipes, dumpies and iron spikes. These vectors could be useful and necessary for improving the connections and redundancy of the network, and for subsequent control of associated terrestrial surveys.

3.4 Mining New Data

Since the most recent data mining event in August 2012, additional observations have been gathered by LPI staff or submitted by external organisations. Now that our methodologies are maturing, and our existing dataset is nearly clean, it will be necessary to increase the frequency of data mining so that our analysis is more current and our visualisation tools become more and more useful for the planning of future campaigns.

3.5 Mining Metadata

Since the Australian tectonic plate is not just moving but also rotating (Stanaway et al., 2012), any state-wide or national GDA201x adjustment will require vectors to be rotated to a common epoch before adjustment. For this reason, as well as for the completeness of any new database of geodetic observations, additional metadata is required for each observation. Now that the vectors of interest have been identified, more information is required about the date of observation, the GPS/GNSS solution type, etc. Gathering relevant metadata will require the development of more tools and another mining of the archives.

3.6 Distances, Directions and Levelling

At this stage, the intention is to only include GNSS vector observations in this large scale geodetic adjustment. The 20,000 marks involved represent only about 8% of the marks currently held in SCIMS, and 14% of the existing 140,000 established marks with Class C or better. Other marks in SCIMS are connected by terrestrial techniques such as directions and distances or by levelling only. Where necessary, other observations can be included in order

to add marks of particular significance. Gathering all terrestrial and levelling observations could be an even larger task than the GNSS data mining described here. In the absence of a simultaneous adjustment of all observation types, subsequent adjustments (or novel transformations) will need to be employed to re-coordinate the remaining SCIMS marks as required.

While the present adjustment is 3-dimensional, the height values produced are ellipsoidal heights in GDA94(2010). The scope of this adjustment does not currently include any reference to the Australian Height Datum (AHD) and would not affect AHD71 values in SCIMS. However, through the application of AUSGeoid09 (Brown et al., 2011), orthometric levelling observations could be added to this state-wide adjustment to detect gross errors and improve the AHD71 surface.

3.7 Connection of GNSS Islands

Our investigation has identified a number of 'islands' of GNSS observations that are currently not connected to any of the constraining CORS or AUSPOS stations. This knowledge helps to inform our field staff when planning future campaigns in order to obtain these connections, thus strengthening the network. In addition, 'local tie surveys' to some existing and all new CORS still need to be observed (and/or data-mined) in order to fully constrain the network to GDA94(2010).

3.8 Review of Vector Weighting and Constraints

This GNSS archive dataset has been adjusted 'en masse' using the weighting as originally applied to each observation. However, these observations have been gathered over two decades, and a variety of business rules regarding the weighting of GNSS vectors have been applied over that time. It would be useful to re-weight each GNSS vector using the same algorithm (to be determined) before the final state-wide adjustment. Similarly, the constraints applied have been preliminary and for testing purposes only. A review of the constraints applied is required before any final national adjustment.

4 CONCLUDING REMARKS

History has demonstrated that the drivers for datum change generally include the increased quality and quantity of observations and the resulting user requirement to remove measurable distortions. Now, using literally a continuous stream of high-precision geodetic observations from a large number of stations, the limitations and distortions of GDA94 have been demonstrated and a new Australian datum is being carefully considered. Many new and more precise geodetic observations are available between local ground control since the last datum update. All states and territories in Australia have been mandated to collate and clean a primary network of geodetic data to facilitate investigations into a possible datum update. The intention is to adjust all observations, nationwide, in a simultaneous adjustment using the DynaNet software in order to create an improved and consistent datum across Australia, here hypothetically called GDA201x.

To this end, a collection of all geodetic GNSS observations across NSW has been created from the archives at LPI. At the time of writing, this dataset contains more than 20,000 stations and 62,000 unique baselines. Not surprisingly, a simultaneous state-wide adjustment

of this dataset, combining adjustments spanning thousands of kilometres and two decades, requires a significant amount of testing and cleaning. Significant progress has already been made. The handful of errors remaining can generally be attributed to outstanding standpoint or naming errors in the dataset, and/or marks that are known to be unstable.

The computed Positional Uncertainty of the 20,000+ stations in the adjustment is better than 20 mm for the majority of marks in the network, and up to 100 mm in the western division, i.e. up to an order of magnitude better than in GDA94. These values will likely improve with more connections to CORS and AUSPOS in future adjustments. Expected horizontal coordinate changes between SCIMS and any new adjustment on GDA94(2010) are up to 250 mm at the North Coast, and generally 100 mm or less in the Newcastle, Sydney, Wollongong, South Coast and inland areas.

Through the DynaNet software, we now have the ability to incorporate new observations into a state-wide or national adjustment immediately after they become available. Therefore, it makes sense to have these data ready and cleaned, not just for this datum definition, but in preparation for future requirements. LPI aims to create a current, searchable and visualised database of its geodetic observations to assist with planning and datum maintenance. LPI is on track to submit this extensive network, far in excess of the requested primary network, for initial testing of a nationwide simultaneous adjustment in the middle of 2013.

In summary, we have 'dusted off' all of our yellow folders, tipped them all on the floor, sorted them out and put them back together again. The result is a new massive yellow folder with a desk of its own that is a living and changing adjustment across NSW. When soon combined with the similar 'folders' from all other states and territories, we will start to see a homogenous datum across Australia that is capable of adapting to the next-generation(s) of technologies and spatial data.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the decades of work that have gone into collecting, processing, adjusting and maintaining quality control over the wealth of survey information held by NSW Land and Property Information. Many thanks also to Roger Fraser (VIC DSE) for his continual work to improve DynaNet and to Steve Tarbit (QLD DERM) for a useful DynaNet-to-ArcMap utility.

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Discussion Forum: Impacts of a Next Generation Datum for Australia

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ABSTRACT

It is well known that our national datum is plagued by distortions, e.g. GDA94 shows 200 mm distortions near Ballina. CORSnet-NSW operates in a different realisation of GDA94 to ensure that modern positioning services such as Network RTK and Virtual RINEX function correctly, but these solutions are generally not compatible with GDA94 coordinates of ground control marks stated in the state's Survey Control Information Management System (SCIMS) database. Using Geoscience Australia's free online processing service, AUSPOS, generates similar problems in regards to SCIMS. Therefore surveyors have to perform site transformations to essentially degrade perfectly good measurements to fit the existing fabric. GDA94 as we know it is getting old. Meanwhile, modern smart phones measure position using the GPS and GLONASS satellite constellations. Soon Galileo and Beidou signals will be included which could mean sub-metre, maybe even decimetre positioning in real-time for the mass market. Geoscience Australia is tasked with datum maintenance for Australia. The improved positioning capabilities brought about by satellite positioning techniques have exposed movements which could previously be ignored with traditional datums. Plate tectonics, ground subsidence and surface creep will become increasingly detectable by mass market positioning users. A next generation datum will need to accommodate these users whilst maintaining its integrity with a precision that is an order of magnitude higher than the current GDA94 datum. Users can be classified as expert users (geodesists), professional users (surveyors and geospatial professionals) and general users (mass market). There is no doubt that the numbers of general users will swamp expert and professional users. So how will a modern, next generation datum satisfy the needs of all these user groups? How can this modern datum accommodate the complexity of earth motion for expert users whilst insulating the mass market user from this complication and maintaining the utility of the datum for the professional user? This interactive discussion forum will seek to gather feedback from a segment of the professional user community about the potential impacts of a next generation datum and how we as a community can minimise any disruption during this transition.

KEYWORDS: *Next generation datum, infrastructure, GDA94, Australia.*

Tying It All Together: CORSnet-NSW Local Tie Surveys

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ABSTRACT

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

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

1 INTRODUCTION

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

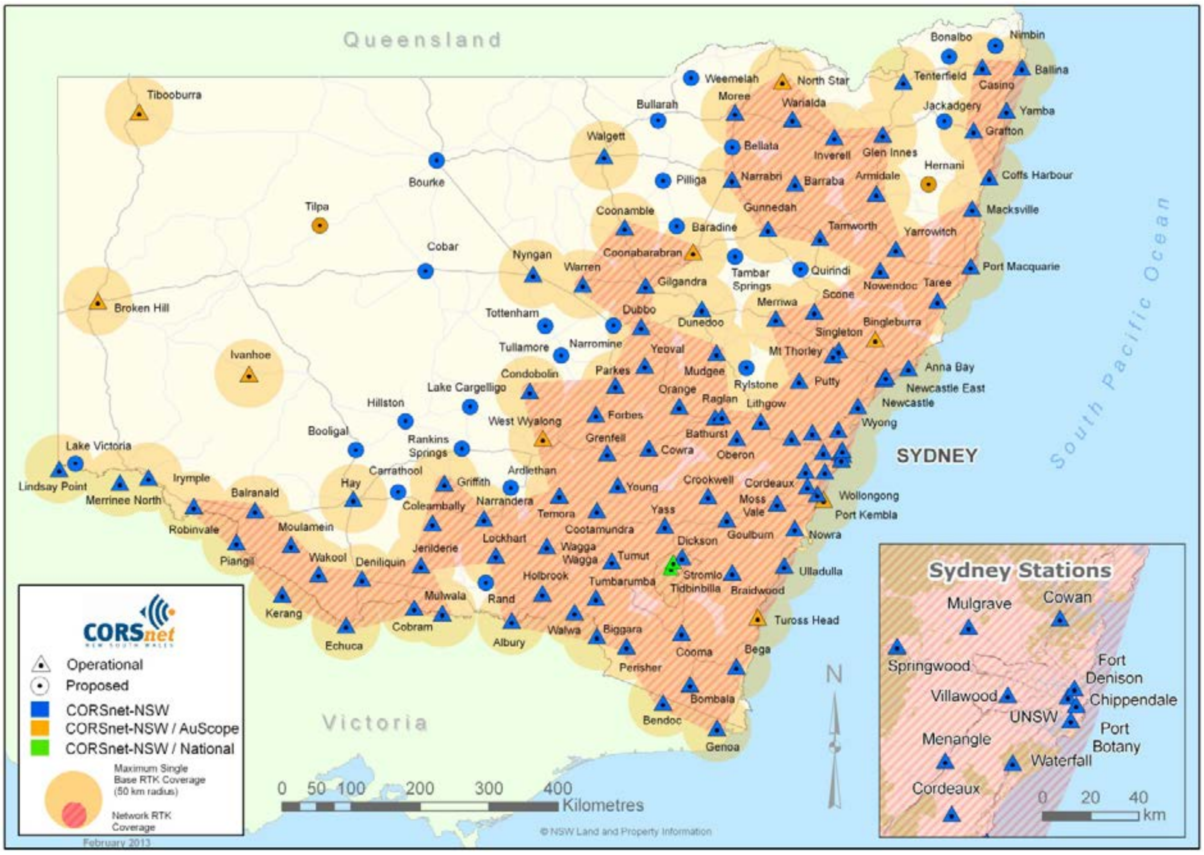

Figure 1: Current coverage of CORSnet-NSW (February 2013).

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

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

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

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

2 METHODOLOGY

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

2.1 Network Design

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

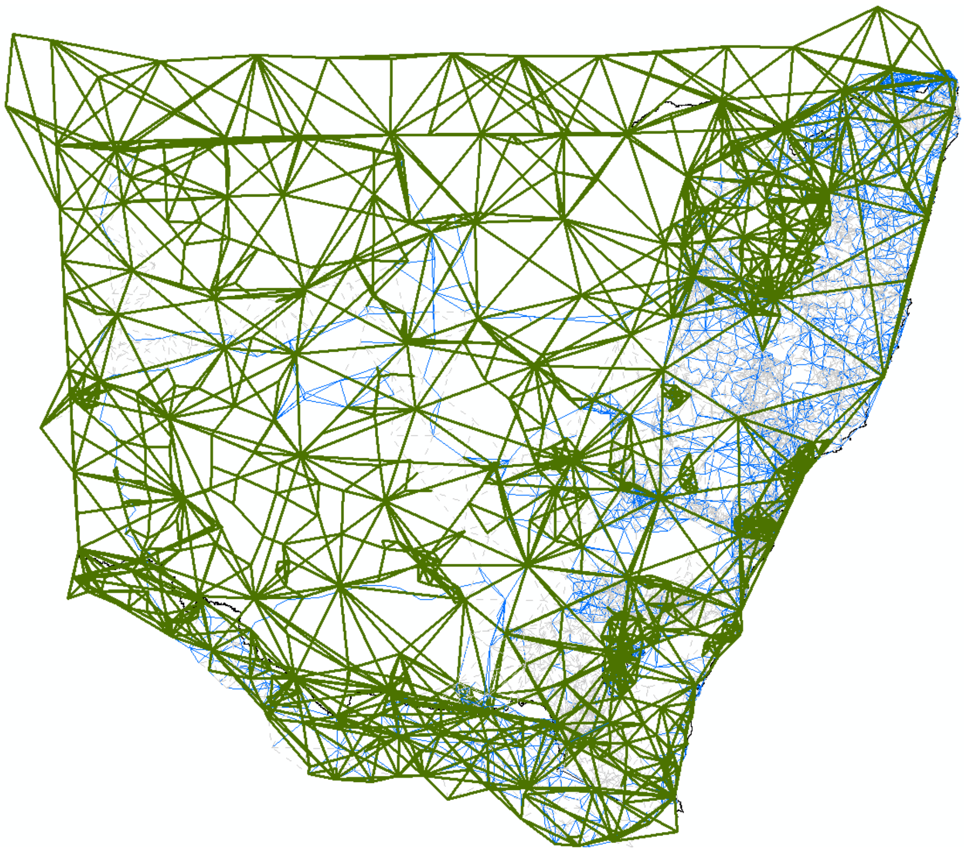

Figure 2: GDA94(1997) NSW spine network composed of GPS (green) and terrestrial (blue/grey) observations.

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

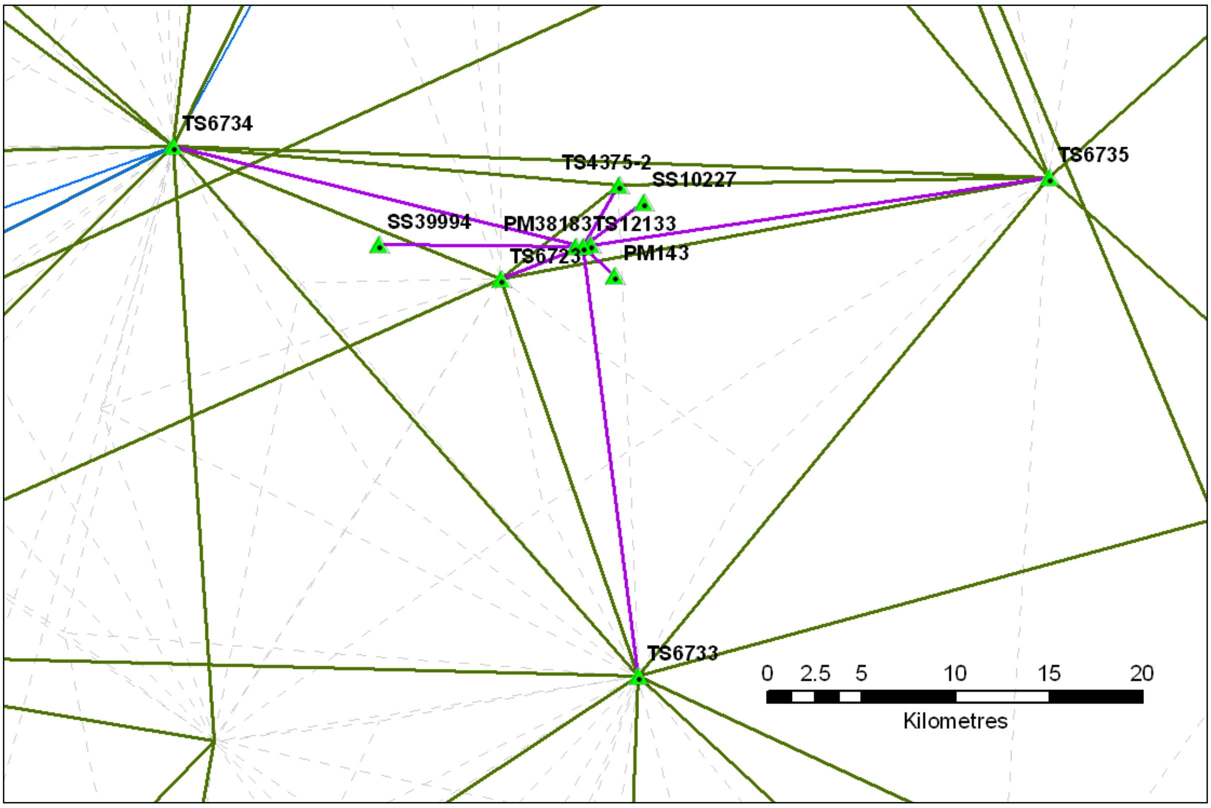

Figure 3: A typical far array network (here for Cooma CORS), showing the tie survey baselines (purple) along with the existing GPS spine (green) and DDS spine (blue/grey).

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

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

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

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

network will be considered suitable for this purpose. For a detailed discussion on the allocation of class and order, see section 4.

Marks are selected according to their:

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

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

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

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

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

2.1.3 Planning

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

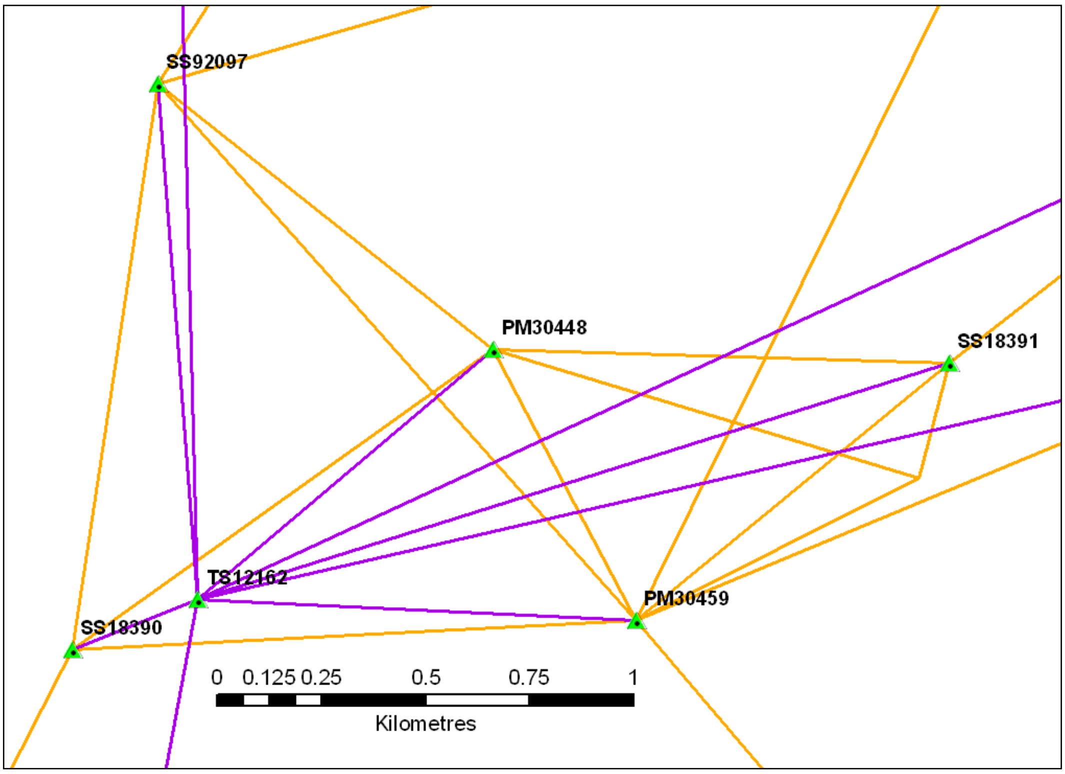

Figure 4: A typical local array network (here for Lockhart CORS), showing the tie survey baselines (purple) along with the existing A1 sub-spine (orange).

2.2 Processing, Reduction and Adjustment

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

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

2.2.1 Transfer of Height from AHD71 Ground Control

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

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

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

3 CASE STUDIES

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

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

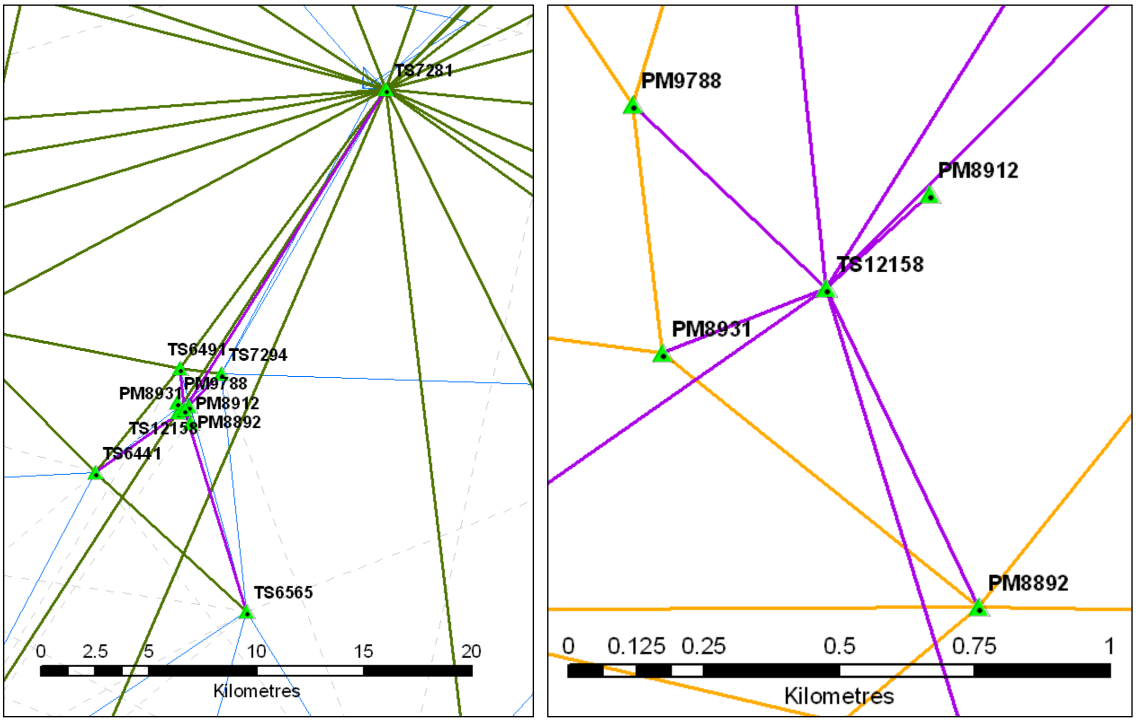

Figure 5: Parkes CORS (TS12158) local tie survey (purple) amongst GPS spine (green), DDS spine (grey/blue) and A1 sub-spine (orange).

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

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

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

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

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

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

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

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

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

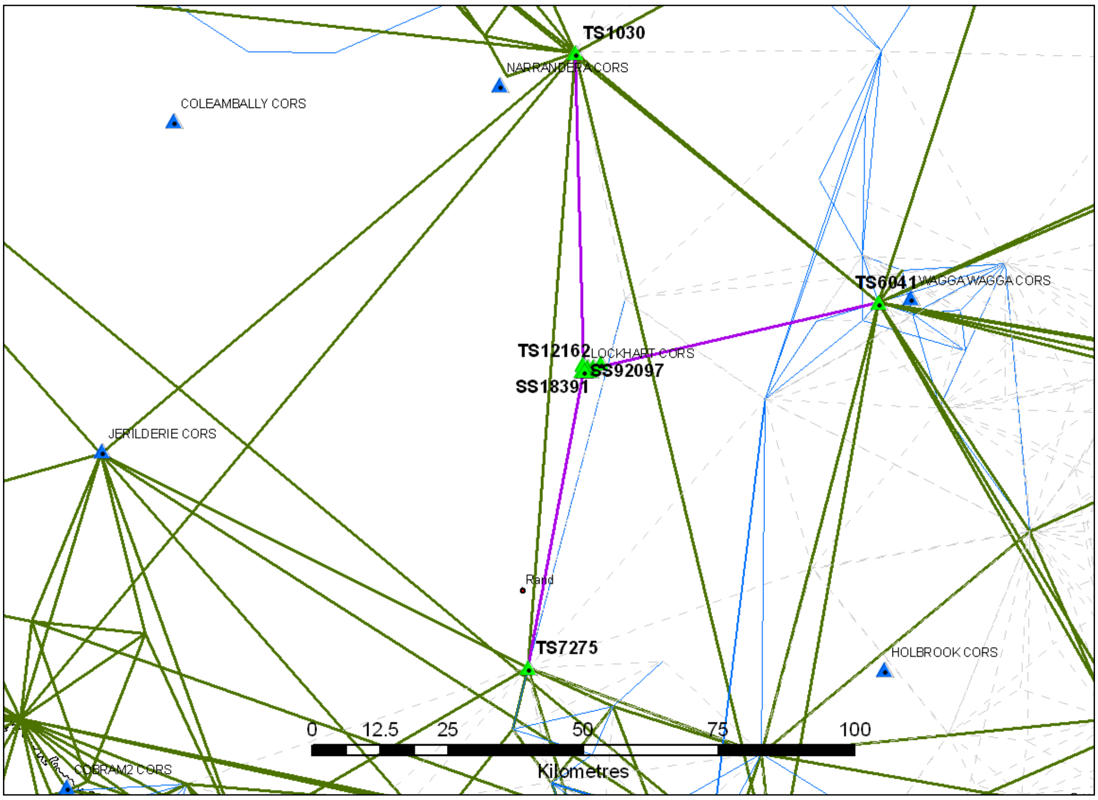

Figure 6: Lockhart CORS (TS12162) local tie survey (purple) amongst GPS spine (green) and DDS spine (grey/blue).

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

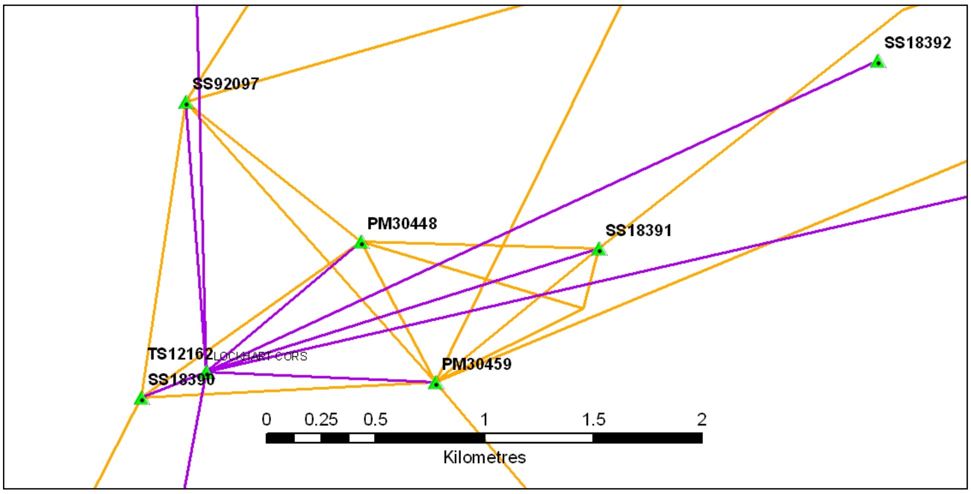

Figure 7: Lockhart CORS (TS12162) local tie survey (purple) amongst A1 sub-spine (orange).

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

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

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

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

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

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

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

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

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

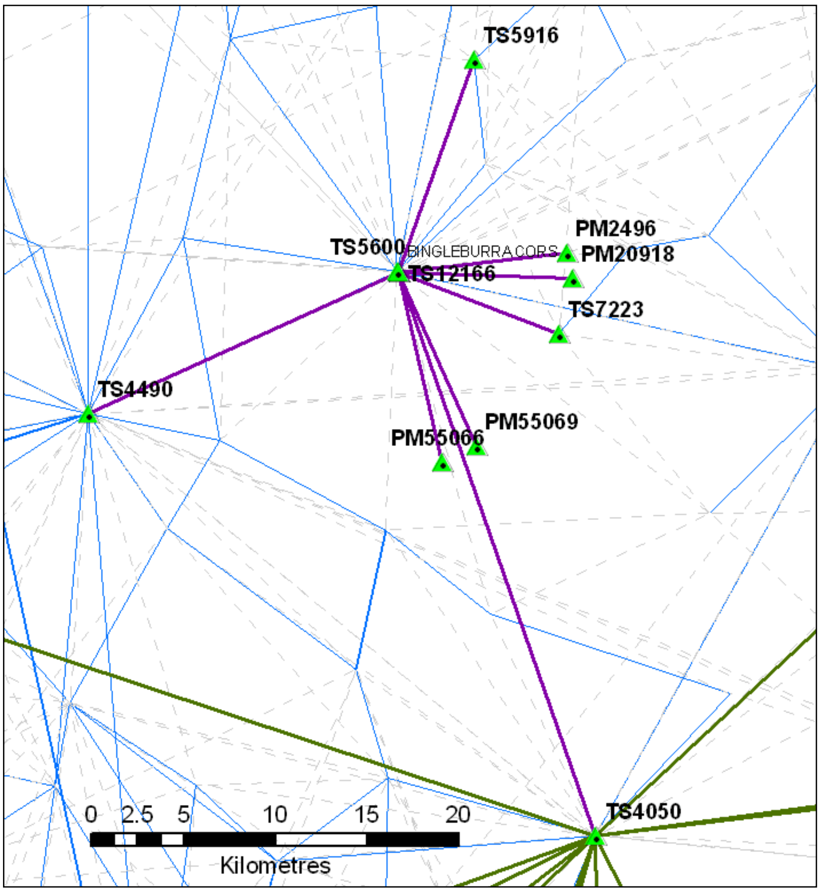

Figure 8: Bingleburra CORS (TS12166) local tie survey (purple) amongst GPS spine (green) and DDS spine (blue/grey).

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

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

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

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

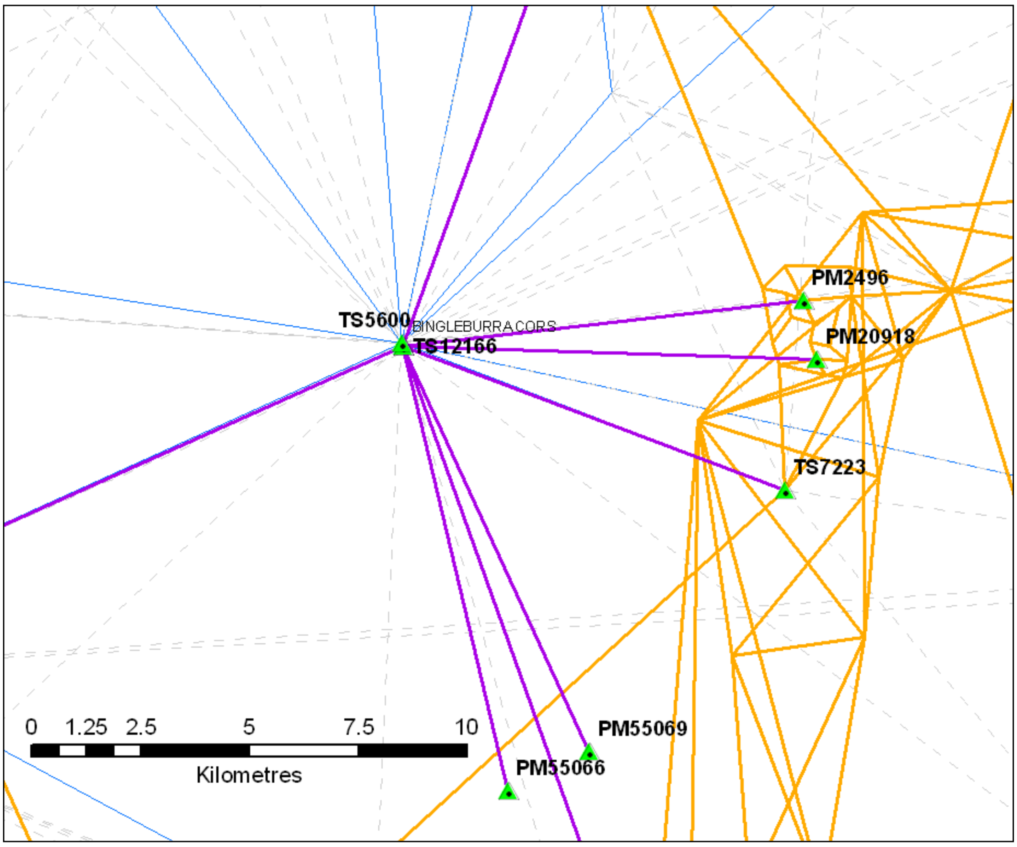

Figure 9: Bingleburra CORS (TS12166) local tie survey (purple) amongst regional sub-spine (orange) and DDS spine (blue/grey).

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

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

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

4 ALLOCATION OF CLASS AND ORDER TO CORSnet-NSW STATIONS

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

4.1 Class

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

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

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

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

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

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

Table 6: Classification of horizontal control surveys from SP1.

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

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

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

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

4.2 Order

SP1 defines order as "*a function of the class of a survey, the conformity of the new survey data with an existing network coordinate set and the precision of any transformation process required to convert results from one datum to another*." As stated earlier, the immediate goal of CORSnet-NSW local tie surveys is to produce 'local-fit' coordinates, and this is usually achieved by holding the A1 sub-spine control fixed in addition to the 2A0 spine control.

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

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

The subject of CORSnet-NSW local tie surveys is a classic example where the relevant authority (i.e. LPI) is allowed the liberty of allocations of class and order that do not satisfy the standard rules of SP1. Inserting a CORSnet-NSW station (essentially a modern spine station) into a dense survey ground network means a sub-mm error ellipse would be required to satisfy the standard rules of SP1. Even if the allocation was downgraded to A1, this would result in a required error ellipse of less than a few millimetres over short distances. This is

impossible to achieve with standard survey GNSS observations. Therefore, taking into account the intent of the mark, LPI will issue a class and order allocation for CORS of 2A0 as a business rule when deemed appropriate. However, in areas of particularly notable distortions or exhibiting a lack of available control, this allocation may be downgraded to A1, or even B2, at the discretion of an LPI Senior Surveyor. For example, Ballina CORS has been allocated horizontal class A and order 2.

5 TOWARDS A NEW DATUM ADJUSTMENT

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

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

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

6 CONCLUDING REMARKS

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

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GNSS-Based Animal Tracking: An Indirect Approach

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ABSTRACT

Global Navigation Satellite System (GNSS) technology has revolutionised the way 3-dimensional positions are determined on and above the surface of the Earth. Over the last two decades or so, GNSS has evolved into a vital positioning tool for a wide range of applications reliant on spatial data. One such application is the tagging and tracking of animals to better understand animal behaviour and ecology (the study of the relationships that living organisms have with respect to each other and their natural environment). Monitoring animal populations is also necessary for conservation purposes and to limit negative effects on the human population, particularly in an era of human expansion into traditional animal habitats. GNSS technology has allowed significant advances in this field by providing the ability to obtain accurate, regular and frequent estimates of the changing distributions of many rare animal species. However, employing conventional GNSS-based animal tracking methods to study species that spend most of their time in treetops is extremely difficult because the tree canopy regularly causes extended periods of complete GNSS signal loss. This paper proposes an indirect GNSS-based approach for the tracking of tree-dwelling animals. This involves tracking the prey rather than the predator in order to map the animal population in a particular area. Using a case study on drop bears, it is shown that this method can be used to effectively estimate the number of animals present in the area and provide valuable insights into its hunting behaviour.

KEYWORDS: *Animal tracking, ecology, drop bears, GNSS.*

1 INTRODUCTION

The advent of Global Navigation Satellite System (GNSS) technology has revolutionised the way 3-dimensional positions are determined on and above the Earth's surface. GNSS-based positioning has become a vital tool for a wide range of applications in areas such as surveying, mapping and asset management, precision agriculture, engineering and construction, airborne imaging and sensors, and utilities management. A lesser known application that has benefited immensely from the introduction of GNSS technology is animal tracking.

Australia is home to many unique animals, particularly monotremes (i.e. echidna and platypus) and marsupials such as the kangaroo, wallaby, koala, possum, wombat, drop bear and Tasmanian devil. Monitoring these animal populations is important to ensure their conservation and to limit negative effects on the human population (e.g. in the tourism and agricultural sector), particularly in an era of ever-increasing human expansion into traditional animal habitats. Several species, such as the Tasmanian devil, are currently declining, and others, such as the drop bear, are rarely seen. At present, relatively little is known about several indigenous species whose status may be threatened.

Animal tagging and tracking, i.e. the monitoring and recording of the animal's sequential positions, has been used for about 50 years to better understand animal behaviour and ecology (the study of the relationships that living organisms have with respect to each other and their natural environment). Initially, animal tracking relied on VHF (very high frequency) radio technology. Disadvantages of this approach include the requirement of receivers being close enough to the animals to triangulate animal positions and the low temporal resolution of position fixes.

The use of GNSS technology has been responsible for significant advances in this field by providing the ability to obtain accurate, regular and frequent estimates of the changing distributions of many rare species of animals (Tomkiewicz et al., 2010). At first, only large vertebrates such as elephants (Douglas-Hamilton, 1998) and bears (Schwartz and Arthur, 1999) were able to be tracked due to the considerable sensor size and the reliance on rather large, heavy battery packs. Technology improvements and the miniaturisation of equipment allowed the tracking of much smaller animals, including possums (Dennis et al., 2010) and pigeons (Steiner et al., 2000). In all these cases, the GNSS sensor is directly attached to the animal of interest. This makes studying species that spend most of their time in treetops extremely difficult because the tree canopy regularly causes extended periods of complete GNSS signal loss.

This paper addresses these shortcomings by proposing an indirect GNSS-based method for the tracking of tree-dwelling animals. Rather than tracking the animals themselves, the prey is tracked in order to infer the location and size of the population. Using a case study, it is shown that this approach can be used to effectively estimate the number of drop bears in a given area and obtain valuable insights into the animal's hunting behaviour.

2 DROP BEARS

The drop bear (*Thylarctos plummetus*) is an arboreal (i.e. tree-dwelling), predatory marsupial that closely resembles the koala (*Phascolarctos cinereus*) and is therefore difficult to spot. Colloquially, it is often referred to as the carnivorous 'evil twin' of the koala because it is a vicious creature sharing a very similar habitat. Based on megafauna bones discovered in Aboriginal middens, it is believed that the two present species evolved from a single ancestor during the late Holocene. Theories that its dropping skills follow from genetic similarities with sugar gliders remain empirically untested.

The drop bear is a strongly built animal with powerful forearms and claws for climbing and holding on to prey. In stark contrast to the very similar looking but smaller koala, it has large canine teeth that are used very effectively as biting tools. The drop bear generally hunts during the day by ambushing ground-dwelling animals from above, skilfully latching onto the victim's neck to kill its prey. Quietly waiting in a tree for several hours, it closely resembles a sleeping koala. Once prey is within striking range, the drop bear will drop several metres out of the tree to pounce on top of the unsuspecting victim (Figure 1). The initial impact generally stuns the prey, allowing it to be bitten on the neck and quickly subdued. The examination of kill sites and scats indicates that medium to large species of mammal make up most of the animal's diet (Hosking, 2012). Often, the prey is considerably larger than the drop bear itself. A nocturnal variation of the species (*Thylarctos plummetus vampirus*) has resorted to draining the prey of its blood rather than feasting on its flesh (Lestat, 2010).

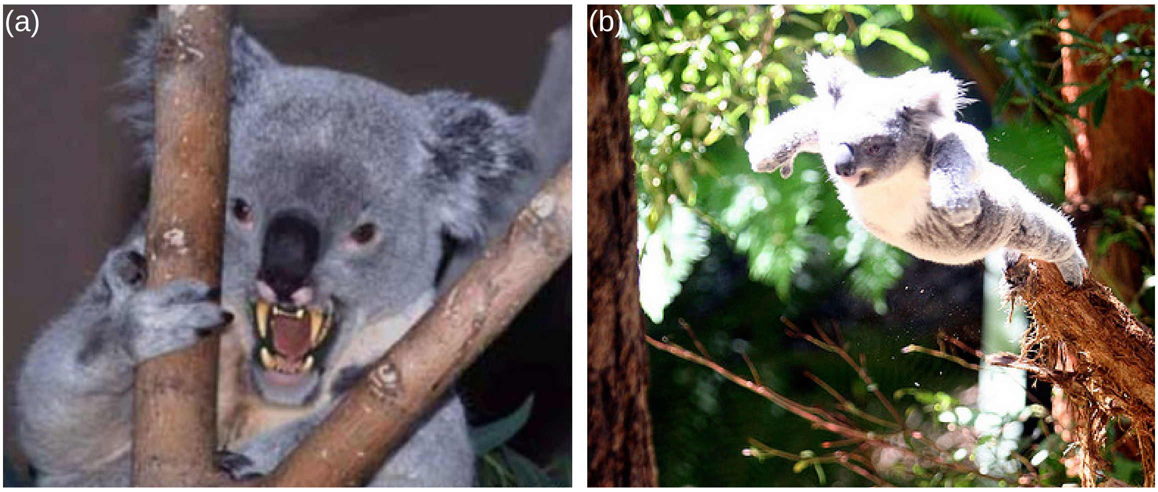

Figure 1: Drop bear (a) in its habitat and (b) attacking prey.

The drop bear is mainly found in coastal regions of eastern and southern Australia, stretching from the Cape York Peninsula to Tasmania. Populations also extend for considerable distances inland in regions with enough moisture to support suitable woodlands not limited to eucalypts. Woodland is crucial since drop bears are not easily able to drop from spinifex bushes and desert plants. It should also be noted that fewer victims in more arid environments reduce the ability to work downwards through the food chain and thus considerably lower survival rates. Reports of periodic attacks on opal miners in Coober Pedy may be questionable and related to excessive consumption of cooling amber fluids in dry areas.

The distribution of drop bears across Australia is quantified by the National Drop Bear Index (NDBI), which indicates the average population density per square kilometre (Figure 2). Aboriginal dreamtime legends suggest that the drop bear was once much more widespread, hence the need for contemporary conservation.

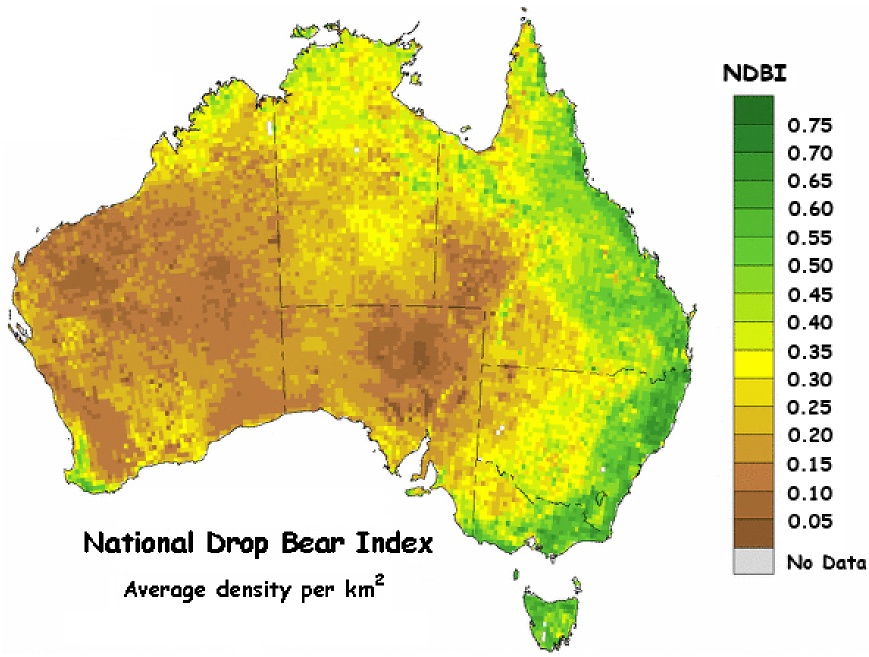

Figure 2: Distribution of drop bears in Australia, quantified by the National Drop Bear Index (NDBI).

Unlike other peculiar Australian animals such as the bunyip and the hoop snake, which are rarely encountered in even thinly populated areas, drop bears pose a considerable risk to unsuspecting bushwalkers, particularly tourists, because they closely resemble the koala. While the Australian government has been accused of orchestrating a conspiracy to cover up the existence of drop bears in order to protect the tourist industry (Langly et al., 1999), these claims have never been substantiated.

Drop bears do not specifically target human beings, but there have been several cases where humans have fallen victim to drop bear attacks, resulting in serious lacerations and even death (Home and Away, 2011). Disappearances which may (or may not) be attributed to drop bears have occurred frequently across Australia (e.g. Holt, 1967; Hussey, 1989; Mulder and Scully, 2000).

Several methods have been proposed to protect humans from drop bear attacks, although their effectiveness often remains scientifically inconclusive (e.g. Skywalker, 2008; Janssen, 2011). These methods include wearing forks in the hair, spreading vegemite or toothpaste behind the ears or under the armpits, urinating on oneself, and avoiding talking in a foreign language or an accent other than Australian.

Other studies have indicated that by-products of the interaction between chemicals found in vegemite and those found in human sweat repel drop bears (Honeydew, 2003). Most Australians and immigrants who have lived in Australia for long periods of time tend to eat vegemite consistently (usually at least once a day), so exuding these chemicals through their skin permanently, and are thus protected. Visitors, on the other hand, do not have this ‘natural’ protection and are therefore advised to apply a liberal amount of vegemite to the skin, the most suitable area being just behind and towards the top of the ear because this area is prone to sweating and closest to the top of the head.

While it is recognised that more research is required, there is unmistakable evidence that tourists are much more likely to be attacked by drop bears than Australians. Genetic analyses suggest that this may be related to the Australian ‘mateship’ trait, which extends to animals unique to Australia (Crikey and Beauty, 2008). Furthermore, it has been shown that drop bears can detect foreign languages and are prone to target the origin of such sounds, but using the Aussie lingo may fool the average drop bear (Stewart, 2005). This indicates important and unusual parallels with the equally rare invasive alien species, the Bundy bear, which similarly favours arboreal habitats and preys on tourists, especially young female blonde foreigners. However, drop bear attacks on humans are rare, mainly because Australians are familiar with drop bear ecology, tourists are deliberately diverted, and reality TV survivor series are usually undertaken elsewhere.

Investigating the effectiveness of several methods of protection against drop bear attacks has shown that the best protection is achieved by wearing a motorcycle helmet when bushwalking in drop bear territory, although this may be impractical in tropical regions (Skywalker, 2008). An accomplished method of determining whether a drop bear may be lurking in the flora canopy is to lie down beneath a tree and spit upwards. If a drop bear is sleeping above, it will most likely wake up and spit back (Young et al., 1981). However, this approach includes some risk, and the consequences can be devastating if drop bears are on the hunt for prey or in the middle of the mating season. Bushwalkers are advised to exercise caution in areas frequented by drop bears, hence the value of the present research.

3 INDIRECT GNSS-BASED ANIMAL TRACKING

Monitoring drop bears is essential to ensure that a sustainable animal population is maintained, while limiting the possibility of attacks on humans. Employing conventional GNSS-based animal tracking methods (e.g. Dennis et al., 2010; Tomkiewicz et al., 2010) on drop bears or other tree-dwelling animals is extremely difficult because the dense tree canopy often results in extended periods of complete GNSS signal loss. Due to the viciousness of the drop bear (even under sedation), there is a considerable risk of injury when the sensor is attached. In addition, the GNSS sensor is prone to severe damage and loss during attacks on prey and due to the animal's habit of rubbing its body against tree branches. This severely reduces the availability of meaningful tracking data and substantially increases the cost of drop bear tracking.

In order to avoid these disadvantages, an indirect GNSS-based approach is proposed. This indirect method involves tracking the prey rather than the predator, thus pinpointing the location and timing of drop bear attacks in order to map the animal population in a particular area. Drop bears are known to be very territorial and generally do not stray far from a relatively small number of trees, located in close proximity, that are used as hunting ground. The location of attacks therefore provides a good indication of where a drop bear resides.

4 CASE STUDY

A case study is used to demonstrate the effectiveness of the proposed indirect GNSS-based animal tracking method. The study area is located in the northern part of Morton National Park, about 120 km southwest of Sydney. The indirect tracking approach was used to estimate the number of drop bears inhabiting this area.

Several research assistants (mainly thrill-seeking international students in dire need of financial support) were equipped with GNSS sensors to track their position during bushwalks off the beaten track. The GNSS sensors utilised the differential positioning technique to provide high-quality real-time positioning solutions relative to a Continuously Operating Reference Station (CORS) nearby. Heavy-duty bike helmets and neck protectors were worn by all data gatherers to guard against potential injuries.

The field work was undertaken on seven consecutive days starting on 1 April 2012. At times, dense tree cover caused some tracking problems and subsequent data gaps. However, due to the application of the differential positioning technique and the availability of the full GPS and GLONASS satellite constellations, coordinate solutions along the paths taken by the data gatherers were generally accurate at the decimetre level or better. This is a significant improvement over conventional GNSS-based animal tracking techniques which routinely provide positions with an accuracy of several metres.

4.1 Location and Size of the Population

The GNSS trajectories of the bushwalkers were used to determine the location (and timing) of drop bear attacks. An example of two typical tracks culminating in an attack is shown in Figure 3a, while a map illustrating the spatial distribution of all drop bear attacks observed is shown in Figure 3b. It can clearly be seen that the attacks appear in distinct clusters,

indicating that six drop bears were involved and leading to the conclusion that at least six drop bears inhabit the study area. The timing of the attacks (data not shown) supports this result.

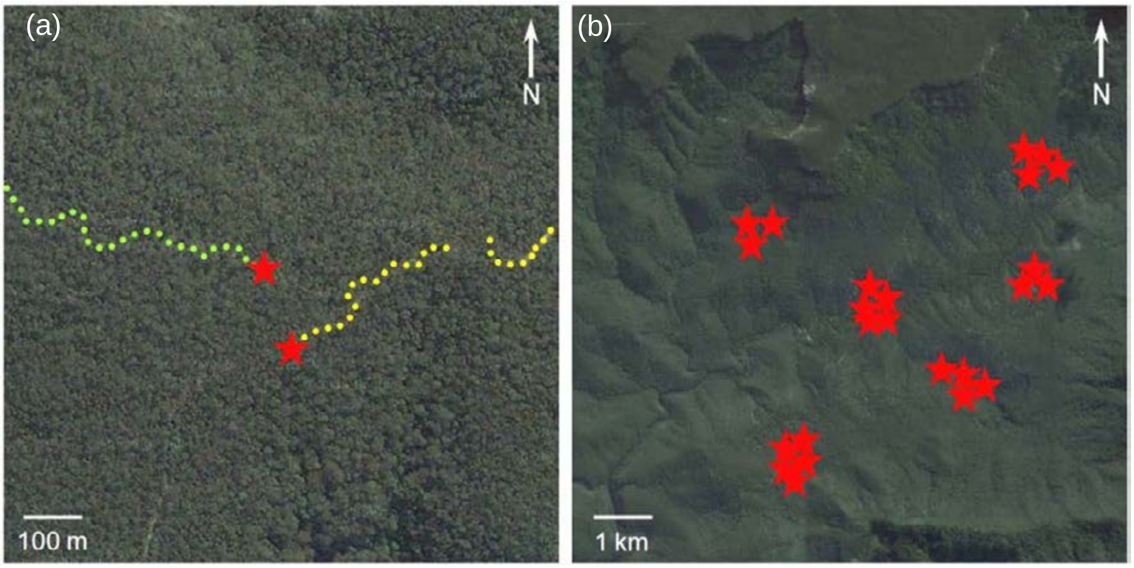

Figure 3: (a) Example of two GNSS tracks ending with a drop bear attack (denoted by a star), and (b) summary of all drop bear attacks observed.

An examination of kill sites and scats in the study area was conducted a month before and after the GNSS field work was carried out. This provided an independent method of estimating the number of resident drop bears and confirmed the findings obtained using the indirect GNSS-based animal tracking method.

4.2 Hunting Behaviour

In an additional investigation, pairs of data gatherers bushwalked along the same path in order to examine whether foreigners were more prone to drop bear attacks than locals. In the first scenario, an Australian was followed at a distance of about 50-100 metres by an international research assistant. In the second scenario, the two data gatherers would swap positions.

While the relatively small data sample collected precluded rigorous scientific analysis, some general comments can be made. In both scenarios, Australians were far less successful in being ‘dropped on’ than foreigners. Only 10% of Australians were targeted in the event of a drop bear attack. It was later discovered that those Australians were not fond of vegemite, lending further weight to Honeydew’s (2003) incisive study. The results also indicate that drop bears do not necessarily target the last person walking in a line. However, more research into the behaviour of drop bears is required in order to confirm these findings, which may reflect seasonality and the presence of alternative food sources.

It should be noted that no animals were harmed during this case study. Likewise, none of the bushwalkers were injured, with the exception of occasional bruising and a few minor lacerations that were graciously endured in the name of science.

5 CONCLUDING REMARKS

This study has presented an indirect approach for tracking tree-dwelling animals using GNSS technology. Rather than attaching sensors to the animals themselves, the prey is tracked in order to map the location and size of the population. Using a case study focused on drop bears, it was shown that this method is effective in both determining the number of animals present in the study area and revealing their particular nutritional targeting preferences. Analysis of the drop bear's hunting behaviour confirmed that foreigners are much more likely to be attacked than Australians. Bushwalkers should be vigilant when hiking along less frequented paths in Australia and take precautions in areas known to be inhabited by drop bears, where conservation practices can now be enhanced.

This bush-path breaking research has begun to provide a much better understanding of the ecology of the drop bear (Janssen, 2012). Extending this research into other seasons and field sites would further enhance our understanding of drop bear behaviour and allow a more thorough exploration of the suggested parallels to Bundy bears.

While GNSS positioning quality was generally at a sufficiently high level, occasional data gaps were encountered due to dense tree canopy (cf. Figure 3a). Following the deployment of additional satellite constellations currently under development (e.g. the European Union's Galileo and China's Beidou), a much larger number of GNSS satellites and frequencies will be available in the near future. This is expected to significantly enhance tracking performance, particularly in Australia which will be a 'hotspot' for global and regional satellite systems (Rizos et al., 2010). Additional benefits could be gained by combining the GNSS sensor with an Inertial Navigation System (INS) to bridge anticipated periods of GNSS signal loss in the forest (Soloviev et al., 2012).

It should be noted that this study was conducted entirely outside normal working hours and not funded by the taxpayer in any way, shape or form. All views expressed in this paper are those of the author and do not necessarily reflect the views of his employer.

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From Riverina Water Shortage to Snowy Surplus: Charles Scrivener's Task to Locate a National Capital

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ABSTRACT

Any biographical study of Charles Scrivener requires abbreviation because of his energetic completion of more than 2,000 surveys while employed with the NSW Lands Department (1876-1910). For a quarter of a century, he followed the usual career development of a staff surveyor, posted first as a draftsman to Hay and then Orange. He next passed the Surveyor-General's Department examination to top the list of 17 successful candidates with a 100% score. His first surveys on contracts from the Newtown survey office led to surveys of Botany, then Ryde, followed by a 2-year posting to fix the eastern boundary of the Australian Agricultural Company north of Port Stephens. This established his bushman skills, and from 1890 he formed part of a small team engaged in triangulation surveys on the expanding fringe of Sydney. Scrivener was posted to Deniliquin a decade later, when rural settlement moved towards the Moama and Wakool river flats, just as drought raised expensive ideas of irrigation. However, he and Alfred Chesterman were loaned to the Commonwealth government to survey prospects for an 'alpine' federal capital. Scrivener assessed Dalgety as best site (gazetted by both Houses of Parliament on 15 August 1904). Scrivener moved to Wagga as Acting District Surveyor while the NSW Premier raised alternatives to Dalgety. Promoted to District Surveyor and acting chairman of the local land boards, Scrivener became directly involved in the Murrumbidgee Irrigation Area expansion and the conversion of Riverine semi-arid mallee country to crop production. He saw railway diversion as the key. The Commonwealth chose Scrivener to prepare 'federal seat of government' surveys, a Yass-Canberra territory and a city site early in 1909. With warnings of possible contamination of the future Burrinjuck catchment, he returned to Hay. Scrivener was appointed in charge of all Commonwealth surveys a year later until 1915. This paper traces Scrivener's professional career and outlines his task to locate the nation's capital, Canberra.

KEYWORDS: *Charles Scrivener, federal capital city, Canberra, Murrumbidgee Irrigation Scheme, history*.

1 INTRODUCTION

This paper summarises portion of a heavily referenced biography of Charles Robert Scrivener prepared from family letters, newspapers, government records and maps, with close attention to Scrivener's own words and advice (Birtles, 2013).

'Charley' was born on 2 November 1855 at 'Bexley' farm, Canterbury, on the rural edge of Sydney to immigrant parents. He attended a small Episcopalian grammar school in Liverpool run by his father, but from the age of eight, delivery chores for a family general store restricted his schooling to afternoon hours. Three years later, poor health led to two years of

seaside convalescence at Woy Woy with an active outdoor life on boats. His teenage years required him to assist his father's Liverpool real estate business but he became interested in land surveying, and on 11 December 1876 he was accepted as a cadet 'geodetic computer' in the trigonometrical branch of the NSW Surveyor-General's Office. He passed the draftsman's examination a year later.

2 NSW LANDS DEPARTMENT PROGRESSION TO STAFF SURVEYOR

To gain field experience as a surveyor's apprentice, Scrivener was posted to the western Riverina town of Hay (Figure 1) from 3 January 1878, under the supervision of Surveyor Robert McDonald who monitored much of his future career. He became familiar with conditional land selections and problems with an unpopular land auction system that allowed absentee capitalists to hold title in perpetuity. Marriage to 'Lena' Rogers in April led to his transfer a year later to Orange for birth of their first child. His return to Sydney (1880) as a draftsman allowed him three months to prepare for the tough Surveyor-General's Department examination, with special coaching to compensate for incomplete schooling. Only 17 of 46 candidates passed, but Scrivener topped the list with a unique 100% score that earned him the nickname 'One Hundred'.

Figure 1: New South Wales locality map (compiled by Terry Birtles, drafted by Frank Blanchfield).

As a licensed surveyor, Scrivener's first surveys were short contracts before his attachment to the Newtown survey office under the supervision of District Surveyor Francis Bensen William Woolrych who initiated first colonial use of the steel survey band in preference to chain links for alignment work. During 1881-82, Scrivener engaged in field surveys at Botany for new residential subdivision, earning his promotion to second-class surveyor. This advancement led to relocation and new duties as detail surveys within the Field of Mars Reserve, Ryde, until the tragic death of 'Lena' from typhoid fever in May 1883. Scrivener's name disappeared from the staff list in annual reports of the Surveyor-General's Department

for 1883 and 1884. In March 1885, Scrivener married Beatrice Harding but her death from puerperal fever after childbirth a year later further disrupted Scrivener's career. He returned to fieldwork in 1887 to finish the Ryde surveys and further surveys in Petersham, Gladesville and Dundas.

Posted in September 1888 to the Hunter Valley, Scrivener engaged for two years in fixing the true position of the eastern boundary of the giant Australian Agricultural Company estate north of Port Stephens. Azimuth observations were required every 10 or 12 miles as he pegged the boundary through difficult, heavily vegetated rainforest terrain. This task established recognition of his bushman skills. He married Annie Pike in April 1889.

Major restructuring of the Lands and Survey Department after an 1887-89 board of inquiry led to Scrivener's attachment to the triangulation survey in September 1890 as an A3-grade staff surveyor. For three years, his team engaged in street alignment surveys, residential estate subdivision and triangulation surveys on the fringe of Sydney, including Liverpool, Ermington, Rydalmere, Penrith, Fairfield, Camden, Kogarah and the Macdonald valley. With a second licensed surveyor, he then retraced the surveys of James Meehan and Robert Hoddle in the upper Hawkesbury valley, especially for the five towns of Windsor, Richmond, Castlereagh, Pitt Town and Wilberforce. He also undertook topographical traverses in the southern segment of the Blue Mountains (Nattai and Kowmung Rivers), followed in 1897 by a series of 'miscellaneous' surveys of roads, portions, cemeteries and schools. His survey of deviations to the Main Western Road in the Springwood district was followed by determination of a baseline through Mount Wilson for a trigonometrical survey of the state. From 1898 to 1901, he returned to Burragorang valley, a survey of Picton Lakes, surveys of the Grose Valley and Bell's Line of Road, and innumerable reports relating to small surveys in and around Sydney.

3 RIVERINA SURVEYS

The posting of Scrivener to Deniliquin (see Figure 1) in July 1901 coincided with NSW governmental concern over the declining status of pastoral settlement of a semi-arid environment. The 1901 Royal Commission on Western Lands into acute economic hardship among Crown tenants raised many questions about the achievements of Crown lands policy that had allowed the Deniliquin Lands Office to dramatically break all NSW records for land selection during 1873 and again in 1897. The commission concluded that economic distress had been caused by low rainfall, the frequency of drought, the rabbit plague, overstocking, sandstorms, pastoral infestation by non-edible scrub, a fall in prices for livestock output, a 'loss of revenue thereon' and the high mortgage on holdings (Western Division of New South Wales, 1901). Much of Scrivener's attention was directed to applications for homestead selections, especially along riverside land downstream from Moama and in the Wakool district.

The challenges of frequent rural drought had raised questions of Riverina irrigation potential ever since 1852 when squatters north of Jerilderie (see Figure 1) began to improve water supply by cutting channels from the Murrumbidgee River. An 1897 report on irrigation prospects for the colony prepared by Colonel R.E. Home, Royal Engineers, an engineer with Anglo-Indian experience, could identify only two possible projects – a canal from near Yanco Creek and a canal from the Murray River near Bangowannah. Home warned of high capital costs well beyond the means of the average man. However, Samuel McCaughey of

'Coonong' purchased 'North Yanco' station in 1900 and with Irish immigrant labour began construction of a complex irrigation system with 322 km of channels to pump water from the Murrumbidgee River. His success was to influence state government ideas for closer settlement.

4 FEDERAL CAPITAL SURVEYS

Federation required that a federal district of 259 km^2 be set aside in NSW for a commercially neutral 'seat of government' to be located at least 100 miles (161 km) from Sydney. At least 45 local aspirations were offered as sites through federal capital leagues and the NSW Government commissioned Alexander Oliver, president of the state Land Appeal Court for his advice. Oliver inspected 23 prospects but disturbed by extreme drought devastation claimed that none received adequate rainfall to support a city of 40,000 people. He enlarged the site maps of his preferences ten times to fit river catchment boundaries and he identified the value of Snowy River surplus flow to recommend the 'southern Monaro' or 'Bombala-Eden Territory' on a plateau 762 m above sea level as the best of three possible sites (Oliver, 1900). Strategically located about midway between Australia's largest two cities, Oliver proposed a railway link that would include access to Twofold Bay, a deepwater harbour. Oliver also germinated the concept of a federal city that overlooked an ornamental lake.

Choice of location rested with the Commonwealth Government which through the influence of Sir William Lyne, Commonwealth Minister of Home Affairs, required Oliver to revisit his three nominated sites and evaluate the two additional sites of Gadara (near Tumut) and Albury (both within Lyne's federal electorate). Lyne arranged for most members of the two Commonwealth chambers to visit fifteen possible locations and he established a Royal Commission chaired by John Kirkpatrick to report on nine localities (The Parliament of the Commonwealth of Australia, 1903a; 1903b). The result of debates and an exhaustive ballot led to the House of Representatives choice of a site 'at or near Tumut' (as Lyne hoped) but the Senate preference 'at or near Bombala'. To resolve the stalemate, Prime Minister Alfred Deakin requested the services of two NSW surveyors to investigate suitable sites in both districts. Charles Scrivener was chosen to study the southern Monaro district and Alfred Chesterman, who had assisted both Oliver and Kirkpatrick, would survey the Tumut district. Each surveyor prepared two detailed reports, with advice from Scrivener leading both houses to reach agreement (in August 1904) that Dalgety (see Figure 1) on the Snowy River should become Australia's 'alpine' capital city, with railway access to Eden as a seaport.

Scrivener returned to the Riverina to take up the Wagga Land Board position of acting District Surveyor on 21 September 1904, but almost immediately was called upon by Joseph Carruthers, NSW Premier, to report further on the southern Monaro district. A federal territory needed to be determined. Scrivener's response included a recommendation of Snowy River hydroelectric power generation from a reservoir near Jindabyne. Carruthers did not like the Commonwealth choice of Dalgety nor its suggestion of a proposed area of 900 square miles, and he ordered his Public Works engineers to seek alternative sites closer to Sydney.

For much of 1905, Scrivener focussed on Wagga Land Board matters. He was aware of the Water Conservation and Irrigation Conference that initiated the Murrumbidgee Irrigation Scheme under the chairmanship of Charles Lee, Carruther's Secretary for Public Works, who proposed rural development for what became the Yanco Irrigation District now centred on Leeton.

Formation of Deakin's second ministry (July 1905) triggered considerable correspondence with Carruthers who sought a High Court determination whether the 100-mile distance limit from Sydney could in any way be interpreted as equivalent to Commonwealth choice of 'within a radius of 17 miles from Dalgety'. Carruthers also argued very publicly that a site on the Victorian border would unconstitutionally change the state boundaries of New South Wales. Deakin replied that a common decision reached in favour of Dalgety could not be changed and he arranged for the Commonwealth Attorney-General, Isaac Isaacs, to prepare appropriate legislation. In addition, he requested technical advice from Scrivener regarding possible territorial boundaries. An inflamed Carruthers promptly cancelled reservation of all Crown lands in the vicinity of Dalgety. During December, Deakin introduced a new Seat of Government Survey bill with Scrivener's map of possible territorial limits, but debate lapsed without any support from NSW members.

5 MURRUMBIDGEE IRRIGATION

Transferred to the Hay Land Board office, Scrivener took up duties as acting District Surveyor on 31 October 1905. The main changes since his apprenticeship days were the completion of the Hay railway terminus and improved public access to Murrumbidgee River water, with almost every Hay householder irrigating fruit or olive trees. Scrivener's surveys of rural homestead leases and roads took him as far north as Lake Cudgellico (now Cargelligo) and Hillston (see Figure 1), and he inspected proposed artesian irrigation at 'Beunbah' near Coonamble, north of Dubbo. Because new railways were improving transport access, Scrivener began to consider the prospect of extending the track west from Temora to open up Crown land for closer settlement near Cudgellico or west of Barellan. In June 1906, he was promoted to District Surveyor and he began to investigate Deakin's initiatives through the Victorian Irrigation Act 1886 to convert mallee country near Renmark and Mildura. Scrivener visited Mildura for first-hand observation of techniques introduced from California by the Chaffey brothers.

During January 1908, Scrivener's additional responsibilities included acting chairman of the local land boards for the districts of Balranald, South Deniliquin, Hay, Hillston and Narrandera. This included his involvement with Murrumbidgee Irrigation Area (MIA) expansion westward from McCaughey's 'North Yanco' station to follow Mirroul Creek (now Mirrool Creek) in channels to be supplied by the Barren Jack Reservoir as headwater storage (envisioned to be the world's second largest mass gravity dam of the time but not completed until 1928).

Scrivener's visit to western Victoria to study conversion of semi-arid mallee country to agricultural crop production suggested that this process could be transplanted to the MIA. Scrivener's recommendations influenced NSW closer-settlement land policy for similar mallee forests on blood-red soils north-east of the Hay saltbush plains. In particular, Charles Lee had proposed a railway extension from Barellan as a straight track to Hillston, forecast as a prospective rural growth centre, but Scrivener recommended that the track be diverted westwards to serve a possible irrigation area on Crown land alongside the Lachlan River from Yenda to Gunbar (Figure 2). Both Lee and Scrivener were aware of enthusiastic lobbying by Robert Gibson who promoted proclamation of Gunbar village as a town in 1904 to serve MIA expansion. By 1917, such expansion would be identified as the Mirrool Irrigation Area (centred on the later town of Griffith) and the Tabbita, Benerembah and Wah Wah irrigation

districts. As well as irrigated produce, railway cartage could divert local wool traffic and livestock from Hillston to Sydney instead of Melbourne, but neither Hay nor Hillston ever achieved the economic status anticipated in 1908 and the irrigation channels only reached halfway to Gunbar, which simply faded away.

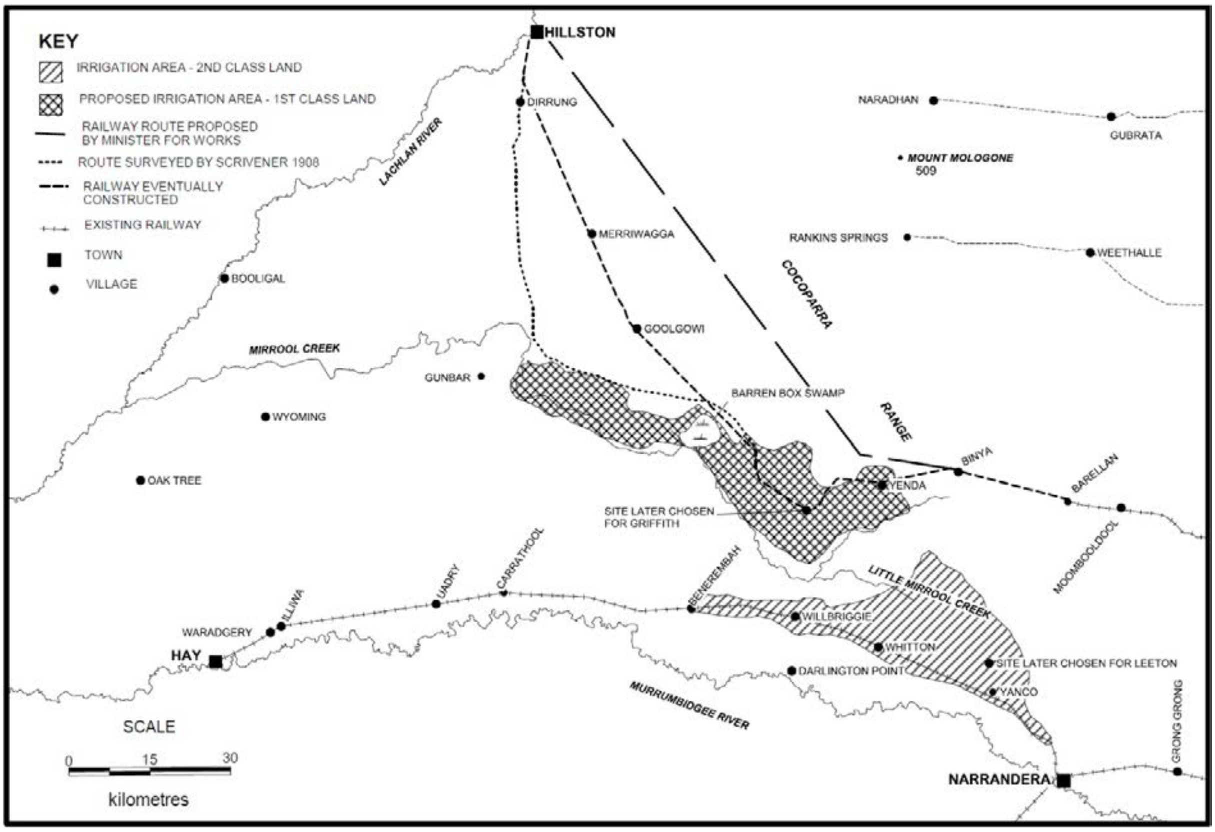

Figure 2: Proposed Murrumbidgee Irrigation Area expansion, 1909. The irrigation scheme never extended west of Barren Box Swamp despite channel construction (compiled by Terry Birtles, drafted by Frank Blanchfield).

6 COMMONWEALTH SERVICE

Early in 1909, Scrivener again found himself involved with federal capital surveys, but in a new location. The squabble between Deakin and Carruthers had persisted, and Scrivener must have been bemused by the newspaper coverage. As many as 14 possible sites were investigated by Public Works staff ordered to find an alternative to Dalgety. As one fanciful and desperate idea, Carruthers was advised that a dam across the Molonglo River would submerge at least 10,000 acres as a storage to boost Lake George by tunnel and that a federal city site might be chosen between Lake George and the proposed Barren Jack Reservoir to receive water pumped uphill from both. Site 'K' on the 'Canberra' pastoral property won some NSW favour, although it was rejected as inferior for water supply by Sir John Forrest, Deakin's key advisor. During the extreme 1907-08 summer, nearby Lake George evaporated and the land was cleared for grazing. NSW Public Works promotion of Site 'K' then highlighted a possible Murrumbidgee dam upstream from the Barren Jack Reservoir, without reference to downstream irrigation discussions. Concerted NSW opposition to the Dalgety site persisted after Charles Gregory Wade replaced Carruthers as Premier.

Wade favoured Canberra but a new House of Representatives ballot of 11 sites eliminated both Dalgety and Canberra, before the final vote on 8 October 1908 achieved preference to

last-minute redefinition of 'Yass-Canberra'. The Senate reached an identical choice on 6 December. For Commonwealth surveys of this Yass-Canberra site and 'a suitable harbour on the coast', NSW Chief Surveyor Robert McDonald chose Charles Scrivener.

Scrivener's first report warned that the federal capital site should not be too near the Barren Jack Reservoir with its priority for irrigating 196,000 acres of 'high-class land' (Scrivener, 1909). He made particular comment about the high risk of water pollution from a large urban population and drew attention to the impact of drought: 'While Barren Jack Reservoir will form an imposing sheet of water when at top level, it would present few beautiful features when, by a reduction of level, large areas of river flat and undulating country would be exposed.' Scrivener concluded that neither this reservoir nor a dam on the Cotter River could be used to generate power (he preferred Snowy River outflow) and that any city beautification by water conservation should be from streams within the Federal territory under Commonwealth control. His assessment did not match advice from Public Works engineers.

Scrivener's analysis of the 'Canberra' site identified 'an amphitheatre of hills with an outlook towards the north and north-east, well sheltered from both southerly and westerly winds.' Surrounding this, he proposed a boomerang-shaped federal Yass-Canberra territory as the entire catchment of the Cotter, Molonglo and Queanbeyan Rivers (even though he noted that all three ceased to flow during hot dry summers). He pitched a survey camp as an operational base for preparation of a contour map that included Oliver's concept of a central ornamental lake (2 March 1909). With revision to the boundaries, the NSW Government formally surrendered the proposed territory (18 October 1909). Scrivener returned to Hay to resume irrigation surveys of Deniliquin and Gunbar.

Within weeks, the federal Department of Home Affairs negotiated further access to Scrivener's services to demarcate the territorial boundaries and other surveys relevant to engineering and city design. As a result, he formally began duties as Director of Commonwealth Lands and Survey until his retirement on long service leave during 1915. In order to undertake a triangulation survey of the territory, an astronomical observatory at Mount Stromlo was constructed as the prime meridian. Scrivener's national responsibilities rapidly widened to include oversight of the proposed Port Augusta-Kalgoorlie transcontinental railway from July 1911, inspection of a Cockburn Sound naval base (Western Australia), organisation of the first Australian and New Zealand conference of Surveyors-General (May 1912), contour surveys for a new Commonwealth Small Arms factory at Lithgow, and selection of a site for a naval college at either Jervis Bay or near Pittwater on the edge of Sydney (Scrivener, 1914).

Progress with construction of the national capital ceased dramatically after Walter Burley Griffin was invited from Chicago to defend his winning entry in an international competition for a federal city design. Griffin's forecast of a city of 75,000 appeared excessively extravagant and his revised plan of 1913 lacked dimensions or any clear relationship to surveyed topography. His communications with Scrivener broke down once he dreamed of further expansion of Canberra, including relocation of key survey pegs, and then sought command of Scrivener's staff. Nor did Griffin appreciate Canberra's drought-prone location when in April 1915 he announced a 95 km^2 scheme for 'a mountain lake' on the Murrumbidgee to allow steamers from the 'heart of the Capital' access to 50 miles of rugged gorge and mountain scenery. By this time, Scrivener had vacated office, although a lasting legacy to Canberra is the more modest central lake of his design behind Scrivener Dam. Later political motivation to honour a city-founder has bestowed the name of 'Lake Burley Griffin'

which filled during 1964 but does not adhere to the more geometrical design of two lakes and three basins advocated by Griffin.

7 CONCLUDING REMARKS

This paper has explored a small moment of history to highlight the development of a conflict between the use of Snowy Mountains water resources for the irrigation of semi-arid Riverina settlement expansion and the requirements of Australia's national capital city. The conflict persists but surveys by Charles Scrivener revealed the key elements.

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The Consequences of Watershed Boundaries of the ACT

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ABSTRACT

About a hundred years ago, it was decided to establish Canberra as the capital of Australia. The boundaries generally followed watersheds ignoring existing cadastral boundaries. The Federal Government purchased properties affected by the boundaries and a consequence of the boundaries not following cadastral boundaries was the creation of numerous residue parcels within New South Wales (NSW) adjacent to the Australian Capital Territory (ACT) boundaries. Many of these residue parcels still exist in the ownership of the Commonwealth, and Landdata Surveys was contracted to undertake surveys of the parcels and to prepare a report identifying issues associated with boundaries, improvement, access and easements. This paper describes the survey as well as issues associated with differing coordinate, land administration systems on either side of boundaries and access in mountainous terrain and through sensitive government controlled land. The use of the original boundary survey and its amazing accuracy and detail in determining property boundaries is outlined. The various methods used in our survey are described, highlighting difficulties and accuracies achieved. The scope also included investigating zoning and land use, legal access and how to achieve it in the current cadastre, and suggesting recommendations regarding the disposal and future use of the sites. A contour survey of sites was required and the heighting and contour determination is described. The scope included two interesting non-border property sites. The Tidbinbilla Space Centre is a significant site in rural ACT. It is partly managed by NASA and comprises a main site with three satellite sites. The Commonwealth acquired a strip of land on which Two Sticks Road is constructed. The road runs through steep parts of ACT and NSW. Management of the road is thus split amongst a variety of jurisdictions. The report concludes by highlighting problems associated with ignoring existing property boundaries in the determination of ACT's boundaries.

KEYWORDS: *Cadastre, access, administration, improvements, contours.*

1 INTRODUCTION – "CAPITAL ALMOST GOT SOLD DOWN THE RIVER"

A year ago, a newspaper article in the Canberra Times described the water issues associated with the selection of Canberra as the nation's capital (Warden, 2012): "*Canberra has been green and lush for months and now we've just had these deluges of flooding, refreshing, cabbage-swelling rains. And so it's amusing to recall that during the "Battle of the sites" (1899-1908) opponents of Canberra as the federal capital used to call it a shrivelled wilderness. No city was possible here they warned. A lack of water would make it unsanitary and paradise for typhoid. Farms and gardens would be impossible. In the unlikely event of anyone here ever managing to grow a single stunted cabbage, it would be front page news. 'What crime have we committed that we should be exiled to the unknown regions of Yass-Canberra?' the pro-Dalgety Senator James Stewart whinged to the upper house in 1908. He said he'd heard it was 'an arid desert bleached with the bones of animals that have died of*

thirst'."

In 1900, the Commonwealth of Australia Constitution Act 1900 was enacted. This provided for the site for a capital city within New South Wales (NSW), but at least 100 miles from Sydney. Charles Scrivener was tasked with investigating options and recommending a site. Water was a critical issue in the site selection and when Canberra was eventually chosen, boundaries between NSW and the Australian Capital Territory (ACT) were defined by watersheds of nearby rivers. The reader is referred to the wording of the Seat of Government Surrender Act 1909 (Commonwealth of Australia, 1909) in the Annexure.

In 1910, Percy Sheaffe commenced the survey of the borders, which included defining the relevant watersheds without regard for the existing cadastral boundaries. The Commonwealth acquired all of the land within the borders and also the residue land within NSW of the portions divided by the watershed boundaries. As a consequence, the Commonwealth took ownership of a number of small residue parcels within NSW. In 2010, Landdata Surveys were contracted to undertake surveys of the various sites and prepare reports on a range of issues associated with the sites.

2 SCOPE

The scope was wide, including features generally beyond the expertise of a surveying company or department. However, the primary component involved surveying work. The Department of Finance contracted a large multi-disciplinary company, ironically without local surveying expertise, to undertake the project.

Landdata Surveys was thus employed as a subcontractor to undertake the surveying and planning aspects of the scope, which included:

- Undertaking "ID" surveys of 33 sites. This was interpreted as being an Identification Survey where improvements, burdens and encroachments on the site are identified and where possible surveyed, and an associated report provided.
- Identifying services on the site. This entailed surveying any services found on the site, undertaking a Dial Before You Dig search of the land, and mapping and reporting on such services and the implications thereof.
- Identifying access to the sites. This involved determining and mapping how to access the site, and to report on legal access to the site.
- Providing contours for the site.
- Identifying zoning and town planning issues associated with the site, and compliance therewith.
- Identifying any heritage issues found on or associated with the site.
- Providing a "GIS" of the site. This was interpreted as providing a digital Computer-Aided Design (CAD) file of the survey.
- Providing recommendations regarding the resolution of issues associated with the site and opportunities for the disposal thereof.
- In addition to the border properties, two interesting non-border properties were included in the brief. The Tidbinbilla Space Centre houses satellites used in NASA's space program, and the main site, together with associated satellite sites, was included. The Commonwealth had acquired a road reserve for a road known as Two Sticks Road, spanning the NSW-ACT border. The road extended well beyond the acquired reserve and the status of the road needed resolution.

3 ACT-NSW BORDER SURVEY 1910-1915

The ACT-NSW border was surveyed between 1910 and 1915. The surveys were drawn on a series of maps FC1-18 (Figure 1), which are now heritage listed (ACT Heritage Council, 1995).

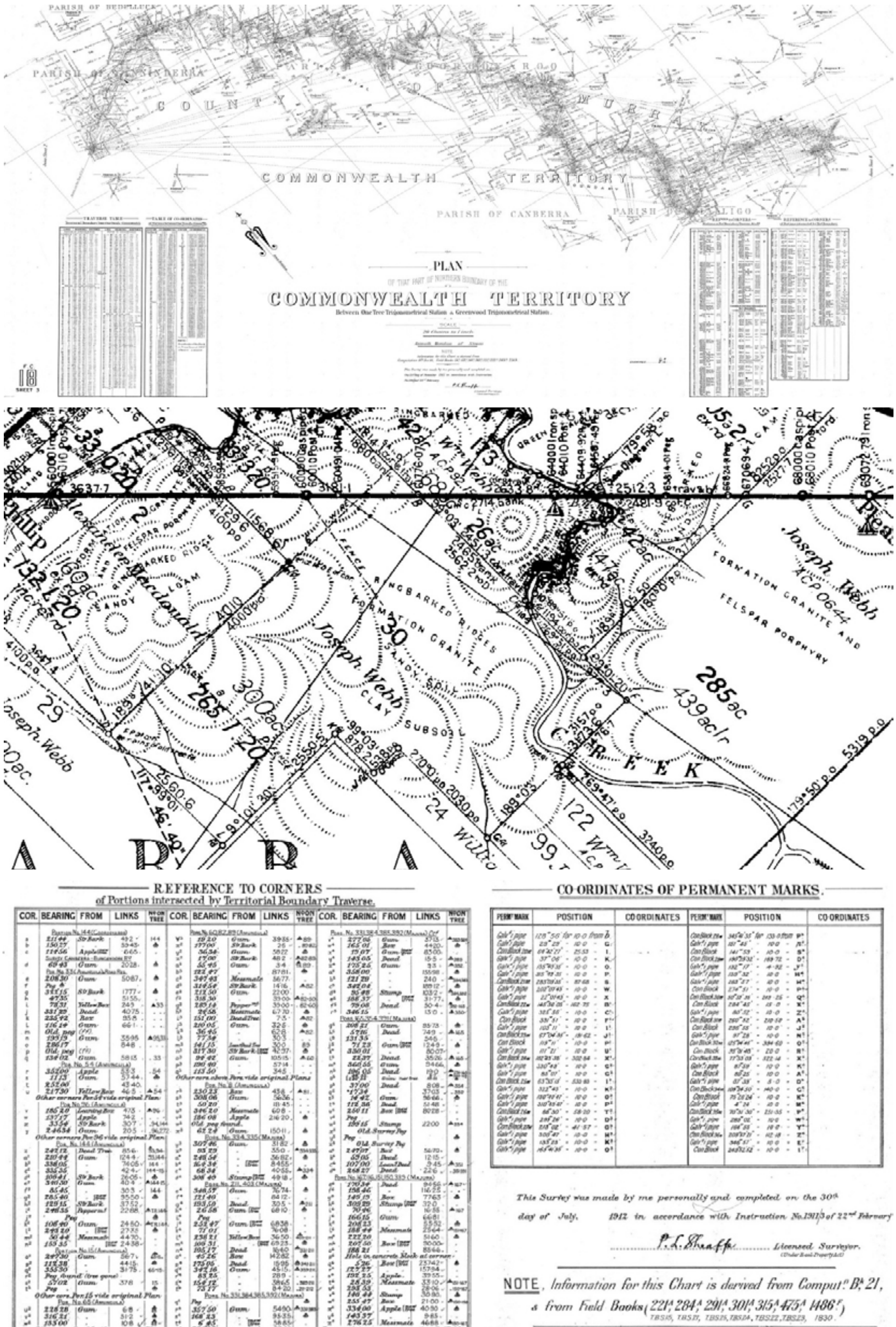

Figure 1: Plan of ACT-NSW border survey.

The survey was very accurate considering the instruments in use at the time, and the boundaries were very well monumented with very large wooden pegs and reference marks consisting of iron pipes and concrete blocks (Figures 2-4). Many of these marks still exist, and consequently the determination of the site boundaries common to the border was relatively easy. Landdata surveyors were amazed at the excellent agreement found between the new surveys (Figure 5) and that of 1911.

Furthermore, in determining the border, the terminals of boundaries cut by the border were generally also located and surveyed. Thus, whilst many of these terminals no longer exist, by locating border marks and determining the border location it was generally possible to confidently determine the boundaries of the relevant border properties. As well as being dimensioned, corners and references were coordinated relative to still existing trigonometric stations.

Figure 2: Rock spit marking bend in border (Evans, 2012).

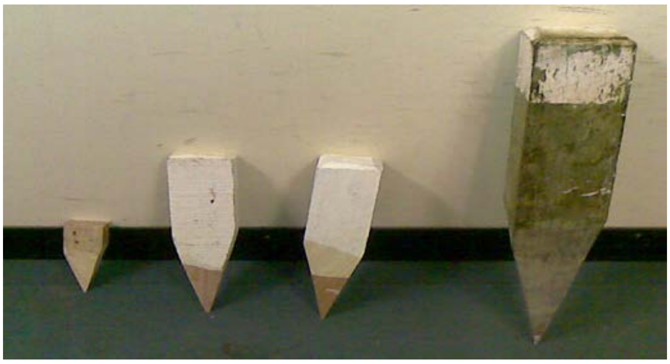

Figure 3: Border boundary peg (right) compared to modern pegs.

Figure 4: Oak Trig Station – adopted as corner mark.

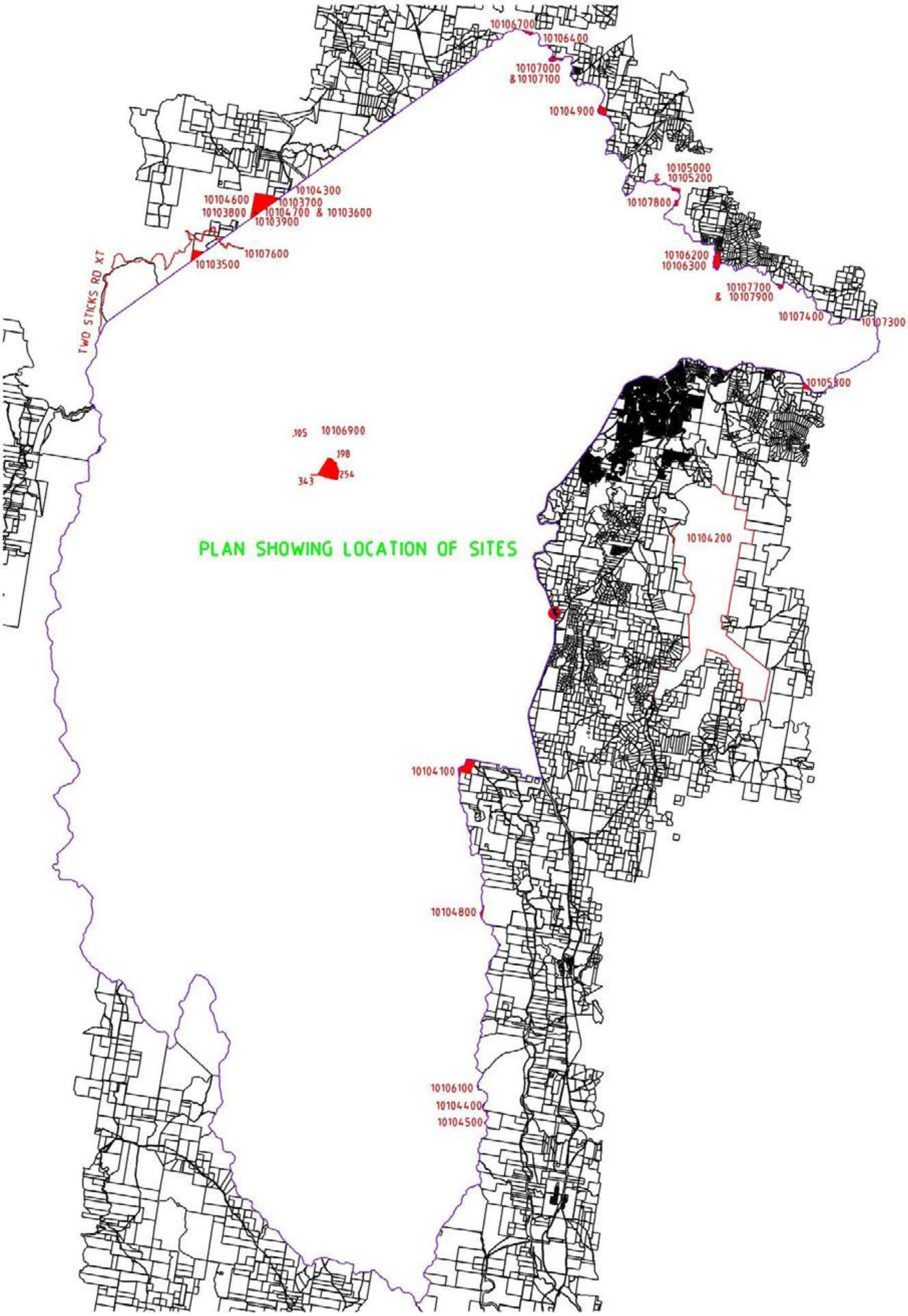

Figure 5: Location of the sites to be surveyed on the ACT border.

4 ACCESS

The access requirements of the project were two-fold:

- Determine how best to get to the site, i.e. practical access.
- Establish whether the site had legal access.

4.1 Practical Access

This involved in the first instance the examination of available aerial imagery, which was readily available thanks to the NSW and ACT databases as well as private providers such as Google and Nearmap. This enabled Landdata to identify roads, tracks and feasible routes to reach the site. Relevant owners were then approached for permission to access the sites via the chosen route.

This sometimes was quite challenging due to the physical nature of the access, requiring very careful 4-wheel driving. Challenges also presented themselves in dealing with government authorities who managed many of the sites through which access was sought. Examples included:

- Obtaining access through a Defence Force firing range. Staff were required to be 'chaperoned' while passing through this property.
- Due to the extreme nature of the terrain, the ACT government department responsible for the management of reserves would only allow Landdata access if a satellite phone was carried and staff had formal 4WD and chainsaw training. As the available course timetables in Canberra did not meet the required survey schedule, it was chosen to obtain access via the more difficult access routes through NSW.

4.2 Legal Access

Prior to the establishment of the ACT, most of the sites had legal access via Crown or public roads. When the ACT was created, many of these roads were severed, leaving remnant road pieces and effectively removing legal access to the parcels (Figure 6). It was thus necessary to identify where legal access was lacking and make recommendations regarding how it could be obtained.

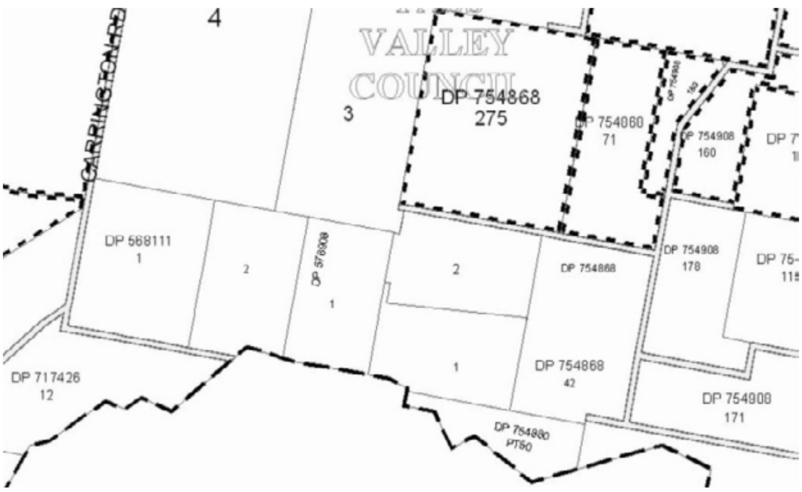

Figure 6: Legal access removed.

5 CONTOURS

The scope of work required the provision of contours in digital form. To undertake a full new contour survey of each site would have made achieving the required timeframes and budgets impossible. Some of the sites were heavily wooded and very steep. Consequently, the method used generally involved the heighting of our own survey control either from existing nearby control or a Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS). Additional heighting was done on features surveyed for other purposes such as boundary determination, fences and services. The heights of surveyed points were then used to confirm existing contour sources such as existing maps (Figure 7). It was fortunate that the ACT has been comprehensively contoured and the contours often extend into the neighbouring parts of NSW on which the sites are located.

Contours, where not readily available digitally, were digitised from existing paper copies of plans to provide the required digital version. An appropriate disclaimer was obviously inserted. It is believed that the required heighting met the need of the client who did not object to the adopted methodology.

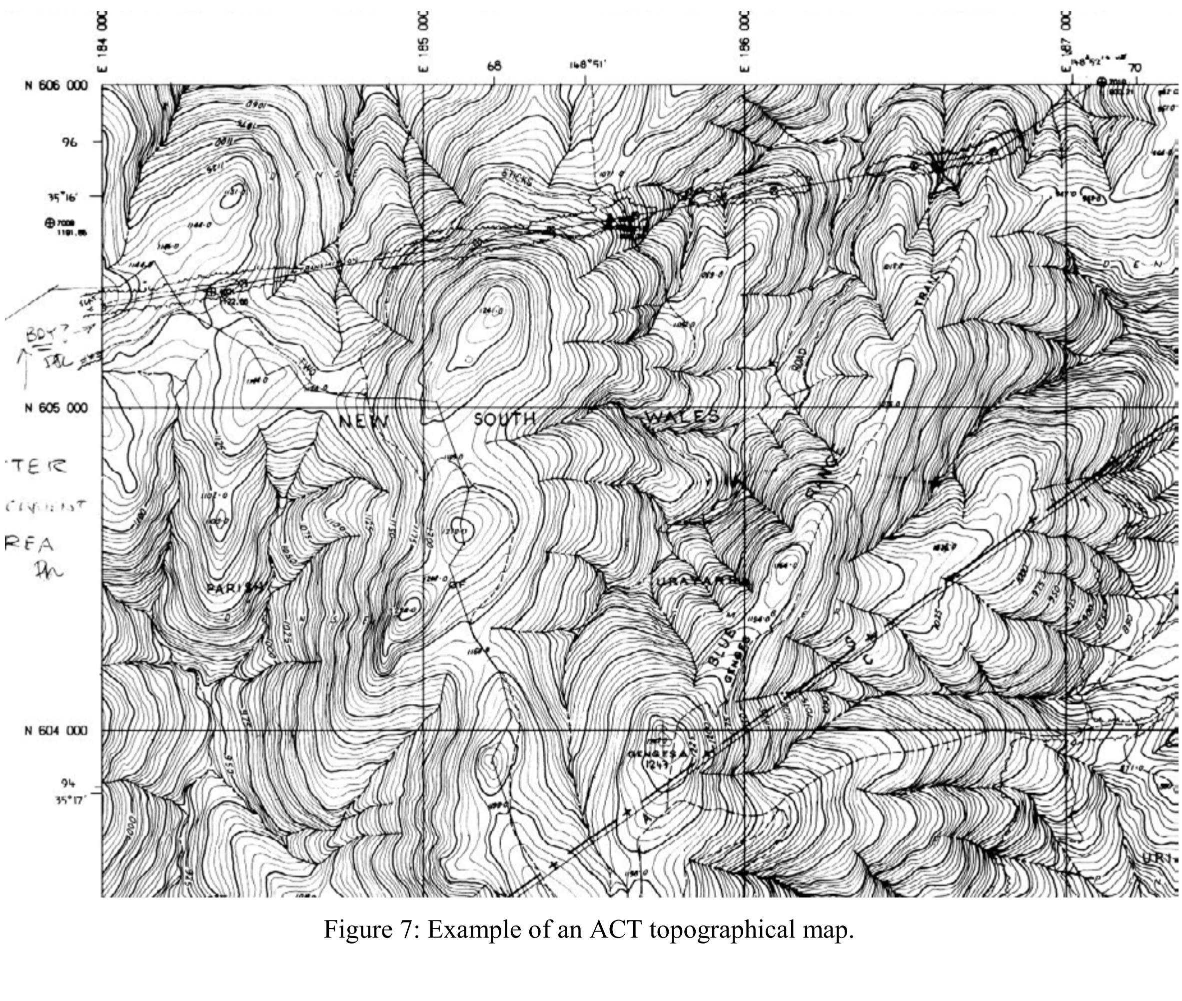

Figure 7: Example of an ACT topographical map.

6 ZONING AND OTHER TOWN PLANNING ISSUES

The brief required the identification of the zoning of the sites as well as any other planning issues that affect the site. The existing land use was required to be identified to check conformance with the zoning.

The ACT is surrounded by four shires, i.e. Yass, Palerang, Queanbeyan and Cooma-Monaro. Satisfying this requirement involved the following steps:

- Identify the shire in which the site is located.
- Research the relevant Shire Local Environmental Plan (LEP), usually found on the Shire webpage.
- Locate the site on the LEP maps and hence determine the relevant zone.
- From the site visit, determine the existing use and also that of surrounding properties.
- Identify any other issues that may affect the site.

The process was complicated a little by a recent change of shire boundaries. This resulted in LEPs from adjacent or former shires applying to the site (e.g. Yarrowlumla Shire Council, 2002). Figure 8 illustrates an example of the former Yarrowlumla Shire Council LEP 2002. Furthermore, the shires were in the process of preparing new LEPs. Consequently, one needed to investigate the current zoning but also determine whether any changes were envisaged in the new LEP.

Whilst most of the sites were themselves zoned rural, adjacent uses in the ACT included a military zone and nearby gun club, forestry uses, national park and expanding residential areas in the north. Other issues that affected the site included the aforementioned adjacent uses and their associated impact on access and future use, and the flight path of Canberra International Airport that impacted on many of the sites along the eastern border of the ACT (Figure 9).

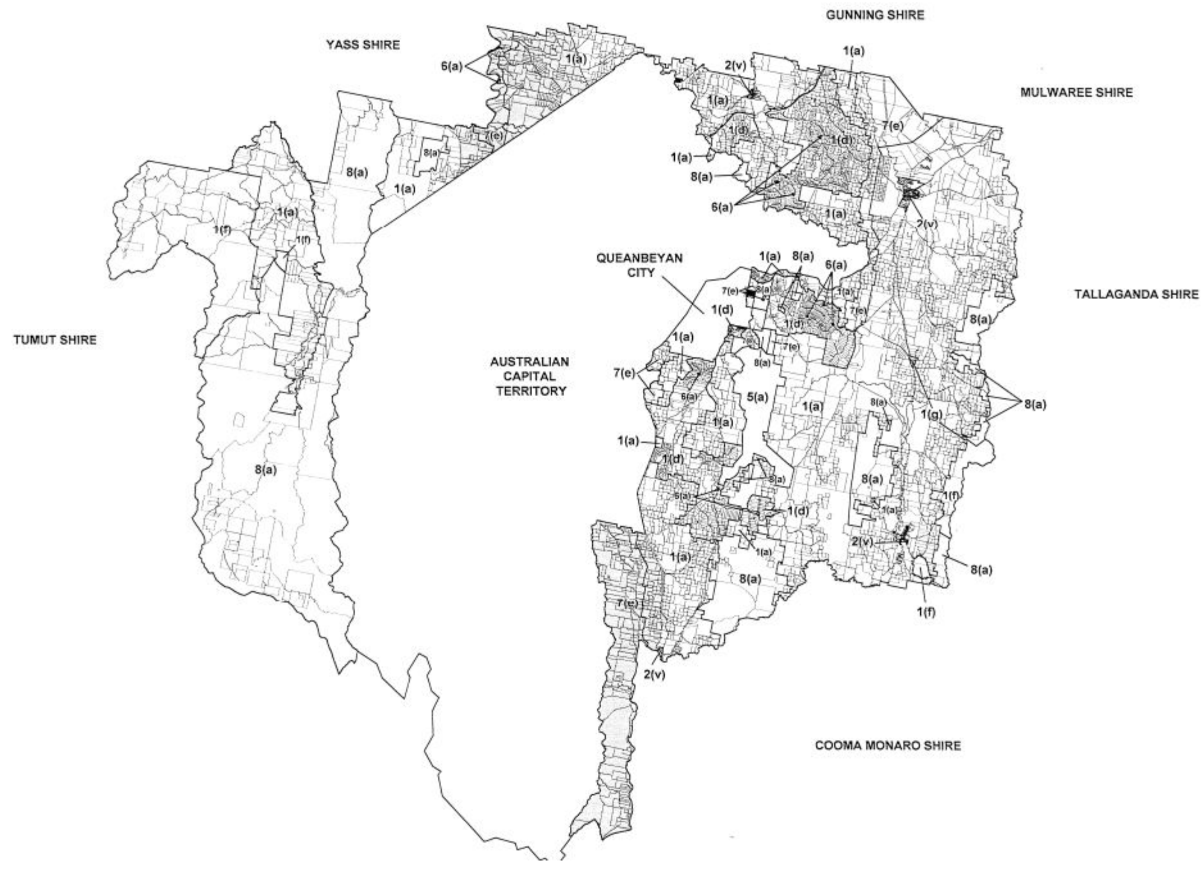

Figure 8: Former Yarrowlumla Shire Council LEP 2002 (NSW Government, 2002).

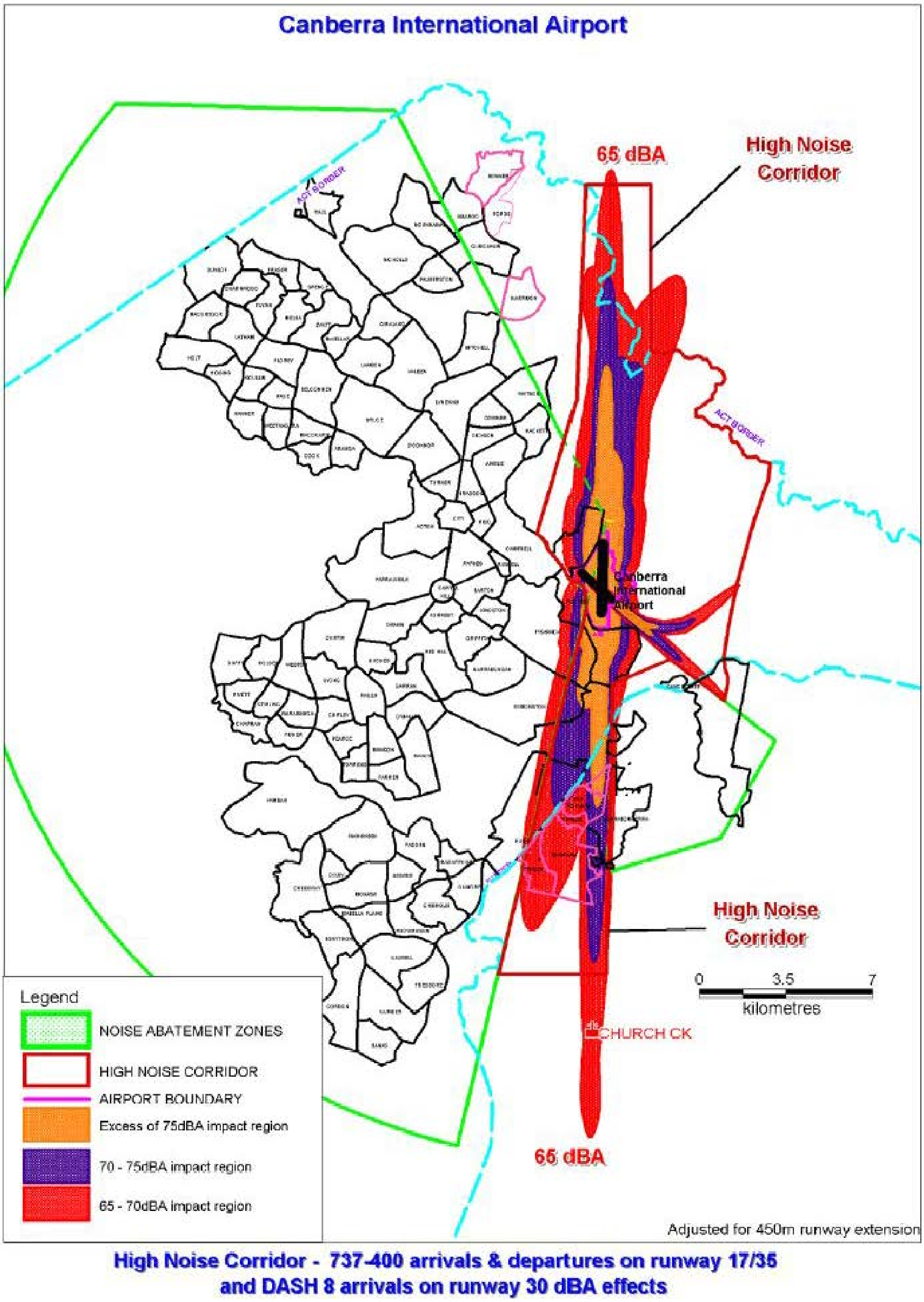

Figure 9: Noise map used to determine noise impacts on sites (Canberra International Airport, 2012).

7 HERITAGE ISSUES

Some of the ACT-NSW border survey marks have been heritage listed. It is unclear to the author why not all of the remaining marks were listed. The site on the National Trust register of significant places is "*a strip of land twenty metres in width, centred on the ACT-NSW*

border and following the border for approximately 97 kilometres between Mt Coree and the Boboyan Road/Shannons Flat Road. The place comprises a total of 272 sites, being:
1. *Original border markers.*
2. *Original reference trees.*
3. *Original mile markers.*
4. *Original mile reference trees*."

The crossings of Two Sticks Road with the border are included within this 'place'. The sites generally fell in areas where the marks were not listed and themselves did not contain heritage sites. It was, however, necessary to check whether nearby heritage items could affect access to and future uses of the border sites. Thus, investigations of the heritage documentation of the relevant jurisdictions needed to be made.

8 RECOMMENDATIONS

Recommendations were generally fairly common-sense suggestions involving investigating options for sale and consolidation with adjacent owners or extension of existing national park boundaries. It was also necessary to suggest ways of resolving site legal access issues. In making the recommendations, it was necessary to justify such suggestions based on adjacent land uses, zoning and heritage issues described above.

9 ADMINISTRATION

The border sites were situated in areas governed by a number of authorities or government departments. As described earlier, sites were located within three local government authorities, i.e. Yass Valley, Palerang and Cooma-Monaro. Other government departments that influenced issues associated with the sites included:

ACT
- ACT Planning and Land Authority (with respect to land use in ACT).
- Territory and Municipal Services (with respect to the management of ACT roads, forestry, national parks and reserves).

NSW
- Forestry NSW.
- Land and Property Information (LPI) – Crown Lands.
- NSW Office of Environment and Heritage.
- NSW National Parks and Wildlife Service.

Federal
- Defence.
- National Capital Authority.
- Finance and Deregulation (client).
- Department of Sustainability, Environment, Water, Population and Communities.

10 THE LANDDATA SURVEY

Generally, control was established on sites using GNSS and nearby CORS belonging to LPI's CORSnet-NSW network (Janssen et al., 2011) as it existed at the time (i.e. Dickson, Stromlo and Tidbinbilla).

Provisional coordinates of the ACT border component of the sites were taken from the ACT cadastral database. For the remaining boundaries, provisional coordinates were determined, where possible, using the border survey maps. This was possible due to the extent of the border survey, which generally included the surveying of the terminals of boundaries crossed by the border. Preliminary coordinates were thus determined for the required reference marks to enable the staking out of their positions and the locating thereof. Generally, marks were found very close to their calculated positions, testifying to the high accuracy of the border survey.

Where existing survey control marks were in the proximity of the site, they were connected to provide local heights to be used in the contour check. If no such marks were available, the height obtained from GNSS observations in conjunction with AUSGeoid09 (Brown et al., 2011) was used. A survey was then undertaken of critical features, locating fences, and improvements and services if present.

The field trips also included annotating maps to illustrate the access used, where this was not clear from aerial photography. The existence of locked gates and any issues associated with access were recorded. Notes were also taken describing land use of the site and adjacent land. Surveying on the border has additional challenges in dealing with coordinate systems and plans from different jurisdictions.

11 RESEARCH SOURCES

In undertaking this project, besides researching the obvious sources such as the local government authority or relevant government department websites, the relevant site was 'googled' to see whether there were any extraordinary aspects recorded relating to the site. In doing this, a very useful and interesting website was discovered. A local bushwalker has developed a fascination for discovering the ACT border survey marks and created a blog on which he posts his experiences in walking the border as well as numerous photographs (Evans, 2013). His interest was such that he obtained the corner coordinates from the ACT survey office and then with his handheld GPS located such marks and photographed many. This source proved to be valuable and some of his photographs are used in this paper.

Other sources included the border survey sheets, portion plans and parish maps, topographical maps, local government and departmental documents and information obtained using the Google search engine.

12 NON-BORDER PROPERTIES

Two sites were included in the brief that were not considered as border properties, and Landdata was asked to separate the report on these sites from the border properties report. The sites in question were the Tidbinbilla Tracking Station (together with its satellite sites) and

Two Sticks Road.

12.1 Tidbinbilla Tracking Station

The Tidbinbilla Space Centre, now known as the Canberra Deep Space Communication Complex (CDSCC), is operated and maintained on behalf of NASA by the CSIRO (NASA, 2013). The land used by the tracking station consists of a large primary site and three secondary sites being two remote sites for communication purposes and a thin passage site containing water pipes from a nearby river to the primary site (Figure 10). The sites for the tracking station were removed from the existing rural lease at the time.

Figure 10: The Tidbinbilla Space Centre with two close satellite stations in blue (ACT Government, 2012).

The site now contains extensive improvements of very high value and a significant network of services. For the purpose of the project, neither was required to be fully surveyed. Instead, use was made of supplied plans, previous work done on the site and digital imagery. The perimeter of the main site was surveyed to determine any encroachments or near encroachments.

Whilst the main site was very large and thus took time to survey, the small remote sites provided more challenges. The boundaries of one of the sites within ACT land had not been defined by survey, and, whilst it was shown on the ACT cadastral database, finding documentation to confirm its location was difficult. The situation was exacerbated by the Landdata survey, which indicated that the existing structures on the site did not fall within the boundaries as defined by the ACT database. The recommendation in this instance was to have the site surveyed and a formal survey plan lodged with the ACT survey office. There were further encroachments associated with a second site. ACT control marks were located within it. The boundaries of the third site created to contain water service infrastructure to the main site were vague and appeared to terminate short of the river from which water was being pumped. Water service infrastructure was found apparently outside of the site boundaries.

12.2 Two Sticks Road

The Two Sticks Road site involved the survey of a road that runs in both the ACT and NSW, crossing the ACT western border twice. The site requiring survey was uncertain, as the

Commonwealth did not appear certain of their extent of ownership. Consequently, the survey and site report covered the full extent of the road from its intersection with Mountain Creek Road.

Two Sticks Road is well summarised on the Bonzle website (http://maps.bonzle.com): "*The Two Sticks Road is an unsealed road in New South Wales and the Australian Capital Territory. ... The Two Sticks Road's highest elevation along its length is 1320 m and the lowest point is at 588 m. ... Two Sticks Road is mountainous along its 25.6 km length, with about 7.9 km that is steeper in incline/grade than 5% (2.5 km is steeper in incline/grade than 10% and 1.2 km of that has an incline/grade more than 15%!). The total ascent / descent along the length of the Two Sticks Road is 956 m / 541 m.*"

The road in the ACT is in two parts. The northern part is defined by a road reserve that is illustrated in plans DP435676, DP109594 and RP1009. It is now a gazetted road. The reserve forms part of the land acquired by the Commonwealth in 1943. The area within the ACT is 4.79 ha. The western section, which starts at a location known as Piccadilly Circus at its intersection with Brindabella Road (Figure 11), runs in a northerly direction through the Namadgi National Park until it crosses the ACT-NSW border. The southern section does not have formalised road reserve boundaries and is not a gazetted road.

Figure 11: Heritage border mark at the Piccadilly Circus end of Two Sticks Road (Evans, 2013).

In NSW, the northern section lies within road reserve boundaries. The road reserve is illustrated in DP109594 and DP1032871. The road reserve extends to the western boundary of Lot 1 DP1032871. This forms part of the land acquired in 1943 and has an area of 7.57 ha. West of Lot 1, the road passes through the Brindabella State Conservation Area and Brindabella National Park, but no road boundaries are defined. The road is not a public road under the Roads Act. The road is managed by the National Parks and Wildlife Service of the NSW Office of Environment and Heritage. It is listed by Yass Valley Council as a "rural unsealed road of hierarchy category 5". This provides one maintenance grade every two years. Further south, the road again crosses into the Namadgi National Park in the ACT, but is not located within a road reserve.

That part of the road acquired by the Commonwealth was acquired as a "road" and not as a freehold (NSW) or leasehold (ACT) parcel. It has been treated as a road for public access. In the ACT it is designated a "road", while in NSW it is treated as a "reserved road".

As can see from the aforementioned description, one of the main challenges was accessing the site, due to its steepness (Figure 12). In winter, the access was exacerbated by frost making the icy road very slippery and dangerous, and tree falls across the road were common. The density of tree cover also limited the use of GNSS survey techniques. Thus, long traverses were surveyed closing between spaced control marks where sufficient GNSS signal reception was possible. Fortunately, it was possible to make use of contours from existing topographic maps.

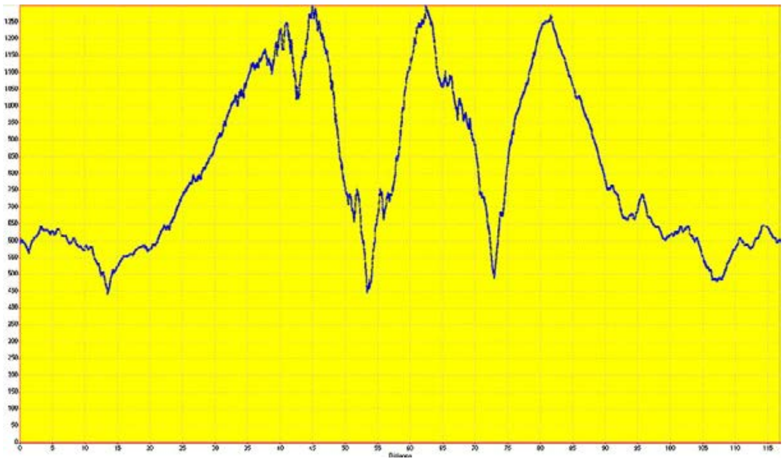

Figure 12: Graph illustrating the vertical profile of Two Sticks Road (Vernon, 2012).

Whilst from the cadastral map of the Two Sticks Road acquisition site it was possible to determine the extent of that part of the road, it was less easy to determine the authority responsible for the road in NSW. Parts had been dedicated as public road and thus fell under the jurisdiction of Yass Valley Shire Council, and those parts within road reserves in the ACT were under the control of ACT roads. However, those parts of the road in the Brindabella National Park and Brindabella Reserve were not within road reserves and thus did not have road status. They were generally managed by the NSW National Parks and Wildlife Service and the ACT Parks Conservation and Lands.

13 CONCLUDING REMARKS

One wonders whether using watersheds for the definition of the ACT-NSW border was the most appropriate policy. It may have been more appropriate to follow the existing cadastre beyond the watershed. This would have avoided the consequences of severing existing properties to create the border.

The Seat of Government Surrender Act 1909 (Commonwealth of Australia, 1909 – see Annexure) describes many of the boundaries on the ACT-NSW border as watersheds. Could such watersheds be considered somewhat ambulatory or a "natural boundary"? One wonders how the border surveyors determined the locations of the watershed.

The NSW Registrar General's Directions define a natural boundary as follows (NSW Government, 2013): "*A boundary that is formed by a natural feature (bank of stream, mean high water mark, edge of cliff etc.) must be surveyed so that each change of course or direction is determined to the appropriate accuracy. This may be achieved by the surveyor adopting a series of bearings and distances that approximates the boundary. These bearings*

and distances are derived from the end points of a series of radiations taken from one or more field stations to each change in direction of the bank of the stream etc. In order to ensure the plan of survey remains clear and legible it is common practice to list each bearing and distance in a table of short lines. The actual bank etc. is delineated on the plan as an irregular line." Could the definition in the survey plans of the border be challenged on the basis that the watershed was not adequately defined?

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ANNEXURE: SEAT OF GOVERNMENT SURRENDER ACT 1909

The State shall surrender to the Commonwealth, and the Commonwealth shall accept, for the purposes of the Seat of Government, the territory (hereinafter called the Territory), now being part of the State, described hereunder, namely—

Counties of Murray and Cowley, area about 900 square miles: Commencing on the Goulburn-Cooma Railway at its intersection with the Queanbeyan River at Queanbeyan, and bounded thence by that railway generally southerly to the south-eastern corner of portion 177, Parish of Keewong, County of Murray, by the southern boundaries of that portion and portions 218, 211, 36, and 38 generally westerly to the Murrumbidgee River, by that river downwards to a point east of the south-east corner of portion 68, Parish of Cuppacumbalong, County of Cowley, by a line partly forming the southern boundary of that portion west to the eastern **watershed** of *Gudgenby River*; by that **watershed** and the eastern and southern **watersheds** of *Nass Creek* by part of the western **watershed** of *Gudgenby River*, generally southerly, westerly, and northerly to the southern **watershed** of *Cotter River*, by that **watershed** and the western **watershed** of that river, passing through Mount Murray and through Bimberi Trigonometrical Station, generally northerly to Coree Trigonometrical Station; thence by a line bearing north-easterly to One-Tree Trigonometrical Station; thence by the **watershed** of *Molonglo River* north-easterly and generally south-easterly to the Goulburn-Cooma Railway aforesaid, and thence by that railway generally south-westerly to the point of commencement.

Finding Bennelong? Surveying Solves a 200-Year-Old Mystery

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ABSTRACT

When the English First Fleet arrived in Sydney in January 1788, Woollarawarre Bennelong was about 25 years old. He went on to become a crucial informant and played a very important role in communications between the indigenous population and the early European settlers. In a report to City of Ryde Council's Heritage Advisory Committee in 2010, regarding the search for Bennelong's grave, Dr Peter Mitchell requested that Council's surveyors look at his findings and evidence to verify his conclusion as to where he placed the grave site. This paper outlines the surveyor's response. The starting point was a photograph taken around 1900. Dissection of information shown in this photograph led to identifying sites and markers. This was followed by intersecting sight lines and calculation of distances and ratios, finding the location in the present day and validation from circumstantial evidence and reasonable deduction using current photo images. What is the likely order of error? Sydney newspaper articles followed, with public awareness and interest being raised and some public verification eventuating.

KEYWORDS: *Bennelong, grave site, mystery, surveying*.

1 INTRODUCTION

Woollarawarre Bennelong was about 25 years old when the English First Fleet arrived in January 1788. Bennelong's life then changed forever. Phillip's instructions from King George III included "endeavour by every means possible to open an intercourse with the natives, and to conciliate their affections". Phillip tried, but by November 1789 he was in such despair over ever achieving native confidence by "fair means" that he ordered "two men should be taken by force". At the time of his capture, Bennelong was wiry and muscular, standing 170 cm tall (Figure 1). His skin was marked by smallpox (from which he had obviously recovered) and First Fleet officers described Bennelong as a merry fellow with a mischievous twinkle in his large dark eyes.

Bennelong soon became a valuable informant and go-between, willingly providing information about Aboriginal clans, customs and language. He learned to speak English and resided at Government House. In December 1792, Bennelong took the bold step of accompanying Governor Phillip on the long voyage back to England. Bennelong returned to Sydney Cove in September 1795, with Governor Hunter, and resumed an influential position among his people and the new settlers. Bennelong died on 3 January 1813 and was buried on the land of his friend James Squire, in an orchard at Kissing Point (now Putney) in Ryde.

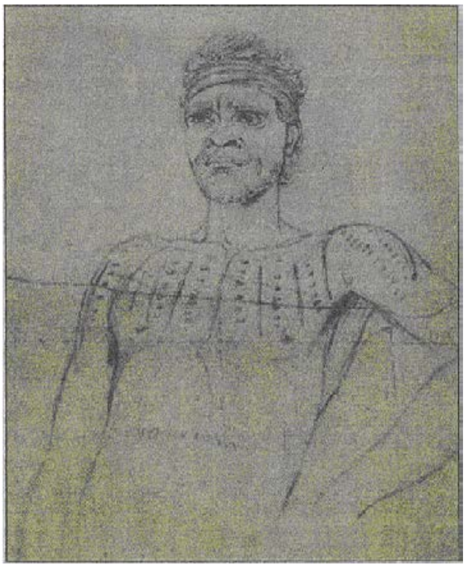

Figure 1: Drawn from another time... a sketch of Bennelong by William Westall, 1802.

2 SEARCHING FOR BENNELONG'S GRAVE SITE: MITCHELL'S REPORT

In 2010, the City of Ryde Council's Heritage Advisory Committee instigated a report in relation to Bennelong's grave site. Historian Dr Peter Mitchell was asked to determine where the grave site was located. He followed a paper trail, which pointed the way. In the absence of any maps that showed the grave site, there were two key pieces of information.

The first was a letter (reproduced below) written by Charles Cobham Watson to the Editor of the Sydney Morning Herald and published on 8 July 1927. Watson was a great grandson of James Squire.

……….oOo……….
TO THE EDITOR OF THE HERALD
Sir, -- I was very much interested in Mr.
Weirter's account of the aborigine Benne-
long, which appeared in last Saturday's
"Herald". I am the owner of a portion of
the late Mr. Squire's old brewery property
at Kissing Point, and in that property there
is a black-fellow's grave. A very old resi-
dent of Kissing Point told me that the man
had worked at the brewery, and had died
and was buried there. Seeing that history
tells us that Bennelong was buried at Kis-
sing Point in Squire's grounds, and this grave
being the only one known on the property,
it seems to me that there can be no doubt
that the grave is that of Bennelong.
I am, etc.,
C.C.Watson
Rydedale-road
July 7 West Ryde.

The second key piece of information was a small photograph, taken around 1900, that allegedly shows the grave (Figure 2). The Ryde Library catalogue entry for this photograph states that it is annotated on the back in pencil with the wording "Photographed about 1900. Remains of J. Squire's orchard at Kissing Point, then in possession of Mr C.C. Watson and family…" Figure 3 illustrates the present day scene photographed from approximately the same spot.

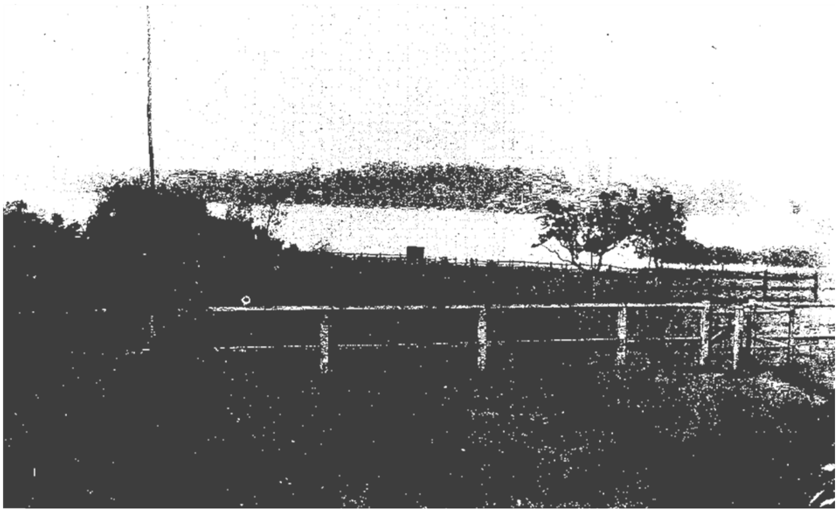

Figure 2: Photograph taken around 1900 and allegedly showing the grave site in the foreground.

Figure 3: Photograph taken in 2012 and showing the present day scene from approximately the same spot.

Dr. Mitchell concluded that the grave site was under a former tennis court, which is now the southern end of Hordern Avenue near to its junction with Watson Street (Figures 4 & 5). He further recommended that Council ask their survey team to verify the boundaries described in his report and to take steps to have the land identified as a local heritage item, with consideration for State Heritage listing (Mitchell, 2010).

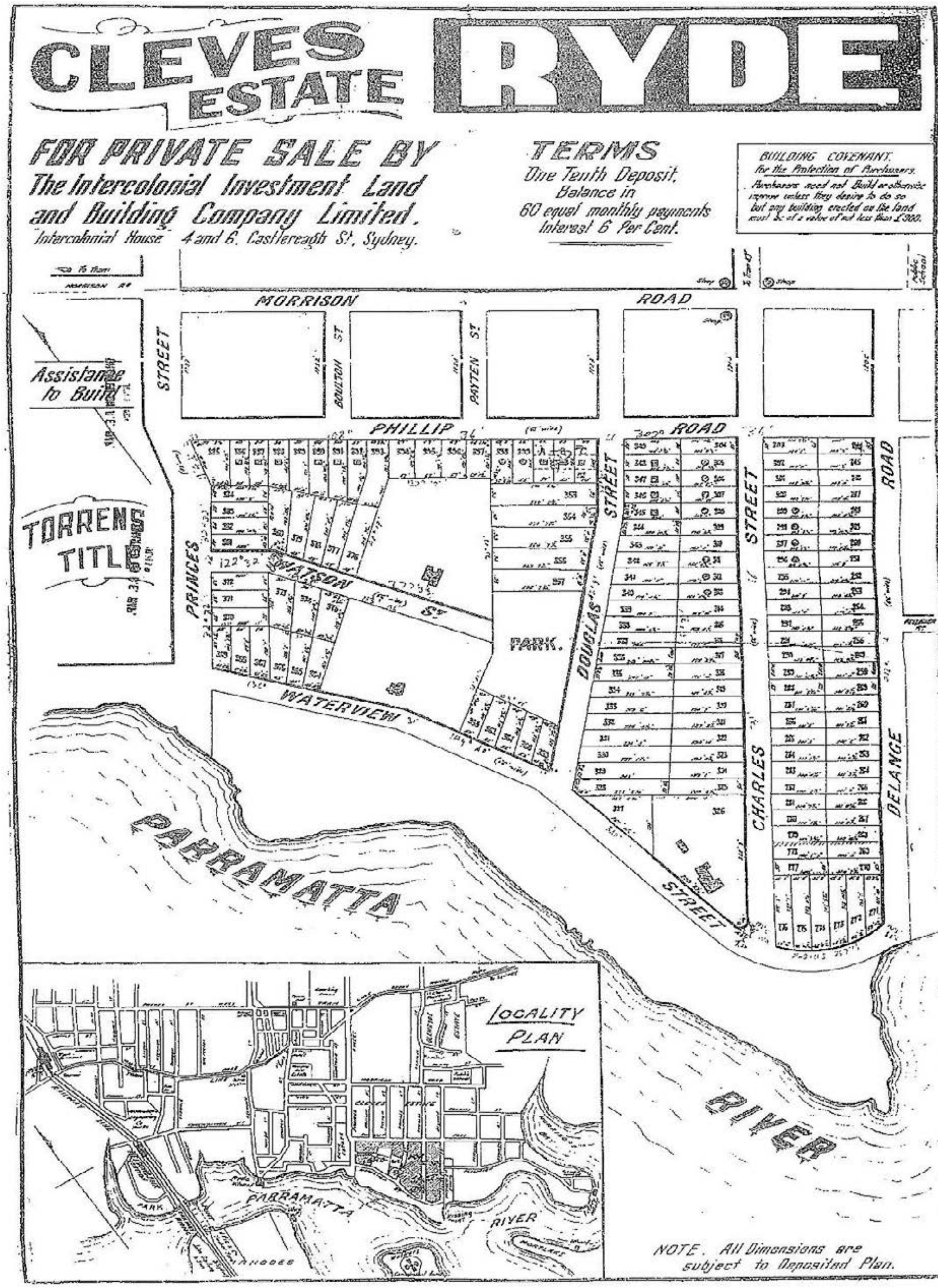

Figure 4: The advertising banner for the Cleves Estate subdivision of 1922 (DP 11471 – Adelbert Schleicher), showing Watson Street before the creation of Hordern Avenue.

Figure 5: Current land-use pattern showing the site of the former tennis court where Dr Mitchell concludes Bennelong is allegedly buried.

3 SURVEYOR'S REPORT TO THE RYDE HERITAGE COMMITTEE

The photograph in Dr Mitchell's report shows the "blackman's grave" circa 1900 (see Figure 2). Inspection of this photograph reveals many items of interest:

1. The grave itself.
2. Two close parallel lines of fencing.
3. Other fences running southwards towards the Parramatta River.
4. An area that appears to be a vacant paddock.
5. On the west of this area is a plantation row of low trees.
6. A built structure, at centre, in silhouette against the river.
7. A tall built structure on the opposite river bank.
8. Other built structures on the opposite shore and westwards upstream.
9. Mud flats running from the opposite shore and disclosing a bay behind.
10. The northern bank of the Parramatta River is not visible.

In dealing with the grave itself, it was enlightening to find that an enhancement of the photograph revealed some detail, i.e. what appears to be a roughly circular edging of stones with a placed timber stake. One thing that is evident is that the grounds appear to be well maintained, like a house garden. The parallel fencing clearly suggests the boundaries on either side of a road. The road is unformed and clear of any obstructions, and there appears to be little evidence of frequent traffic, i.e. it does not appear to have many nor frequent horse and cart users.

The line of road fencing closest to the camera is of a dressed timber post and rail (arris-type) construction. The type of fencing directly across the road is round and split timber post construction with probable strands of drawn wire (though not visible in the photograph). The fencing type on the street frontage of the vacant lot is three rail and mortised timber post construction. The fencing on the rear appears to be timber post and rail, but it is hard to determine if that fencing is three rail or two (Is there again a parallel row of fences indicating another road?). These different fence types tend to indicate separate ownerships of land or

separate parcels of land. Thus, the round fence post is at a lot corner. A conversation with Julie Watts, a granddaughter of the property owner after Watson, confirmed that the white painted arris fence surrounded the original homestead.

The plantation of trees is located in a row as evidenced by a visible line of tree trunks. These trees are similar in appearance and all undercut to a uniform height; note the Parramatta River is visible beneath the tree canopy. It is clear that these trees are on the brow of a rolling hill, which obscures the northern riverbank (no mangroves are visible nor can any beach be seen). This remnant row of trees can be seen in a 1930 aerial photograph but not in the 1943 aerial photograph mentioned below (see Figure 9). The built structure in the centre of the 1900 photograph has not been identified but is suggestive of a sign or billboard. Was this photograph taken as the result of a purchase of the property?

The opposite bank of the river has been identified as Rhodes and the tall built structure is a brick chimney stack, which was part of the timberyard site of McKenzie in 1906 (Figures 6 & 7). The stack was demolished in 1968 but appears in aerial photographs of 1928, 1930, 1943 and 1964.

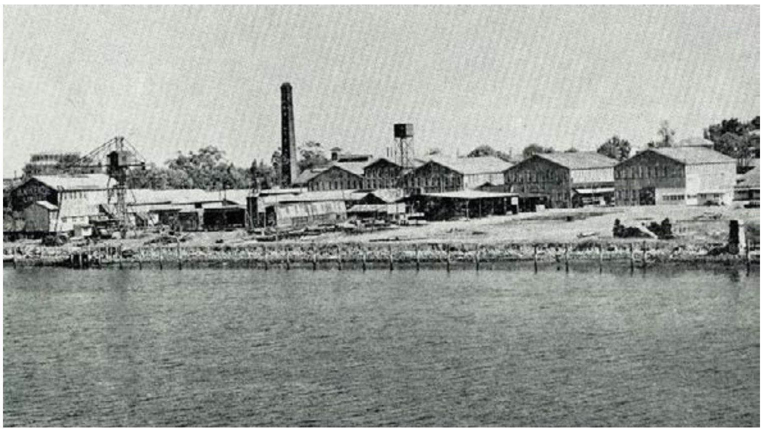

Figure 6: Undated photograph of McKenzie's timber yard at Rhodes showing brick chimney stack.

Figure 7: Looking over McKenzie's timber yard at Rhodes around 1928, showing the brick chimney stack adjacent to Concord Road.

Other built structures include the long wharf of the timberyard and scattered houses erected along the shoreline. The mud flats running from the southern shore of the Parramatta River are still visible today (Figure 8).

Figure 8: Recent photograph, taken in 2012, showing the Parramatta River mud flats at Rhodes.

The site of the chimney stack has been located on an aerial photograph of Ryde taken in 1943 and its position coordinated (Figure 9). The lot corner in Watson Street has also been re-established and coordinated from survey reference marks found (concrete blocks), which were placed for the creation of Hordern Avenue (DP 27410 in 1956).

Figure 9: Aerial photograph (taken in 1943) showing sight lines from the brick chimney stack and mud flats towards the grave site.

4 DISTANCE MEASUREMENTS WITHIN THE OLD PHOTOGRAPH

The spacing of fence posts and other known points of reference in the 1900 photograph were used to obtain distance measurements (Figure 10). Note that a sight line from the chimney stack at Rhodes through the round fence post (at the lot corner) in Watson Street passes directly adjacent to the grave site.

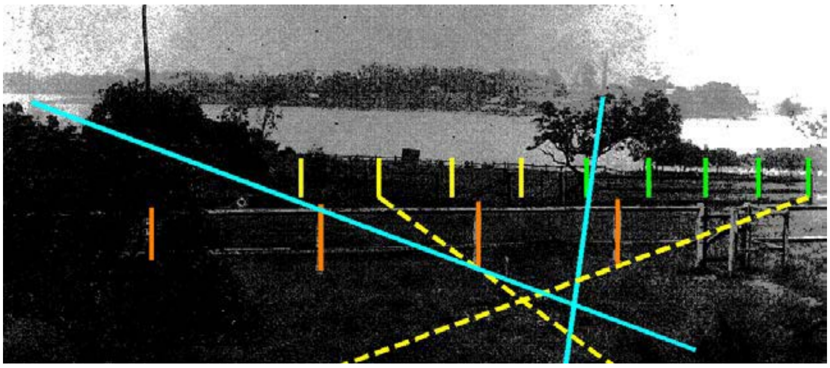

Figure 10: Diagram showing sight lines from the chimney and mud flats together with fence post positions along Watson Street.

Reconstruction of the fence post positions along the Watson Street frontage allows the site of the grave to be more accurately located. The arris fence and the mortised fence each display a regular spacing between posts, i.e. the measured dimensions between posts in the photograph show a uniform expansion or contraction. Research with a present-day heritage fencer revealed that the standard post spacing for a mortised fence was 2.4 m (8 feet) or 1.8 m (6 feet). Similar research with another heritage fencer revealed that some fence spacings were also 2.74 m (9 feet), e.g. at the Rouse Hill Heritage Centre where he had just completed some replica restoration work. Field verification by the sighting of remnant examples in Ryde supported a post spacing of about 2.6 m for the arris fencing.

Several combinations of these fence spacings were tested by drawing intersecting lines, with the overall circle of error being approximately 0.6 m. The resulting position was coordinated and is shown on an aerial photomap (Figure 11). Note that an estimation of the camera position (grey circle) falls short of the homestead.

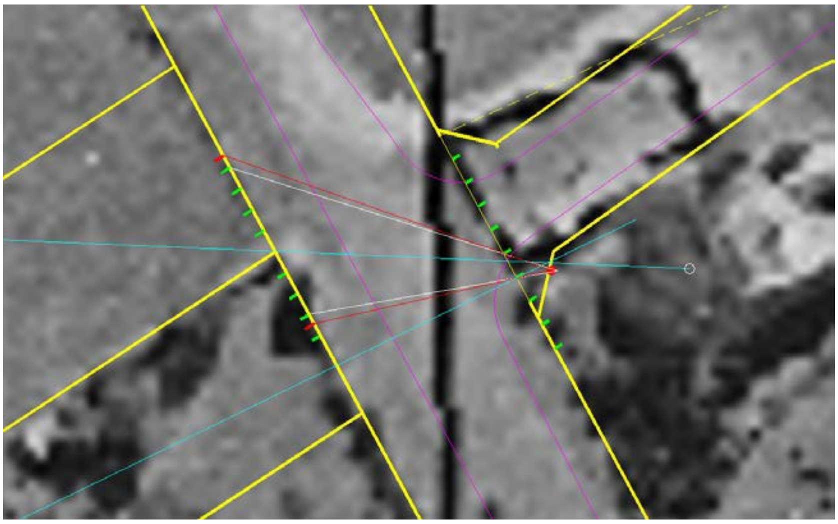

Figure 11: Diagram showing sight lines and construction lines through fence-post positions along Watson Street. The red dot indicates the final accepted position.

5 WHAT HAPPENS NEXT?

An underground sensing device has been used with results being inconclusive. Modern underground services that pass closest to the grave site are telecommunications and Sydney

Water. Sydney Water has a 100 mm cast iron cement lined water main, which runs along the northern side of Watson Street. This water main was constructed in 1934 up to house no. 25 (the homestead), extended in 1952 to house no. 29 (following subdivision) and again in 1957 following the subdivision and opening of Hordern Avenue. This main passes up to 4 m from the grave site. Underground telecommunication lines also run along the northern side of Watson Street but turn with the splay corner and continue into Hordern Avenue. These lie directly adjacent to the site and may have had an impact.

The City of Ryde Council has been working with the adjoining landowners, the Aboriginal Heritage Office, the Sydney Metropolitan Land Council and the NSW Heritage Office to decide what happens next (City of Ryde, 2011). The Sun Herald newspaper published several feature articles that have led to many public responses and interest (Duff, 2011a; 2011b; 2011c; 2012). During 2013, the City of Ryde is planning a Bennelong exhibition (e.g. Smith, 2013).

6 CONCLUDING REMARKS

Is the grave site really Bennelong's? Contemporary writings from the early 1800s leave several clues. On 3 January 1813, Bennelong died and was buried "among the orange trees in James Squire's orchard". On 12 August 1821, Nanbarry, "a black native of this colony", died at James Squire's orchard and "he lies interred in the same grave with Bennelong and his wife, in Mr. Squire's garden". In 1828, the Reverend Charles Wilton said "the garden of the late proprietor James Squire is celebrated for containing the remains of Bennelong" (Figures 12 & 13).

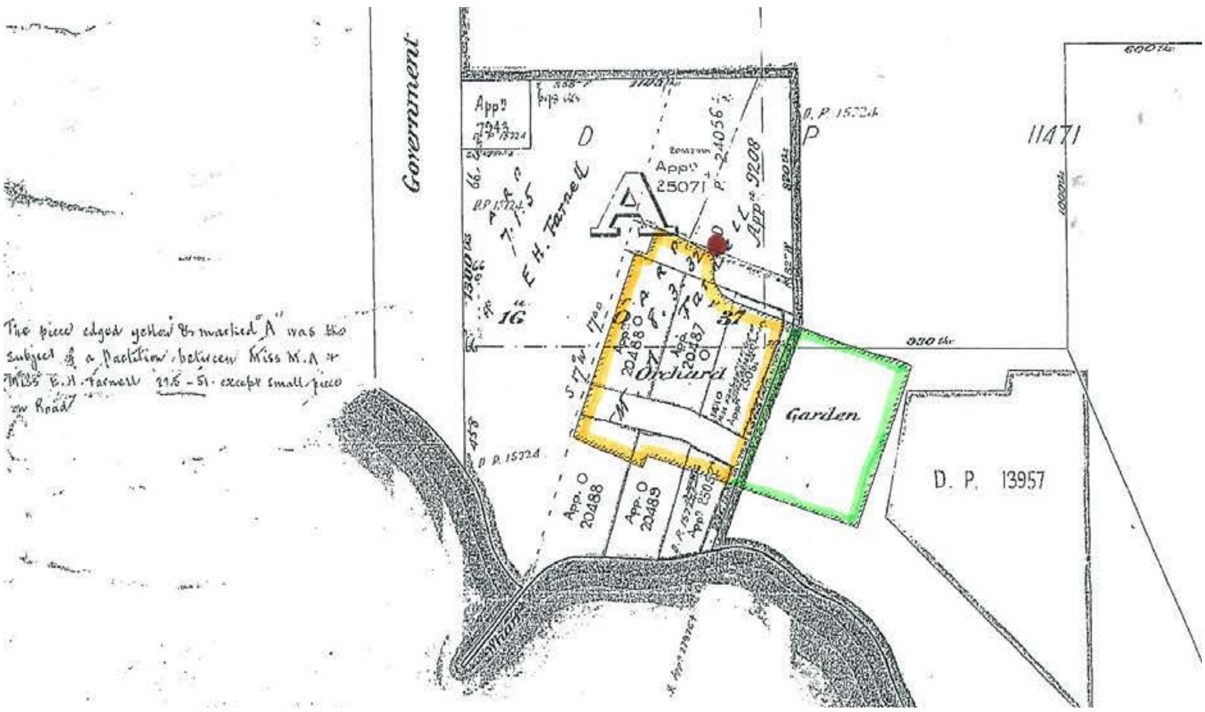

Figure 12: Part of DP 192080, from 1878, which was copied from the 1842 map shown in Figure 13. The red dot shows the grave site in relation to the orchard and garden of James Squire.

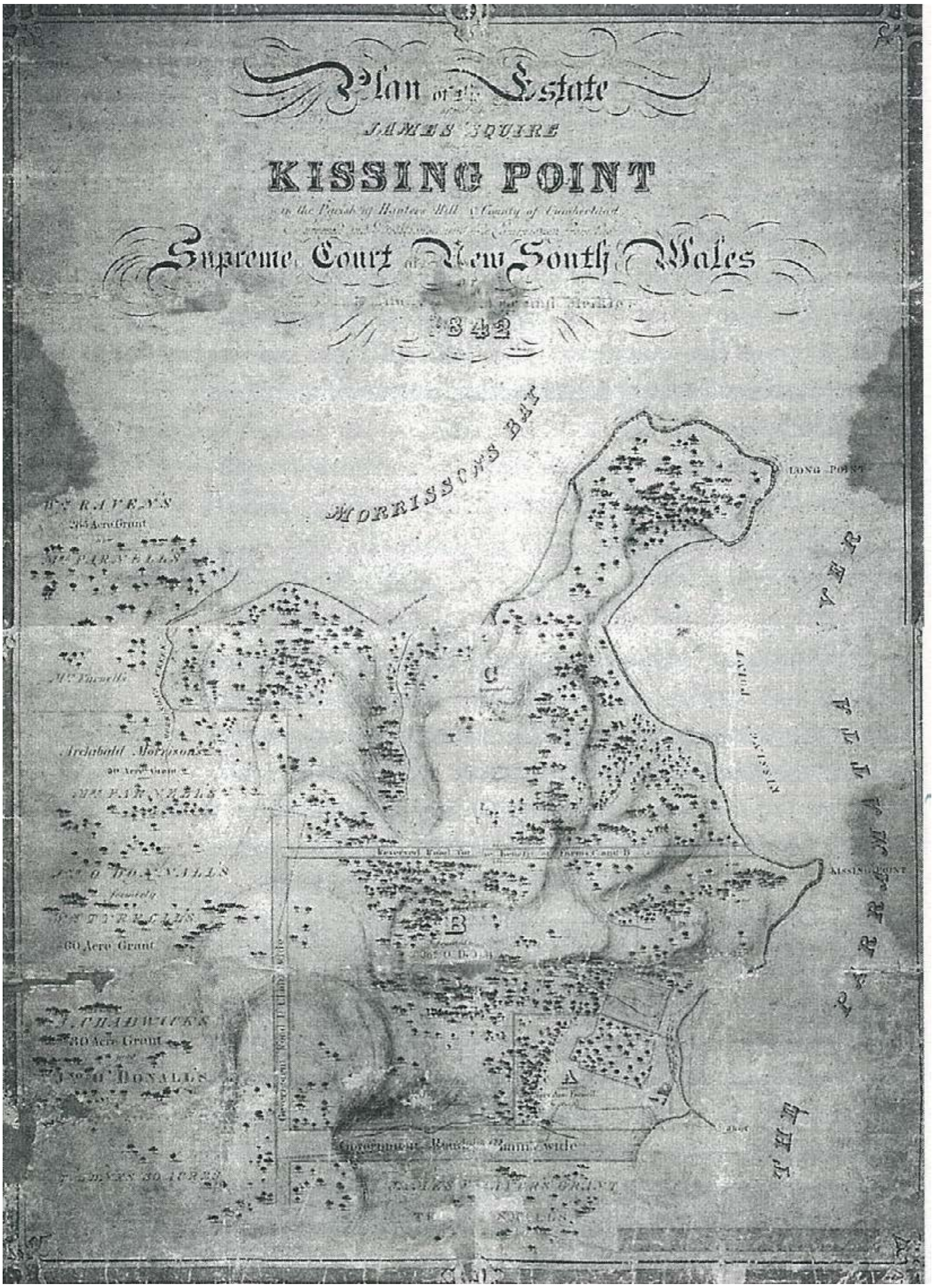

Figure 13: Supreme Court map of 1842, used to finalise the will of James Squire.

ACKNOWLEDGEMENTS

I must acknowledge historian Keith Smith for his valuable assistance in providing such a mass of information on the life of Bennelong and would like to add his quip upon hearing about the finding of the location of the grave site: "I have to say, it's the first time I've ever had a history book interrupted by breaking news."

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Impact of the New Surveying and Spatial Information Regulation 2012

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ABSTRACT

The Surveying and Spatial Information Regulation 2012 commenced on 1 September 2012, replacing the Surveying and Spatial Information Regulation 2006. The objectives of the Regulation are to ensure the competency of surveyors, maintain the integrity of the cadastre for New South Wales, ensure measurement and marking standards are delivered from modern surveying and communication technologies (including E-Plan) and street addressing is integrated spatial information. This paper outlines a number of reforms that were introduced in the 2012 Regulation. These include:

- *New definition for Bench Marks, to assist E-Plan.*
- *Survey marks (i.e. PMs, SSs and BMs) used to define the datum of the survey are treated similarly.*
- *Ensure only reliable survey marks are used to define the datum line of the survey.*
- *Measurement accuracies amended to suit instrument specification and industry expectations.*
- *Insist that all Lots are described by complete information to facilitate E-Plan. The misclose tolerance for Residue Lots was relaxed.*
- *Minor reform in marking requirements for surveys.*
- *Street address of all Lots is a new requirement to facilitate the integration of land titles with spatial information.*
- *Reforms for the 3-dimensional cadastre identified in the early consultation did not eventuate in the final Regulation.*

KEYWORDS: *Bench marks, complete dimensions, measurement accuracy, street address.*

1 INTRODUCTION

Under the Subordinate Legislation Act 1989 (NSW Legislation, 2012a), all statutory rules (i.e. regulations) must be remade every 5 years to ensure they remain relevant and current to government, community and industry needs. The Surveying and Spatial Information Regulation 2006 (NSW Legislation, 2012b) had previously been granted an extension of 12 months for the remake and was due to be repealed on 1 September 2012. Consultation with the surveying and spatial information industry during 2010-2012 ensured that emerging issues and needs were addressed in the remake of the Regulation.

The Regulation is made under the Surveying and Spatial Information Act 2002 (NSW Legislation, 2012c). The Act incorporates all aspects of the Regulation and oversight of land and mining surveying in NSW. The major objective of the Act is to ensure the maintenance

and on-going development of the State survey control network, which provides a reliable and accurate spatial referencing system underpinning surveying, land information and mapping systems in NSW.

In order to achieve this objective, the Act requires that surveyors must be registered and must comply with minimum standards of education and competency. The Act establishes the Board of Surveying and Spatial Information (BOSSI, 2013) to oversee the registration of surveyors, set professional education requirements and conduct disciplinary investigations to ensure consistency and quality in the delivery of surveying services.

The main outcomes from the new Surveying and Spatial Information Regulation 2012 (NSW Legislation, 2012d) are:

- Facilitate the implementation, maintenance and management of cadastral survey standards.
- Maintain the positional integrity of the cadastre to assure public confidence in the land titles system in NSW.
- Introduce additional forms and styles of survey marks to ensure uniform outcomes for the marking of surveys to facilitate electronic lodgement and examination of survey plans.
- Cater for evolving technologies, such as Global Navigation Satellite System (GNSS) and Continuously Operating Reference Stations (CORS).
- Enhance the standards of accuracy to accord to the higher performance of using new technologies.
- Encourage standardised forms and styles for all survey information to facilitate electronic lodgement and examination of surveys.
- Encourage integration of spatial information with street addressing for the benefit of emergency services and for the community generally.

2 GENERAL PROCESS

During 2010 and 2011, many workshops were conducted with regional surveyor groups to determine the issues and principles within the Surveying and Spatial Information Regulation that needed reform. From these workshops, a detailed working brief was forwarded to the Parliamentary Counsels Office with a request to draft a new consultation draft Regulation. In addition to the draft Regulation, a Regulatory Impact Statement (RIS) is also prepared (LPI, 2012). The objective of the RIS is to outline who is making the new Regulation, why it is being made and to consider all options for the proposed changes to ensure the best outcome is to be achieved. The RIS weighs up the costs and benefits of the proposed Regulation and also considers alternative options for achieving the required options, including remaking the Regulation, introducing a Code of Practice or allowing the Regulation to lapse. In this case, making a new Regulation was considered the best option.

The RIS, together with the consultation draft Regulation, was advertised in the media and to all relevant surveying and titling industry groups (such as the Institution of Surveyors NSW, Law Society of NSW, government agencies, etc.) and to all surveyors. The intent of the advertising is to ensure that all surveyors and participants in the surveying and spatial information industry are aware of the draft changes and to invite submissions on the draft Regulation. Both documents were available for public and industry consultation during July and August 2012. Many submissions were received resulting in amendments being made prior to the final Regulation being approved by the Minister.

3 SUMMARY OF CHANGES AND ANNTICIPATED IMPACT

A summary of the changes from the Surveying and Spatial Information Regulation 2006 to the Surveying and Spatial Information Regulation 2012 is outlined in Table 1. Proposals that were not approved or were deleted before the final remake of the Regulation are also stated. The sequence or numbering of the changes is based upon the clause numbering in the draft Regulation.

Table 1: Summary of changes from the 2006 Regulation to the 2012 Regulation.

2006 Clause Number and Title	2012 Regulation	Reason for Change
5 Definitions The adjoining definitions were added:	*Bench Mark* – defined to be a survey mark referred to in Sch1, which prescribes the forms and styles of bench marks that can be used.	*Bench Marks* – To ensure a standard form and style for all bench marks and to enable automatic assessment of bench mark via electronic lodgement.
	Compiled plan – defined to be a plan prepared on the basis of information recorded on plans held on public record, not on the basis of a survey of the land...	*Compiled plan* – The Regulation makes reference to "compiled plans" in Clauses 26 and 60 as well as in Form1 in Sch6 (Survey certificate), necessitating a definition.
	SCIMS – defined to be the information management system known as the "Survey Control Information Management System".	*SCIMS* – The Regulation makes reference to information relating to survey marks being recorded in SCIMS, rather than the register of public surveys.
	Surveyor-General's directions – defined to be the directions of the Surveyor General published on the LPI website.	*Surveyor-General's directions* – defined to be the directions of the Surveyor General published on the LPI website.
	Road – amended to include "other means of **public** access..."	*Road* – The amendment reduces the current requirements for marking roads by limiting the other forms of access that fall within the definition of a road.
	Established survey mark - reference to register of public surveys replaced with reference to SCIMS.	*Established survey mark* – as records relating to survey marks are held by the Surveyor General in SCIMS, the amendment provides a more accurate definition.
	Survey Drafter was deleted.	*Survey Drafter* – The Board has not determined the relevant experience necessary to qualify as a Survey Drafter, hence no current requirement for a definition.
6 General principles of survey	An additional principle has been added as cl 6(d) requiring that when carrying out a survey the surveyor must ensure the MGA co-ordinates and AHD values derived for the survey are correct.	Historically, surveys were primarily concerned with calculating the dimensions of a parcel of land. Today, the emphasis is on positioning/location.
	Old cl 6(f) now cl 6(g) – Where required, a surveyor must prepare **and certify** a survey plan.	It is a current requirement for all survey plans prepared by a surveyor to include a Survey Certificate. This requirement is to be included as part of the general survey principles.

2006 Clause Number and Title	2012 Regulation	Reason for Change
10 Surveys for identification or re-marking	New cl 10(3) – providing that a survey made for the remarking of a parcel may not be used for the purpose of any disposition of land or any interest in land. Cl 10(4) – Plans of identification now also to comply with clauses 23, 24 and 25.	This requirement was previously included in the regulation as a Note. It is now included as a specific clause. Clauses 23, 24 and 15 require a surveyor to check angular work and relate to accuracy of angular and length measurements. These clauses should also apply to surveys for identification or remarking.
12 Datum line .	New cl 12(2)(c) added to require that where a rural survey is not within 1000 metres of 2 established survey marks, the bearing used for orientation may be adopted from 2 survey marks that have a horizontal position equal to or better than Class D. New cl 12(3) – added to require that the survey marks used to define the datum line must have an approved mark status of Null, Not Found or Found intact.	The clause has been amended in recognition that marks classified as Class D should be suitable to define the datum line for a rural survey. It also accommodates GNSS positioning techniques better. Only use marks recorded in SCIMS that are assumed to be stable and reliable to define the datum of the survey. Do not use marks that are reported to have been disturbed, damaged, subsided, or uncertain.
13 Bench marks	New cl 13(6) added requiring the position of bench marks to be determined by a survey technique equal to or better than that derived from using hand-held GNSS.	The bench marks used to establish height levels must be able to be easily located.
18 Surveys for affecting interests	Subclauses have been rearranged and renumbered. The draft Regulation proposed a new cl 18(5) added requiring that where a survey is carried out only for the purpose of creating an affecting interest, the area of the site of the affecting interest must be shown for each lot, or group of lots, held in separate ownership (except where the affecting interest comprises a physical feature or structure only (such as a track in use or party wall)). This proposal was deleted as a result of the industry consultation.	Subclauses have been rearranged for better clarity. The original proposal required the area of an affecting interest to be shown on the survey plan. That would have enabled the landowner and future purchasers to appreciate the extent of the affectation and will assist in the task of valuing the affecting interest. The area of easements is not required as a part of the 2012 Regulation.
19 Re-survey of property boundaries	New provision proposed as cl 19(2) (b) requiring a plan of resurvey to disclose the position of any existing road formation and fencing. This proposal was deleted as a result of the industry consultation.	The position fencing is an important consideration in re-establishing boundaries. There is no requirement to show the location road formation.
24 Accuracy of angular measurements	Cl 24(2) has been amended to require that the angular misclose must not exceed 10 seconds plus $10\sqrt{n}$ seconds or 2 minutes (whichever is the lesser).	The accuracy has been amended to reflect the accuracy that can be obtained from modern instrumentation.
25 Accuracy of length measurements	Cl 25(2) has been amended to require all lengths to be measured to an accuracy of 10 mm + 50 parts per million or better at a confidence interval of 95%.	The amendment will ensure a higher level of accuracy is obtained to better meet community expectations for accurate boundary definition given increasing pressures on land use. It reflects the accuracy obtainable from modern instrumentation.

2006 Clause Number and Title	2012 Regulation	Reason for Change
26 Checking accuracy of measurements	Cl 26(2) amended to require calculation of the internal closure of any survey, and of each parcel of land surveyed.	Requiring the internal closure of all survey work to be calculated allows an additional check to ensure the accuracy of the measurements.
	New cl 26(3) added to require that where complete dimension of a compiled or partially compiled parcel are shown in a survey plan the surveyor must calculate the closure of the parcel. A table was added setting out the allowable tolerance of the misclose vector. Dependant on the age of the survey on which the compiled parcels are based and on the nature of the terrain.	Where dimensions are available, checking the accuracy will give more integrity to the residue. In the electronic environment parcels without dimensions will be unable to be validated. As this requirement only applies where complete dimensions of are available additional cost will be minimised.
	New cl 26(4) provides that if the misclose vector calculated as specified above exceeds the relevant lengths provided for in the table, the surveyor must resolve the inaccuracy by surveying additional boundaries or explain the discrepancy in a comprehensive report.	This requirement will identify parcels that require further survey investigation. This investigation can be carried out at the time of the survey or when otherwise more appropriate.
28-30 Boundary Marks	**28 Boundary Marks** Provisions relating to boundary marks removed from existing clauses 28-30 & 36 and amalgamated in new cl 28.	Clauses amalgamated for clarity and consistency. Previously cl 29(1), relating to rural surveys, however, provision should also apply to urban surveys.
	(1) Surveyor must mark with boundary marks: • boundaries between parcels; • each corners	Previously cl 30(1). Previously cl 36(1).
	(2) Boundary marks must be discernible.	Previously cl 30(2).
	(3) Reference mark to be used where boundary mark on corner not practicable.	Boundary marks placed on a bank or MHWM boundary are likely to be lost through erosion etc.
	(4) New provision added requiring that where a boundary is a bank or MHWM liable to erosion the boundary mark must be placed a safe distance from the MHWM or bank and the distance to the boundary must be noted.	Previously cl 29(2).
	(5) Makes provision for the marking of an unfenced boundary in a rural survey.	Previously cl 30(3).
	(6) No further marking of a corner is required on a rural survey where a fence post is on a corner at which a reference mark has been placed.	Previously cl 36(2).
	(7) Size of marks placed in ornamental structures to be reduced to minimise damage.	
28 Marking of urban survey	**29 Marking of urban surveys** Cl 29(1) amended to require certain reference marks to be placed in respect of an urban survey that abuts a road, other than a road used to provide a means of pedestrian access only.	Road is defined in cl 5 to include pathways. The amendment in cl 29(1) provides an exception to the requirement to mark roads in respect of roads used only for pedestrian access.

2006 Clause Number and Title	2012 Regulation	Reason for Change
29 Marking of rural surveys survey	Renumbered as; **30 Marking of rural surveys** Cl 30(4) amended to ensure requirement for additional marking applies to boundaries exceeding 2400 m, whether or not the boundary includes one or more bends.	Previously 29(5) with amendment to clarify intention of requirement.
	Cl 30(6) added to require additional reference marks: • where land abuts a road, at the extremity of the land surveyed; • at each road intersection; • where land has a stream frontage greater than 500 metres, near each stream bank and side boundary intersection.	The requirements for additional marks to be placed for large parcels of land will assist landowners to better identify their boundaries on the ground.
	Cl 30(c) added to require the survey plan to show: • the width of roads that abut the land surveyed; • connections across abutting roads, where survey marks are available.	Added to ensure complete information is provided on the survey plan. The information will help to ensure adjoining plans better relate to each other.
30 Corners to be marked with Boundary Marks	Now clause 28.	
31 Roads to be marked with reference marks	Cl 31(2)(a)(i) where a road intersection is cut off a reference mark is to be placed at either end of the triangle, or at the intersection.	Corrects an anomaly in the previous Regulation to re-instate usual practice.
	Cl 31(2)(a)(i) where a road intersection is rounded off a reference mark is to be placed at either end of the tangent point, or at the intersection.	
35 Surveyor to note nature and position of survey marks	Cl 35(1)(b) amended to require field notes and survey plan to also note MGA co-ordinates of bench marks. The survey method used to determine to co-ordinates is also to be noted.	No current requirements for surveyor to note MGA co-ordinates for bench marks. Knowing the method used to calculate coordinates will help a user assess their likely accuracy.
	Cl 35(1)(e) added to require that where the purpose of a survey is to limit height and depth, the AHD values of permanent marks or bench marks are to be stated, along with an estimate of their accuracy.	Clause 35 of the former regulation did not previously require AHD values are to be shown.
	Cl 35(6) added to require that the position of each benchmark is to be determined by a survey technique equal to or better than that derived by hand-held GNSS.	Enables bench marks to be located by a cost-effective means.
36 Marking of survey boundaries	Clause deleted. Provision amalgamated within clause 28.	Clauses amalgamated for clarity and consistency.
Clauses 37-41	Clauses renumbered 36-40 without further amendment.	

2006 Clause Number and Title	2012 Regulation	Reason for Change
42 Surveys redefining or creating multiple parcels, roads or affecting interests.	Renumbered as: **41 Surveys redefining or creating multiple parcels (etc.)** Cl 41 (3) amended to apply only where the survey redefines a formed road, or creates a road.	Current requirement to place survey marks at frontage of unformed roads can be unnecessary.
	Cl 41(4) amended to apply only to affecting interest exceeding 200 m.	Previous requirement too onerous in respect of small affecting interests.
	New cl 41(5) added requiring a survey creating an affecting less than 200 m to connect to two permanent survey marks, if permanent survey marks are available within 300 m.	By requiring smaller affecting interests to be connected if permanent survey marks are available encourages survey coordination without the cost of mark placement for a small survey.
43 Connection to permanent survey marks.	Renumbered as: **42 Connection to permanent survey marks** Cl 42(1) amendment to require that the permanent survey marks are to be connected to separate corners by direct lines.	The benefits of relating the survey to more than one survey mark can be lost where the connection is by a series of circuitous lines rather than by direct line.
	Cl 42(3) amended to delete the words "Measurement between".	Amended to clarify that the connection between a permanent survey mark and the land surveyed is to be checked.
44 New permanent survey marks	Renumbered as: **43 New permanent survey marks** New cl 43(1)(b) added requiring that permanent survey marks must be placed in a position that will ensure that it is unlikely to be disturbed.	Aligns with the requirement for reference marks and standard practices. Ensures ongoing integrity of the cadastre.
	Cl 43(2) amended to apply the requirement relating to AHD values to urban surveys only.	The availability of permanent survey marks with AHD values assists surveyors to propagate heights in urban areas.
45 Definitions	Renumbered as: **44 Definitions**	No amendment made.
46 Surveys where boundary includes tidal or non-tidal waters or other natural features	Renumbered as: **47 Surveys where boundary includes tidal or non-tidal waters or other natural features**	No material amendments made.

2006 Clause Number and Title	2012 Regulation	Reason for Change
47 First survey of boundary adjoining Crown reserve or Crown road	Renumbered as: **45 First survey of boundary of land adjoining Crown reserve or Crown Road** Two additional requirements added to Cl 45(2): • The position of any existing road formation or fencing must be shown on the survey plan, • The boundary need not be marked but a reference must be placed at the terminals and each interval of 1000 m. New provision added as: **46 First survey of mean-high water mark boundary or bank** First survey of a MHWM boundary or bank must be defined with sufficient accuracy to enable it to be re-established despite potential for natural changes. Approval to be obtained from Minister administering the Crown Lands Act to first survey of mean high water mark boundary.	Assist with identifying potential boundary irregularities. Reinstates a provision inadvertently omitted from 2001 Regulation. The first definition of a water boundary must be surveyed and not shown merely as a natural feature. In view of the modified doctrine of accretion and erosion (s 55N *Coastal Protection Act*) need confirmation of the definition of the first water boundary.
48 Changes in boundaries formed by tidal waters	Cl 48(1) - (3) amended to require that where s 55N of the *Coastal Protection Act 1979* applies to a MHWM boundary to modify the doctrine of accretion and erosion, the position of the boundary is to be shown as it was before the change.	Amended for clarity and to ensure that s 55N is properly taken into account on the redefinition of a water boundary.
60 Survey plan to indicate name of locality, street address and type of survey	Cl 60(a) amended to require that either the suburb or locality assigned to the area by the GNB must be shown. Cl 60(c) added to require that where available, the street addresses must be shown on the survey plan in the format required by the Surveyor-General's directions.	Community benefit in tying the street address with the new lot fabric. Enables a layperson to more easily identify new parcels of land. A schedule is to be used on the administration sheet (Plan Form 6A) that shows the primary street address of all lots shown on the survey plan.
61 Method of recording datum line	Cl 61(3) amended to delete reference to register of surveys and replace with reference to SCIMS.	Details for survey marks are contained within SCIMS, being the database used for recording co-ordinates.
62 Method of recording bench marks	Cl 62(b) added to require the survey plan to indicate the level of accuracy of each bench mark. Cl 62(d) amended to require the level of accuracy for new permanent marks (used as bench marks) to be determined by the surveyor.	Having this information on the survey plan enables future users to assess the reliability of the survey. Corrects an anomaly in the current Regulation.

2006 Clause Number and Title	2012 Regulation	Reason for Change
64 Method of showing boundaries generally	Cl 64(1)(a) added to require the survey plan to show sufficient information to connect all survey marks (other than bench marks) shown on the plan by bearing and distance.	Enables survey marks to be located, for the continued enhancement of the cadastre. Enables plans to be examined electronically.
	Cl 64(1)(b) – it was proposed to amend the clause by adding the words "or co-ordinates" among the list of methods used to define boundaries. This proposal was deleted after the industry consultation.	Not amended to reflect new technologies used to define boundaries. Co-ordinates are not be used to define boundaries.
	Now cl 64(1)(e) amended to require the location, as well as the description, of substantial structures within one metre of a boundary.	Minor amendment.
	Cl 64(1)(f) added to require that where there are no substantial structures within one metre of the boundary an appropriate statement is to be included to confirm this.	Added for completeness and to prevent unnecessary requisitions being sent to the surveyor during plan examination.
	Cl 64(1)(g) added to require complete dimensions of each parcel of land surveyed. Cl 64(1)(h) added to require complete dimensions of each compiled or partially compiled parcel, where available.	To ensure that the geometry of the parcel is shown on the current plan for the land. Enables electronic examination and evaluation of the plan.
65 Method of showing natural feature boundaries	Cl 65(b) amended to require natural feature boundary to be indicated by an irregular line generally following the position of the boundary.	To clarify the description of the boundary for the layperson.
	Cl 65(c) amended to require boundary to also be indicated by a series of straight lines by bearing and distances that accurately describe and locate each change in direction.	To clarify the method of providing the mathematics of the boundary so that it can be re-established despite changes to the natural feature.
	Cl 65(d) added to require the connection between terminals of the natural feature in cases where more than 10 straight lines have been used to define the boundary.	Added to enable a mathematical check and for ease of use of the plan.
69 Surveyor to report on doubts discrepancies and differences	Cl 69(2) added to require that discrepancies in excess of 40 mm + 200 ppm must be disclosed.	To ensure consistency, a tolerance triggering the need for a survey report has been specified.
70 Surveyor to furnish survey certificate	Cl 70(1) amended to require that a plan prepared by a surveyor must be endorsed with, or accompanied by, a survey certificate, where it is • a survey plan; • a compiled plan; • a plan partly surveyed and partly compiled.	The amendment clarifies that a survey certificate is required for all plans prepared by a surveyor, whether or not the plan.
71 Standards for public surveys	Cl 71 updated to provide that public surveys must be carried out in accordance with Version 1.7 of the *Standards and Practices for Control Surveys* (SP1) and such other version of those Standards, as approved.	Updated to refer to latest Version of the *Standards*. *Standards* are currently under review. Surveyor General to approve any later version before it can be used as a standard for public surveys.
75 Formal Board determinations	Minor amendments made to the wording of the clause.	Minor amendment.

2006 Clause Number and Title	2012 Regulation	Reason for Change
	New standards prescribed as: **Schedule 1 – Bench marks** Schedule 1 provides standards for the form and style of bench marks.	Defines the form and style of bench marks to be used for stratum surveys (i.e. surveys limited in height and/or depth usually limited to a AHD plane) to enable testing in the electronic environment.
Schedule 1 – Forms	Renumbered as: **Schedule 6 – Forms** **Form 1 – Survey certificate –** updated to allow survey certificate to be given where all or part of a plan has been compiled.	The amended certificate will reflect the manner in which the plan was prepared.

The major impacts of the changes in the Surveying and Spatial Information Regulation 2012 will probably be:

- Use of Class "D" marks to define the datum line for rural surveys.
- Use of Bench Mark Schedule for electronic lodgement and examination.
- Bench Marks and Permanent Survey Marks treated the same.
- Improved or tighter accuracy specifications.
- Uniform marking for rural and urban surveys.
- Complete dimensions for all Lots and a lesser misclose requirement for Residue Lots.
- Street addressing for all Lots.

4 CONCLUDING REMARKS

The Surveying and Spatial Information Regulation 2006 ceased operation on 31 August 2012 and the Surveying and Spatial Information Regulation 2012 commenced on 1 September 2012. Any survey completed after 1 September 2012 must satisfy the requirements of the Surveying and Spatial Information Regulation 2012. This paper has outlined the changes that were introduced in the new Surveying and Spatial Information Regulation 2012 and the anticipated impact these changes will have on the surveying profession.

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NSW Legislation (2012d) Surveying and Spatial Information Regulation 2012, http://www.legislation.nsw.gov.au/maintop/view/inforce/subordleg+436+2012+cd+0+N (accessed Jan 2013).

SCIMS3: The Next Generation Survey Control Information Management System

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ABSTRACT

The Survey Control Information Management System (SCIMS) contains coordinates, heights and related information for about 250,000 survey marks in New South Wales (NSW). It is maintained for the purposes of cadastral boundary definition, engineering surveys, mapping and a variety of other spatial applications. The current system (SCIMS2K) was developed in 1999 to accommodate the introduction of the Geocentric Datum of Australia 1994 (GDA94) and its Map Grid of Australia 1994 (MGA94) coordinate system, and to improve the efficiency in the delivery of data across the internet. Incremental improvements have been incorporated into SCIMS2K since then and the system is currently based on an Oracle 10 platform of about 50 tables utilising a similar number of in-house developed stored procedures to provide conversions of positions and heights in various coordinate systems and formats. SCIMS3 is currently under development with the objective of incorporating and integrating other closely related systems and datasets such as CORSnet-NSW station metadata, the survey mark issue register, geodetic measurement data and mark images. This paper describes some of the major improvements being undertaken and discusses typical productivity improvement envisaged for SCIMS3.

KEYWORDS: *SCIMS, next generation, survey control, infrastructure*.

1 INTRODUCTION

The demand for spatial data with associated high levels of positional accuracy and integrity is increasing. All endeavours striving to meet this demand have one thing in common: the inherent dependency on positions and heights of known accuracy with a stable control reference framework. The Surveyor General and Land and Property Information (LPI) hold responsibility for establishing, improving and maintaining the State's survey control network. Both private and public sector surveyors contribute to the currency of the network by placing and surveying new permanent marks that extend the network on the ground. The network is presently represented physically by over 240,000 permanent ground marks, 6,300 beaconed trigonometrical stations and over 100 Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS). Digitally, the network comprises the Survey Control Information Management System (SCIMS), the records and archive of adjustments and survey measurements as well as the applications to deliver the information to users.

In 2008, LPI Survey embarked on a major capital investment program of Survey Infrastructure Improvement. A significant portion of this investment has been in building CORSnet-NSW (Janssen et al., 2011; LPI, 2013a), but the other components include:

- Infrastructure Preservation, involving replacing and establishing new EDM baselines (Ellis et al., 2013) as well as reviewing and rationalising the maintenance requirements of monuments and beacons at 6,500 trigonometrical stations.
- Survey Systems Improvement, such as the development and deployment of the new SCIMS-SIX online application.

Most users will be familiar with the SCIMS web interface (Figure1), available via the Spatial Information Exchange (SIX) portal. However, the primary investment for Systems Improvement in the project is planned for the development of SCIMS3 and related systems, which is the subject of this paper.

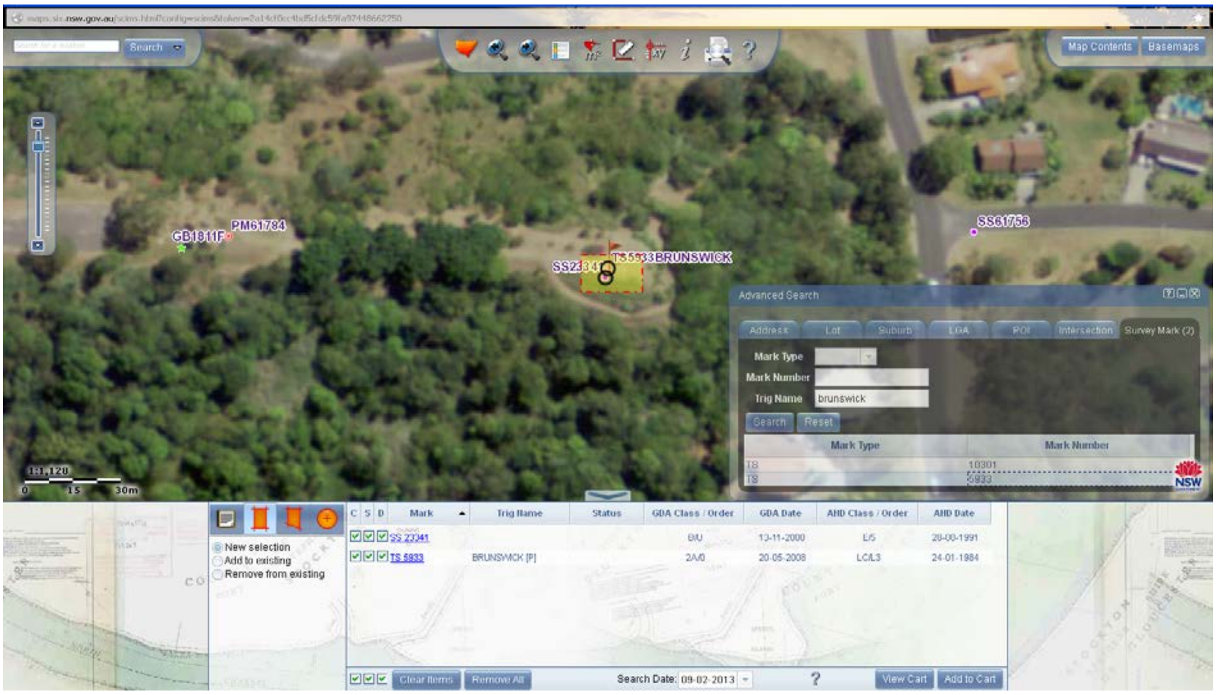


Figure 1: Example of a SCIMS-SIX Online enquiry.

2 SCIMS 2000 AND RELATED SYSTEMS

2.1 SCIMS2000

The current SCIMS2000 (SCIMS2K) was developed in 1999 and launched in July 2000. The development was necessary to accommodate the introduction of the new Geocentric Datum of Australia 1994 (GDA94) and its Map Grid of Australia 1994 (MGA94) coordinate system as well as improve the efficiency in the delivery of data across the internet. SCIMS2K was built on a combination of database technology and products available at the time of development, including the merger of the Geodetic Station Register (maintained by the Central Mapping Authority) and the Survey Control Database (maintained by Integrate Surveys Branch).

Improvements and additions of options were incorporated into SCIMS2K. However, at the time of development, only the existing in-house developed spatial searching tools were available. SCIMS is currently based on Oracle 10g RDBMS of about 50 tables incorporating some 50 in-house developed stored procedures to provide conversions of positions and heights in various coordinate systems and formats.

The datum used for the horizontal position of survey marks is GDA94. Coordinates are provided as Easting and Northing values on the MGA94 projection or as geographic latitude and longitude. Heights of survey marks relate to the Australian Height Datum 1971 (AHD71). Traditionally, the horizontal and vertical (orthometric) datum have been treated independently and this was carried forward into the implementation of SCIMS2K.

Accuracy codes (class and order) are assigned to each position and height. SCIMS2K was designed to store Positional Uncertainty (PU) and Local Uncertainty (LU) values. PU was determined for the 2,500 points adjusted in the GDA94 national adjustment and populated in SCIMS2K. However, LPI currently does not have the necessary business processes required to manage PU in breakdown adjustments. Other related information held in SCIMS2K includes details of mark types, eccentric/witness marks and trigonometrical stations.

There are well established business procedures to update and maintain the integrity of the data elements in SCIMS (LPI, 2006). The majority of coordinates and heights are updated using the SCIMS2K bulk update application in Oracle Forms, which reads and loads a series of MGA Easting, Northing and height (if applicable) values from a Comma Separated Variable (CSV) file. Figure 2 shows the update interface for the SCIMS2K Oracle application. The CSV output is obtained from a least squares adjustment. The process creates a transaction on SCIMS, which is stored and traceable. A number of in-house software tools have been developed over the last decade to increase the efficiency of the preparation for an update. For example, the Transaction Check utility (Dickson, 2009) reads GeoLab and HAVOC output files and reformats the data to display it in a similar way as the Oracle forms in the SCIMS bulk update application. An overview of the existing SCIMS2K and its relationship with update and output to users is shown in Figure 3.

Figure 2: SCIMS update application.

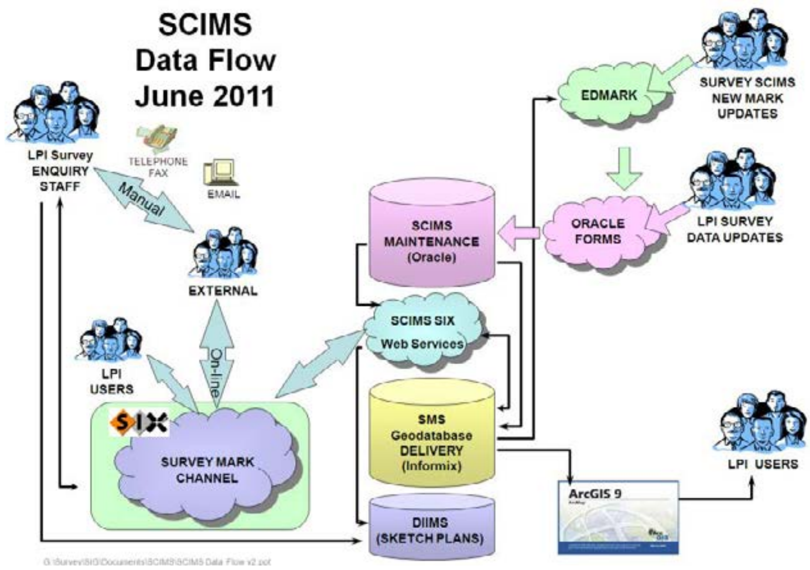


Figure 3: SCIMS2K dataflow.

2.2 Survey Mark Register

LPI is the sole supplier to the State's spatial information industry of survey control mark unique identifiers as well as the wholesale supplier of most of the associated survey mark hardware such as Permanent Mark (PM) cover boxes, numbered brass plates and numbered State Survey Marks (SSMs). Under the Survey Coordination Act (1949), a Register of Permanent Marks was started in the early 1950s. The Register records the name of the surveyor or organisation the mark was issued to, the date of issue and the survey project for which the mark would be used. If a bulk order for marks was supplied to an authorised distributer, this was recorded in the Register, and updated with details of the end user with information supplied by the distributor.

When the Locality Sketch Plan (LSP) is received at LPI, the date of receipt was also recorded in the Register. Generally, confirmation that a permanent mark has been placed occurs when the LSP is received at LPI. Then the permanent mark is initialised in SCIMS with the approximate coordinate shown on the LSP. Previous to the Surveying and Spatial Information Regulation 2006, if an approximate coordinate was not shown on the plan, LPI survey staff used maps or a Geographic Information System (GIS) to plot the mark using the features and measurements shown on the plan. A GIS-based application called Edmark was developed to assist in plotting the correct location of the permanent mark. Sometimes LPI only becomes aware that a permanent mark has been placed when it is shown on a Deposited Plan lodged for registration.

Maintaining the manual series of registers (Figure 4) continued until 2002 when a local PC database was developed. This MS Access database has since been redesigned and commenced operation in 2012. The database, called the Survey Services Data Base (SSDB), has been populated with mark numbers from SCIMS and the 5 separate document collections of LSPs for PMs, SSMs, Trigonometrical Stations (TSs), Miscellaneous Marks (MMs) and Geodetic Bench Marks (GBMs) held in LPI's Document and Integrated Imaging Management System (DIIMS). As at January 2013, the SSDB holds 277,334 records. The information in the manual registers is gradually being transferred to the SSDB on a time permits basis. The system has around 70 data elements, several of which also appear in SCIMS, such as MarkType and MarkNumber and involved party data (Name, Organisation, Address, etc.).

Figure 4: Examples of the Permanent Mark Register in book form.

2.3 CORSnet-NSW Database

All GNSS CORS administered by LPI are categorised as trigonometrical stations and assigned a TS number, which is generated and obtained from SCIMS. When a CORS is first established, the GDA94 latitude, longitude and height entered into SCIMS are derived from an AUSPOS solution (GA, 2012a) using 24 hours of data. In order to manage this information within LPI, it was necessary to establish a separate local database as SCIMS2K was not physically designed to hold 3-dimensional Cartesian coordinates (X, Y, Z) or metadata associated with a CORS.

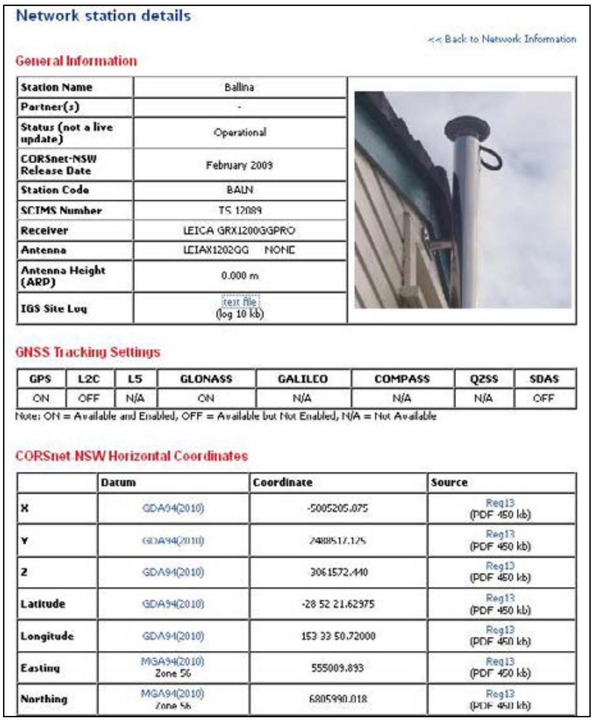
As explained in Janssen and McElroy (2010), it was also required to store the coordinates obtained from the Regulation 13 certification process performed by Geoscience Australia (GA, 2012b) because these coordinates were not necessarily compatible with the GDA94 values of local surrounding permanent marks. The essential attributes of the CORS site such as receiver type and serial number, antenna type and serial number, and monument description must also be meticulously managed. The database is the 'source of truth' for entry of data into the CORSnet-NSW management software. Each CORS is connected by precise GNSS survey to the existing horizontal geodetic network and levelled marks through a 'local tie survey'. An adjustment is completed and the TS number is updated in SCIMS2K with local GDA94(1997) values and an AHD71 height (Gowans and Grinter, 2013).

The CORSnet-NSW database (Table 1), which is essentially a password-protected spreadsheet held on network storage, includes links to the current Regulation 13 certificates. There are currently 60 data elements in the system, including several derived data types. For example, latitude and longitude as well as Easting and Northing can be derived from the Cartesian coordinates. For each CORS, the CORSnet-NSW database also provides a link to an International GNSS Service (IGS) site log, i.e. a text file containing CORS metadata in an international standard format. The site log includes some information not contained in the spreadsheet but duplicates other data elements such as the current receiver and antenna employed.

It has been usual practice by GNSS CORS operators to publish the details of the individual reference stations on their website (see example in Figure 5). This enables users downloading data to access the coordinates, antenna type and other information needed for post processing. A semi-manual process is currently carried out to transfer the information held in the CORSnet-NSW database to the relevant style and location on the LPI website.

Table 1: CORSnet-NSW database elements.

ID	AHD71_98	GLONASS
Name	AHD71_09	GALILEO
Code	AUSGeoid98	COMPASS
Date_Install	AUSGeoid09	QZSS
Status	GDA_Source	SBAS
Partner	EHeight_Source	SCIMS_Latitude
Location	Coords_Source	SCIMS_Longitude
SCIMS_No	Remark_Source	SCIMS_Ellipsoidal_Height
DOMES_No	AHD_Source	SCIMS_Easting
DOMES_Source	AUSGeoid98_Source	SCIMS_Northing
IGS_Site_Log	AUSGeoid09_Source	SCIMS_Zone
Latitude	Mark_Description	SCIMS_AHD_Height
Longitude	Receiver	SCIMS_Source
Ellipsoidal_Height	Receiver_SN	Graph_Source
Easting	Firmware	
Northing	Antenna	
Zone	Antenna_RINEX_name	
Easting2	Antenna_SN	
Northing2	Antenna_Height	
Zone2	Antenna_Alignment_from_TN	
X	GPS	
Y	L2C	
Z	L5	



Network station details

<< Back to Network Information

General Information

Station Name	Ballina
Partner(s)	-
Status (not a live update)	Operational
CORSnet-NSW Release Date	February 2009
Station Code	BALN
SCIMS Number	TS 12089
Receiver	LEICA GRX1200GGPRO
Antenna	LEIAX1202GG NONE
Antenna Height (ARP)	0.000 m
IGS Site Log	text file (log 10 kb)

GNSS Tracking Settings

GPS	L2C	L5	GLONASS	GALILEO	COMPASS	QZSS	SBAS
ON	OFF	N/A	ON	N/A	N/A	N/A	OFF

Note: ON = Available and Enabled, OFF = Available but Not Enabled, N/A = Not Available

CORSnet NSW Horizontal Coordinates

	Datum	Coordinate	Source
X	GDA94(2010)	-5005205.075	Reg13 (PDF 450 kb)
Y	GDA94(2010)	2488517.125	Reg13 (PDF 450 kb)
Z	GDA94(2010)	3061572.440	Reg13 (PDF 450 kb)
Latitude	GDA94(2010)	-28 52 21.62975	Reg13 (PDF 450 kb)
Longitude	GDA94(2010)	153 33 50.72000	Reg13 (PDF 450 kb)
Easting	MGA94(2010) Zone 56	555009.893	Reg13 (PDF 450 kb)
Northing	MGA94(2010) Zone 56	6805990.018	Reg13 (PDF 450 kb)

Figure 5: CORSnet-NSW station information example on the internet (LPI, 2013a).

Geoscience Australia (GA) is responsible for the information on all CORS contributing to the National Geodetic Reference System (NGRS) and the definition of the national datum. The NGRS database maintained by GA holds all the necessary metadata on each CORS, which must be kept current with the help of the CORS operator. Therefore, when any significant piece of equipment is changed (e.g. a receiver is replaced) or firmware is updated at a CORSnet-NSW site, the changed details needs to be updated in each of the following:

1. CORSnet-NSW database.
2. CORSnet-NSW webpage.
3. CORS network management software.
4. IGS site log (GA must be notified and sent an updated site log).

2.4 Geodetic Measurements

The reference or linkage between the coordinates in SCIMS and the measurements used to derive them as well as the reference to the project report, raw data, field notes and other relevant data, is the Source Identifier (source ID). Figure 6 shows the link between the source ID in SCIMS2K and the folder on LPI's network storage where all the related data are stored. An LPI surveyor with access to the SCIMS maintenance application generates a new source ID for each survey project, and selects from pull down lists other information required about the project. The attributes of a source ID are source type, source method and datum.

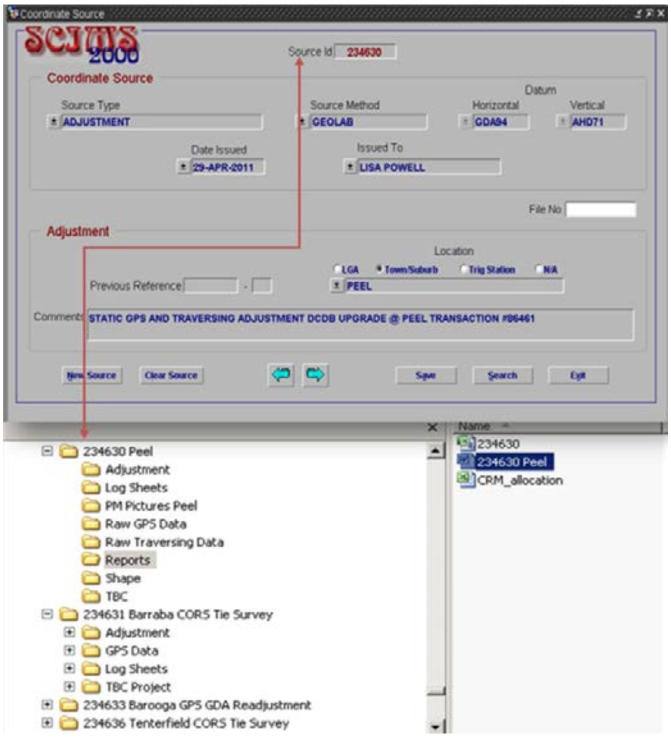


Figure 6: Source ID – the link between coordinates in SCIMS and measurements.

The least squares adjustment input files from the majority of network adjustments carried out by LPI over the last 20 years are archived on network storage within a folder named as the source ID. However, there are a number of disadvantages in only archiving measurements as input text files. The data are often difficult to retrieve and manipulate, due to not necessarily being stored in just one source folder. Measurements for a selected area of interest may be contained in several different input files, requiring time-consuming text editing to extract specific sets of observations or the deployment of data mining applications (Haasdyk and Watson, 2013). Another serious weakness is that in most cases, very limited information about the measurement is contained in the input text file. The attributes of measurements in input files usually includes the 'from' and 'to' station identifiers, the measurement itself and the a priori standard deviation, i.e. the minimum required to perform the mathematics of estimation by least squares. There is usually no reference to the source of the measurement, the instrument used or the date of the measurement, making it difficult to investigate outliers.

In the mid 1990s, just prior to the GDA94 national adjustment, a Geodetic Observation Management System (GOMS) was designed (Kinlyside, 1994) and implemented but only for GPS measurements. The basic schema is shown in Figure 7.

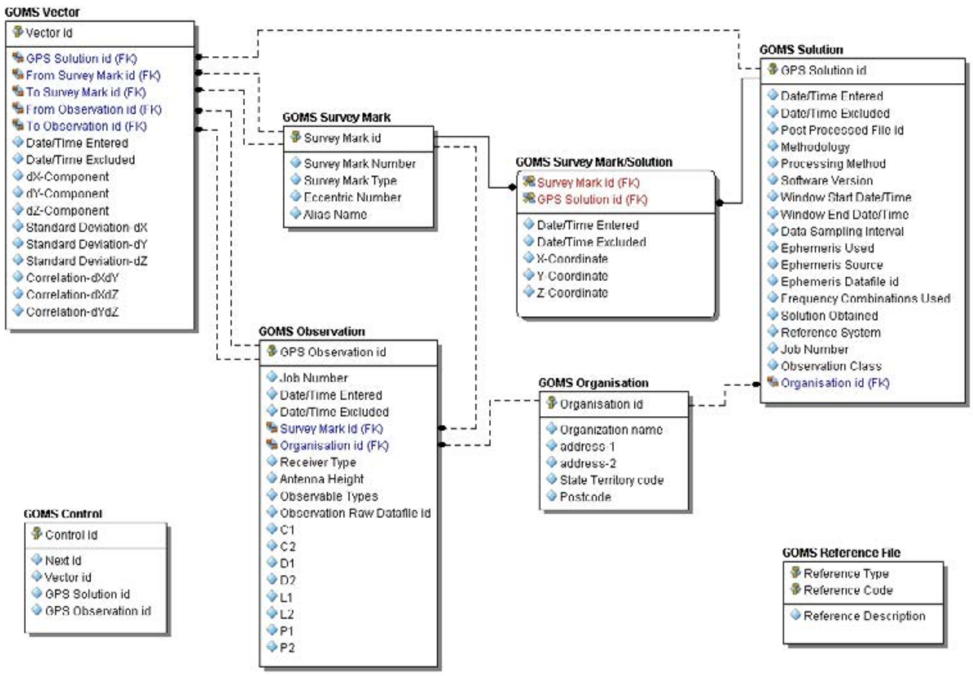


Figure 7: The GPS-related attributes of the Geodetic Observation Measurement System.

GOMS was based on an Oracle database platform, but the extraction of the relevant attribute data from the various post-processing software (predominantly) text output files and the interface to the Oracle tables were based on an MS Access customised interface. The system and interface was developed by an LPI contractor. Similarly, extraction of the vectors from Oracle to produce a GeoLab or other adjustment package input file relied on the MS Access application.

As GPS post-processing software output from most vendor packages became propriety binary format, the interface through MS Access became increasingly difficult to maintain. About 2,000 GPS vectors were loaded into GOMS prior to 1997. However, due to the difficultly in maintaining the system and the additional work involved in loading and retrieving the data, unfortunately, a decision was made in the late 1990s to abandon the process. If LPI survey had persevered with the system, it is likely that the current data-mining efforts described by Haasdyk and Watson (2013) would have been considerably easier.

2.5 Survey Mark Images

As discussed in section 2.2, locality sketch plans of survey marks are added, maintained and accessed in DIIMS, but only as bi-tonal 200dpi TIFF images. While DIIMS can also hold colour TIFF and PDF files, there is no provision in DIIMS for storing JPG images at this time. As at January 2013, there were 6,346 trigonometrical stations (Mark Type = ‘TS’) in SCIMS. Over many decades, TS surveyors and maintenance piling overseers have taken photos of their work, especially at unusual TS sites. Many of these photos have now been scanned and stored on LPI’s network. With the introduction of low-cost digital cameras, smart phones and with cameras even embedded in GNSS receivers and controllers, LPI

survey staff are now requested to collect a series of images whenever they visit a trigonometrical station. The convention used for naming these images is '9999 trigname yyyymmdd direction.jpg' where:

9999 = TS number.
trigname = name of the Trigonometrical Station.
yyyymmdd = year month and day of the month in which the image was taken.
direction = cardinal direction in which the image was taken.

These images are particularly useful for assessing requests from government agencies and private companies to construct objects (typically communication towers and buildings) near the trigonometrical stations. As at January 2013, approximately 12,000 images have been stored covering about 3,000 TSs. The images are stored in the TS number and name folder on LPI network storage (see example in Figure 8).

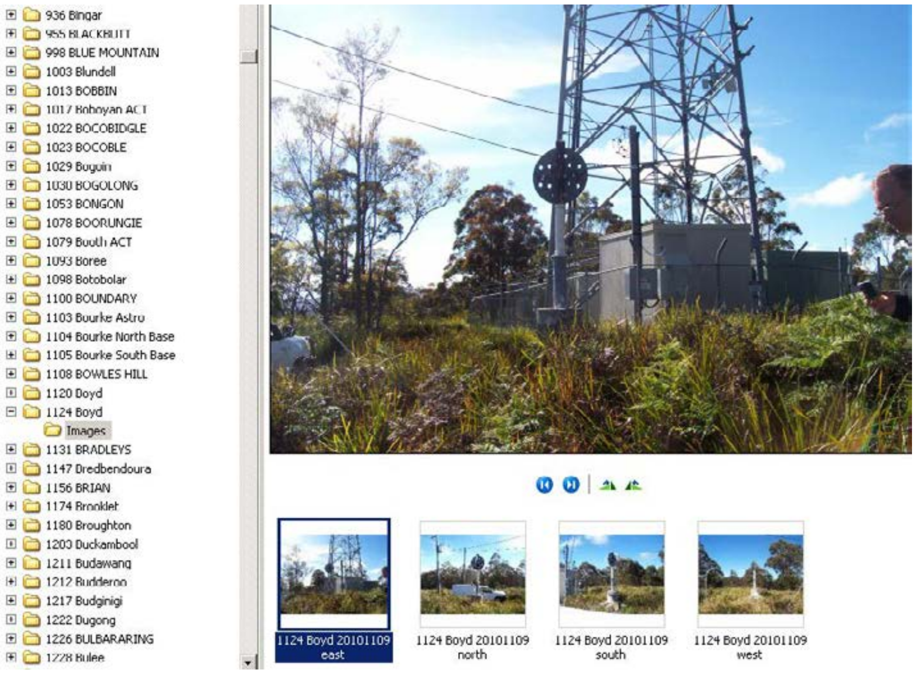


Figure 8: Example of TS images stored on the LPI network drive.

Occasionally, individuals or organisations contribute to the collection. Historical societies particularly may be interested in particular TSs in an area of interest to publish historical research such as described by Dawson (2007). An increasing number of images are taken of permanent survey marks, particularly if the mark was difficult to find using the LSP or if the mark appears to have been disturbed. LPI Cadastral Integrity staff will often take photos of marks during audit surveys; especially if there is evidence the marks do not comply with standards of marking. A similar folder as the TS image collection will be established to manage these images.

Collecting near and close images of marks placed for mapping control is now standard practice within LPI survey operations. Selected terrestrial images of the marks are embedded in the mapping control point record, which can aid the photogrammetrist in identifying the control point on the aerial image. PMs are usually placed at these control points and if they are not, Control Punts (CPs) are also a valid mark type in SCIMS. However, there is no direct link between SCIMS and a CP record, although it may be feasible to store a PDF version of the CP record in DIIMS.

3 THE CASE FOR CHANGE: SCIMS3

3.1 General

From the previous section, it should appear obvious that greater efficiency would be gained by integrating several related systems with SCIMS. Why SCIMS3? It was initially intended as a project name following SCIMS2000, but it does reflect the intention to develop a 3-dimensional system as opposed to the current SCIMS2K 2D + 1D system. While SCIMS2K holds foundation position and height information, the Oracle based maintenance system is not spatially enabled. Only when the subset of 22 SCIMS data elements are refreshed nightly in the delivery system, are the stored coordinates extracted and converted to a spatial 'point' in the Informix based delivery system (cf. Figure 3). It should be noted that updates between maintenance and delivery databases of the other primary LPI spatial systems happen in real time.

3.2 Enabling Technologies

A significant effort has been made over the last decade in integrating LPI systems in titling, valuation and mapping following the formation of LPI in 2000. Web services, Application Programmer Interfaces (API) and transfer of Simple Object Access Protocol (SOAP) data packets between maintenance and delivery systems and between delivery servers and client systems have certainly increased complexity but have very much improved currency and accessibility of many LPI spatial systems such as the SIX portal (LPI, 2013b).

3.2.1 XML Schemas and eGeodesy

Extensible Markup Language (XML) is an internationally established method of describing data for transferring data from one system to another. LandXML is one example of such a schema and LPI has been an ardent adopter of the Intergovernmental Committee on Surveying and Mapping's (ICSM's) form of LandXML, primarily for the objective of implementing a fully automated Electronic Deposited Plan (ePlan) lodgement, plan examination and Digital Cadastral Data Base (DCDB) update processes. A SCIMS web service was developed and implemented for the validation of SCIMS information contained in a deposited survey plan submitted for lodgement. The service enables the ePlan validation process on LPI's website to search for SCIMS marks and coordinates (existing and historical) in the Oracle maintenance database to ensure the marks and coordinates at the date of the plan are valid.

Many of the survey equipment manufacturers now support the capability of exporting data directly from the instrument or from the processing software via various forms of XML. Much of the required metadata about each measurement (e.g. instrument type, serial number, date of measurement) are now available in the XML export along with the measurement and the variance or standard deviation of the measurement.

Members of ICSM's Permanent Committee on Geodesy (PCG) have also been developing a GeodeticXML schema since 2005 (Fraser and Donnelly, 2010). Although jurisdictions have built many applications around LandXML, many geodetic data types are not supported in the LandXML schema. The Geodetic XML schema is close to being adopted nationally by the PCG (Donnelly et al., 2013).

3.2.2 Least Squares Software

LPI Survey has been using GeoLab software as its primary 3-dimensional least squares adjustment software since 1987 and currently holds nearly 40 licences. The 2-dimensional in-house software package, HAVOC, has been used since the early 1970s and is still used for adjusting measurement data between permanent marks that appear on Deposited Plans. Both software packages are limited in the number of stations and number of measurements that can be included. As such, it is difficult for LPI to rigorously determine positional and local uncertainty for the complete network of about 250,000 points.

DynaNet network adjustment software (Geocomp, 2013), developed from the University of Melbourne's DNA software, is capable of the least squares adjustment of survey networks of any size. The phased least squares adjustment techniques enable very large networks to be adjusted using a fraction of the time and resources required for a more traditional simultaneous adjustment. Over the last few years, Dynanet has been rewritten in C++ and extensively tested by PCG member organisations. Input and output formats are being designed around the proposed Geodetic XML standard.

3.2.3 Geodetic Measurements

Many sources of accurate geodetic measurements are now readily produced by surveyors and engineers, especially position measurements from Real Time Kinematic (RTK) GNSS, AUSPOS and CORS networks. As discussed in Kinlyside (1994), the main benefits arising out of implementing a geodetic measurement database are:

- More effective management of geodetic measurement, especially handling the increasing volumes of GNSS data.
- Minimising the risk of disaster recovery cost by having all measurement data in a form that can be easily backed up and transferred off site to other agencies.
- Developing uniform standards and formats for measurements, enabling external contributors to submit data in a more efficient way.
- Providing a common format interface (e.g. GeodeticXML) for transferring to adjustment software and, following adjustment, providing a more efficient controlling mechanism for faster updates of coordinates in the spatial information system.
- Creating a measurement control system that will enable measurements to be excluded from future epoch adjustments because of mark movement detection.
- Enabling sets of transformation parameters to be included in the system, giving a choice which reference frame coordinates are supplied to users.
- Providing more efficient access to geodetic measurements for special projects and for external users.

3.2.4 Digital Images

The capture of digital images is now easier than ever before. For images of survey marks and trigonometrical stations to be useful both internally and to the public, the SCIMS3 design is required to include the capability of storing and retrieving photographic images. Perhaps, Locality Sketch Plans in the future may consist of photographic images annotated with measurements.

4 CONCLUDING REMARKS

In the authors view, there is considerable scope for improving survey control information management. In mid 2012, LPI engaged a data architect contractor to examine the 'as is' data model for SCIMS and related systems, and LPI has now engaged a business systems analyst to develop the use cases for SCIMS3. Ideally, the basic data flow of SCIMS3 may appear similar to Figure 9, in which a least squares adjustment engine is constantly operating between a measurement database and a coordinate database to possibly allow in future the availability of fully dynamic coordinate sets.

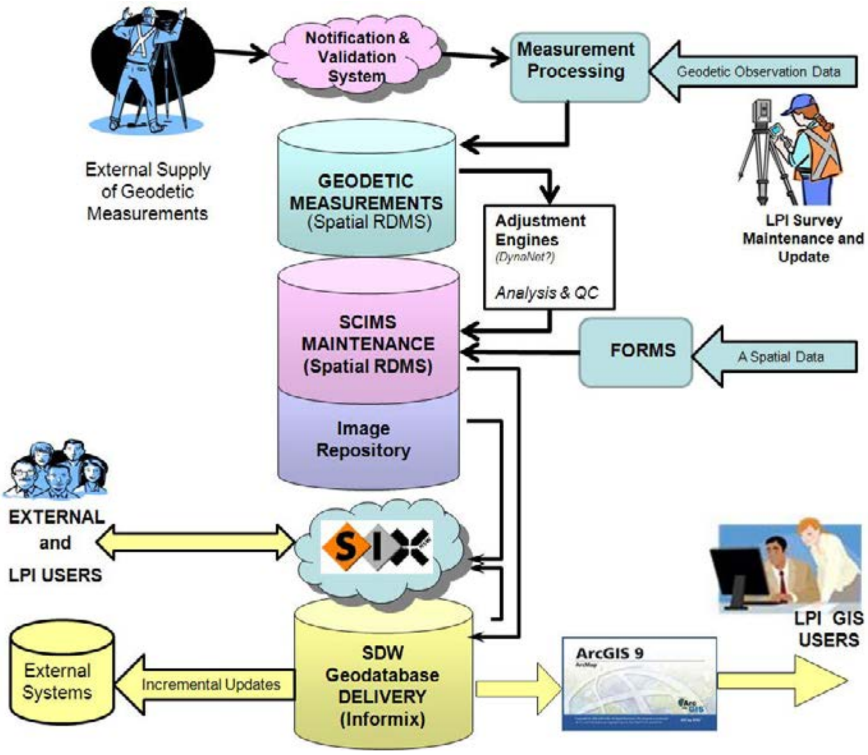


Figure 9: Data flow of a proposed SCIMS3.

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Improving Survey Infrastructure in NSW: Construction of the Eglinton EDM Baseline

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ABSTRACT

The Surveyor General is a Verifying Authority under the National Measurement Act 1960 and responsible for ensuring that surveyors use verified measuring equipment. This is achieved, for example, through the provision and maintenance of Electronic Distance Measurement (EDM) baselines. Consequently, the Surveying and Spatial Information Regulation 2012 requires surveyors to verify their measuring equipment in relation to an Australian standard of measurement of length at least once a year. Land and Property Information (LPI) is the sole organisation responsible for constructing, maintaining, monitoring and verifying all these baselines within New South Wales. LPI is currently in the process of improving its survey infrastructure by upgrading existing baselines if possible (to include a larger number of pillars) and building new baselines for the calibration of EDM instruments. This paper outlines the issues that need to be considered in the construction of a state-of-the-art EDM baseline, using the newly constructed 7-pillar Eglinton EDM baseline (located in Bathurst) as an example. Topics covered include site selection, planning, logistics, Work Health and Safety considerations, pillar construction and baseline verification.

KEYWORDS: *EDM, baseline calibration, survey infrastructure, legal metrology.*

1 INTRODUCTION

The Surveyor General is a Verifying Authority for reference standards of measurement under the National Measurement Act 1960 (Australian Government, 2013a) and in accordance with the National Measurement Regulations 1999 (Australian Government, 2013b), thereby being responsible for ensuring that surveyors use verified measuring equipment. Consequently, the Surveying and Spatial Information Regulation 2012 (NSW Legislation, 2013) requires surveyors to verify their measuring equipment in relation to an Australian or state primary standard of measurement of length at least once a year. This instrument verification establishes traceability of its measurements to the national standard.

Since the beginning of the 20th century, the Surveyor General has been responsible for the standardisation of length. Initially, the task of standardising steel bands was carried out in the basement of the old Lands Department building in Bridge Street, Sydney. Following the introduction of Electronic Distance Measurement (EDM) instruments in the 1970s (e.g. Rüeger, 1996), the Surveyor General has been responsible for establishing and maintaining baselines for the calibration of such instruments. Fulfilling the role of the Surveyor General, Land and Property Information (LPI) is the sole organisation responsible for setting standards and providing infrastructure for EDM calibrations in NSW.

In 1983, the Surveyors General of the Australian states and territories introduced a new national EDM calibration scheme under the National Measurement Act. A working party on the calibration of EDM equipment was established by the National Standards Commission (now the National Measurement Institute, NMI) and met on 1 February 1983. It prepared eight recommendations on how legal traceability to the national standards of physical measurements could be provided for practicing surveyors using EDM instruments. These recommendations – see Rüeger (1985) for details – were endorsed by the Commission at its 85th meeting on 9 February 1983 and resulted in documented instructions regarding the field observations and analysis procedures for the calibration of EDM instruments on baselines (Rüeger, 1984).

Initially, the EDM baselines constructed in NSW consisted of three or four concrete pillars. Two baselines have since been extended to include more pillars, i.e. Dubbo in June 1999 and Kingscliff in June 2008 (Table 1). The field procedures currently prescribed for EDM calibrations in NSW are documented in Surveyor General's Direction No. 5: Verification of Distance Measuring Equipment (LPI, 2009).

Table 1: EDM baselines in NSW (before the most recent modernisation efforts).

Baseline	Length (m)	No. of Pillars	Year of Construction
Armidale	600	4	1984
Bankstown	605	4	1984
Bathurst	888	4	1979
Bega	503	4	1984
Blacktown	465	3	1982
Dubbo	650 (765)	4 (6)	1984 (1999)
Goulburn	497	4	1984
Grafton	610	4	1984
Kingscliff	600 (721)	4 (7)	1989 (2008)
Moruya	429	4	1986
Newcastle	611	4	1982
Nowra	581	4	1984
Tamworth	550	4	1984
Taree	515	4	1984
Ulan Coal (near Mudgee)	650	6	2002
Wagga Wagga	535	5	1984
Wakehurst	430	3	1979
Wollongong	600	4	1983

The EDM instrument correction is dependent on many variables, including distance, temperature, time, supply voltage and ambient atmospheric conditions (Rüeger, 1996). It comprises at least two terms, i.e. the additive constant (a constant term expressed in mm) and the scale correction (a linear distance-dependent term expressed in ppm), with additional terms added to describe the instrument correction in more detail (e.g. including non-linear

distance-dependent terms and cyclic error terms). However, it should be noted that it is not possible to determine instrument corrections with more than six parameters on 4-pillar baselines (Rüeger, 1991). 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, thereby allowing a more reliable determination of the instrument correction.

This has led to LPI’s commitment to improve its survey infrastructure for the calibration of EDM instruments by upgrading existing baselines to include a larger number of pillars if possible. Consequently, the Dubbo and Kingscliff EDM baselines have been successfully upgraded to include six and seven pillars, respectively (see Table 1). However, such a baseline expansion is often extremely difficult in practice. Alternatively, new baselines are being built to replace existing ones that cannot be upgraded. The first new 7-pillar baseline was constructed in Lethbridge Park (located in western Sydney) in mid 2012. This paper focuses on the Eglinton EDM baseline in Bathurst, also constructed in 2012, in order to outline the issues that need to be considered in the construction of a modern EDM baseline.

2 DESIGNING A NEW EDM BASELINE FOR BATHURST

2.1 Background

The existing 4-pillar EDM baseline in Bathurst has been in use since its construction by the Central Mapping Authority (CMA) in 1979. The location at the base of Mt Panorama on Crown land was deemed ideal at the time, with easy access to the CMA building. Geodetic and mapping work was booming, and the baseline was constantly being used internally and externally to verify the numerous EDM instruments in use. However, it was found that a combination of slope and soil type meant that following each period of either drought or increased rain the pillars appeared to move slowly downhill, at different and unpredictable rates (Figures 1 & 2). The problem was exacerbated by the construction of a contour bank immediately below the second pillar, which pooled water for an extended period after heavy rain events, as well as a council gravel stockpile constructed on line with the baseline (Figure 3). In the early 2000s, it was decided that the Bathurst EDM baseline could not be maintained into the future. It was felt by local surveyors that travel to Dubbo (6 pillars), Ulan Coal near Mudgee (6 pillars) or western Sydney (4 pillars) was not a cost-effective option. Consequently, investigations into an alternative EDM baseline site in the general area around Bathurst commenced in mid 2007. In order to provide high-quality survey infrastructure far into the future, it was decided to build a 7-pillar baseline.

Figure 1: (a) Pillar 1 looking north along Bathurst baseline (note rifle range to the east), and (b) Pillar 1 looking south (note effects of erosion).

Figure 2: Pillar 3 looking south (note rifle range abutments and steep slope).

Figure 3: (a) Pillar 2 looking north (note contour bank added after construction), and (b) Pillar 4 looking south (note council gravel stockpile on line).

2.2 EDM Baseline Requirements

Several sites were investigated for suitability to host a 7-pillar EDM baseline in the Bathurst area. The following constraints were imposed in the search for candidate sites:

- Public land, i.e. either Crown or council land was preferred (free of cost).
- Easy public access, i.e. easily accessible by surveyors in the Central West (preferably without the requirement for keys and in close proximity to a major population centre). This also reduces construction costs.
- Safe, i.e. no apparent hazards for those using the baseline and the general public passing by (human and vehicle traffic).
- The right shape, i.e. up to 1,000 m long, clear and ideally dipping in the middle to flat.
- Stable and consistent soil and geology, i.e. preferably flat ground.
- Free from development changes, road widening and drainage works for many years into the future.
- Easy construction and subsequent clearing/maintenance.
- Clear of overhead obstructions and surrounding vegetation, and suitable for GNSS.

A number of road reserves, public reserves and parks were investigated, but future clearing and access issues generally limited the suitability of these sites (Figure 4). The best option appeared to be road reserves close to Bathurst on quieter rural roads. However, a number of

locations were discarded due to high vehicle volumes and high speed on adjacent roads. It quickly became clear that finding a suitable site would be a difficult and time-consuming task.

Figure 4: (a) Bathurst Airport access road (note trees and underground utilities), (b) Eugenie Rd, Raglan (note overhead lights, trees and development), (c) Tarana Rd, Tarana (note high-speed road), and (d) Macquarie Woods Arboretum, Vittoria (note future tree growth).

2.3 Final Site Selection

In 2011, funding became available to proceed with the design and construction of the new EDM baseline. After being suggested as a possibility by Bathurst Regional Council (BRC) surveyors at an initial meeting, the site along Thomas Drive, Eglinton was selected (subject to soil tests) because it complied with almost all EDM baseline requirements:

- Council road reserve close to Bathurst.
- Rural zoning and according to Council not earmarked for subdivision in the next few decades.
- Very low vehicle volumes (dead-end rural road with only three properties using the road for access).
- Only one underground facility located in the road reserve (telecommunication cable).
- Clear of trees and easily mowed and maintained.
- Ease of construction (apart from a 132 kV overhead power line).
- Easily accessed by the public all year round.
- Not visible from the main road (thereby reducing the chance of vandalism).
- Consistent soil and geology over the entire length.
- Excellent access to the State's local control network of TSs and PMs for GNSS and conventional surveys and the primary AHD71 level network.

2.4 Baseline Design

Baseline designs generally aim to achieve an equal distribution of all measured distances between the shortest and longest line on the baseline, with no or minimal repetitions. Some designs require each length to be a multiple of a basic unit length. The unit length is the scale on which the EDM instrument measures the distance. It is derived from the fine measuring frequency and equal to one half of the EDM's modulation wavelength (Rüeger, 1996).

The Heerbrugg design 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). All baselines in NSW follow this design, which is based on four input parameters to determine the spacing between the pillars: unit length of the EDM(s) to be calibrated, shortest distance on the baseline (a multiple of the unit length), desired total length of the baseline, and the number of pillars. It should be noted that a larger number of pillars provides an increased number of observations, translating into a higher precision of the resulting additive constant.

An optimal balance between cost and precision is generally obtained with six to seven pillars when using the Heerbrugg design. Applying this procedure for the design of the 7-pillar Eglinton baseline resulted in a total baseline length of 849 m with the shortest section being 21 m (Figure 5).

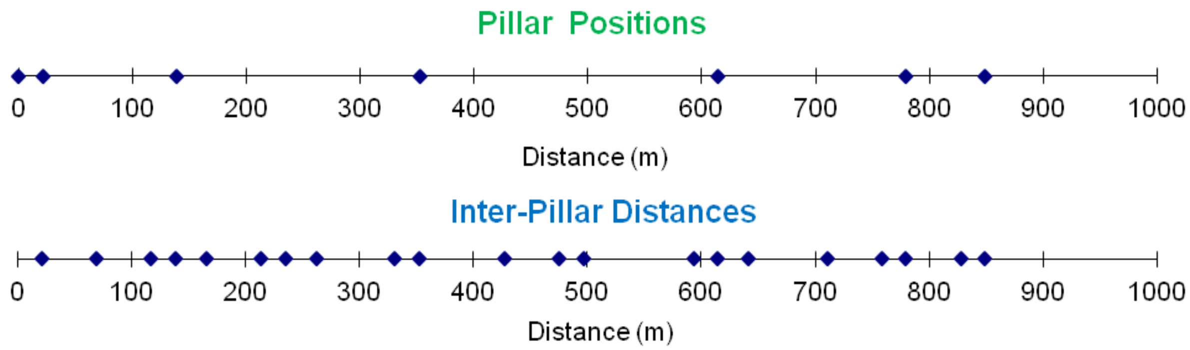

Figure 5: Design positions for the seven pillars (top) and distribution of the 21 inter-pillar distances (bottom) for the Eglinton EDM baseline.

Using the modulo function (which returns the remainder obtained when dividing one number by another, e.g. 7 mod 2 = 1 and 21.08 mod 3 = 0.08), it can be tested whether the baseline design delivers an equal distribution of the distances measured in all combinations over the unit length of the EDM. Obviously, it is desired that the baseline be suitable for EDM instruments of various unit lengths. As illustrated in Figure 6, the Eglinton baseline design achieves an almost equal distribution for unit lengths of 1.5, 2.0, 3.0, 5.0 and 10.0 m.

The vertical design profile of the Eglinton baseline exhibits a slightly concave shape with minimal height undulation, allowing intervisibility between all pillars while minimising the average height differences between pillars (Figure 7). This design also avoids the use of extremely tall and/or low pillars, thereby supporting Work Health and Safety considerations by providing maximum comfort to the observer.

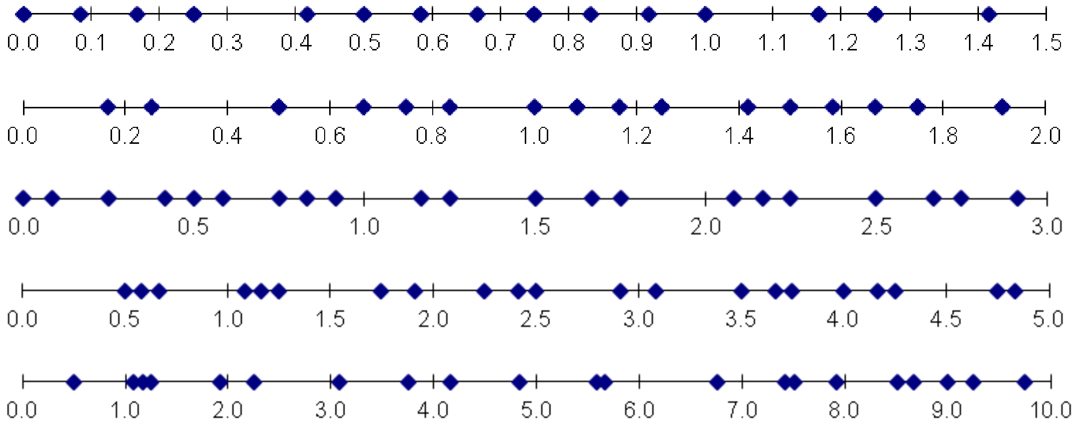

Figure 6: Distribution of the 21 inter-pillar distance measurements over various EDM unit lengths between 1.5 and 10.0 m for the Eglinton EDM baseline (all values in metres).

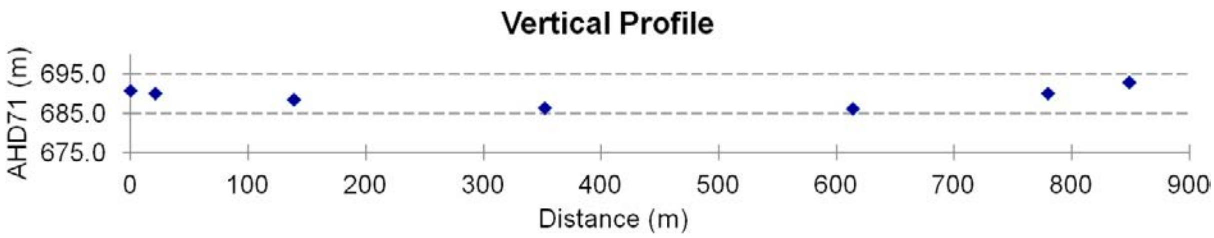

Figure 7: Vertical profile design for the Eglinton EDM baseline.

2.5 Expression of Interest to Bathurst Regional Council

As BRC survey staff were in support of a local EDM baseline from the beginning, a Development Application was not required. In this case, an Expression of Interest (EOI) outlining the purpose of the baseline and what it would look like when completed was sufficient.

Prior to the EOI being submitted, LPI was required to perform the following:

- Undertake a cadastral and detail survey: Necessary to determine the correct location of the cadastre with regards to fencing and the road as formed and the shape of the ground. Nearby established and accurately levelled permanent marks were connected and all survey work was related to the Map Grid of Australia 1994 (MGA94). The location of the 132 kV overhead power line had to be located as well.
- Model the shape for a baseline design: The area was covered by 0.2 m pixel recent aerial imagery, and LiDAR data were available at a mesh of approximately 1 m. As all datasets referred to MGA94, they could easily be overlaid and then verified by field observations.
- Create a baseline design proposal: Using all available data, a sample profile was created and the data were entered into LPI's EDM baseline design spreadsheet. This spreadsheet uses a number of different settings and constants to calculate a range of different pillar locations. These locations were then tested against the profile, as the main constraint was to avoid placing a pillar near the lowest section due to anticipated problems with a high water table.
- Confirm underground utilities: Dial Before You Dig (DBYD) was again confirmed and a Telstra diagram obtained. A Telstra cable locater was engaged and the Telstra diagram was found to be incorrect. The cable was located accurately (within 0.1 m) and found to be close to the proposed final pillar locations.

- Peg-out proposed pillar locations and create digital images: The initially proposed pillar locations were pegged and heighted to confirm profile design was correct, and then digital images were taken of each pillar site.

An EOI was then generated and submitted to Council. The digital images were used as a base for 'artistic impressions' of what the final pillars and the EDM baseline would look like when completed (Figure 8). A number of previous pillar construction designs were also included to give Council an idea of the scale of the exercise.

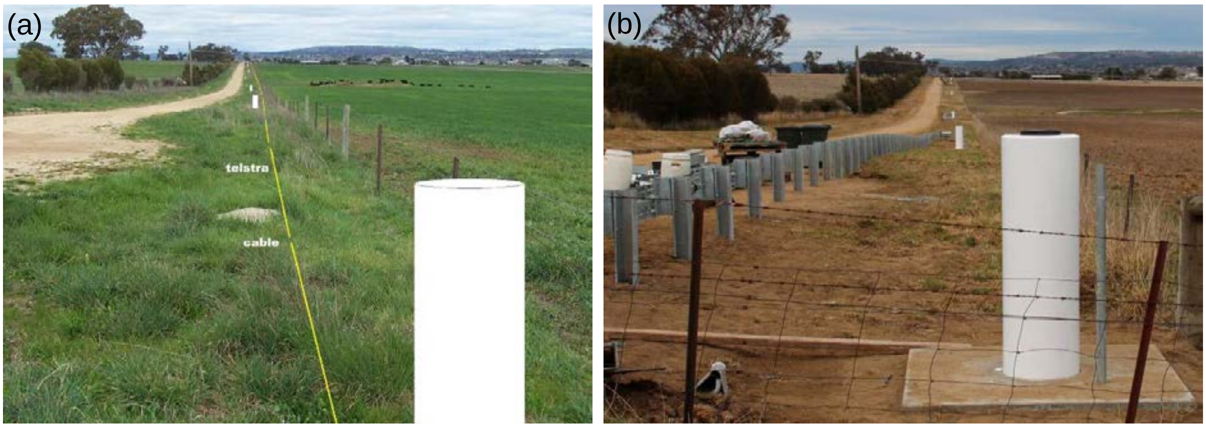

Figure 8: (a) Baseline proposal in EOI to Council (Nov 2011), and (b) baseline at completion of construction (July 2012).

3 EGLINTON EDM BASELINE CONSTRUCTION

3.1 Approval of EOI and Final Design

The EOI was approved by Council subject to a number of conditions. It was decided that these conditions were within the design guidelines and projected budget. Core sampling was then required to confirm that a stable baseline could be constructed economically. A local geotechnical company was contracted to conduct tests at critical positions along the profile of the planned baseline to confirm the underlying geology.

The results of the core testing and a technical diagram of the Tier 2 GNSS CORS pillar design previously used by LPI (LPI, 2012) were sent to Public Works engineers in order to obtain recommendations on the final pillar design. The original design was modified by increasing the size of reinforcing steel and requiring a depth of 6.5 m for all base piles to reach stable sandy strata.

3.2 Request for Quote (RFQ)

It was deemed that the size and scope of this project was beyond the capabilities of LPI staff, given the risks involved and the budgetary timeframes. A Request for Quote (RFQ) document was created following LPI guidelines and circulated to Central West engineering companies identified as being capable of delivering this type of project. A local engineering company's quotation was selected after following strict LPI guidelines and assessment principles. A number of issues were raised in the selected quotation, which had to be addressed quickly in order to proceed, in particular regarding the relatively large cost of safety barriers. Consequently, a timeframe for the project was quickly confirmed.

3.3 Construction of the Eglinton EDM Baseline

The construction project commenced on 13 June 2012 with the set-out survey under rather unfortunate winter weather conditions. At the request of the construction company, the location of all pillars was re-surveyed with the addition of two 3 m offset pegs (Figure 9). All 21 pegs were then levelled to second order specifications to confirm that heights agreed with the design and to provide additional height checks at each pillar.

Figure 9: Offset pegs (pink 75 x 75 mm) and pillar peg (yellow 75 x 75 mm) plus Telstra peg (yellow 32 x 75 mm) at Pillar 7. All cable locations were potholed before boring.

As part of the conditions of the quotation, the first author was nominated to be the LPI liaison and provide technical survey support and advice during the construction phase. Once concrete pouring had commenced, he was available for pre and post concrete pour checking of the PVC formwork while construction continued on other pillars. The option to adopt the PVC pipe pillar design proved valuable and simplified the accurate location of formwork for pours.

Pre-made steel formwork was placed on site and the boring machine was used to lower the steel into the boreholes. This allowed the boring of holes, placing of base steel formwork and pouring of concrete bases to be performed on the same day. The use of a concrete pumping machine allowed the filling of the boreholes with concrete with very little disturbance to the sides of the holes (Figures 10 & 11).

Figure 10: (a) Typical finished borehole, and (b) boring machine at Pillar 3.

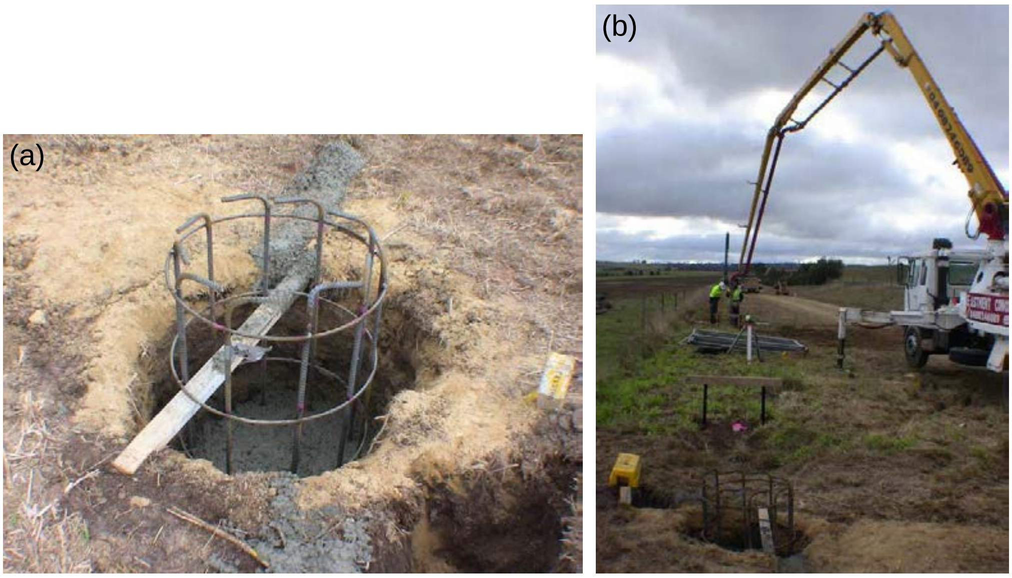

Figure 11: (a) Completed base pour at Pillar 1, and (b) pouring base of Pillar 2 with concrete pump.

Once the bases were poured, boxing was set up for the pillar section pour (Figure 12). As the PVC pipe forms the outside of the pillar, it only had to be set up vertical, on line and at the correct height. This was easily carried out with stringline offsets and the top of the PVC pillar accurately located by total station. Prior to, and after, the second concrete pouring a bracket and prism were used to confirm that no movement had occurred (Figure 13).

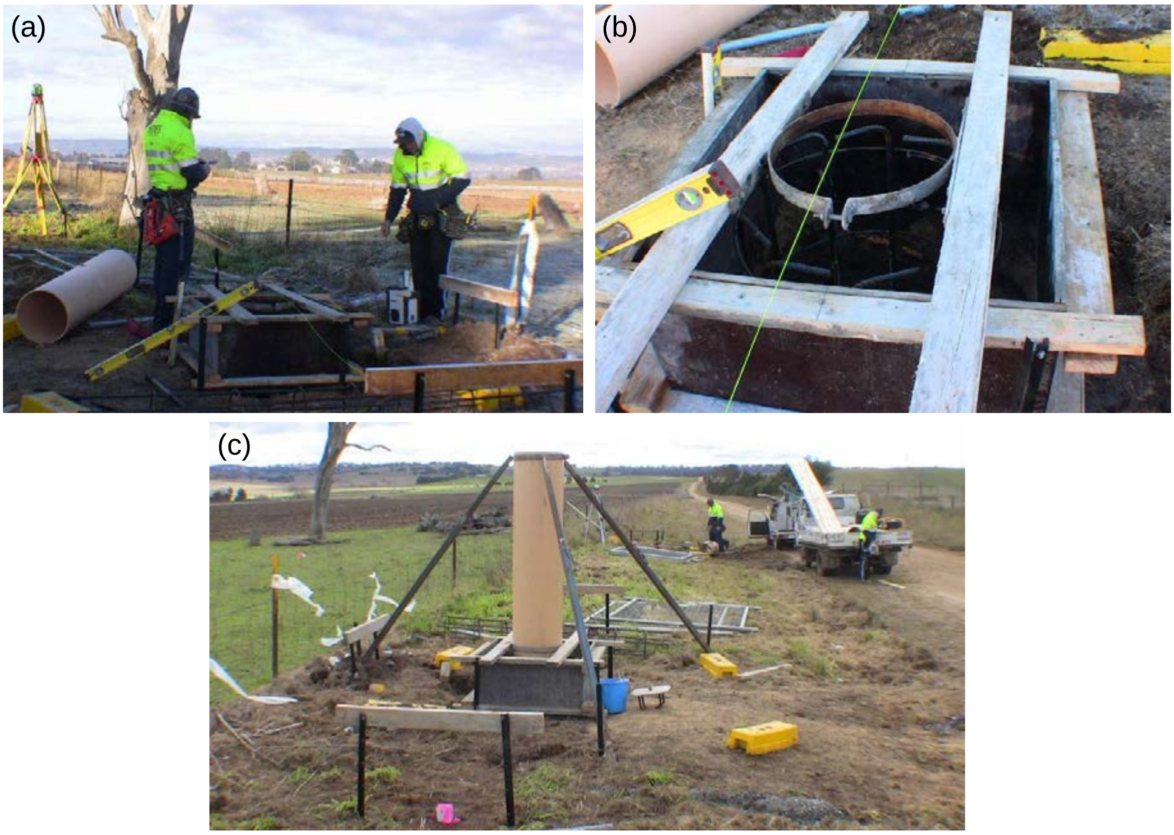

Figure 12: (a) Boxing set up at Pillar 1, (b) LPI bracket to hold base of PVC pipe in place, and (c) pillar tripod developed by LPI to position and hold the top of Pillar 1 in place (the pillar was raised 500 mm to ensure visibility if grass grows long along the baseline).

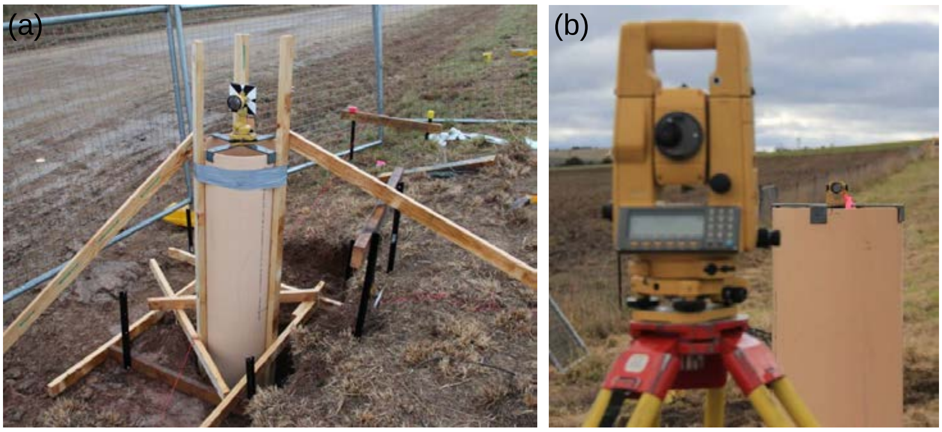

Figure 13: (a) Pre-pour check of line and height, and (b) post-pour marking for pillar plate alignment.

Once all pillar pours were completed, the pillars were allowed to cure for one week before the pillar plates were grouted into place. During this period, the bases around the pillar were formed and poured, and final landscaping and clearing of the site occurred. In addition, the safety barrier construction commenced. The pillar plates were installed using a low-shrinkage grouting mix. The two end pillar plates were installed first and each plate was accurately levelled. Each subsequent pillar plate was grouted and levelled and its position confirmed accurately from either end of the baseline. Brass number plates were placed in the exposed grout to avoid confusion with pillar numbering. All seven pillars were then sanded, undercoated and painted with white gloss paint to protect the PVC pipe. Finally, a stainless steel etched plaque was affixed to each pillar (Figure 14).

Figure 14: (a) Pillar ready for grouting and pillar plate, (b) pillar plate accurately centred and levelled, (c) within 2 hours pillar plate is ready to be used to confirm position of intervening pillar plates, and (d) painting, landscaping and plaques added during the following week to complete construction.

The erection of the safety barriers completed the project on 13 July 2012. It was realised that the devil is often in the detail and communication is paramount. A small statement in Council's approval stated "*...even though a low risk has been determined, it is recommended that an appropriate safety barrier be installed at your cost, as per the RTA's Road Design Guide...*" (RMS, 2011, 2012). As this dead-end rural road had no posted speed limit, the contractor's traffic engineer deemed that it defaults to 100 km/h, thus requiring highway-specification safety fencing, which accounted for over half of the construction cost (Figure 15). In total, the construction project was completed within one month.

Figure 15: (a) Safety barrier type initially deemed adequate, and (b) final safety barrier installation.

4 ASSESSMENT OF BASELINE CONSTRUCTION

In order to confirm that the baseline was constructed according to design specifications, a set of 1-way observations (based on a mean of 10 measurements) was made at dusk on the day of the placement of the pillar plates. The pillar plate design height for Pillar 7 (693.000 m) was adopted as the bench mark (Table 1).

Table 1: Check using Trimble S3 on 29 June 2012, from Pillar 7 (PM90407) adopting pillar plate RL 693.000 m (note 1-way observations only). Asterisk indicates probable presence of refraction error due to non-reciprocal, 1-way vertical angle observation over longer distances.

From	To	HZ Obs (0 set)	HD Measured	HD Design	HD Diff	Trig Height	Trig Height Design	Trig Height Diff
PM90407	PM90401	0°00'00" set	848.996	849.000	-0.004	690.763	690.800	-0.037*
	PM90402	0°00'00"	827.922	827.920	0.002	690.183	690.200	-0.017*
	PM90403	0°00'02"	710.500	710.500	0.000	688.596	688.600	-0.004
	PM90404	179°59'59"	496.742	496.750	-0.008	686.386	686.400	-0.014
	PM90405	0°00'00"	234.823	234.830	-0.007	686.214	686.200	0.014
	PM90406	0°00'00"	69.243	69.250	-0.007	690.207	690.200	0.007
	PM90407					693.000	693.000	set

A month later, the baseline was measured with the Network RTK GNSS technique (e.g. Janssen and Haasdyk, 2011) using CORSnet-NSW (Janssen et al., 2011). Three individual observations were averaged with local established permanent marks and the resulting coordinates were block-shifted to SS20030 (a mark of A1 horizontal and LBL2 AHD71 class and order) and checked with SS20029 (Table 2). For a recent discussion of the terms class and order, the reader is referred to Dickson (2012). Note that while the adopted Reduced Level (RL) for the pillar plate of Pillar 7 (PM90407) appears to be approximately 0.2 m different,

relative height differences between the pillars remain very consistent. This difference can be explained by the design heights being relative and based on the peg height of Pillar 1 (rounded to the nearest decimetre). Before construction, the final peg position of Pillar 1 was moved west (i.e. away from the road) by 0.75 m. However, the peg height was not changed accordingly and assumed equal to the ground height in order to avoid confusion with previous calculations. Although it is recognised that this check can only be regarded as 'rough', the results confirmed that the baseline was constructed according to design and also showed the capability of Network RTK GNSS.

Table 2: Check using Topcon GRS and NRTK on 24 July 2012, calculated from the means of three individual position observations at each pillar. Note that the AHD71 height was obtained via block shift using SS20030.

From	To	HZ Obs (MGA94)	HD Calculated to Ground	HD Design	HD Diff	AHD71 Height (approx)	AHD71 Height Design	AHD71 Height Diff
PM90407	PM90401	9°49'41"	848.993	849.000	-0.007	690.601	690.800	-0.199
	PM90402	9°49'41"	827.919	827.920	-0.001	690.010	690.200	-0.190
	PM90403	9°49'41"	710.496	710.500	-0.004	688.417	688.600	-0.183
	PM90404	9°49'40"	496.737	496.750	-0.013	686.198	686.400	-0.202
	PM90405	9°49'39"	234.822	234.830	-0.008	686.014	686.200	-0.186
	PM90406	9°49'34"	69.235	69.250	-0.015	690.000	690.200	-0.200
	PM90407					692.805	693.000	-0.195

5 BASELINE VERIFICATION

Following a pillar-settling period of four months, the Eglinton EDM baseline was verified by LPI legal metrology staff in November 2012. During verification, all 21 inter-pillar distances were observed under careful consideration of accurately measured meteorological data (i.e. temperature and atmospheric pressure using calibrated instruments). The relative height differences between the pillar plates were determined to second order specifications in December 2012. Initially, absolute RLs were obtained via static GNSS using CORSnet-NSW and applying AUSGeoid09 (Brown et al., 2011). A levelling connection to surrounding AHD71 marks will be carried out over the next few months in order to provide final RLs for the pillar plates. While this will involve substantial levelling, it allows the EDM baseline to replace ageing geodetic bench marks in the area. It is planned to release the Eglinton EDM baseline to the profession in the first quarter of 2013.

6 CONCLUDING REMARKS

The Surveyor General is a Verifying Authority for reference standards of measurement under the National Measurement Act 1960 and responsible for providing a state primary standard for length. Together with relevant legislation, this ensures that surveyors use verified measuring equipment. The correct measurement of length is a fundamental requirement that underpins a huge amount of spatial data used for a wide range of applications. Fulfilling the role of the Surveyor General, LPI is the sole organisation responsible for setting standards and providing infrastructure for EDM calibrations in NSW. Currently, LPI is in the process of improving its survey infrastructure by upgrading existing baselines to include more pillars or building new 7-pillar baselines for the calibration of EDM instruments.

This paper has outlined the issues that need to be considered in the construction of a modern, state-of-the-art EDM baseline, using the newly constructed 7-pillar Eglinton EDM baseline as an example. It was shown that this process is not straightforward and requires careful consideration of various issues faced during the planning, site selection, baseline design and pillar construction stages. The Eglinton baseline in Bathurst and the Lethbridge Park baseline in western Sydney are the first two new 7-pillar EDM baselines built to improve survey infrastructure in NSW and position the State for the future.

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Shaping the Cadastral Infrastructure for a Digital Future

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ABSTRACT

Australia's cadastral network, represented by the Digital Cadastral Database (DCDB), plays a fundamental role in Australia's Spatial Data Infrastructure (SDI), supporting decision making across all levels of government. The accuracy and integrity of the DCDB is essential to ensure critical decisions are made based on current and correct land information. With the introduction of e-Conveyancing and e-Plan digital lodgement, land information from a variety of external sources will rapidly populate the SDI with Global Navigation Satellite System (GNSS)-based information. The integration of this highly accurate information will compound the inherent historical inaccuracies within the DCDB, causing considerable impact on service and information delivery. In order to ensure responsive service delivery in a digital land administration of the future, cadastral fabric technology is transitioning the decades-old static DCDB to a dynamic survey title-based Numerical Cadastral Database (NCDB) that accurately models the nation's cadastral network. This paper provides government professionals with a comprehensive overview of how improved rigour and accuracy of the DCDB will provide powerful spatial infrastructure to generate technical and legal certainty for all stakeholders. It outlines the Tasmanian Numerical Cadastral Database Project and discusses the vision, the challenges and the benefits a project of this nature can deliver.

KEYWORDS: *DCDB, cadastral fabric, spatial data infrastructure.*

1 INTRODUCTION

For over 150 years in Australia, surveyors have been establishing the geodetic framework and establishing or re-establishing boundaries; the two most important themes in a spatial information infrastructure. The role of the surveyor in these functions is still critical – the only difference between the surveyors of the past and our current surveyors are the tools of the trade. They still continue to capture the evidence, make informed decisions and manage information.

Since the establishment of Australian colonies, surveyors have been establishing and maintaining the most important information system in Australia's economy – the cadastral framework. Initially, this was a piece meal approach but over the last 30 years, it has been recognised that a national approach is required for this framework. In the early stages of creating this framework, each state produced their version of a Digital Cadastral Database (DCDB) from survey plans. In New South Wales (NSW) for example, the DCDB started with a cadastral fabric created by the utilities authorities in the Sydney area. The land agency now known as Land and Property Information (LPI) progressed the DCDB out to the state's borders. Over time, the DCDB has become the adopted representation of the cadastre and has been used as the basis for most Geographic Information Systems (GIS).

As with all tools and technology, progress has been rapid and this has never been more true than in the last few years. This increase in computing power – in surveying technology and the ability to use remotely sensed satellite systems such as Global Navigation Satellite Systems (GNSS) – has dramatically changed the way information is captured and managed. The DCDB is just one of the information management systems that have been positively impacted by the change in technology advancement.

This paper looks at the benefits of the technology advancements in managing the information in the current DCDB cadastre frameworks. In order to demonstrate these benefits, this paper investigates a case study from Tasmania. The Tasmanian government has invested in a project to upgrade their DCDB to a Numerical Cadastral Database (NCDB). The NCDB is designed to upgrade the spatial accuracy of the cadastral fabric. This paper will also investigate what the future holds for the nation's cadastral infrastructure, with Tasmania and other jurisdictions either actively progressing or considering moving towards spatially improving the accuracy of their state's cadastral fabrics. Finally, the paper will discuss the impacts of changes in spatial systems to the management of cadastral fabrics and the potential benefits to the spatial industry, the government and the community.

2 THE HISTORY OF DIGITAL CADASTRAL DATABASES

A DCDB consists of tables and layers, representing different aspects of land and property boundaries. These different aspects include but are not limited to (LPI, 2013):

- Government boundaries, including Local Government Areas, state and federal electoral boundaries and other administrative areas.
- Property boundaries, lots within Deposited Plans and Strata Plans.
- Suburbs.
- Proclaimed boundaries of state forests, National Parks & Wildlife reserves and Livestock Health and Pest Authority districts.
- Road corridors and centrelines.
- Boundaries of bodies of water.

In 1992, Australia's Surveyors-General gathered to discuss the importance of national datasets, including a digital cadastral databases. The important aspects of the discussion included:

1. The reasons for building the DCDBs.
2. The methods used to compile the DCDBs.
3. The computing capability required to store and maintain DCDBs.

These three aspects are discussed in the following sections.

2.1 Reasons for Building DCDBs

There are a range of reasons that DCDBs were required to be built. A statement made by Effenberg and Williamson (1997) is an excellent summary: "*The processes for updating and upgrading DCDBs are gaining considerable attention world-wide as GIS users recognise the importance of the currency, quality and content of the DCDB that underpins their GIS application.*"

The uses of DCDBs were gaining momentum in the late 1990s as one of the most critical datasets required as base layers in GIS. With the cadastre viewed by many as the basis of most economic systems globally, it is logical that it forms the basis of most information systems that are based on land.

Some of the uses for a DCDB include:

- Local government asset management.
- Environmental monitoring and mapping.
- Mining and exploration.
- Defence and security.
- Forestry.
- Asset management for utilities.
- Management of roads.
- Statistical analysis.
- Mapping of a whole range of items of interest.

2.2 Methods Used to Compile DCDBs

The first land agencies in Australia used similar methods for the creation of the first DCDBs. They all selected a nominated starting point and used the latest survey plans available to build the DCDB by digitising the latest survey plans – entering the dimensions of the boundaries or importing sections of the DCDB created by local government authorities or utilities organisations. The database was compiled and progressed until all the boundaries within the jurisdiction were added. This was a significant task for the jurisdictions. However, in a period of about 10 years they were able to produce DCDBs for all of Australia, which included over 15 million parcels.

Over the next 10 years, the role of the state jurisdictions was to maintain and improve the DCDBs based on the changes that constantly occur with the trading, subdividing and amalgamating of parcels within the cadastral fabric. The issue with the upgrade and maintenance of the DCDB was that any changes needed to be 'rubber sheeted' into the existing structure of the DCDB. The ability to spatially upgrade the DCDB was limited to fitting any new data into the DCDB. This resulted in more accurate surveys being degraded to fit the accuracy of the DCDB. This produced a dataset that was pictorially representative of the cadastral fabric but was not spatially accurate.

2.2 Computing Capability Required to Store and Maintain DCDBs

The 1990s saw the beginning of the computer revolution, and the internet started to become mainstream. The storage capability of computers began to grow exponentially, but at the same time, the beginning of computer miniaturisation ensured that storage devices could handle larger capacity – but in hardware that was about the size of a large personal computer. The hand-size mobile phones started to become common in the 1990s.

Prior to the 1990s, the ability of computers to store massive vector datasets was confined to large mainframe servers. These were generally only available to government departments and universities. As such, the use of GIS was largely confined to organisations with the ability to host these large computers. During the 1990s, the computing power of personal computers grew by over 100 times and made it possible for GIS to be used on these types of computers. During this period Esri released ArcView 1.0 – this product was the beginning of the

development that led to ArcGIS Desktop as it is known today. This was the first Esri GIS product that allowed non-traditional GIS users to view and query maps. These capabilities began to drive the demand for mapping applications. As this demand grew, so did the demand for the base data, including the cadastre.

3 CHALLENGES AND ACCURACY OF THE EARLY DCDB

The accuracy of the DCDB was always an issue from its inception. The methods of data capture, the mix of old and new data, and the methods for combining these data all but guaranteed the accuracy of the DCDB would be compromised. Initially, this was not a major issue. Users would match the DCDB to other datasets, e.g. aerial photographs, topography or other data they may have captured. It was realised the DCDB was a visual representation and as such the accuracy issues were not of concern.

However, accuracy was a key priority to managers of high-value assets such as utilities, mines, power stations and other similar facilities. These users required high degrees of accuracy between their assets and features that defined boundaries. The reason for this was that utilities were located in the footpaths and on the roads, generally about 600 mm from the property boundaries. Mines and power stations needed to ensure the assets they assisted in building were within the boundaries of the leases or parcels. With any inaccuracies in the DCDB, maps displaying these types of assets could easily show the assets in the wrong property, or in some cases totally misplaced. During surveying experiences in South Australia, NSW and north-western Queensland, the author often found errors of up to 500 m between the coordinates derived from the DCBD and sub-metre GPS positioning.

In order to ensure accuracy, these users would create their own localised DCDB from the original survey plans and accurately locate their assets to features such as kerb lines, existing defined property boundaries and other easily definable features. Once the assets were defined in relation to these boundaries, the utility companies would use the assets as a point of reference and move the boundaries in relation to the asset if new information was obtained. During this period of time these companies typically had an entire branch of surveyors and supporting staff working continuously on locating their assets and performing boundary reinstatement to locate these assets to the boundaries. These companies would use their assets as the basis for their GIS, and the cadastre was used as a context layer that could be moved if accuracy issues were identified. Other GIS users also used the DCDB as a context layer, but generally accepted the errors or made manual adjustments to ensure the DCDB and other layers were representative of the relationship between the layers without any accuracy consideration.

Other challenges faced by GIS users were also presented during the early DCDBs. If attributes were linked to the boundaries of the DCDB, with each new version of the DCDB the attributes would have to be unlinked, with the new DCDB data loaded and the linkages recreated. A similar process was required each time a boundary was manually moved. This made the process of upgrading the DCDB extremely time-consuming and expensive. As such, users would delay the upgrade process until it was absolutely necessary.

3.1 What Changed?

In 1957, U.S. scientists discovered that they could track the orbit of a satellite in space by listening to the changes in radio frequency – now known as the Doppler effect. This led to the

creation of the U.S. Navy's TRANSIT Navigation System in the 1960s. A series of six satellites were initially launched with the purpose of tracking submarines. The full constellation for this system was 10 satellites, but users would have to wait up to several hours to pick up a signal. During this time, engineers Ivan Getting and Bradford Parkinson were the project leaders of a U.S. Department of Defense project, designed to provide continuous navigation information. The project was initially called NAVSTAR Global Positioning System (GPS) and was launched in 1973 during the Cold War. The first of the GPS satellites was launched in 1978 and the constellation of 24 satellites was completed in 1995 (Bellis, 2013).

The GPS and consequent Differential GPS (DGPS) techniques enabled users to accurately position assets and features to an accuracy of between one and 20 metres consistently. This new capability offered a new accurate data capture method to GIS users without the slow and labour-intensive survey techniques previously used by surveyors to coordinate features. This new capability enabled GIS users to capture large quantities of accurate data to put into their GIS. However, a new source of error was discovered – the datum. The Australian Geodetic Datum (AGD) and the World Geodetic System 1984 (WGS84) used by the GPS differed by approximately 200 metres. In order to solve this issue, the Intergovernmental Committee on Surveying and Mapping (ICSM) created a new Geocentric Datum of Australia 1994 (GDA94) and the consequent Map Grid of Australia (MGA94) to support the increasing use of GPS/GNSS. The use of GPS has been a driver for improving the accuracy of spatial systems such as the DCDB. New equipment and techniques now mean that features, survey marks and corners can be located within a few centimetres with GNSS.

Additional to the advances in the professional tools for positioning, the ever-progressing mobile hardware is now capable of positioning within two to five metres on a regular basis with the appropriate satellite constellation and access to an open skyview. As technology capability increases, the demand for information and data that reflects the accuracy of the technology is expected by users.

4 IMPACTS OF NEW MEASUREMENT SYSTEMS ON THE DCDB

Since the inception of the modern GIS in the 1960s, the work of surveyors and GIS users has been predominantly separate. GIS users have relied on data captured by surveyors, but there was no direct linkage. This has changed, with the GIS becoming the repository for survey measurements, boundary dimensions and the associated attributes. The cadastral fabric of today is providing more than a pictorial representation of the cadastre. It is based on the geodetic framework and is the basis for all information relating to the land parcels. In this paper, these new DCDBs will be referred to as NCDBs. The term NCDB has its origins in the work currently being undertaken in Tasmania (see section 5).

The modern GIS has the ability to create linkages called associations between features and aspatial attributes (i.e. attributes with no spatial components such as a property owner's name), called topologies. While this linking ability in itself is not new, the NCDB provides the additional capability to change, upgrade, add or delete boundaries within the GIS and at the same time retain the topological relationships between the original features and the aspatial attributes. The NCDB also makes it possible to alter the aspatial attributes without impacting the parcel boundaries.

4.1 Benefits to GIS Users

The benefits for GIS users begin with the ability to make the upgrade of the NCDB a simpler process. The new updates to the NCDB versions of cadastral data are able to be added without impacting topology or data that do not require change. As systems improve for surveyors to provide data transfer files in place of survey plans, a more efficient process can be created for updating the GIS with new data and making these data available to the public. The benefit to the GIS user is an authoritative and reliable base data 'layer' that can be provided through web services and kept up to date almost in real time. The need for GIS users to store large base datasets is also no longer necessary as information services, such as the cadastre, topography and water networks, are delivered as information services that can be mashed up to create the required 'map' at the time of use.

4.2 Benefits to Surveyors

Surveyors will still be the primary source of cadastral information in the NCDB but will need to grasp the concepts of GIS. The reason is that data will be provided to them from the GIS, in a format such as LandXML. The surveyor will need to provide it back to the land agency in the same format. The information contained in LandXML is more extensive than a normal AutoCAD file provides. The ability to take a dataset supplied by a GIS, add or amend it and provide it back is a more substantive process than drafting a plan in AutoCAD. This will enable surveyors to employ staff skilled in using GIS and therefore these skills are another capability the company is able to offer to their clients.

The plan searching process will be more digitised and streamlined as a result of NCDBs. With the survey measurements able to be stored in the cadastral fabric, the surveyor will just require the information service for the area of the new survey. Additionally, the surveyor should be able to obtain the cadastre representation line work as the basis for the survey submission. The requirement to submit a 'survey plan' will also no longer be required. The descriptors will simply be attributes to the survey data. The use of the original survey information service will ensure the location of the survey is known and the submission will just be a revised version of the previous download. The LandXML transfer file is the first step in this direction. It is, however, a way to transfer the data contained on the current survey plan and has limitations. Over time, the LandXML format should be modified to make it more useful for the transfer of information, instead of replicating a survey plan digitally. Over time, this transfer method will be refined as the legislative requirements are changed to reflect the capability of the technology such as the Esri Parcel Editor.

The creation of standards relating to transfer of data between surveyors and the land agencies will lead to more consistent national survey standards of practice. In the past, the differences in regulations between the jurisdictions were often associated with the production of the survey plan. As the plan is replaced by the transfer of information, an opportunity exists to make this transfer nationally consistent.

5 THE TASMANIAN EXAMPLE

In 2008, Tasmania created the Tasmanian Spatial Information Council (TASSIC). The Honourable Gary Nairn was appointed the Chair, with the new council consisting of delegates from state government, local government, industry and academia (TASSIC, 2012). TASSIC

was formed to maximise opportunities for government, industry and the community through the efficient and effective development, maintenance and use of the Tasmanian Spatial Data Infrastructure (TSDI). TASSIC was awarded project funding, and the Department of Primary Industries, Parks, Water and Environment (DPIPWE) was given the responsibility for the management of the Spatial Information Foundations (SIF).

SIF is a 2-year project to develop a contemporary platform for the management and distribution of spatial information across all tiers of government and the private sector and facilitate the improved use of spatial information for key priorities of the Tasmanian government. There are seven SIF projects in total, with five of these projects being well underway, and scheduled for delivery before 30 June 2013. Some of the projects are under review and their future is uncertain at this stage. The SIF program will improve the quality and timeliness of services and decision-making, especially in the areas of planning, economic development, policy development and emergency management. The SIF project is part of the Tasmanian government's ICT Strategy, and it supports the Economic Development Plan, strategies for planning reform and the SenseT (Sensing Tasmania) program.

This investment enhances the technological framework of the Land Information System Tasmania (LIST), which was developed in the 1990s (Tasmanian Government, 2009). Key anticipated outcomes of the project include:

- A new web interface for the LIST – for improved access to a wider range of spatial information.
- A web-based spatial data and services directory – providing improved discoverability of spatial data and services for use, analysis and reuse by more users.
- High speed image servers – with rapid delivery of remotely sensed imagery through LISTmap and web services.
- A data management and delivery system for planning data – providing new web-based capabilities for the visualisation and spatial integration of planning information.
- An address validation service – for automatic verification and more efficient management of address information within government agencies.
- A web-based spatial data delivery service – providing new capabilities for downloading and delivering spatial data.
- A web-based, emergency services Common Operating Picture (COP) for Tasmania – providing emergency management organisations with an authoritative, shared view of critical emergency and incident information.
- A new Tasmanian land parcel and property boundary database (numeric cadastre) – an enhanced cadastral dataset that is able to maintain boundary alignment with core administrative data, e.g. planning zones.
- A sustainable strategy for the ongoing acquisition and delivery of remotely sensed imagery for Tasmania – allowing the detection of changes in natural and built assets over time.

At the heart of the SIF is the NCDB project, which is a fundamental component to all the other projects within the SIF. The aim of the NCDB project is to create a framework for the spatial improvement of the Tasmanian cadastre. The Tasmanian government released a Request For Tender (RFT) in May 2012 and a consortium of Esri Australia, Geodata Australia and Applied Land Systems was the successful tenderer.

Since August 2012, the Esri Australia NCDB team has been working to create the framework for the NCDB using the capability of the Parcel Editor technology within the ArcGIS for

Desktop product suite. This capability has its origins in Australia and was created by Geodata Australia. In 2008, Esri acquired the capability and in 2010 it was embedded with the core ArcGIS product suite.

The Esri Parcel Editor technology is designed to import the survey measurements from the latest survey plan for a parcel or an area into a cadastral database, called the Parcel Fabric. The 'lines' of the parcels are linked to form the fabric. The fabric must be located accurately in location and the geodetic network of survey marks and the connection between the parcel corners and these marks are added to the fabric. The technology – through its adjustment engine – provides residuals for the differences between the location of the parcel corners from the fabric and the location of the same corner from the survey mark connection. It allows gross errors to be detected and removed and an adjustment is performed to create a new set of coordinates for each parcel corner. The important aspect of this adjustment is that the survey measurements are not changed but retained.

Throughout the import process, the attributes are associated with the appropriate parcels. The adjustment does not impact these associations and the attributes do not need to be reassociated with their parcel. The parcel fabric is able to be exported for GIS users to use as their base layer. The difference is that the parcel fabric is now aligned to real coordinates and can be adjusted as changes to the fabric are made.

The Esri Australia NCDB project team has been undertaking the following activities as part of phase 1 of the project:

- Modification of the Cadastral Data Model to fit the Parcel Editor Data Model.
- Loading the pilot area data into a database.
- Resolving topology issues, e.g. overlapping polygons.
- Loading of natural boundaries and ensuring they align appropriately with surveyed boundaries.
- Loading of easement and other encumbrances on the parcels.
- Ensuring administrative boundaries are aligned with the parcel boundaries.
- Ensuring attribute data are loaded and linked to the appropriate parcel boundaries.

Phase 1 is focused on a pilot area located at Launceston, with a total number of approximately 40,000 parcels. At the time of writing, the project team are about to visit Tasmania to conduct a week of User Acceptance Testing (UAT) on the work completed in the pilot area.

6 THE FUTURE

Currently, South Australia, NSW and the Northern Territory are moving closer towards working within the framework of the NCDB, and are all using some variation or version of the original Geodata Australia product called GeoCadastre or the Esri Parcel Editor technology. Victoria has produced a business case for consideration by the Victorian government to move in this direction. Queensland is about to begin writing a business case to seek funding to start a spatial improvement of their DCDB. Western Australia is keeping a watching brief on the other projects in progress around the country. They will consider their options in approximately two years.

One of the big changes to the Australian positioning environment that will impact these projects is the move towards a dynamic datum of Australia. This will have significant benefit

to the users of the system as it will future-proof the cadastral fabric for the best part of the next decade. With the speed of change in technology, this is a significant achievement.

7 CONCLUDING REMARKS

The cadastral fabric remains one of the most important spatial information services our profession produces for the benefit of the community and the Australian economy. As technology changes, the methods used for maintaining, updating and upgrading this vital information service also need to change. The community is hungry for information that is accurate, current, and available in real time and from a range of devices. The information age is gaining momentum and our profession is expected to keep up. Advances in technology offers land administration agencies within Australia and around the globe the ability to produce an information service that will be relevant not only today, but well into the future.

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Cadastral Modelling and the Role of the Government Surveyor

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ABSTRACT

Industry must adapt to changes in technology to be successful and digital database technology together with cadastral modelling will challenge the future of surveyors. While governance in survey and titling roles is weighed down by variables beyond commercial existence, such as statutory requirements, there is significant scope for improvement in these areas. In the past, survey plans modelled the cadastre and surveyors were necessary to locate boundaries. That historical cadastre will be modelled more effectively in a digital database, and accurate measurement tools are more freely available. Already there is a perception that anyone will be able to identify their boundaries with a Global Positioning System (GPS) device. This is not an unreasonable assumption based on the technology. However, under our current Torrens system of governance, a Registered Surveyor will always be required for boundary definition and validation. Understanding the status and opportunities presented by cadastral modelling will be vital to the role of the government surveyor in order to be relevant in integrated data management systems. This paper discusses how the digital environment can provide considerable efficiencies in survey and land administration and how it is critical that the survey profession is foremost in the transition from measurement-based systems of the past to the position-based systems of the future. Accuracy and data integrity in the database will be the key to those efficiencies and that will be provided by integrating as much historical measurement data as economically possible to model the real-world cadastre. The authors have been involved in modelling survey data for cadastral databases for government and infrastructure projects across Australia and pursue the agenda that surveyors must be an integral part of the process. This includes long-time survey data modelling in the Northern Territory, the NSW ePlan pilot and a 'whole of state' integration project in Tasmania.

KEYWORDS: *Survey data modelling, cadastral databases*.

1 INTRODUCTION

In the earliest times in Australia's history, the Surveyor General was considered the leading public servant based on the importance of their technical skills and contribution to the society. That relative status has changed over time and, similarly, the survey profession is facing many challenges. Surveyors have always embraced measurement and computing technology but the extent of change in wider technology now threatens aspects of the surveyor's role and challenges them to remain relevant to our property-based economy that is now being managed in a digital database environment.

This paper discusses how the digital environment can provide considerable efficiencies in survey and land administration, how it is critical that the survey profession is foremost in the transition from measurement-based systems of the past to the position-based systems of the future, and the role of the government surveyor in regards to these developments.

2 EXISTING SPATIAL DATABASE STRUCTURE

Geographic Information System (GIS) property layers in land administration databases have grown in relevance since their introduction. Their first use was a pictorial representation of spatial information in the same way early survey plans provided measurements as a guide to locate monuments or survey marks. Measurements on modern survey plans are now relied on to accurately represent property boundaries. This is a realistic premise which is underpinned by technology. In the past there was no option as to how those measurements were represented, but digital technology and coordinates do provide an alternative way to represent measurements.

The role of the cadastral database is now taking over the role of supplying freely available boundary information and the available technology generates the perception that this information is accurate because it has 3 decimal places and is supplied by the government. Original GIS cadastres were generated by mapping solutions such as digitising 'charting' maps. They represented the spatial relationships of properties for land administration purposes. The effectiveness of that role grew as the capacity of GIS technology grew. The accuracy could vary considerably but initially this was not relevant as computing technology limited the accuracy of GIS coordinates. The introduction of computers using 64 bit integers has overcome that limitation but existing databases generally retain that lesser spatial accuracy with the extent of the accuracy variations being unknown. The application of GIS grew from general land administration into infrastructure management and accuracy became important to its effectiveness, particularly at a local level.

3 THE DIGITAL SPATIAL DATABASE FUTURE

Technology is providing new and better tools that include:

- Distance measurement.
- Position measurement, e.g. using GPS/GNSS or mobile telephones.
- Imagery, e.g. via satellite, aircraft, drone or toys.
- LiDAR.

Whilst technology is changing, the rate of change in that technology is also a big challenge. It is considered that a significant amount of information has a spatial component and technology is providing powerful tools to represent that information in a spatial context. The importance of this is recognised at the highest levels with a federal Office of Spatial Policy (OSP). The federal budget is now spatially enabled to provide evidence of how and where funds are being distributed.

Another trend is that the digital possibilities provided by GIS technology is seeing a focus on larger and more complex systems to meet the e-government agenda and considerable resources are being pushed in this direction. The focus on the expenditure is moving to management and delivery systems as well as the data component.

For many years, surveyors were never challenged in their role as map makers. GIS systems then provided a rapid means to generate colourful and informative maps that management soon recognised as an effective way to manage and inform, so GIS has grown rapidly. Technical capability has allowed GIS to expand into 3D visualisation, which raises the bar on effective management and representation of information. At all levels of government and marketing, interactive 3D modelling and visualisation is seen as a powerful tool of influence and decision making.

4 THE DIGITAL CADASTRAL FUTURE

The future will see a transition from a measurement-based title system to a position-based system, driven by technology. Accurate measurement technology is no longer restricted to the domain of the surveyor but boundary definition and creation and legally validating measurements still requires statutory recognition and surveyor registration.

There are various terminologies in use that can have different meanings, but for a homogeneous future it is important those definition nuances are understood. They include:

- Survey Accurate Cadastre (SAC) – A true SAC would require every boundary to be defined on the ground by a Registered Surveyor and accurately coordinated. The level of precision would be high but the method of compilation would not be economically realistic.
- Coordinated Cadastre (CC) – All databases are coordinated and as such this is a generic term that refers to any cadastral database. The status of any CC is subject to the method of creation and any governance.
- Survey Data Model (SDM) – The SDM technology is based on the process where survey measurement data from all sources (current and historical) are input to generate a geometry model. The process applies a Least Squares Adjustment (LSA) to the measurement data based on the age or quality of the data. Thus, modern measurements would generally carry a higher weighting in the LSA than older measurements using lesser technology.
- Survey Accurate Cadastral Model (SACM) – Based on the SDM above.
- Numerical Cadastral Database (NCDB) – A term that is considered an outcome of the SDM as the input to the cadastral model are numerical survey measurements.
- Parcel Fabric (PF) – The Esri Corporation has licensed an SDM process as the cadastral management engine within the ArcGIS technology, in use by governments and the private sector around the world. The terminology is based on the premise that the outcome is a seamless ‘fabric’ of property, replicating the real-world cadastre.

5 THE SURVEY DATA MODEL (SDM)

GIS representations of the cadastre have always been coordinate based, as coordinates are the most efficient way to digitally record the outcomes of geometry computations. Survey coordinate geometry software has also always been coordinate based. Measurements are input and computations completed with all outcomes stored as coordinates. Survey plan measurement outcomes are then computed from that coordinate database and produced as spatial records to meet current statutory titling requirements. Thus coordinates are already at the core of our survey systems with office and field digital systems.

Our current property governance is based on the Torrens title system where registered survey plans represent monuments placed or adopted on the ground. Redefining the location of those existing boundaries is an intuitive process that considers various factors. The highest weighting in that evidence is the location of original survey marks or monuments. Other factors to consider include measurements on survey plans and occupations. It is an intuitive process and the outcomes are recorded on registered survey plans. Being an intuitive process makes it difficult to replicate in a digital workflow.

The legal survey boundary definition process is rigorous and surveyors have workflows that validate their work. Surveyors recognise that to provide a legal outcome that they will endorse, this must be the case. While the SDM process does not generally provide a legal outcome, it has several levels of validation to get the most accurate outcome in the database. Measurements shown on registered survey plans have a legal status and a unique aspect of the SDM process is that those original measurements are stored inside the system and contribute to the adjustment outcome. This reflects the fact that all historical survey plans have remained accessible and often are utilised in a boundary definition.

The GIS world has always been focussed on the speedy delivery of information and this is reflected in the way cadastral databases have been created. The rigour in the SDM process has meant that a speedy delivery was not always possible and the SDM process was initially not readily accepted in the database environment. Now there is recognition that accuracy of the database is a critical component for efficiency of management and operations and as such there has been an acceptance that the extra up-front cost of developing an NCDB is justified. The true business case is that those costs are amortised very quickly by efficiencies in operations. There is also the case that many problems caused by inaccurate cadastral databases are not correctly attributed. The case where such inaccuracies could contribute to the severing of an optical fibre cable is not unrealistic. The cost ramifications for this type of incident are substantial. A validated accurate cadastral database can mean that liability for such an incident can be apportioned more directly. Thus, an accurate SDM should be seen as a powerful risk management tool.

The technical level and legal status of any database needs to be recognised. Many people unknowingly use them for various spatial identification without knowledge of the quality of the information.

6 CADASTRAL MODELLING PROJECTS

Implementation of the SDM technology has occurred at various levels in Australia and the U.S. The range of projects considered in this paper includes:

1. Northern Territory – A territory-wide SDM has been generated by entering the measurement data from most of the survey plans. This has included survey traverses that define boundaries of pastoral leases of up to 80 km. Whilst the traverse generally follows a line defined by a specific latitude, traverse pegs defining the boundary have been placed which gives them a monument status. The boundary traverse is replicated in the model such that these pegs are effectively coordinated and the slight angle variations between them are represented in the model. The NCDB will support NT legislation enacted in the 1990s, enabling land titles to be legally defined by coordinates in the future.

2. New South Wales – In the ePlan project undertaken by Land and Property Information (LPI, 2013a), the SDM technology has facilitated the development of a portal lodgement of LandXML survey plans with immediate validation testing followed by automated spatial examination. This is currently in an implementation stage and results in considerable savings in time and resources with respect to the registration of survey plans.
3. Tasmania – A pilot project aimed at testing the outcomes of replacing the Tasmanian Digital Cadastral Database (DCDB) structure with the NCDB structure is being undertaken. The conversion of the DCDB data into the NCDB structure should enable increased efficiency and effectiveness in updating accuracy and land administration processes within the existing Department of Primary Industries, Parks, Water and Environment (DPIPWE) systems and workflows. As part of the process, measurement data from new and old survey plans will be entered into the model and stored where beneficial.
4. Infrastructure projects – accurate SDMs are being generated for the spatial foundation of large and small projects. The initial planning and design of these projects benefit at the earliest times with a minimum of field work required. The model should be managed and upgraded during the life of the construction stage so that an accurate asset management database will be provided to the client at handover.

7 THE ROLE OF THE GOVERNMENT SURVEYOR

Government surveyors at the highest level have played a key role in the development and maintenance of our cadastral system and this continues today. In the light of changes in technology, they regularly review the laws and regulations for cadastral surveys and work with the parliamentary draftsmen to draft changes. Government cadastral surveys also are a solid anchor in the overall plan network. Because they are not subject to the same cost and time constraints as the private sector, they have the ability to do a more thorough and detailed analysis of an area if this is required. In many ways, government surveyors 'set the standard' with their work.

Over the years, it has been initiatives from the government sector that have brought in major changes such as survey coordination, integration of surveys, the ePlan process and Continuously Operating Reference Station (CORS) network infrastructure. While the survey profession as a whole readily adapts changes in instrument technology, the government sector has to manage the infrastructure and record systems that underpin the cadastral system.

The complexity of modern Strata, Stratum and Community title plans are a challenge to the current record system. It is likely that our 2D 'plan-based' cadastre will have to be replaced with a 3D GIS system. The design of this system and its method of management will be critical to the efficiency of the whole titling system. Cadastral modelling is a proven technology that could be used to build and maintain such a system, but this will need some fundamental re-thinking about the whole cadastral process. If you look at a modern survey plan, how much of the information on that plan is essential to the maintenance of the cadastre and how much is there simply because we have 'always done it that way'? Now that the CORSnet-NSW infrastructure (Janssen et al., 2011; LPI, 2013b) is established, is there any point in placing more PMs and SSMs?

Existing GIS cadastral systems such as the DCDB are really 'passive' in that the fabric is updated some time after plan examination has been completed. However, there is no reason

why the checking and charting process should not update the DCDB in real time and post the results on the web. In other words, the titles office would generate and maintain a cadastral model of the state as part of the checking and charting process for new plans. Then we would have one 'point of truth' for the DCDB and it would be 'up to date' and of known accuracy. At present, there are over a hundred versions of the DCDB in NSW, each different and each maintained by a local organisation. They have been built and developed to satisfy local needs in regards to accuracy and timeliness of the data. The need to maintain all these different versions would disappear if this reform were carried out.

Such a change would mean a complete reassessment of workflows and job tasks but that will have to happen eventually anyway. The government surveyors are in a unique position to direct change, but to do so they will need to really grasp the full implications of developments in technology in order to take full opportunity from these changes.

An SDM database will benefit the State and will entrench the role of the survey in managing the database, but the ability to output a survey database to stakeholders means that surveyors will receive much more intelligent information to use in their surveys and they will just as efficiently be able to feed more intelligent data back, for the benefit of the database. At a time where there are fewer resources across all jurisdictions, these efficiencies are needed.

At local or service authority level, the field survey role is similarly diminishing. Where location information of local government or service infrastructure was required, the surveyor was the 'go-to' person for maps and plans. This is not the case anymore as the GIS manager is the 'go-to' person now. If they are an informed operator, they would seek the counsel of a surveyor where there are issues of boundary location, but often they do not. The only way to overcome this is an awareness of seeking the counsel of a surveyor wherever possible problems exist. Many government surveyors are now data or database managers. It must be ensured that authorities look to surveyors for validation of the database environment.

How the survey database and cadastral modelling process is introduced will determine the role of the cadastral surveyor. The surveyor's role under the Torrens title system is not under threat unless changes are made to the legislation to 'dumb down' the level of spatial validation. If that happens, it will be a progression towards title insurance, which was introduced to support systems that do not have the legal strength and spatial indefeasibility of the Torrens system.

8 CONCLUDING REMARKS

This paper has discussed how the digital environment can provide considerable efficiencies in survey and land administration and how it is critical that the survey profession is foremost in the transition from measurement-based systems of the past to the position-based systems of the future. The important role of the government surveyor in regards to these developments has also been outlined.

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Mobile Laser Scanning: Field Methodology for Achieving the Highest Accuracy at Traffic Speed

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ABSTRACT

Mobile Laser Scanning (MLS) is a new technology that has had great success and immediate results in corridor surveys. The technology allows us to measure all features along roads and railway lines accurately and quickly. Measurements are taken at traffic speed, i.e. without any impediment to traffic flow. There is no need for surveyors to be on or near the carriageway during the course of the survey because all data is collected from the safety of the cab of the working vehicle. Traffic lanes do not need to be closed or traffic diverted. The power of MLS is evident, and as surveyors we are interested to (a) explore the boundaries of accuracy that such a system can provide by understanding the technology used (scanner, GPS, IMU) and by developing field methodologies to eliminate or mitigate these errors, (b) develop field procedures to ensure surveyors can work safely at traffic speed and do not have to access the road at any time, and (c) continue research into the potential of the technology and the impact that it may have on standard surveying procedures. This paper describes several methods and techniques that have been developed by McMullen Nolan to meet these aims and how they have been implemented on the various MLS jobs that the company has completed throughout Australia.

KEYWORDS: *Mobile laser scanning, point clouds, corridor surveys, road safety, accuracy of MLS data.*

1 INTRODUCTION

Mobile Laser Scanning (MLS) technology emerged in the survey market in 2009 as an ideal tool for high-accuracy, comprehensive corridor surveys. MLS is a Light Detection And Ranging (LiDAR) technology combining the principles of airborne LiDAR with the accuracies achievable with Terrestrial Laser Scanning (TLS). The benefits that MLS offers include the increased work safety for road or rail workers, more detailed and comprehensive measurement of all features on the corridor, high-speed data acquisition and the accuracy of the final result.

As surveyors, we are particularly interested in the accuracy that can be achieved by MLS. Each of the component parts of an MLS system – i.e. Global Navigation Satellite System (GNSS) units, laser scanners and Inertial Measurement Units (IMUs) – are subject to error budgets that contribute to the overall accuracy of the system. Apart from incorrect ambiguity resolution after a loss of lock, the largest errors affecting MLS point cloud positioning include

satellite multipath, jumps due to changes in satellite configurations and the accuracy of the geoid model (relationship between GNSS heights and orthometric heights). Traditional approaches to error minimisation or mitigation are based on placing multiple control targets along the corridor. The targets enable the point cloud to be monitored for positional accuracy, corrected for any drifts and then ‘pinned down’ to the local control. This approach is supported by MLS manufacturers and is widely used throughout Europe and the USA.

Since entering the MLS market in Australia in 2009, the McMullen Nolan Group (MNG) has developed specific methodologies and processes for MLS surveys. This resulted in a system that works at traffic speed, can easily identify and eliminate any errors caused by satellite multipath, does not require multiple targets placed along the corridor, is portable and flexible, and provides the highest possible accuracy result through the averaging of redundant observations.

This paper introduces MLS survey technology and discusses some of the major sources of positioning errors that can limit absolute accuracies of the generated point cloud. The current approach to reducing and eliminating the error sources of MLS are outlined and the limitations and advantages of this approach discussed. The Multi-Pass approach developed by MNG to increase the accuracy of MLS data is then presented. This approach is compared with traditional MLS survey methods and the advantages and limitations are discussed. Finally, some of the recent developments taking place in the MLS world and their potential impact on this fast-evolving technology are outlined.

2 MOBILE LASER SCANNING

Mobile Laser Scanning (MLS) has been actively used in the survey market since 2009. MLS is the process of mounting a ‘line scanner’ on a moving platform. The line scanners in use today typically collect several 100,000 points per second. Thus, as the platform moves forward, a cloud of points is generated. This point cloud is usually so dense that it appears like a picture (Figure 1). Every feature within the line of sight of the scanner is picked up within the survey corridor. Data is later extracted from the point cloud into strings and point features that are used for a range of engineering and survey purposes. MLS has had a significant impact on corridor surveys as comprehensive data is collected quickly, safely, accurately and economically.

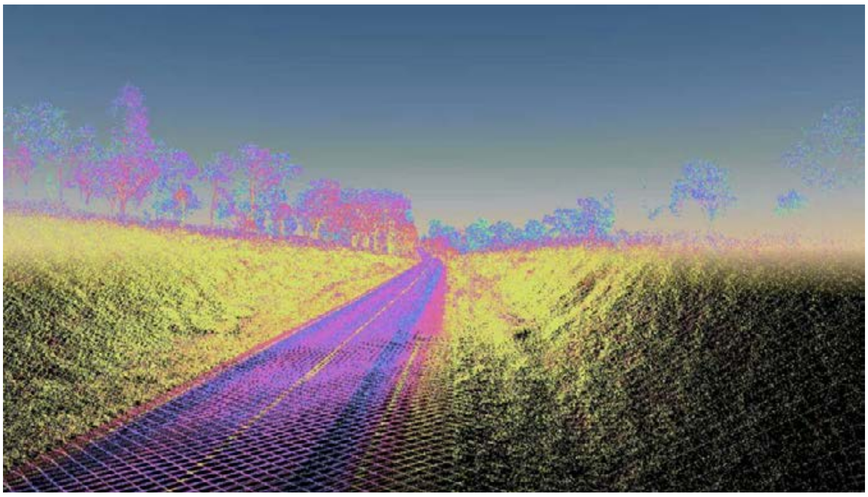

Figure 1: Point cloud of Dawson Highway, Queensland.

There are a range of scanners on the market that employ different observation techniques. For high-accuracy survey requirements, both phase and pulse lasers are used. Their accuracy is in the order of millimetres or centimetres depending on the type of scanner, range to targets, reflectivity of the measured surface, etc. The accuracy of each laser measurement from the scanner is specified to 10 mm accuracy (compared to true distance) and 5 mm precision (comparing measurement repeatability) (Riegl, 2012). As the scanner rotates quickly (100-200 Hz), all the points within each rotation and between subsequent rotations of the scanner head are highly correlated. This system feature results in high 'relative' accuracies of points within the point cloud. Measurement of point features collected at one location in the point cloud are accurate to millimetre level.

As surveyors, we are also concerned about the 'absolute' accuracy of the system. This is the accuracy of the point cloud relative to the local reference frame. High absolute accuracy enables surveyors to use data extracted from the point cloud for survey and engineering applications with confidence that they will tie in closely with the local survey control.

A typical MLS system for use on a vehicle is shown in Figure 2. Positioning the scanner is the role of GNSS combined with the IMU. In a MLS survey, it is common practice to employ multiple GNSS base stations along the corridor. These base stations can be either temporary local sites or permanent sites belonging to a Continuously Operating Reference Station (CORS) network such as CORSnet-NSW (Janssen et al., 2011), although the latter are generally not available at the desired density. Typically, the GNSS unit on the working vehicle collects data once per second and provides an Easting, Northing and ellipsoidal height at that epoch. The IMU collects data at a much faster rate (200 Hz) and provides the pitch, roll and yaw of the working vehicle, but also augments the GNSS-derived positions in times of satellite blockage and outage. The IMU enables all the vehicle vibrations from road corrugations etc. to be measured and taken into account.

Figure 2: MLS system components and mounting on working vehicle.

3 SOURCES OF SATELLITE POSITIONING ERROR

GNSS provides excellent absolute positioning accuracy over long distances. Positioning accuracy can be challenged, however, in urban canyons, heavily vegetated areas and under bridges and tunnels due to loss of satellite lock. The IMU assists the GNSS solution and aids in cycle slip detection and recovery when satellite lock is impaired. As GNSS is used as the major positioning tool for the MLS system, any satellite errors that affect it will translate

directly into the accuracy of the point cloud position. In order to achieve high 'absolute' accuracy of a MLS survey, it is important to identify and eliminate these errors.

The biggest error that needs to be identified is loss of lock, which may lead to incorrect ambiguity resolution. Incorrect ambiguity resolution can lead to jumps in absolute position to the order of decimetres. By using today's GNSS processing algorithms, and augmenting the positioning solution with IMU data, this scenario is minimised. Assuming that incorrect ambiguity resolution is eliminated, the three further contributors to the GNSS positioning error budget include multipath, changes to the satellite configuration and geoid undulation (causing variations in the orthometric height).

Multipath is the error caused by GNSS signals being reflected off nearby surfaces and arriving at the GNSS antenna from a slightly deviated path. Multipath effects change with location (different reflective surfaces) and over time (changing location of satellites). There are many publications (e.g. Leick, 2003; Lau and Cross, 2007; Schön and Dilßner, 2007) about the effects of multipath and it is generally accepted that it can introduce positioning errors of the order of 1-3 cm.

The satellite configuration is ever changing, and GNSS data is usually observed with some minimum elevation cut-off to avoid using low-elevation satellites. As satellites rise or fall in the constellation, the geometry (Dilution of Precision or DOP factor) of the satellites changes and the position solution at the rover receiver can also be affected. In essence, this simply highlights the multipath errors, which are much more pronounced for low-elevation satellites.

As GNSS positioning is based on the ellipsoid and not the geoid (the basis for AHD71 – see Roelse et al., 1971), it is important that the relationship between these two surfaces is fully understood – known as the geoid undulation. Any errors in the determination of the geoid undulation will directly affect the AHD71 values resulting from the point cloud. In Australia, the AUSGeoid09 model can be used to obtain AHD71 heights from GNSS-derived ellipsoidal heights (Brown et al., 2011).

3.1 Minimising Positioning Error in Static GNSS Surveys

For static GNSS surveys, there are a range of actions that can be taken to mitigate satellite errors. These actions include (ICSM, 2007):

- Lengthening site occupations to average the effects of multipath and changing satellite configuration.
- Multiple set-ups on network stations to average set-up errors and measure under different satellite configurations.
- Measuring a number of 'known' control points to monitor the difference between orthometric and ellipsoidal height.

Real Time Kinematic (RTK) surveys on static points can be tested by increasing the number of occupations at each point of interest (repeat observations) where every occupation is taken with different satellite geometry (e.g. Janssen et al., 2012). Routine practices are in place to minimise satellite errors in static surveys (or surveys occupying static points). However, what actions can be taken to minimise these errors in kinematic surveys?

4 ACCURACY OF MLS SURVEYS: GNSS KINEMATIC SURVEYS

It is difficult to monitor the effects of satellite errors on a kinematic platform, unless the exact trajectory of the GNSS antenna is known. This is possible if an independent measurement device (say a robotic total station) is available and work is performed on a fixed and known track (say a railway track), or the GNSS antenna is fixed to a 'rotating arm' that allows monitoring the repeatability of GNSS measurements. However, for field surveys, monitoring the accuracy of kinematic GNSS is much more difficult. The ability to identify and minimise GNSS positioning errors is a major challenge for MLS systems in order achieve high-accuracy results. This section describes the current approach to achieving high absolute accuracy MLS surveys. The following section compares this approach with the 'multi-pass' methodology developed by MNG.

4.1 Standard Approach to High Absolute Accuracy: Multiple Control Targets

The current approach to eliminating satellite errors is to establish a dense network of survey control along the corridor, from which the GNSS-derived positions of the survey vehicle can be compared. The control is used to monitor any drift in satellite-derived positions (of the order of 1-3 cm) and then to pin the point cloud down to the control marks.

Conventional MLS surveys are completed using:

- One pass of scanning.
- Two scanners angled to each other to measure a '3-dimensional' point cloud.
- Measurements to multiple targets established along the corridor. Once these targets are identified in the scan, they can be used to correct any drift in the point cloud trajectory that has occurred since the last target was placed. The targets are placed from control stations that have been traversed in along the corridor.
- Levelling each of the target marks to allow determination of the relationship between geoid and ellipsoid (i.e. geoid undulation).

The advantages of this method are that, firstly, it provides a direct measurement of the orthometric (AHD71) heights over the area, which minimises the errors introduced by potential errors in the geoid model. Secondly, it leaves a trail of control along the corridor that can be used for later construction works and as a platform for picking up detail survey points that cannot be measured from the scanner.

However, adopting this approach has the following consequences and limitations:

- The requirement to place survey control and targets on the road shoulder means surveyors need to work along busy traffic corridors. Road and rail corridors are inherently dangerous places to work and therefore traffic management needs to be put in place. Lanes may need to be closed and work may have to be carried out at night.
- This approach is optimised at slower road speeds. When collecting one pass of data, it makes sense to drive the corridor at a limited speed as the point cloud is denser when travelling slowly, enabling more detail to be discerned. The approach may also require the working vehicle to slow down when passing the targets, so that they can be easily identified in the point cloud. When working on corridors at less than posted speed limits, the working vehicle will be required to have a trailing 'traffic control' vehicle to warn drivers of the 'slow vehicle ahead'.
- The method provides no guarantee of eliminating all satellite-based errors for the length of the corridor. Positioning certainty can be confirmed at each control target, but there is no

way to tell whether multipath or satellite configuration changes have occurred between targets.

Figure 3 shows the variation in trajectory of a kinematic survey along 3 km of road. The chainage is shown on the horizontal axis (metres) and the variation from 'true' position is shown on the vertical axis (metres). In this example, the kinematic position oscillates around the 'true' position by up to about 3 cm due to the effects of multipath and changes in satellite configuration. If targets were placed every 250 m to pin the point cloud to the reference frames at these intervals, the drift in the point cloud between chainages 500 m and 750 m would provide a high-accuracy solution for all data between these marks. However, pinning the point cloud to the control between chainages 1,500 m and 1,750 m would not properly model the kinematic movement of the working vehicle.

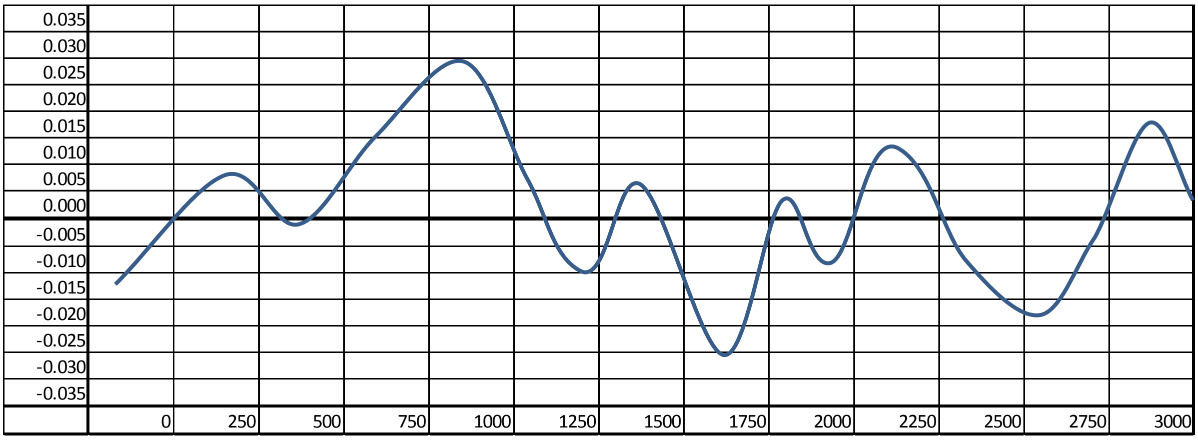

Figure 3: Multipath effects for kinematic GNSS along a 3 km stretch of road (all units in metres).

The only way to ensure high accuracies can be achieved is by placing even more control. One of the major suppliers of point cloud processing software, Terrasolid, suggests that for the highest accuracy point clouds, horizontal targets should be placed every 200 m and level points will need to be placed every 50 m (Soininen, 2012). Meeting this requirement can prove an onerous task.

5 McMULLEN NOLAN GROUP MLS: A NEW APPROACH TO SCANNING

When the McMullen Nolan Group started working on its MLS system in 2009, it was based on the following aims:

- Work the MLS at traffic speed.
- Create a system that allows the identification and correction of satellite drift issues.
- Minimal requirement to establish control along the road corridor.
- Maximise the accuracy that can be achieved by the system.
- Acquire a high-resolution, dense point cloud for identifying features.
- Create a portable system that can be mounted on a range of vehicles.

A MLS group was set up in the company, which has developed a MLS system meeting these goals and continues to work on new developments. The basis of our approach is based on repeat MLS measurements over the same corridor, as described in this section.

5.1 Multi-Pass

In a nut shell, Multi-Pass is the idea of removing any multipath errors through multiple measurements of the same trajectory. Each of the trajectories is processed and its position is compared with the other measurements. To increase the accuracy of the point cloud, a mean value from all the trajectories is calculated. It is interesting to note that this method takes advantage of the measurement power of MLS to enable comparisons between trajectories. A linear feature is identified (e.g. fog lines, centrelines or railheads) and extracted for each pass. The position of the features can then be compared from one run to the next (Figure 4). It is interesting that the ability to extract data from the point clouds enables us to determine the variation of each point cloud from its 'true' position. Without using MLS, it would not be possible to make this comparison.

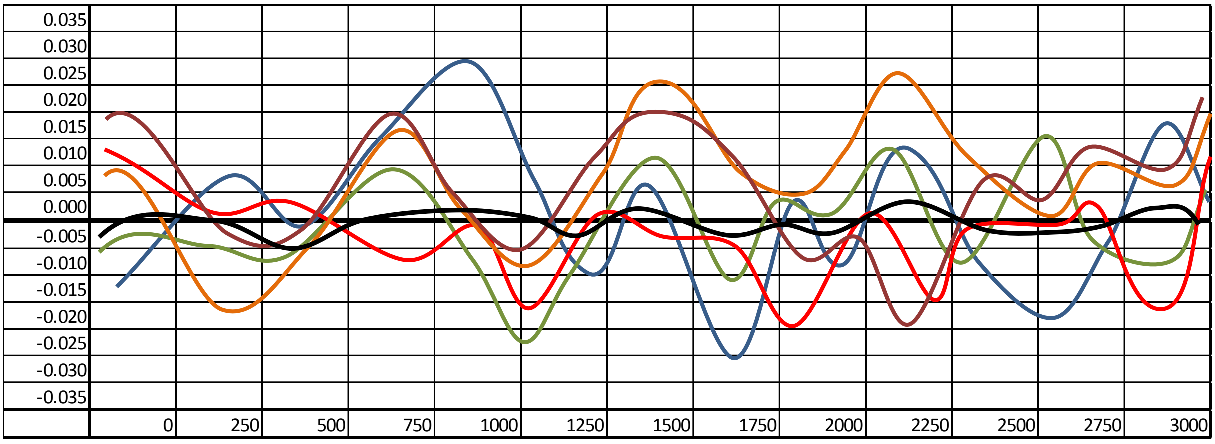

Figure 4: Multipath comparison of 5 passes of data and the mean trajectory, shown in black (all units in metres).

By comparing the individual point clouds, it is possible to:

- Identify and eliminate any suspect data (e.g. from satellite blockages).
- Increase the survey accuracy by averaging the effects of multipath and other satellite errors over repeat measurements. Inspection of the different point cloud layers provides an opportunity to analyse the data, determine the mean trajectory and the standard deviation of the trajectory. This provides a level of statistical certainty to the data.
- Increase the density of the final point cloud, as it is the result of combining all the point clouds together.
- Use one line scanner in the system. Once it is accepted that a corridor needs to be measured multiple times, one can realise that the 3D image can be measured by swinging the scanner into a different orientation once half the observations have been taken. Using only one scanner makes the equipment lighter and more portable.

The Multi-Pass approach uses the principle of repeatability of GNSS measurement to control the positional accuracy of the working vehicle, rather than pinning them to multiple targets. Adopting this approach means that control can be placed at much greater separation distances than using other methods. MNG has conducted rural surveys where the control targets are not placed every 300 m, but every 5 km or 10 km. As a sidenote to this point, it is possible in urban canyons and in heavily vegetated areas to place control more densely if required. The major advantage to this approach is that surveyors are not required to place dense control along the corridor, i.e. the requirement to close lanes, work at night and implement traffic management is minimised.

Without levelling up the entire corridor, there is no direct measurement of the geoid undulation along the corridor. Orthometric heights can be calculated using a geoid model, such as AUSGeoid09, that is constrained by spirit-levelled targets. AUSGeoid09 claims to have an absolute accuracy of 50 mm and 2 ppm relative accuracy across most of the country (Brown et al., 2011). Experience has shown that for longer corridors the accuracy of adopting AUSGeoid09 is similar to the accuracy of 3rd order levelling (Table 1).

Table 1: Comparison of vertical accuracy over distance for AUSGeoid09 (2 ppm) and 3rd order levelling (12√k).

Length (km)	AUSGeoid09 (mm)	3rd Order Level 12 √ k (mm)
0	20	37.9
20	40	53.7
30	60	65.7
40	80	75.9
50	100	84.9

In order to monitor any deviation from the AUSGeoid09 model, the targets are spirit-levelled from the control survey. Comparison of the spirit-levelled height with the height calculated from GNSS and AUSGeoid09 can be made at each target placed. If the variation is outside expected tolerances, additional level runs can be made.

5.2 Brisbane Motorway MLS survey: Description and Results

In order to demonstrate the power of the Multi-Pass approach, some data was analysed from a 30 km MLS survey that was conducted in December 2012. The survey required data to be collected for 30 km along the M1/M3 motorway in Brisbane. Survey control for the MLS was established using a spirit level traverse along the full route with control points located approximately every 200 m along both carriageways (163 control stations total). The survey specifications required us to use every second control point as a 'target' point (separated by 400 m), and to use the intermediate stations as control stations for QQ strings (to test the model). This dataset, however, allowed us to re-process the data in a number of ways, to demonstrate the absolute accuracies that can be achieved with the Multi-Pass approach when target separations are extended.

5.2.1 Single-Pass Data

Figure 5 shows data from one pass of MLS along the entire 30 km corridor. The ellipsoidal heights associated with the point cloud have been corrected with AUSGeoid09 to orthometric heights, and a comparison was made with 153 of the control points along the corridor. It should be noted that it was not possible to compare the heights at all 163 control points, as passing cars and other interference did not allow the targets to be identified.

The rough saw-tooth appearance in Figure 5 can be largely attributed to the effect of multipath on the GNSS signal as the vehicle traverses along the highway. There is also a noticeable jump approximately three quarters along the route. This may be due to a change in satellite constellation (i.e. a satellite rising or setting) causing an abrupt change in the error signature. These drifts and errors can be minimised by pinning the point cloud at key control points along the road.

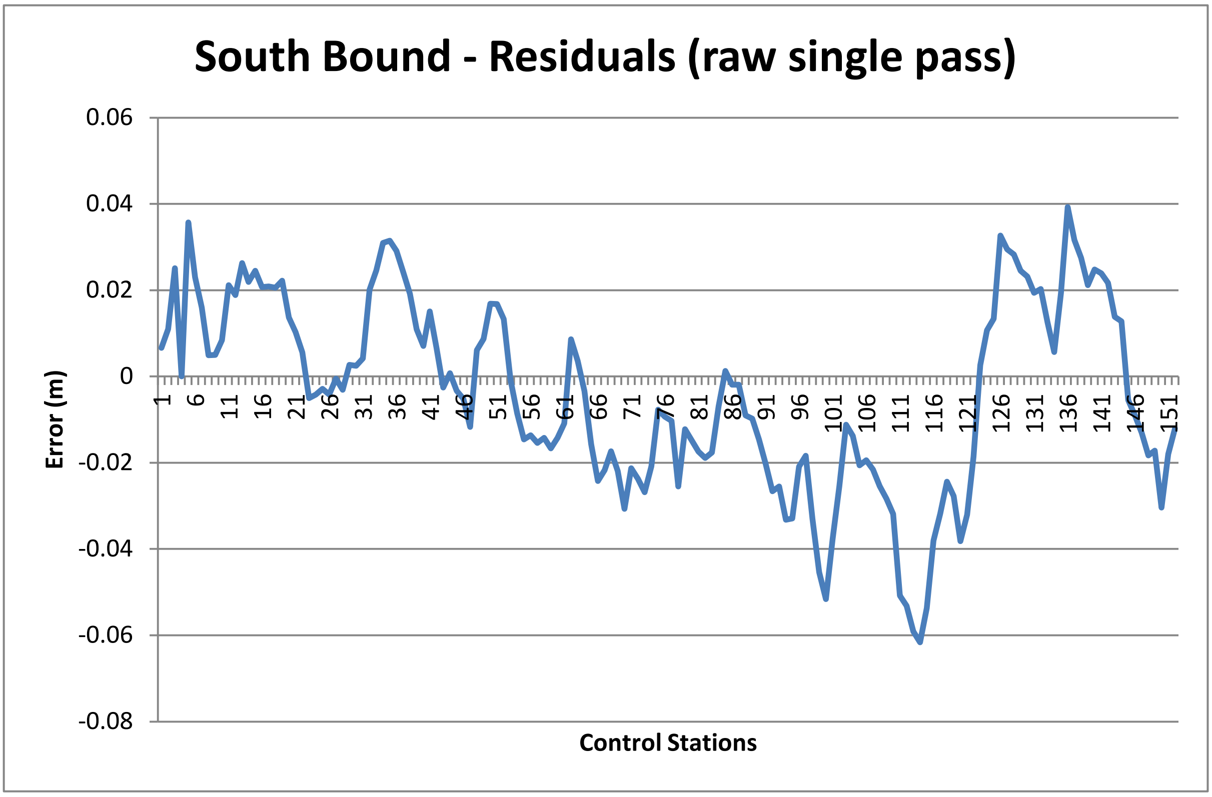

Figure 5: Monitoring the height deviation of GNSS with ground truth over 30 km motorway.

Figure 6 shows the deviation to ground truth when a single pass of MLS data is pinned to control points every 400 m along the corridor. The resulting heights are compared to the 'ground truth' provided by the QQ strings from the alternate control marks in-between (i.e. 200 m from the pinned control). It can clearly be seen that in most cases this provides suitable accuracy when the GNSS data is good. The standard deviation for the data is 6.0 mm.

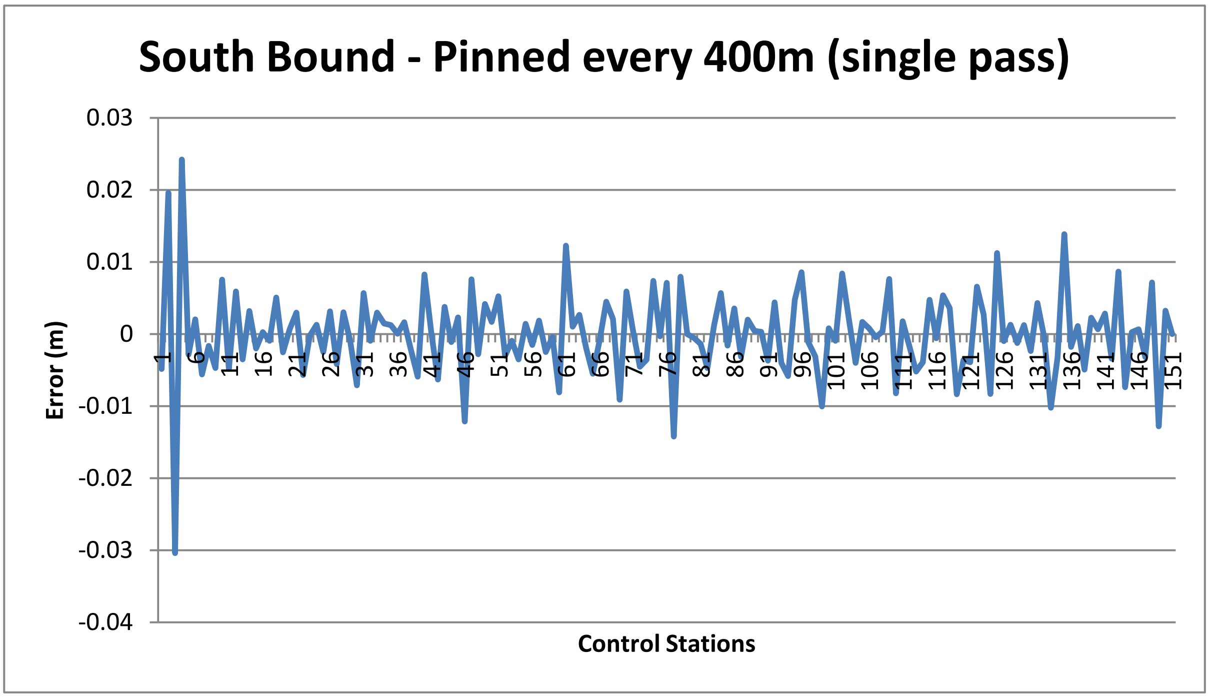

Figure 6: Comparing MLS height with ground truth (single pass) – 400 m control station separation.

The processing can be repeated using control stations that are more widely separated. Figure 7 compares the residuals when the MLS data is pinned to control every 800 m and every 1,600 m. As expected, the standard deviation of the residuals increases with wider control separation. This process can be repeated for a range of control point separations, and a graph of the one sigma errors plotted (Figure 8).

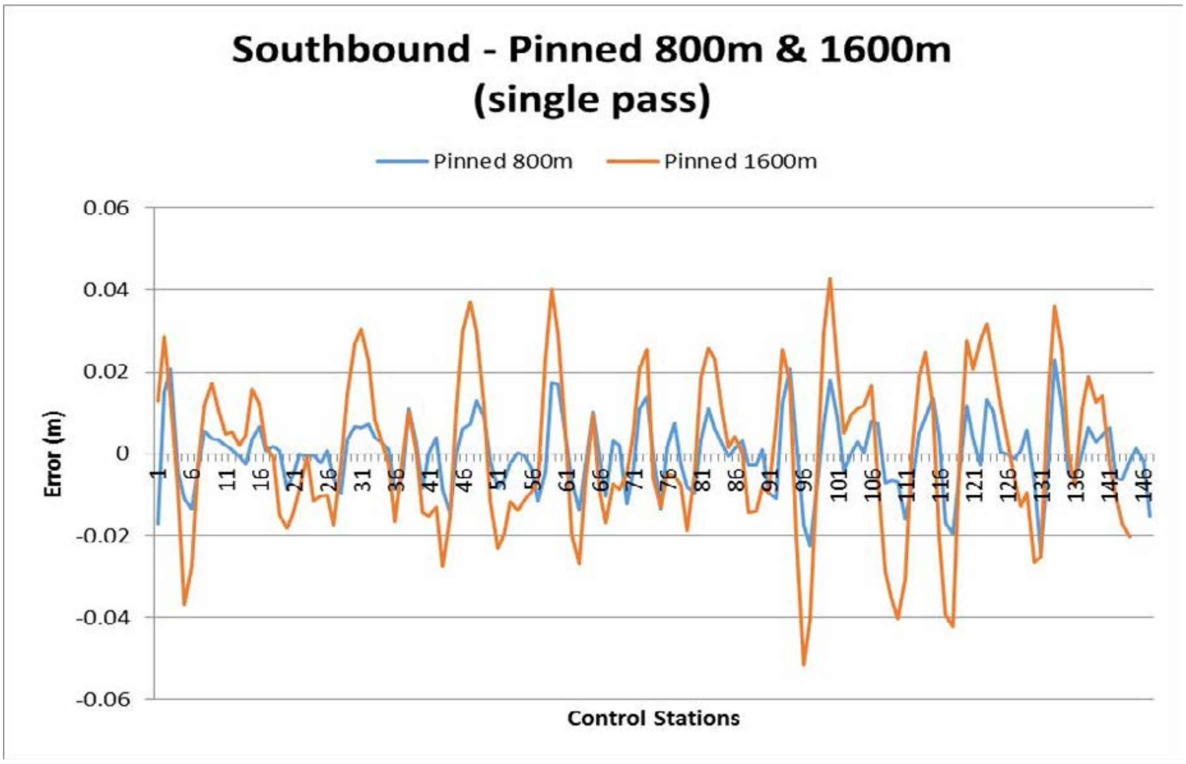

Figure 7: Comparing MLS height with ground truth (single pass) – 800 m and 1,600 m control station separation.

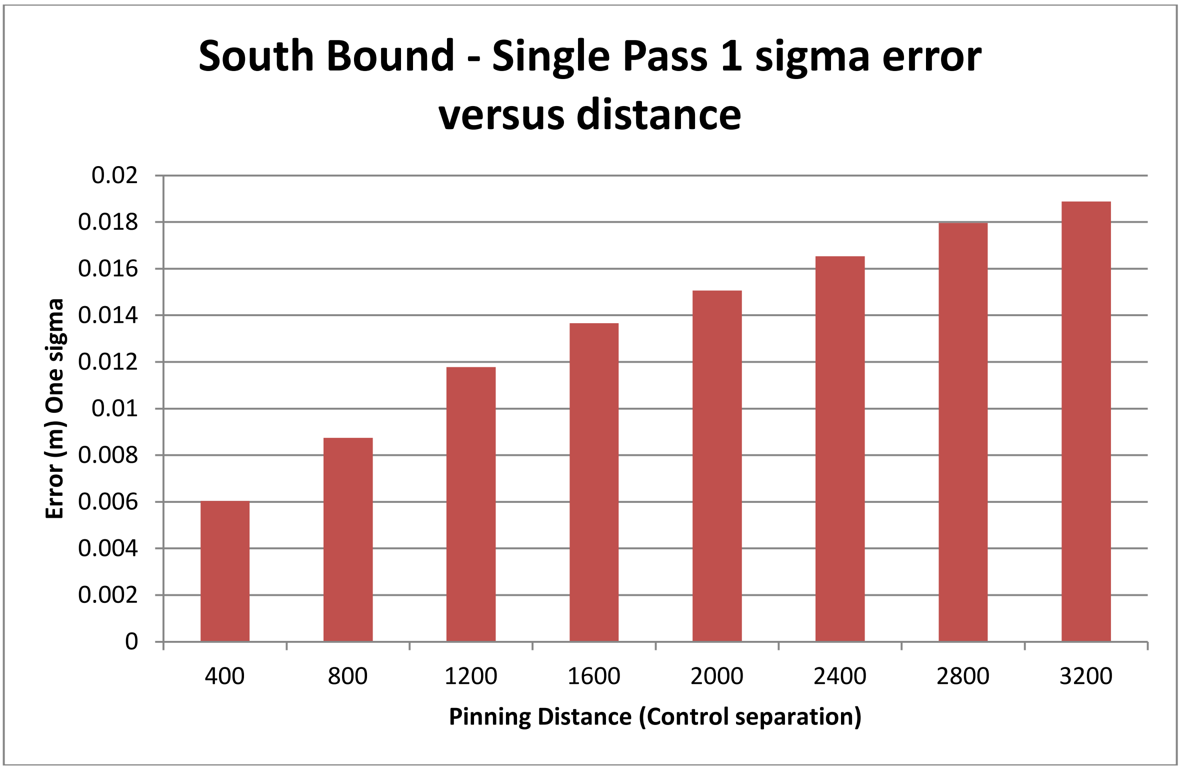

Figure 8: Standard deviation of the height error using differing control station separation spacing.

5.2.2 Multi-Pass Data

Multi-Pass data combines 6 independent passes of MLS data along the same road section. Each pass is considered 'independent' if more than 15 minutes different in time from the original pass. This allows satellite configurations and the multipath signature to change between each run. Figure 9 shows the results of pinning every 400 m with 6-pass data. This provides a 1-sigma standard deviation of approximately 3 mm.

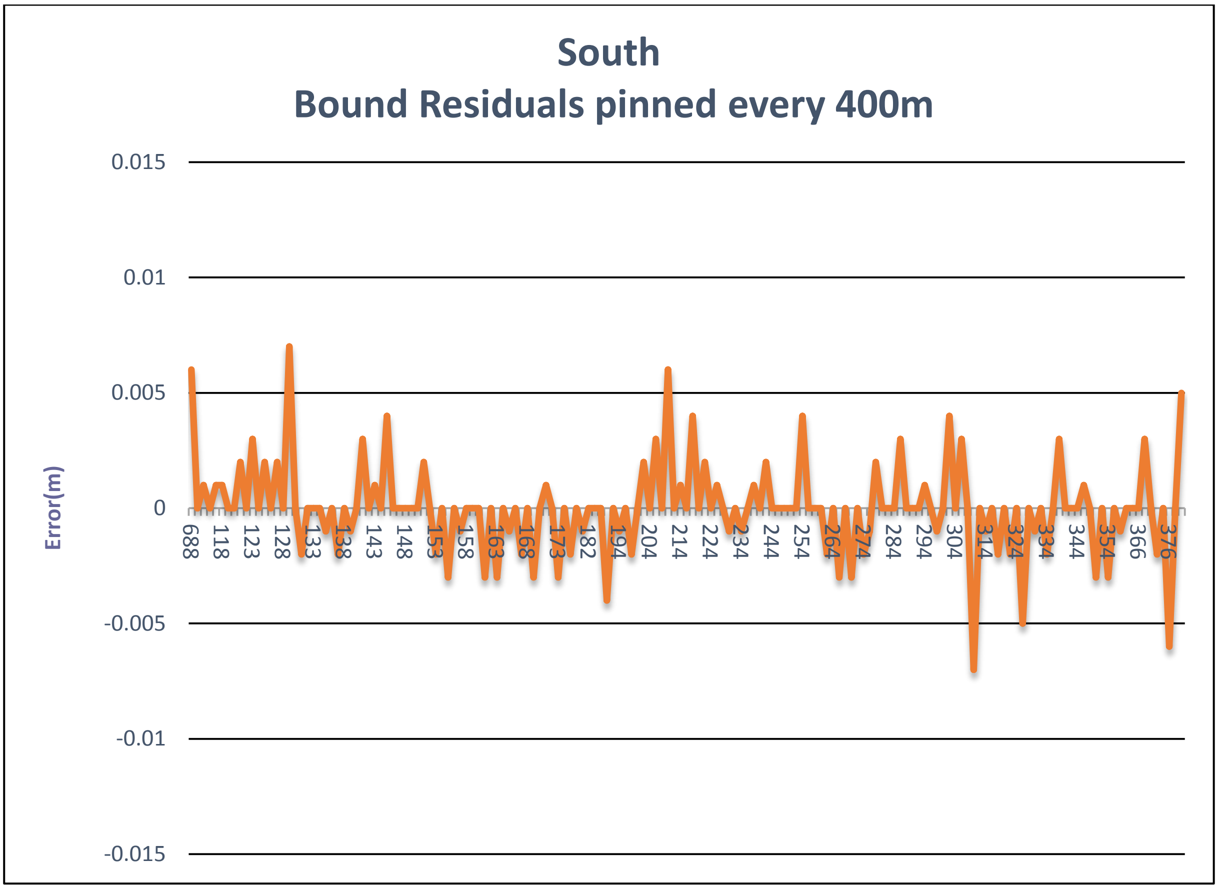

Figure 9: Comparing MLS height with ground truth (6 passes) – 400 m control station separation.

If the same datasets are processed using Multi-Pass data, a similar relationship to single-pass data can be seen. The relationship between pinning distance and error follows a similar curve; however, the magnitude of the error is reduced. Empirically, the error is reduced by the square root of the number of independent passes. Hence, when 6 independent passes are combined, the accuracy is increased by $\sqrt{6}$ (= 2.4) or some 60%. The empirical data supports this theory.

The issue of accuracy can be viewed another way. If a MLS survey is specified to provide a 2-sigma accuracy of 12 mm, the results can be obtained by using one pass and pinning every 400 m or using 6 passes and pinning every 2.0 km (Figure 10).

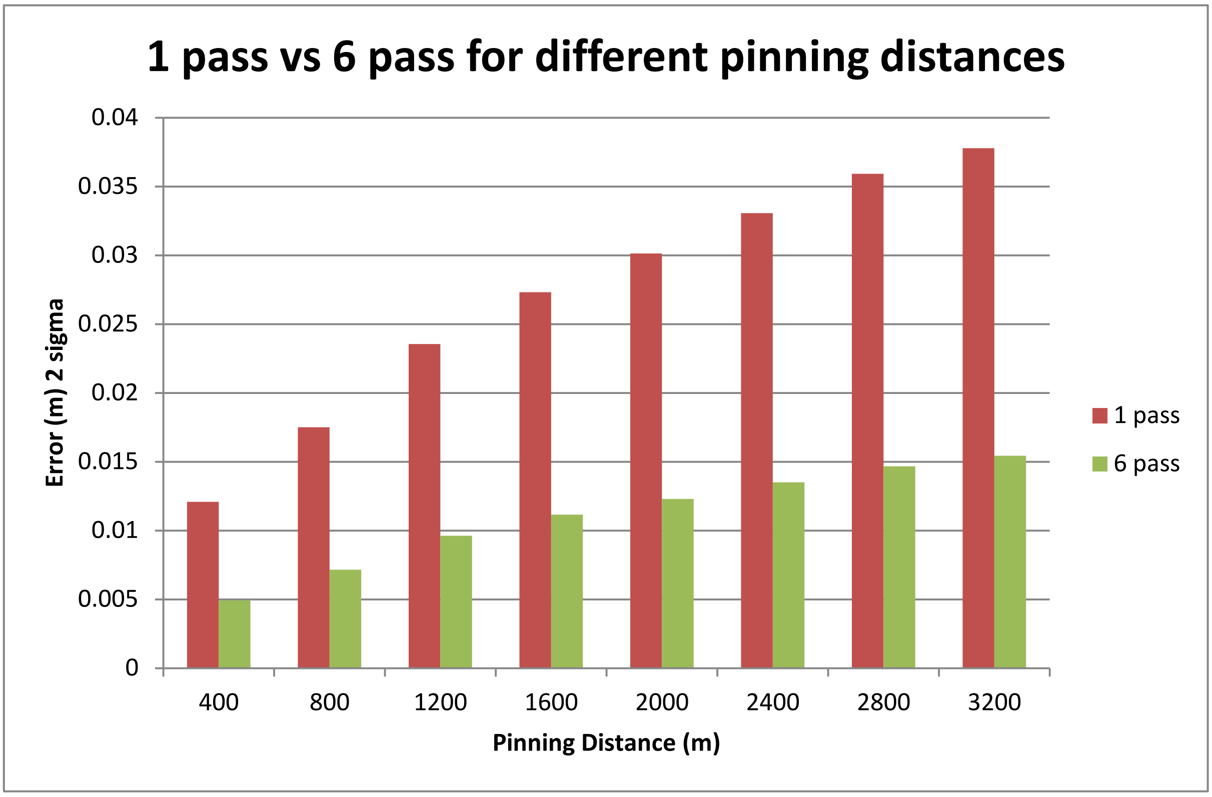

Figure 10: Standard deviation of height error (single-pass and multi-pass) using differing control station separation spacing.

6 CONCLUDING REMARKS

The Multi-Pass approach provides the solution MNG sought for Mobile Laser Scanning. Using the Multi-Pass approach, it is possible to:

- Work at traffic speed – there is no need to slow the working vehicle.
- Identify and correct for satellite drift and multipath.
- Minimise the amount of control required along the road corridor.
- Acquire a high-resolution, dense point cloud for identifying features – overcoming traffic blockages of targets.
- Build a portable system that can be mounted on a range of vehicles.

But most importantly:

- Maximise the accuracy that can be achieved by the system.

MLS is a 'young' technology that is improving with leaps and bounds. There are many exciting developments taking place all around the world that exploit the potential of the technology. MNG understands the importance of MLS and has a dedicated team working with MLS to stay up-to-date with hardware developments, further develop field methodologies, improve processing algorithms and create customised software solutions for our customers. The Multi-Pass approach is a fundamental building block upon which all of these developments take place.

ACKNOWLEDGEMENTS

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The Impact of Natural Disasters on the Cadastre

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ABSTRACT

Natural disasters are a global phenomenon that can strike without warning. Our growing population and urbanisation means that these impacts are an increasing dilemma that needs to be addressed as they have a significant economic, social, environmental and political impact on the community. The surveying and spatial information sector plays a critical role in not only recovering from natural disasters but also in building our resilience to such catastrophic events. Our economy is underpinned by property values that rely on the correct definition of cadastral boundaries. Unfortunately, cadastral boundaries are affected by natural disasters, either through the destruction of survey marks by bushfires, floods and tsunamis or movement of the actual ground in landslides, subsidence and earthquakes. The confusion and uncertainty that result from this constitute a major economic problem. The guarantee of ownership under Torrens title in Australia is a significant benefit that we have over other countries where substantial time has been spent re-establishing land ownership following a natural disaster. But Torrens title does not guarantee dimensions or areas, and we rely on the use of survey monuments to define our cadastral boundaries. The question arises that if we cannot rely on the monuments due to deformation or because they are simply now gone, what do we use? This presentation investigates how the governments and surveying professions in Japan, California and New Zealand have responded to the destruction of their cadastral boundaries following a variety of natural disasters. It looks at the processes they have put in place to ensure the resilience of this important infrastructure. It also examines how Australia has reacted to the impact of natural disasters in the past. After comparing the different approaches taken by each country, this presentation concludes by making a series of recommendations for our government and the surveying sector. If implemented, these will strengthen our cadastre so that in the event of a natural disaster we will have a robust model to reinstate cadastral boundaries consistently and with certainty. This presentation is the product of research funded by the 2011 NSW Surveyor General's International Fellowship in Surveying and Spatial Information.

KEYWORDS: *Natural disasters, cadastral boundaries, New Zealand, Japan, California*.

PRELIMINARY RECOMMENDATIONS FOR NSW

Traditionally, in Australia, recovery of the cadastre or cadastral marks has been undertaken by the surveying and spatial information profession on a largely volunteer basis. Two examples of this are the 2009 Victorian bushfires and the 2010/11 Queensland floods where groups of volunteer surveyors assisted in recovery efforts by locating and coordinating cadastral reference marks or physically remarking affected property boundaries. While these efforts are extremely kind and honourable, in our current climate of increased occurrences and severity of natural disasters they are not economically sustainable.

The key to being able to reinstate a cadastral boundary following a natural disaster is knowing with some certainty and accuracy where it was before the disaster occurred. Unfortunately, in NSW we cannot say that this is the current status quo. Our knowledge of existing cadastral boundaries varies significantly across the state due to a variety of reasons from the age and methods of surveys and plans to a variety of different datums and a lack of accurate state survey infrastructure in some areas.

Following research in Japan, California and New Zealand, a number of key factors were identified that require further investigation in order to increase our cadastre's resilience to the effect of natural disasters. The first of these is the need to continue to increase the density of our Continuously Operating Reference Station (CORS) network. As evidenced by overseas examples, in the event of a future earthquake, land subsidence or other land movement, a dense CORS network allows for the identification and monitoring of land movement and the determination of appropriate deformation parameters. The densification of the existing network would also support the further coordination of our passive control network and possibly open up possibilities for the use of Network Real Time Kinematic (NRTK) technology for cadastral boundary definition in the future.

The CORSnet-NSW network is unlikely to replace our existing passive control network, even if we were given the option in the future to use NRTK for cadastral boundary definition, and it will therefore always be critical state infrastructure. Presently the density and accuracy of our current network does not completely support our cadastral system as there are a significant number of marks in the ground that are not coordinated or connected to our cadastral fabric. If we ever want to move towards a system where every cadastral survey is on the one datum, then we need the infrastructure to support it. This idea is supported by the current thinking of Land Information New Zealand (LINZ), who continue to increase the density and accuracy of their passive control network while also supporting the densification of their CORS network.

While the author personally does not believe that a coordinated cadastre similar to that found in Japan will ever be feasible in NSW, we should be following the example of our New Zealand neighbours and create a survey accurate Digital Cadastral Database (DCDB) that includes not only cadastral boundaries but also our state survey control and all cadastral/reference marks. It is realised that this is a significant project that ideally would be funded by the government, realistically though it could be achieved by a combination of government and industry support. This could be realised through the adoption of LandXML for cadastral surveys and plans as it would allow us to build a survey accurate dataset over time. This would only work if all surveys were completed on the same datum, and for it to become economically feasible for the profession it needs to be an interactive database that allows surveyors to download existing datasets for their survey area. It is believed that this would be achievable through upgrades to the existing Survey Control Information Management System (SCIMS) and the Spatial Information Exchange (SIX) portal.

In conclusion, it appears evident that the NSW Government and the surveying and spatial information industry need to work together in order to develop an action plan on how the resilience of the cadastre to the impacts of natural disasters can be increased. Avoiding the issue or continuing with the status quo is not an acceptable alternative. Considering that within the past year NSW has suffered from both a number flood and fire events, we are neglecting our professional obligations if we do not begin protecting our critical survey infrastructure from such events.

PROJECT **THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE**

DATE 13-14 MARCH 2013 | CLIENT ASSOCIATION PUBLIC AUTHORITY SURVEYORS

RESEARCH GOALS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

1. The role of surveyors in natural disasters
2. **Surveying, boundary definition and marking in disaster affected areas**
3. Increasing the resilience of the cadastre
4. The role of surveying professional institutions

Japan

GREAT EAST JAPAN EARTHQUAKE & TSUNAMI
MIYAGI PREFECTURE

GREAT EAST JAPAN EARTHQUAKE & TSUNAMI
TSUNAMI BREACHING SEAWALL IN MIYAKO

GREAT EAST JAPAN EARTHQUAKE & TSUNAMI
SENDAI AIRPORT

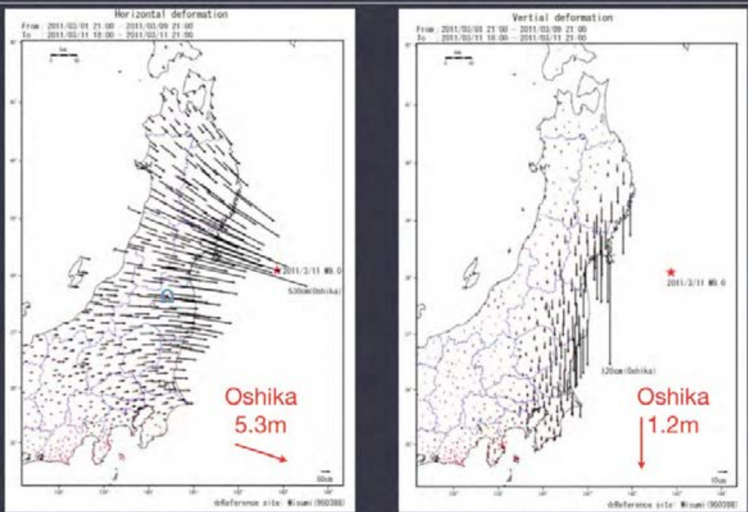
GREAT EAST JAPAN EARTHQUAKE & TSUNAMI

SOMA, FUKUSHIMA PREFECTURE

GREAT EAST JAPAN EARTHQUAKE

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

Date & Time	11/03/2011 14:46 (JST)
Epicenter	Off coast of Sanriku area
Depth	24km
Magnitude	9.0
Fault	length: 450km width: 200km
Tsunami Height	9.3m (limit of tidal gauge) >40m (field evidence)



GREAT EAST JAPAN EARTHQUAKE - LAND MOVEMENT

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

GSI - JAPANESE CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

Control Points in Japan (maintained by GSI)

Category	# of Stations	Sub-category	Average Interval
GNSS-based control stations (GEONET)	1,240		20 km
Triangulation Stations (horizontal)	109,074	1st order - 975 2nd order - 5,060 3rd order - 32,326 4th order - 70,713	25 km 8 km 4 km 1.5 km
Bench Marks (vertical)	18,239	fundamental - 86 1st order - 14,682 2nd order - 3,471	150 km 2 km 2 km
Total	128,553		(March 31, 2011)

GSI - ORIGIN OF THE JAPANESE CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* The Survey Act provides that all survey data should be relative to the origins of the horizontal and vertical control networks
* The official origin coordinates and height are published in the Order for Enforcement of the Survey Act
* The Great East Japan earthquake moved the origin monuments such that there was a noticeable difference between their actual coordinates/height and their legal published values. Therefore a revision of the published origin values was required

GSI - ORIGIN OF THE JAPANESE CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* One of the most critical decisions to be made was when to conduct the revision surveys following the Earthquake and Tsunami
  - A - "as soon as possible" to enable the quickest recovery possible as any delay in survey means a delay in national recovery
  - B - "stand by" and wait until subsequent ground movement has settled down to avoid needing future revisions and possible confusion
* Regulation of Public Survey Specification allows a maximum error of 2ppm between neighbouring stations
* Following mathematical modelling of slip it was decided that the new surveys could be conducted from the end of May 2011.

GSI - REVISION OF HORIZONTAL ORIGIN

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

1. Determine the coordinate of VLBI station Tsukuba as of May 24 2011

2. Carry out GNSS observations at Tsukuba and the Origin. This was supplemented by observations from surrounding GEONET stations

3. The coordinates of the stations were then calculated under the condition that the coordinate of the VLBI station Tsukuba is fixed

As a result of these observations the horizontal origin coordinate was shifted east by 27cm

GSI - REVISION OF VERTICAL ORIGIN

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

A precise differential levelling run (76km) was completed between the Aburatsubo Tidal Station and the Origin following the earthquake

This level run is completed annually and based on the assumptions of no long term sea level rise and no displacement at Aburatsubo caused by the earthquake they were able to calculate the new height of the Origin

As a result of these observations the vertical origin was shifted down by 2.4cm

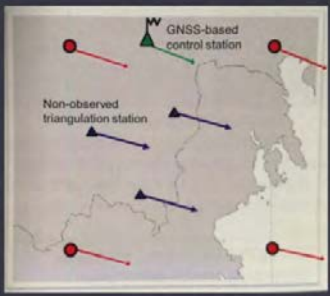
GSI - RE-ESTABLISHMENT OF CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* 364 affected GEONET coordinates were suspended on March 14
* 438 Revised GEONET coordinates were made available May 31
* Approx. 44,000 passive triangulation marks were affected
* Nearly 1900 of these were resurveyed using GNSS by 70 private contracted companies
* All processing of the adjustment was done internally at GSI
* Results were published on October 31

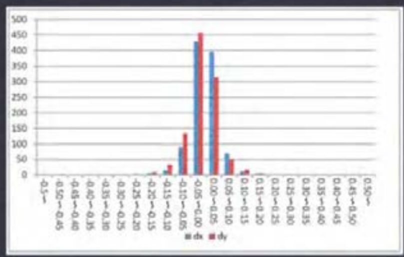
GSI - HORIZONTAL CORRECTION PARAMETERS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE



Correction parameters were calculated and determined for a 1km grid which was then applied to all other marks

Correction vectors at a further 1300 stations were then checked by comparison between calculated and observed coordinates



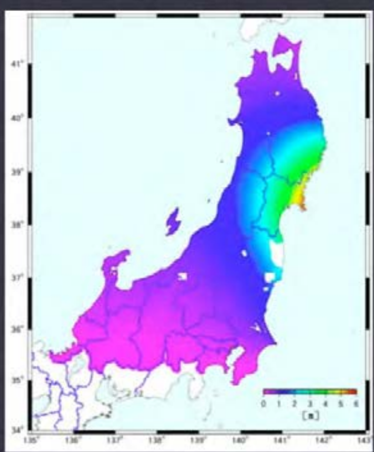
GSI - RE-ESTABLISHMENT OF CONTROL NETWORK

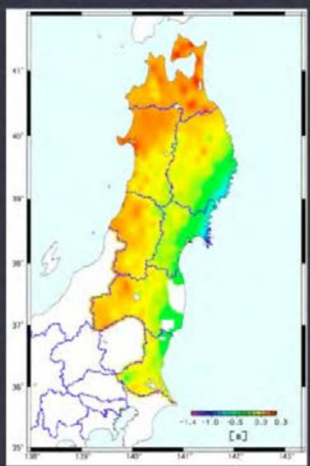
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- Unfortunately the parameters developed using GNSS surveys were not accurate enough to be applied for height corrections
- Approx. 1900 1st order bench marks along a 3660km levelling route were resurveyed using differential levelling
- The survey was completed by 24 private companies under contract
- All processing of the adjustment was done internally at GSI
- Results were published on October 31

GSI - HORIZONTAL & VERTICAL CORRECTION PARAMETERS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE





GSI - TOOLS FOR REVISION WITH CORRECTION PARAMETERS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- GSI developed software known as "PatchJGD" which can be downloaded from their homepage
- It contains all of the relevant correction parameter files so that they can be applied to all other control and boundary marks
- Revision of public survey data by these parameters is regarded as survey

MLIT - JAPANESE CADASTRE

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- The current cadastral system was introduced in 1951
- Approximately 50% of Japan is defined by cadastral survey which is based on a coordinated cadastre
- The Cadastre is the responsibility of each individual Municipal Government
- In normal circumstances the cost of cadastral surveys are the responsibility of the Government
  - 50% MLIT (National)
  - 25% Prefectures (State)
  - 25% Municipal Government (Local Council)
- Following the declaration of a natural disaster a special budget is developed and the National Government fund all recovery efforts

MLIT - ACCURACY OF CADASTRAL SURVEYS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- The Enforcement Order of the National Land Survey Law defines the required accuracies for cadastral surveys
  - 1 - 7cm in urban areas
  - ~25cm in paddy fields
  - ~100cm in mountain forests
- These accuracy requirements were not relaxed following the Great East Japan Earthquake
- Even though marks and monuments were destroyed as a result of the earthquake and tsunami, areas that were covered by cadastral survey had been digitised and coordinated. So although there may be no trace of the boundary on the ground they are able to re-establish the boundary based on the recorded or adjusted coordinates for the parcel

MINISTRY OF JUSTICE - LEGAL AFFAIRS BUREAU

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* Following the South Hyogo Earthquake of January 7 1995, where horizontal movement of the earth's crust was confirmed, the Ministry of Justice decided to take the following measure:

  "In cases where the land surface has moved horizontally over a large are due to the crust movement caused by an earthquake, land boundaries shall be handled as they have also moved relatively. In cases of soil movement (landslide etc) on a local land surface, land boundaries are handled as if they did not move"

* Land and House Investigators conducted the work on behalf of the Ministry to assess land parcel distortion
* Status investigation - 300m meshes were plotted over the affected areas and the 4 corners and center were assessed to judge whether the error was within the cadastrally allowable range.

HOUSE AND LAND INVESTIGATORS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* Block correction method
  - Where the status investigation reveals that several locations or parts of boundary points in a block have moved regularly, block points are observed to identify the boundary points in a block. Only the block points are to be surveyed and each boundary point in a block is to be corrected by such methods as a Helmert conversion
* Cadastral map regeneration method
  - Where the status investigation reveals that boundaries have moved irregularly, block points and boundary points are surveyed to identify the boundary points for correcting maps. This method requires the same load of work for standard cadastral survey, much more time and cost than the block correction method, but it is necessary to use this method for areas with significant boundary movement

JAPAN - RECOVERY

TOWN OF MINAMISANRIKU, MIYAGI PREFECTURE

JAPAN - RECOVERY

HARAMACHI THERMAL POWER PLANT, CITY OF MINAMISOMA, FUKUSHIMA PREFECTURE

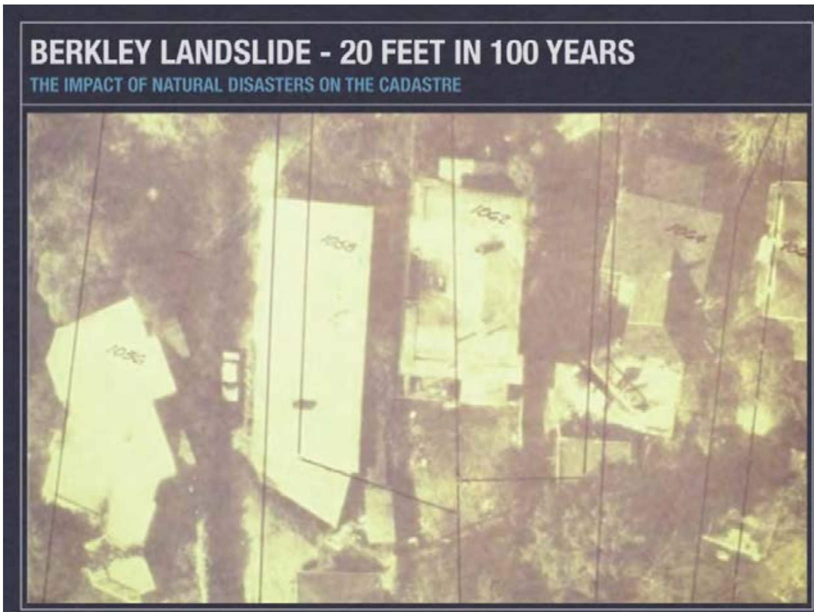
California

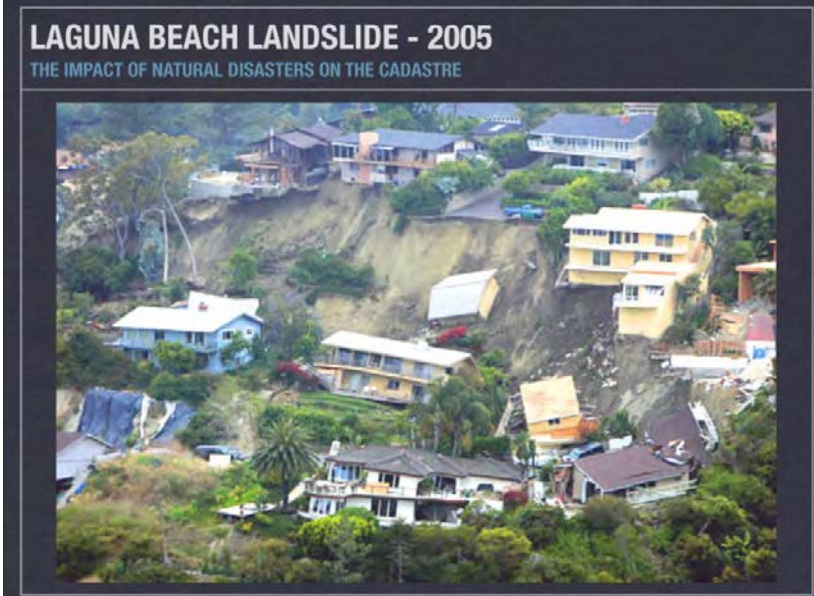
CALIFORNIAN CADASTRE - CULLEN EARTHQUAKE ACT

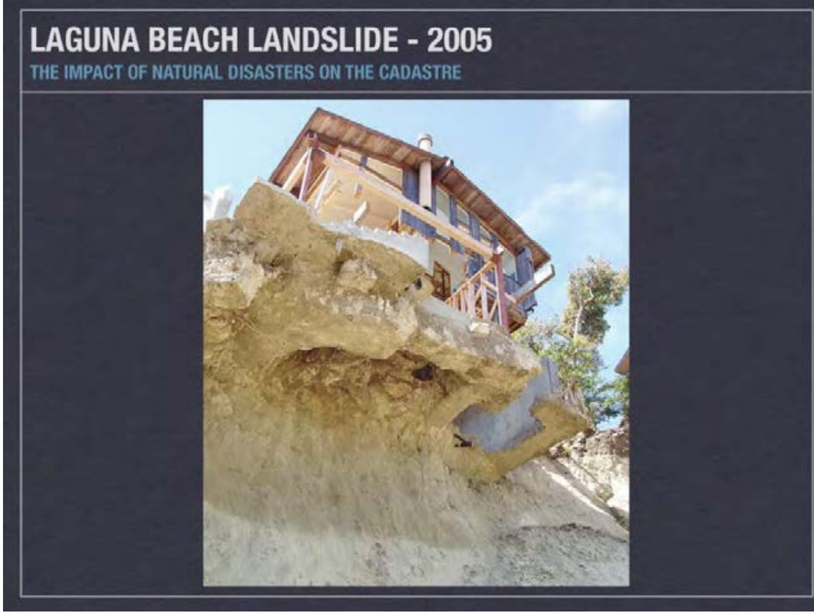
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- California Codes - Code of Civil Procedure Section 751.50

If the boundaries of land owned either by public or by private entities have been disturbed by earth movements such as, but not limited to, slides, subsidence, lateral or vertical displacements or similar disasters caused by man, or by earthquake or other acts of God, so that such lands are in a location different from that at which they were located prior to the disaster, an action in rem may be brought to equitable reestablish boundaries and quiet title to land within the boundaries so reestablished


BERKLEY LANDSLIDE - 20 FEET IN 100 YEARS
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

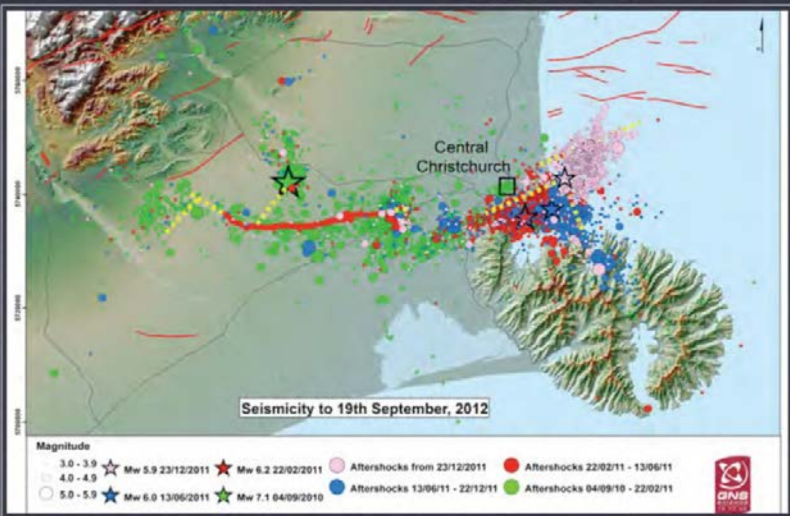

LAGUNA BEACH LANDSLIDE - 2005
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


LAGUNA BEACH LANDSLIDE - 2005
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

LAGUNA BEACH LANDSLIDE - 2005

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

New Zealand

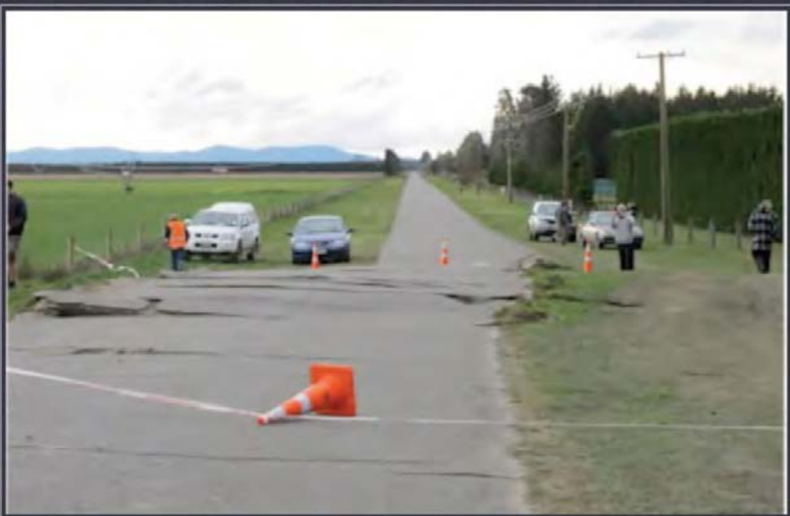


CANTERBURY EARTHQUAKES

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE



DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

ROLLESTON RAILWAY
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

CHRISTCHURCH CBD FEBRUARY 22 2011
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


REDCLIFF FEBRUARY 22 2011
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


BEFORE
AFTER
CHRISTCHURCH CATHEDRAL
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


CHRISTCHURCH CATHEDRAL - JULY 2012
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

NEW ZEALAND - CADASTRAL SYSTEM

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* The New Zealand cadastral system, like Australia, supports the Torrens title system with state guarantee of title
* Land Information New Zealand (LINZ) are the government body responsible for the cadastre
* Re-establishment of boundaries is based on the heirarchy of evidence in accordance with common law
* Monuments over measurements - where the original monuments are still in original position - given that that whole region has been affected by movement, what does that actually mean in practice?

NEW ZEALAND - CADASTRAL SYSTEM

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* Despite being a seismically active locality, prior to 2010 there had been no major earthquakes in New Zealand that significantly affected cadastral boundaries since the Hawke's Bay (Napier) earthquake in 1931
* No statue law or regulation for re-establishing boundaries affected by movement due to an earthquake
* Previous New Zealand post earthquake surveys were dealt with on a case by case basis as there were only a small number of properties affected and were in mostly rural localities

NEW ZEALAND - CADASTRAL SYSTEM

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* New Zealand has a semi-dynamic datum - New Zealand Geodetic Datum 2010 - which accommodates the effect of crustal motion - deformation patches
* New Zealand has a survey accurate Digital Cadastral Database - LandonLine - it connects the geodetic control, cadastral boundaries and survey monuments - based on LandXML data sets - it is compulsory for all cadastral survey data to be submitted as LandXML via LandonLine
* 70% of land parcels (principally urban and peri urban areas) are accurate to within 0.1m - the remaining 30% are usually within 1m and government funding is currently working on improving this

RULES FOR CADASTRAL SURVEY (CE) 2010

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* **Category 1** - Boundaries unaffected by the earthquake
  - No change, the *Rules for Cadastral Survey 2010* apply
* **Category 2** - Boundaries affected by block shifts with relatively uniform movement
  - Parcel boundaries are expected to have maintained relativity with the adjoining parcel boundaries and with local witness and cadastral survey network marks
* **Category 3** - Boundaries affected by deep-seated distortion which has caused boundary points to move but has retained a straight line between them
  - Boundaries affected by deep-seated distortion may change the shape of the parcel but not to the extent that it requires the creation of new boundary angles.

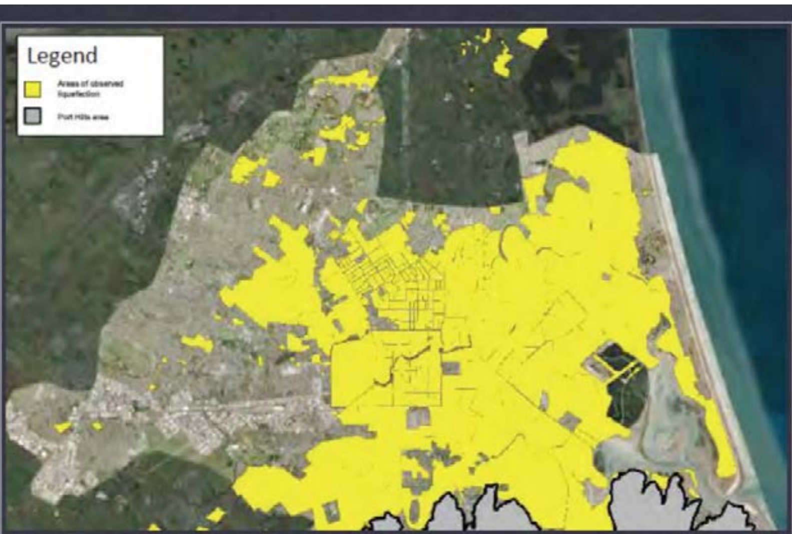
RULES FOR CADASTRAL SURVEY (CE) 2010

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* **Category 4** - Boundaries affected by distortion or shearing along the fault rupture
  - Boundaries subject to distortion or shear movement along the fault rupture may require the creation of new boundary angles
* **Category 5** - Boundaries in areas of localised surface layer movement due to liquefaction of soils or landslip, and may include block shift
  - Boundary points and related boundaries affected by shallow movement of the surface must be reinstated in their original position relative to survey marks that retain the same horizontal relationship to each other as they held before the Darfield earthquake

LAND AFFECTED BY LIQUEFACTION SEPTEMBER 2010

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE



LAND AFFECTED BY LIQUEFACTION FEBRUARY 2011
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

LIQUEFACTION
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

LIQUEFACTION
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

LIQUEFACTION

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

LIQUEFACTION - SEPARATION OF LAND & IMPROVEMENTS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

EFFECT OF LIQUEFACTION ON BOUNDARIES

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

DEFINING BOUNDARIES POST EARTHQUAKE

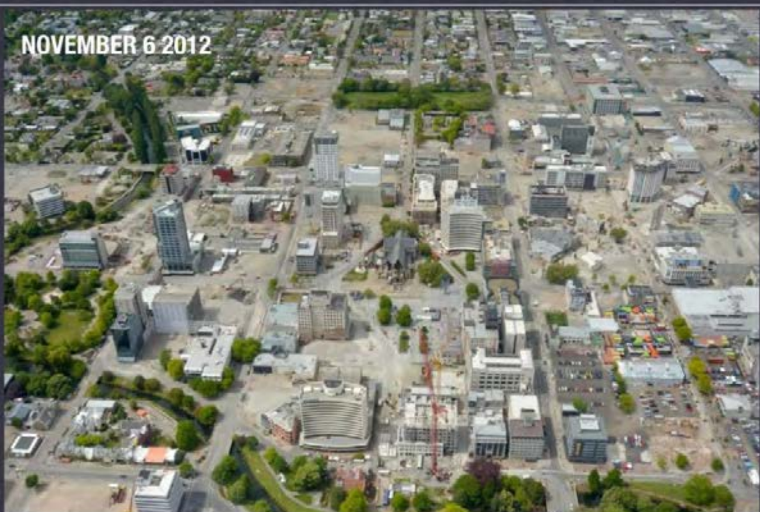
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- It is believed that approximately 50 properties are affected by the Greendale Fault (category 4)
  - To date only one redefinition survey has been received and registered (DP 440446)
- Despite the rules clearly stating that boundaries affected by shallow movement (liquefaction) must be placed back in their original (ie pre earthquake) position, in reality this is not what is occurring
  - Each case is treated on an individual basis based on local disturbed marks, occupations and the Surveyors professional opinion
  - While this makes sense it is not strictly in accordance with the current applicable legislation

DEFINING BOUNDARIES POST EARTHQUAKE

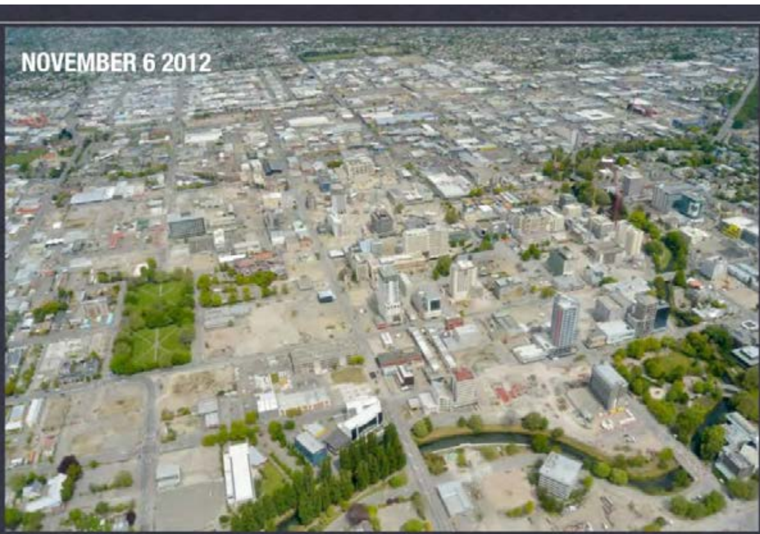
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- The Rules for Cadastral Survey (Canterbury Earthquake) 2010 expired on December 31 2012 - so the Rules for Cadastral Survey 2010 (Amended 2012) have been introduced
  - Rule 18 - Boundaries Affected by Ground Movement
  - The 5 individual categories have not been retained and rules relating to shallow surface movement have been removed as it is believed that common law covers this aspect adequately
  - The major benefit is that it allows the rules developed following the Canterbury earthquakes to be applied across the country following any future earthquakes.



NEW ZEALAND - RECOVERY

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE



NEW ZEALAND - RECOVERY

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

NEW ZEALAND - RECOVERY

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

Want to see how Christchurch is recovering?

FIG WW 2016 CHRISTCHURCH NEW ZEALAND

RECOMMENDATIONS FOR NSW

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* Increase the density of our CORSnet NSW
* Increase the density & accuracy of our passive control network
* The creation of a survey accurate Digital Cadastral DataBase (DCDB)
* Inclusion of cadastral survey/reference marks in the SCIMS and further development of the SIX portal
* The use of GNSS (RTK) technology for cadastral boundary definition???

List of Attendees

(at 19 February 2013)

Surname	First	Organisation
Addison	Rob	Eurobodalla Shire Council
Anderson	Lachlan	NSW Public Works
Andrew	Usher	Usher & Company
Athorn	Mick	RailCorp
Atkinson	Jack	Kleven Spain
Avery	Mark	Ausgrid
Babic	Ivan	3D Surveying
Baitch	George	Formerly LPI
Barrett	Peter	P G J Barrett
Barrington	David	Sole Practitioner & Ultimo TAFE
Begg	Don	Tattersall Lander
Beljanski	Steven	Clarke & Di Pauli
Bennett	Anthony	Usher & Company
Bennett	Neil	Office of Environment
Berrisford	Simon	Usher & Company
Birse	Bob	Crown Lands DT&I
Birtles	Terry	
Blomfield	David	Wagga Wagga City Council
Bosloper	Case	Formerly LPI
Bowler	Geoff	Cowra Council
Brady	Alan	University of Technology Sydney
Brown	David	RailCorp
Brown	Jeffrey	Vekta - Yass Office
Brown	Kevin	NSW Office of Water
Bruhn	Norm	RailCorp
Burge	Andrew	Whelans Insites
Burgin	Peter	Ultimate Positioning Group
Burke	Adam	Position Partners
Burke	David	Roads & Maritime Services
Burrows	Allan	Conway Burrows & Hancock
Burrridge	Alex	Aurecon
Burton	David	Aspect Development
Butler	Mark	Parsons Brinckerhoff
Calvin	Grant	Greater Taree City Council
Campbell	Bill	LAND Data Surveys
Casey	Tom	Casey Surveying
Catzikiris	Jamie	Upper Hunter Shire Council
Chidzey	Ross	RailCorp
Clarke	Matthew	Lynton Surveys
Clifford	Gary	RailCorp
Collyer	Greg	Land & Property Information
Colman	Chris	Inline Surveys
Connolly	Paul	Roads & Maritime Services
Conway	Chris	Conway Burrows & Hancock
Cornish	Peter	Cardno Hard & Forester
Corry	Paul	City of Sydney
Cousin	Ian	Endeavour Energy
Cox	Glenn	Lockley Land Title Solution
Currie	Bill	Whelans Insites
Davis	Wayne	City of Sydney
Dawson	John	Geoscience Australia
de Belin	Fred	City of Ryde
de Witt	Bernie	de Witt Consulting
Donaldson	Barry	Wagga Wagga City Council

Dunstall	Bill	CDE Design Solutions
Dunstall	Stephen	Land & Property Information
Durtanovich	Jim	City of Sydney
Eckels	Rod	McMullen Nolan Group
Edwards	Joel	Land & Property Information
Ellerton	Graeme	RailCorp
Ellis	Dick	Land & Property Information
Emmerick	Chris	CR Kennedy & Company
Evans	Gavin	ACT Environmt & Sustainable Developmt
Evans	John	Port Stephens Council
Fattore	Carlo	RailCorp
Feneney	Steve	City of Sydney
Fenwick	Wayne	Crown Lands DT&I
Ferguson	Marc	Extra Dimension Solutions (12d)
Forsyth	Matt	MPF Surveying
Friend	Matthew	RailCorp
Gaggin	Graeme	RailCorp
Gardner	Les	Land & Property Information
Gilmour	Raymond	Roads & Maritime Services
Gordon	Alan	Roads & Maritime Services
Gordon	Mark	Roads & Maritime Services
Gowans	Nicholas	Land & Property Information
Gregor	John	GPS Australia
Griffiths	Bob	Consult Survey
Grinter	Thomas	Land & Property Information
Groves	Glendyn	Eslers
Haasdyk	Joel	Land & Property Information
Hammer	Murray	RailCorp
Hansen	Ross	Parramatta City Council
Harcombe	Paul	Land & Property Information
Harper	Ian	Geodata Australia
Hartzenberg	Pierre	Cardno Hard & Forester
Harvey	Malcolm	Theiss
Headon	David	
Hern	Greg	Newcastle City Council
Higgs	Charlie	AAM
Hine	Simon	Voerman & Ratsep
Hirst	Bill	ACT Surveyor-General
House	Matilda	Elder of the Ngambri-Ngunnawal People
Howe	Graham	Graham F Howe
Hurcum	Bert	Crown Lands DT&I
Ingham	Richard	CR Kennedy & Company
Janssen	Volker	Land & Property Information
Job	David	Land & Property Information
Jones	Ian	RailCorp
Keats	Garry	
Kelly	David	Ballina Shire
Kenny	Scott	Roads & Maritime Services
Kent	Brian	Kent Gilbert & Assoc.
Kent	Ryan	Position Partners
Kilpatrick	Grant	President, APAS
Kinlyside	Doug	Land & Property Information
Kittell	Brett	Pulver Cooper & Blackley
Kleven	John	Kleven Spain
Kocoski	Michael	Blue Mountains City Council
Lahood	Robert	Land & Property Information
Lander	Bob	Tattersall Lander
Lang	David	RailCorp
Langdon	Rob	Greater Taree City Council
Leach	Chris	Leach Steger Surveyors

Leggatt	Geoff	Hornsby Shire Council
Lenton	Geoff	Roads & Maritime Services
Leslie	Stuart	Leslie & Thompson
Lewsam	Darren	Newcastle City Council
Liang	Chia	Sydney Catchment Authority
Liddell	Mitchell	Tweed Shire Council
Livingstone	Greg	City of Sydney
Lock	Bob	Land & Property Information
London	Michael	Land & Property Information
Long	Adam	Transgrid
Longhurst	Stephen	City of Sydney
Love	Tony	Roads & Maritime Services
Lutton	Col	Tweed Shire Council
Maguire	Gary	President, SSSI
Markham	Bob	Transgrid
McAnespie	Andrew	Department of Planning and Infrastructure
McElroy	Simon	Land & Property Information
McIlwaine	Greg	Retired - NSW Public Works
McNamara	Andrew	Moultrie Survey
McNiven	Scott	Scott D McNiven & Assoc
Mitchell	Geoff	Geoff Mitchell Surveys
Mitchell	Stephen	Mitchell Land Surveyors
Mocicka	Andrej	Listech
Mooney	Des	NSW Surveyor-General
Moss	Owen	Land & Property Information
Moss	Peter	Roads & Maritime Services
Moussa	Otre	Dial Before You Dig NSW/ACT
Moylan	Bess	Illawarra Institute TAFENSW
Naebkhil	Sam	RailCorp
Najjar	George	G & R Surveying Services
Nedelkovski	Peter	Land & Property Information
Nilon	Peter	RailCorp
Nix	Malcolm	Newcastle City Council
Noakes	Steve	LAND Data Surveys
Nolan	John	McMullen Nolan Group
O'Kane	Peter	Land & Property Information
Ortiger	David	Voerman & Ratsep
Panya	Kit	Roads & Maritime Services
Papas	Peter	Peter Papas & Assoc.
Paterson	Graeme	Blue Mountains City Council
Paton	Justine	Crown Lands DT&I
Peasley	Ross	Boardman Peasley
Petrow	Alex	ACT Environmt & Sustainable Developmt
Pettit	Greg	Moultrie Survey
Plokstys	Richard	RailCorp
Poidevin	Michael	Shoalhaven City Council
Porter	Neil	State Water Corporation
Puiu	Dominic	Dial Before You Dig NSW/ACT
Ragen	Peter	Crown Lands DT&I
Rawling	Steve	Sydney Catchment Authority
Rees	David	RailCorp
Riddell	Matthew	Ausgrid
Rigelsford	Andrew	Aurecon
Rizos	Chris	University of NSW
Roberts	Craig	University of NSW
Robinson	Stephen	Roads & Maritime Services
Robson	Daren	RPS Australia Asia Pacific
Rose	Tony	Tony Rose Surveying Pty Ltd
Rumble	David	Retired - Transgrid
Sandy	Craig	ESRI Australia

Sledge	David	Eurobodalla Shire Council
Sloan	David	LAND Data Surveys
Smith	Anthony	RailCorp
Smith	Darryl	NSW Public Works
Songberg	Geoff	Crown Lands DT&I
Spain	Andrew	Kleven Spain
Spiteri	Michael	Bathurst Regional Council
Stankiewicz	Czeslaw	Parramatta City Council
Stapleton	Mike	LAND Data Surveys
Stephenson	Brad	GlobalPOS
Stewart	Graeme	President, ISNSW
Stivano	Paul	Aurecon Australia
Stone	David	LAND Data Surveys
Sussanna	Vittorio	Land & Property Information
Sutton	Stephen	Blacktown City Council
Swan	Paul	TAFE
Thomas	Warren	Government Property NSW
Thompson	Kevin	Crown Lands DT&I
Tierney	John	Formerly Transgrid
Tucker	Brian	University of Technology Sydney
Tweedie	Graham	Aurecon
Underwood	Narelle	Roads & Maritime Services
Veersema	Adam	Usher & Company
Vorster	Ben	McMullen Nolan Group
Wadley	Scott	LCPL
Watt	Simon	City of Ryde
Wearne	Rodger	Transgrid
Webb	David	Transgrid
Webb	Richard	Richard Webb Surveying
Wells	Phil	Newcastle City Council
White	Craig	Bengalla Mining Company
White	Doug	GPS Australia
Wilkinson	Paul	RailCorp
Williams	Mark	RailCorp
Wirth	Graham	Extra Dimension Solutions (12d)
Wood	Geoff	Geoff Wood Surveyors
Wood	Keith	Keith H Wood Surveys
Wormald	Geoff	Land & Property Information
Zygmunt	Marcin	SSSI