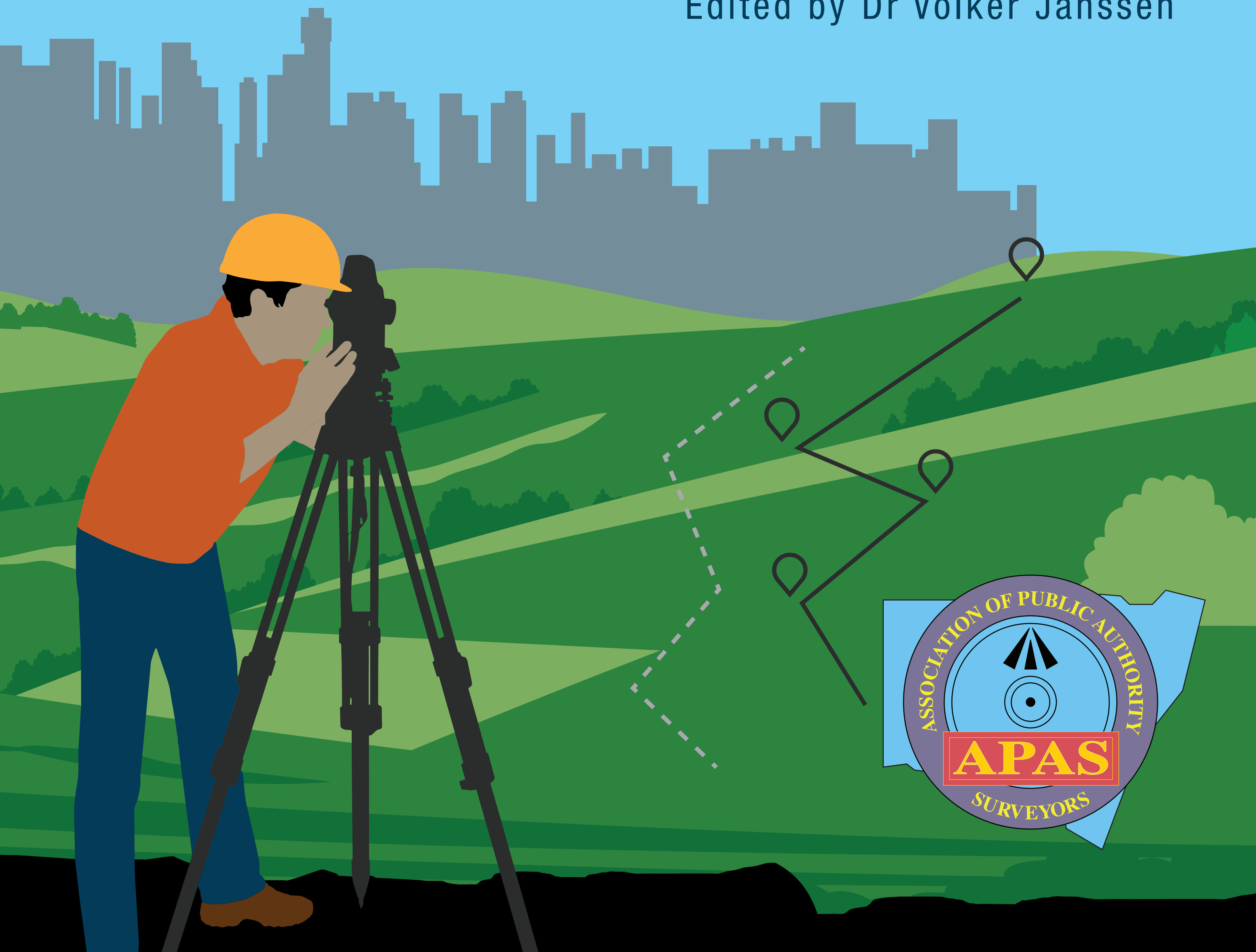
PUSHING THE BOUNDARIES

Proceedings of the

APAS2024 CONFERENCE

HYATT HOTEL, CANBERRA, 18–20 MARCH 2024

Edited by Dr Volker Janssen



Presented by the
Association of Public Authority Surveyors
www.apas.org.au

Association of Public Authority Surveyors (NSW) Inc.

This conference is proudly sponsored by

These proceedings are proudly sponsored by

Table of Contents

Office Bearers for 2023/2024

Association of Public Authority Surveyors Office Bearers for 2023/2024:

President:	Nigel Petersen (Transport for NSW)
Vice President:	Micheal Kocoski (Blue Mountains City Council)
Secretary:	Wayne Fenwick (DCS Spatial Services)
Treasurer:	Joel Haasdyk (DCS Spatial Services)
Committee:	Alex Burridge (Sydney Trains)
	Alecia Goodrich (Transport for NSW)
	Don Urquhart (City of Sydney)
Past President:	Jarad Cannings (Public Works Advisory)
Publications Officer:	Dr Volker Janssen (DCS Spatial Services)
Conference Manager:	Micheal Kocoski (Blue Mountains City Council)
ISNSW Representative:	Micheal Kocoski (Blue Mountains City Council)
Public Officer:	Wayne Fenwick (DCS Spatial Services)

Editorial

These proceedings contain the papers presented at the Association of Public Authority Surveyors Conference (APAS2024), held in Canberra, ACT, Australia, on 18-20 March 2024. Papers were not peer-reviewed but have been subject to changes made by the Editor. The Editor would like to thank all authors for their contributions covering a wide range of topics relevant to the surveying and spatial information community, thus ensuring an exciting and informative conference.

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

Janssen V. (2024) Understanding the RINEX format, *Proceedings of Association of Public Authority Surveyors Conference (APAS2024)*, Canberra, Australia, 18-20 March, 3-18.

APAS is not responsible for any statements made or opinions expressed in the papers included in these proceedings.

DCS Spatial Services, a unit of the NSW Department of Customer Service (DCS), is gratefully acknowledged for providing the front cover artwork and producing these proceedings. The Canberra Convention Bureau is gratefully acknowledged for sponsoring this conference. The APAS committee is thanked for their hard work in organising this conference.

Dr Volker Janssen
APAS Publications Officer, Program Chair and Editor
DCS Spatial Services
NSW Department of Customer Service
Publications@apas.org.au

Understanding the RINEX Format

Volker Janssen
DCS Spatial Services
NSW Department of Customer Service
Volker.Janssen@customerservice.nsw.gov.au

ABSTRACT

The Receiver Independent Exchange (RINEX) format was initially developed by the Astronomical Institute of the University of Bern, Switzerland, in the late 1980s. It has since become the international standard for the storage and exchange of Global Navigation Satellite System (GNSS) data, not only enabling interoperability between receiver brands and processing software packages but also the generation of many valuable products and services to the GNSS user community by the International GNSS Service (IGS). RINEX files are universally used by international organisations, academia, national organisations, all levels of government and private industry. Consequently, users need to understand the contents and format of these files. Focussing on GNSS observation files, this paper provides a brief history of the RINEX format and outlines examples of recent RINEX format versions. It discusses the editing of RINEX observation files and how GNSS data contributes to the datum modernisation efforts in NSW. This also includes the requirements for successful industry-observed AUSPOS datasets to be submitted to DCS Spatial Services for the maintenance of the NSW survey control network and the timely update of survey information in the Survey Control Information Management System (SCIMS).

KEYWORDS: *RINEX, GNSS, metadata, AUSPOS, datum modernisation*.

1 INTRODUCTION

The Receiver Independent Exchange (RINEX) format is the international standard for the storage and exchange of Global Navigation Satellite System (GNSS) data, enabling interoperability between receiver brands and post-processing software packages. It allows efficient and unambiguous archiving of GNSS data and associated metadata in one place (in a human-readable form), while also facilitating the easy transfer and distribution of such data, independent of the equipment used to collect it and the engine employed for data processing.

RINEX files are commonly used by international organisations (e.g. the International GNSS Service, IGS), academia, national organisations (e.g. Geoscience Australia), state government, local government and private surveying companies. Online processing services, such as Geoscience Australia's free online Global Positioning System (GPS) processing service, AUSPOS (GA, 2024), and the CSRS-PPP online Precise Point Positioning (PPP) service provided by Natural Resources Canada (NRCan, 2024), require the user to submit data in RINEX format. Consequently, it is important that users understand the contents and format of these files.

DCS Spatial Services, a unit of the NSW Department of Customer Service (DCS), is responsible for the establishment, maintenance and improvement of the state's survey control network, which comprises more than 250,000 survey marks on public record made available to users via the Survey Control Information Management System (SCIMS). The backbone of the NSW survey control network is provided by CORSnet-NSW, Australia's largest state-owned and operated GNSS Continuously Operating Reference Station (CORS) network. CORSnet-NSW currently consists of 209 stations, providing fundamental positioning infrastructure that is authoritative, accurate, reliable and easy-to-use for a wide range of applications (e.g. Janssen et al., 2016; DCS Spatial Services, 2024a). DCS Spatial Services uses RINEX files in providing services to its customers and the broader surveying profession as well as interacting with federal counterparts to support national initiatives.

This paper provides a brief history of the RINEX format and outlines examples of recent RINEX format versions. It then discusses the editing of RINEX observation files and how GNSS data contributes to datum modernisation in NSW. This also includes the requirements for successful industry-observed AUSPOS datasets to be submitted to DCS Spatial Services for the maintenance of the NSW survey control network and the timely update of survey information in SCIMS.

2 A BRIEF HISTORY OF RINEX

All manufacturers store raw GNSS (and most other survey instrument) data in proprietary, binary (non-human readable) data formats that are designed to be compact, optimise specific observations, enhance performance with their own algorithms and software modules (or complete software suites) and that lock users into their brand. As such, swapping raw survey data between brands was never intended. That was until RINEX was invented.

Initially, the RINEX format was developed by the Astronomical Institute of the University of Bern, Switzerland, to facilitate the easy exchange of GPS data to be collected during the first large European GPS campaign, EUREF89, which involved more than 60 GPS receivers of four different manufacturers (Gurtner et al., 1989). It defined three different file types: observation data file, navigation message file and meteorological data file. The reader is encouraged to appreciate the complexity and delicacy of negotiations and confidence that was entrusted to this organisation to initially gain access, and then continued access over the decades, to the proprietary Intellectual Property (IP) of each of the major manufacturers and the very idea of championing interoperability.

Each RINEX file consisted of a header section containing metadata related to the station occupied and the equipment used, followed by a main body with the actual data. The files were designed to have a maximum line length of 80 characters, written in American Standard Code for Information Interchange (ASCII) to enable humans to read (and edit) the data and guarantee an easy exchange between different computer systems. The cost of being human-readable is that RINEX files are always larger in size than the raw format files. The observed GPS data included the carrier-phase measurement on one or two frequencies, the pseudo-range (code) measurement, the Doppler measurement, the signal strength and the observation time.

Through the use of the RINEX format, it was possible to combine data observed by a multitude of receiver brands and models in order to be processed together. Over many years, and under the umbrella of the IGS, the RINEX format has since been modified, expanded and improved to allow multi-GNSS data to be handled, thus becoming the international standard used for the transfer, archival and distribution of GNSS data by the IGS and countless other users in the

GNSS community worldwide (IGS, 2024a). For example, this has resulted in the computation of the ever-improving International Terrestrial Reference Frame (ITRF – for the latest ITRF2020, see Altamimi et al., 2023). Based on the collation and processing of globally collected GNSS data, the IGS provides a wide range of valuable products to the GNSS user community, including precise satellite orbits and clocks, terrestrial reference frame products (e.g. station positions and earth rotation parameters) and global ionospheric maps (IGS, 2024b). Without RINEX, this collaboration and its benefits, along with open, regional CORS networks such as CORSnet-NSW, would have been impossible. The alternative would have been for each manufacturer to build and operate their own closed proprietary system. Understandably, the costs would have been prohibitive.

In the mid-1990s, the success of the RINEX format spawned a spin-off: the Solution Independent Exchange (SINEX) format, which is used by the geodetic community to store and transfer solutions of various parameters derived in various types of analysis (e.g. AUSPOS solutions containing more detailed information for advanced users). This was followed by a family of other RINEX-like file formats (IGS, 2024a) that are mainly used by the IGS, including exchange formats for satellite and receiver clock offsets determined by processing data of a GNSS network, for Space-Based Augmentation System (SBAS) broadcast data files, for ionosphere models determined by processing data of a GNSS network (IONEX), and for phase centre variations of geodetic GNSS antennas (ANTEX).

To date, the following four versions of RINEX have been developed and published (Gini, 2023):

- The original RINEX version 1 was presented at and accepted by the 5th International Geodetic Symposium on Satellite Positioning in Las Cruces, New Mexico, in 1989.
- RINEX version 2 was presented at and accepted by the 2nd International Symposium of Precise Positioning with the Global Positioning System in Ottawa, Canada, in 1990. It mainly added the possibility to include tracking data from different satellite systems (i.e. GLONASS, SBAS). Over time, it was modified via several sub-versions, culminating in version 2.11.
- RINEX version 3 was developed in the early 2000s and initially released in 2007 to support multi-GNSS and clearly identify the tracking modes of each of the observations by introducing 3-character observation codes for all GNSS constellations. Over time, it was modified via several sub-versions, culminating in version 3.05.
- RINEX version 4 was released in 2021 as a necessary step to support the modern multi-GNSS navigation messages by introducing and defining navigation 'data records' to hold both individual satellite navigation messages, constellation-wide parameters and global parameters as transmitted by the different GNSS constellations. It has since been updated to version 4.01.

3 EXAMPLES OF RECENT RINEX FORMAT VERSIONS

While it is recognised that the RINEX format encompasses observation data, navigation data and meteorological data, along with extensions such as satellite and receiver clock data and SBAS broadcast data files, this paper focuses on RINEX observation files as these are the most important for surveyors in practice (and the most likely to be edited). Apart from using the broadcast ephemeris data collected by their own receiver, surveyors can easily obtain precise orbit files from various sources if required (e.g. via IGS, 2024b), and the other files are generally not used in common surveying applications.

3.1 RINEX 2.11

Following several revisions for improvement and clarification, RINEX 2.11 (Gurtner and Estey, 2012) is the last official RINEX version 2 format. Its major difference compared to the original RINEX version 1 format is that it caters for tracking data from different satellite systems in addition to GPS. This format has been used for archiving AUSPOS datasets by DCS Spatial Services for inclusion into the GDA2020 state adjustment (see section 5.1), partly because AUSPOS remains GPS-only at present (Janssen and McElroy, 2022). However, a move to RINEX 3.05, along with optimising internal workflows, is imminent.

The RINEX file name must not contain any spaces, parentheses or symbols. It is beneficial to use the international RINEX 2.11 file naming convention XXXXDDDS.YYO consisting of 8 characters followed by a 3-character extension, where XXXX is a 4-character site name, DDD is the day of year (i.e. 001 to 365, or 366 during a leap year), S is the session identifier (i.e. 0 to 9, or A to X indicating the first observation epoch's hour of the day with A = 0 hours and X = 23 hours), YY is the 2-digit year (i.e. 24 for the year 2024) and the letter O indicates that this is an observation file.

RINEX file name extensions are sometimes further refined to indicate the type of compression that may be used to reduce the ASCII file size. Hatanaka (2008) developed a compression scheme and related software tools that take advantage of the structure of the RINEX observation data by forming higher-order differences in time between observations of the same type and satellite (indicated by the extension .YYd). This compressed ASCII file is then often compressed again using standard compression programs, e.g. yielding a UNIX-compressed (.YYd.Z) or gzip-compressed (.YYd.gz) Hatanaka RINEX file.

The RINEX file consists of a header section (including mandatory and optional records) followed by a data section and ends with a blank line, each row being a maximum of 80 characters long. A single RINEX file should only include a single occupation on a single mark. The header section contains information for the entire file, including mandatory header labels in columns 61-80 for each line in the header, which must appear exactly as stipulated. The header information must also appear in the correct columns to be valid, e.g. antenna information and antenna height. This is of particular importance when the RINEX header is edited (see section 4).

Figure 1 shows an example of a typical RINEX 2.11 header. It includes the following information:

- Line 1: RINEX version and statement that this is an observation file with mixed GNSS data (e.g. as opposed to GPS-only).
- Line 2: Program used to generate the RINEX file, who ran it (here blank) and when it was run.
- Line 3-4: Comments (can be placed anywhere between the first and last line in the header).
- Line 5: Marker name, in this case the 4-character ID issued to NSW by Geoscience Australia.
- Line 6: Marker number, here the SCIMS number.
- Line 7: Observer and agency, here NSW (i.e. DCS Spatial Services).

- Line 8: Receiver serial number, receiver type and firmware version.
- Line 9: Antenna serial number (for integrated antennas the same as the receiver serial number) and antenna type (using the IGS naming convention).
- Line 10: Approximate site position in WGS84 Cartesian coordinates (X, Y, Z).
- Line 11: Antenna height (measured vertically between ground mark and Antenna Reference Point, ARP) and any horizontal offset from the mark (i.e. small horizontal eccentricities of the ARP to the marker, which are typically zero for all but some scientific applications).
- Line 12: Wavelength factor for the L1 and L2 frequency, in this case indicating full cycle ambiguities for both frequencies.
- Line 13: Number and types of observations, in this case L1, L2, C1, P2, S1, S2 – i.e. carrier phase measurements, code measurements and signal strengths on the L1 and L2 frequency, respectively.
- Line 14: Sampling interval, in this case 30 seconds.
- Line 15-21: Comments, here including the name of the raw binary data file.
- Line 22: Time of first observation epoch, here 00:37:30 hours (GPS time) on 1 June 2021.
- Line 23: Number of leap seconds between GPS time and UTC, in this case 18. GPS time started at 00:00:00 UTC (midnight) on 6 January 1980 (i.e. Sunday morning). Since then, several leap seconds have been introduced to UTC (but not GPS time), currently resulting in GPS time being 18 seconds ahead of UTC.
- Line 24: End of RINEX header indicator.

```
 1      2.11           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
 2 teqc  2016Nov7                          20210617 05:02:57UTCPGM / RUN BY / DATE
 3 Linux2.6.32-279.el6.x86_64|x86_64|gcc|Win64-MinGW64|=       COMMENT
 4 BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION       COMMENT
 5 48DE                                                        MARKER NAME
 6 PM183662                                                    MARKER NUMBER
 7 NSW                 NSW                                     OBSERVER / AGENCY
 8 1516405             LEICA GS15          8.00/7.500          REC # / TYPE / VERS
 9 1516405             LEIGS15.R2      NONE                    ANT # / TYPE
10  -4585969.9235  2736510.8223 -3477269.8581                  APPROX POSITION XYZ
11         1.5190        0.0000        0.0000                  ANTENNA: DELTA H/E/N
12      1     1                                                WAVELENGTH FACT L1/2
13      6    L1    L2    C1    P2    S1    S2                  # / TYPES OF OBSERV
14     30.0000                                                 INTERVAL
15 Source: 6405_0601_103528.m00                                COMMENT
16 Forced Modulo Decimation to 30 seconds                      COMMENT
17 DefaultJobName                                              COMMENT
18 DefaultUserDiscription                                      COMMENT
19 Project creator:                                            COMMENT
20  SNR is mapped to RINEX snr flag value [0-9]                COMMENT
21   L1 & L2: min(max(int(snr_dBHz/6), 0), 9)                  COMMENT
22   2021     6     1     0    37   30.0000000     GPS         TIME OF FIRST OBS
23     18                                                      LEAP SECONDS
24                                                             END OF HEADER
```

Figure 1: Typical RINEX 2.11 header.

Figure 2 shows a typical RINEX 2.11 observation data block. It contains the following information:

- Line 25-26: Date and time of the observation epoch (receiver time of the received signals) in the format year, month, day, hours, minutes, seconds (here 00:37:30 hours on 1 June 2021), epoch flag (0 = OK, 1 = power failure between current and previous epoch, >1 = special event, e.g. 2 = start moving antenna), the number of satellites in the current epoch (here 18), followed by the system identifier (G = GPS, R = GLONASS, E = Galileo, S = SBAS or geostationary) and the 2-digit satellite number (i.e. Pseudo-Random Noise code, PRN, or GLONASS slot number). In this example, 8 GPS, 6 GLONASS and 4 Galileo satellites were observed.

- Line 27-28: Observations recorded for the first satellite listed (G01) – see line 13 in Figure 1 for the corresponding observation types in the RINEX header. In this example, six types of observations were recorded for all but the Galileo satellites (the L2 frequency is not used by Galileo) – L1 carrier phase measurement, L2 carrier phase measurement, L1 code measurement (C1), L2 code measurement (P2), L1 signal strength (S1) and L2 signal strength (S2). Each observation value is defined as a floating-point value of total length 14 with 3 decimals (F14.3). This is followed by two optional single-digit integer records (I1) pertaining to the Loss of Lock Indicator (LLI, range 0-7 or blank, phase observations only) and the Signal Strength Indicator (SSI, range 1-9 for increasing signal strength or blank).
- Line 29-62: Observations recorded for the other satellites in this epoch, with missing observations (or those not observed) indicated as blanks (e.g. no L2 observations to the Galileo satellites).

```
25  21  6  1  0 37 30.0000000  0 18G01G03G04G10G21G22G31G32R02R03R04R13
26                                R18R19E05E09E11E36
27  110137934.272 8  85821775.74248  20958552.220    20958554.400          53.300
28          53.550
29  119766659.544 7  93324688.12247  22790840.660    22790843.240          45.200
30          45.100
31  124156873.931 7  96745619.03746  23626267.600    23626269.980          43.200
32          40.100
33  130281153.04615 101517801.02255  24791680.380    24791685.800          35.450
34          34.100
35  107660051.087 8  83890939.09847  20487029.500    20487028.240          51.400
36          45.600
37  109924937.177 8  85655784.12247  20918020.040    20918017.020          52.900
38          44.550
39  109426889.942 8  85267704.15548  20823245.920    20823244.660          53.300
40          53.250
41  122182552.628 7  95207188.87447  23250567.920    23250568.700          47.650
42          42.200
43  122656371.420 6  95399420.181 6  22985753.460    22985758.360          38.500
44          39.000
45  109283847.384 8  84998559.602 8  20415141.460    20415142.640          52.450
46          48.900
47  114565531.929 6  89106523.251 5  21394302.360    21394302.020          38.150
48          33.950
49  110306911.273 6  85794276.777 7  20656940.920    20656944.020          39.850
50          42.650
51  114943294.330 8  89400354.336 7  21532750.260    21532755.080          50.650
52          47.400
53  112735465.036 6  87683135.364 6  21074705.120    21074707.020          38.950
54          41.550
55  129830473.839 8                  24705917.480                          48.750
56
57  117250086.174 9                  22311949.220                          54.400
58
59  133045175.973 7                  25317654.460                          42.450
60
61  128710168.325 8                  24492734.840                          52.900
62
63  21  6  1  0 38  0.0000000  0 20G01G03G04G10G21G22G31G32R02R03R04R12
64                                R13R14R18R19E05E09E11E36
```

Figure 2: Typical RINEX 2.11 observation block.

The interested reader is referred to Gurtner and Estey (2012) for more detailed information on the RINEX 2.11 format.

3.2 RINEX 3.04 & 3.05

Following several revisions for improvement and clarification, RINEX 3.05 (Romero, 2020) is the last official RINEX version 3 format. Its major difference compared to RINEX 2.11 is that it fully supports multi-GNSS (G = GPS, R = GLONASS, E = Galileo, C = Beidou, J = QZSS, I = NavIC/IRNSS, S = SBAS) and clearly identifies the tracking modes of each of the observations by utilising 3-character observation codes for all GNSS constellations. In particular, the possibility to track frequencies on different channels required a more flexible and more detailed definition of the observation codes.

Some software currently supports formats up to RINEX 3.04 only, which has minor differences to the latest version (apart from missing signals and tracking codes to fully support the 2nd and 3rd generation of Beidou). RINEX 3.04 is also the format currently being used by DCS Spatial Services for archiving CORSnet-NSW datasets and providing them to Geoscience Australia (e.g. to be used by the AUSPOS service).

The RINEX 3.04/3.05 file naming convention (Figure 3) stipulates a much longer file name than RINEX 2.11, providing more detailed information about the dataset collected by being more descriptive, flexible and extendable (this was introduced with RINEX 3.02). In particular, this facilitates the efficient storage and exchange of RINEX data in large communities like the IGS. For practical surveying applications, this naming convention may appear to be too detailed to be adopted. However, it is important that users of IGS products or CORS data understand the new RINEX file naming in order to obtain the desired data for their purposes.

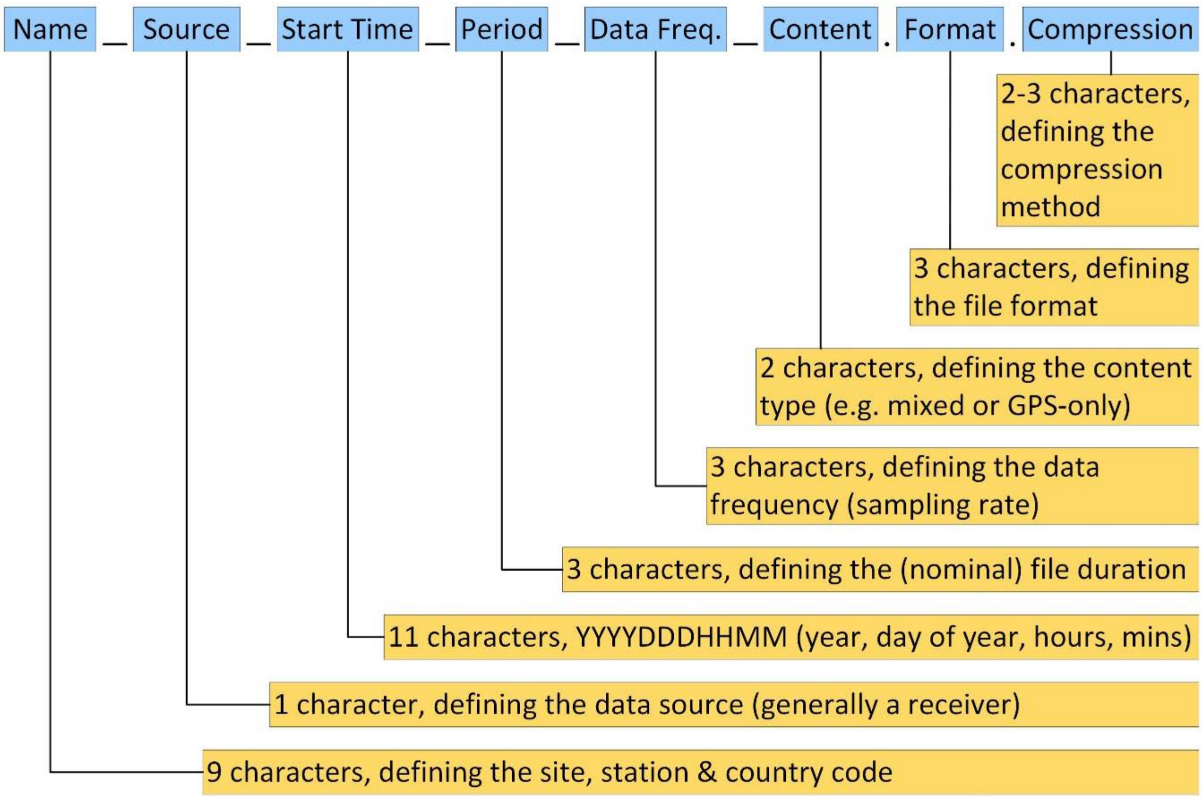


Figure 3: Philosophy of RINEX long file names introduced with version 3.02 (adapted from Gini, 2023).

The following examples illustrate the benefit of the long file naming convention, with data source, start time, duration, sampling rate and data type now easily visible as part of the file name:

- BATH00AUS_R_20240501200_03H_10S_MO.rnx indicates a RINEX observation file for Bathurst CORS (being the first monument [0] and the first receiver [0, unless additional receivers are connected to the antenna] located at this site in Australia), sourced from a receiver (via vendor or other software), observed in 2024 on day of year 050 and starting at 12:00 hours, that contains 3 hours of data at a 10-second sampling rate and mixed GNSS observation data (i.e. from at least two satellite constellations).
- BATH00AUS_R_20240501715_15M_01S_GO.rnx also indicates a RINEX observation file for Bathurst CORS, being the first monument and receiver at this site, sourced from a receiver, observed in 2024 on day of year 050 but starting at 17:15 hours, containing 15 minutes of data at a 1-second sampling rate and GPS-only observation data.
- BATH00AUS_R_20240620000_01D_30S_MO.rnx indicates a RINEX observation file for Bathurst CORS, being the first monument and receiver at this site, sourced from a receiver, observed in 2024 on day of year 062, starting at 00:00 hours, containing 1 day of data at a 30-second sampling rate and mixed GNSS observation data.
- Accordingly, BATH00AUS_R_20240620000_01D_MN.rnx.gz indicates a compressed (the gz extension indicates compression using the standard GNU zip, or gzip, algorithm) RINEX navigation file collected at Bathurst CORS, being the first monument and receiver at this site, sourced from a receiver, observed in 2024 on day of year 062, starting at 00:00 hours and containing 1 day of mixed GNSS navigation data.

As in the older versions, the RINEX observation file consists of a header section followed by a data section and ends with a blank line. While each row in the header continues to have a maximum length of 80 characters, this limitation has been removed for the data section (as explained below).

Figure 4 shows an example of a typical RINEX 3.04 header. It includes the following information:

- Line 1: RINEX version and statement that this is an observation file with mixed GNSS data (e.g. as opposed to GPS-only).
- Line 2: Program used to generate the RINEX file, who ran it (here blank) and when it was run.
- Line 3: Marker name, in this case the 4-character ID issued to NSW by Geoscience Australia.
- Line 4: Marker number, here the SCIMS number.
- Line 5: Marker type, here geodetic (i.e. an earth-fixed, high-precision monument). Selecting an attribute other than GEODETIC or NON_GEODETIC (i.e. a low-precision monument) indicates that the data was collected by a moving receiver (e.g. on a person, car, ship, aircraft, space vehicle, glacier, floating ice or even an animal).
- Line 6: Observer and agency, in this case indicating an organisation external to DCS Spatial Services.
- Line 7: Receiver serial number, receiver type and firmware version.
- Line 8: Antenna serial number (for integrated antennas the same as the receiver serial number) and antenna type (using the IGS naming convention).
- Line 9: Approximate site position in Cartesian coordinates (X, Y, Z) – ITRF (not WGS84) recommended.

- Line 10: Antenna height (measured vertically between ground mark and ARP) and any horizontal offset from the mark (if applicable).
- Line 11-14: For each satellite system, the number and types of observations, here specifying 8 observation types for GPS, 4 observation types for GLONASS, 6 observation types for QZSS and 4 observation types for Galileo. The 3-character observation codes include observation type (C = pseudo-range, L = carrier phase, D = Doppler, S = signal strength, X = receiver channel number), band/frequency (range 1-9) and attribute (tracking mode or channel, e.g. C, P, W, I, Q). For instance, for GPS, L1C and C1C are the L1 carrier phase and pseudo-range derived from the C/A code, while L2W and C2W are the L2 carrier phase and pseudo-range derived from Z-tracking (an effective method to acquire the encrypted P(Y) code under Anti-Spoofing conditions). This example only contains code and carrier phase measurements in order to keep the file width manageable.
- Line 15: Signal strength unit (DBHZ = signal-to-noise ratio given in dbHz).
- Line 16: Sampling interval, in this case 30 seconds.
- Line 17: Comment, here the name of the raw binary data file (can be placed anywhere between the first and last line in the header).
- Line 18-19: Time of first and last observation epoch, in this case 01:46:00 hours and 05:15:30 (GPS time) on 29 June 2023, respectively.
- Line 20: Receiver clock offset applied (0 = no, 1 = yes).
- Line 21-22: GLONASS slot and frequency numbers, indicating the number of satellites in the list followed by each satellite number and its frequency number (range -7 to +6).
- Line 23-25: Phase shift correction used to generate phases consistent with respect to cycle shifts, stated for each affected satellite system and carrier phase observation code. In this case, three observation codes include a correction of -0.25 or +0.25 cycles (blank = none).
- Line 26: Number of leap seconds between GPS time and UTC, here 18.
- Line 27: End of RINEX header indicator.

```
 1      3.04           OBSERVATION DATA    Mixed(MIXED)        RINEX VERSION / TYPE
 2 cnvtToRINEX 3.14.0                      20230901 041049 UTC PGM / RUN BY / DATE
 3 35CC                                                        MARKER NAME
 4 PM85387                                                     MARKER NUMBER
 5 GEODETIC                                                    MARKER TYPE
 6 EXTERNAL            EXTERNAL                                OBSERVER / AGENCY
 7 5729470244          TRIMBLE R10         5.50                REC # / TYPE / VERS
 8 5729470244          TRMR10          NONE                    ANT # / TYPE
 9  -4436326.0200  2842136.4690 -3583184.7181                  APPROX POSITION XYZ
10         1.7780        0.0000        0.0000                  ANTENNA: DELTA H/E/N
11 G    8 C1C C2W C2X C5X L1C L2W L2X L5X                      SYS / # / OBS TYPES
12 R    4 C1C C2C L1C L2C                                      SYS / # / OBS TYPES
13 J    6 C1C C2X C5X L1C L2X L5X                              SYS / # / OBS TYPES
14 E    4 C1X C8X L1X L8X                                      SYS / # / OBS TYPES
15 DBHZ                                                        SIGNAL STRENGTH UNIT
16     30.000                                                  INTERVAL
17 Source: 02441800.T04                                        COMMENT
18   2023     6    29     1    46    0.0000000     GPS         TIME OF FIRST OBS
19   2023     6    29     5    15   30.0000000     GPS         TIME OF LAST OBS
20      0                                                      RCV CLOCK OFFS APPL
21  12 R05  1 R06 -4 R07  5 R08  6 R09 -2 R10 -7 R15  0 R16 -1 GLONASS SLOT / FRQ #
22     R17  4 R18 -3 R19  3 R20  2                             GLONASS SLOT / FRQ #
23 G L2X -0.25000                                              SYS / PHASE SHIFT
24 R L2C -0.25000                                              SYS / PHASE SHIFT
25 J L2X +0.25000                                              SYS / PHASE SHIFT
26     18                                                      LEAP SECONDS
27                                                             END OF HEADER
```

Figure 4: Typical RINEX 3.04 header.

Figure 5 shows a typical RINEX 3.04 observation data block. It contains the following information:

- Line 28: Date and time of the observation epoch (receiver time of the received signals) in the format year, month, day, hours, minutes, seconds (here 01:46:00 hours on 29 June 2023), epoch flag (0 = OK, 1 = power failure between current and previous epoch, >1 = special event, e.g. 2 = start moving antenna), and the number of satellites in the current epoch (here 15). The special character ‘>’ preceding the epoch information was introduced as an epoch record identifier to enable reading programs to easier detect the next epoch in case of a corrupted data file or when streaming observation data in a RINEX-like format.
- Each following line contains the observations from a single satellite, starting with the system identifier and satellite identifier (PRN). In this example, 2 Galileo, 7 GPS, 1 QZSS and 5 GLONASS satellites were observed. There is no data record length limitation as this depends on the constellation observation list declared in the RINEX header and the available observables per satellite per epoch, i.e. the previous length limitation to 80 characters per row does no longer apply.
- Line 29: Observations recorded for the first satellite (E02, i.e. Galileo satellite 02) – see line 14 in Figure 4 for the corresponding Galileo observation types in the RINEX header. Each observation value continues to be defined as a float value of total length 14 with 3 decimals (F14.3), followed by two optional single-digit integer records (I1 or blank) representing the Loss of Lock Indicator (LLI) and the Signal Strength Indicator (SSI).
- Line 30-43: Observations recorded for the other satellites in this epoch, with missing observations (or those not observed) indicated as blanks.

```
28 > 2023 06 29 01 46  0.0000000  0 15
29 E02  25294920.883 7  25294925.691 7 132925708.305 7 100557451.525 7
30 E25  23447480.428 8  23447484.362 8 123217340.681 8  93213132.913 8
31 G04  21494822.352 6                  21494825.080 5  21494829.933 7 112956049.291 6                  88017624.905 5  84350336.386 7
32 G07  20337145.830 7                  20337148.174 7                 106872422.420 7                  83277222.319 7
33 G09  20367487.010 8                  20367490.340 7  20367494.468 8 107031866.687 8                  83401469.315 7  79926420.520 8
34 G14  23881998.475 6                  23882004.464 7  23882010.066 7 125500746.909 6                  97792815.156 7  93718137.735 7
35 G20  23898920.072 6  23898925.616 3                                 125589663.277 6  97862096.929 3
36 G27  23825218.979 5                  23825219.068 4  23825223.775 6 125202379.199 5                  97560279.945 4  93495301.251 6
37 G30  22227137.499 7                  22227142.425 6  22227146.437 8 116804390.872 7                  91016432.610 6  87224096.414 8
38 J07  37434047.147 6  37434051.555 7  37434054.257 7 196717240.891 6 153286182.977 7 146899267.577 7
39 R05  19811646.971 7  19811650.783 6 105904612.687 7  82370142.314 6
40 R06  20261919.814 6                 108121477.98516
41 R09  22436373.073 7  22436380.500 7 119808978.418 7  93184773.342 7
42 R15  21016941.129 7  21016946.524 7 112308166.088 7  87350586.238 7
43 R16  19461669.657 8  19461674.685 7 103960753.501 8  80858379.014 7
44 > 2023 06 29 01 46 30.0000000  0 16
```

Figure 5: Typical RINEX 3.04 observation block.

The interested reader is referred to Romero (2020) for more detailed information on the RINEX 3.05 format.

3.3 RINEX 4.00 & 4.01

As the necessary next step for maintaining the suitability of the RINEX format to store GNSS data and measurements into the future, RINEX 4.00 (Romero, 2021) was adopted by the IGS at the 59th Governing Board Meeting on 7 December 2021. This new version is necessary to accommodate the modernised navigation messages from all the different GNSS constellations. Once fully implemented, RINEX version 4 future-proofs the format of the navigation messages, enabling RINEX to properly store GNSS observations, navigation messages and station meteorological data files for the long-term future.

The RINEX 4.00 *observation* files are backward compatible with RINEX 3.0X and therefore there is no issue in the storage and usage of RINEX 4.00 observation files. It provides a few minor extensions in observation types and extended header lines but no major format change, i.e. adapting to RINEX 4.00 for observation files is a minor evolution.

However, RINEX 4.00 *navigation* files are not backward compatible with RINEX 3.0X files. This is the reason why the RINEX version number was increased rather than utilising another RINEX 3.0X sub-version. On the other hand, no change is necessary in regard to file naming and file storage since navigation files of all types can be stored together in different RINEX versions without any issue. All RINEX files state the version number in the first line and most reader programs will skip over unknown navigation file versions until they are ready to process them.

The development has since continued to add some necessary clarifications and new observation codes for upcoming GPS satellites and for L1 NavIC signals, resulting in RINEX 4.01 (Gini, 2023) being released in July 2023. The RINEX format development has been conducted in collaboration with equipment manufacturers and software generators, ensuring that equipment and software tools that can produce and process RINEX 4.00 & 4.01 files will be available to the GNSS community in due course to enable implementation and broader adoption. More details about the RINEX version 4 format can be found in Gini (2023).

4 EDITING RINEX OBSERVATION FILES

Regardless of the RINEX version used, it is important to note that the RINEX header often contains incorrect or incomplete information when initially generated (e.g. the manufacturer's receiver and antenna names not following the IGS naming convention, a default antenna type or a zero antenna height), so thorough editing is very important in order to avoid confusion further down the track. This particularly applies for data archival, data sharing or submission to third parties (especially where machine-to-machine processes are likely to be employed). Ensuring the correctness of the information in the RINEX header is not only good practice but also very valuable when mining data for purposes that were not envisaged when the data was originally collected.

The RINEX format stipulates the antenna type as a 20-character name (see columns 21-40 of line 9 in Figure 1 and line 8 in Figure 4), including several spaces and ending with a 4-character indication of the radome used (NONE meaning that no radome is present). The authoritative source for resolving antenna queries are the frequently updated IGS files *rcvr_ant.tab* and *antenna.gra* (IGS, 2024c). The file *rcvr_ant.tab* details the international naming conventions for GNSS receivers, antennas and radomes (antenna covers), which are also used by AUSPOS. The file *antenna.gra* provides graphs with physical dimensions of GNSS antennas, including the position of the ARP (generally the bottom of the antenna) and vertical offsets to other features such as the centre of bumper or bottom of choke ring. As an aside, the file *igs20.atx*, containing the IGS antenna models recommended for baseline processing, can be found at the same location (it is frequently updated to include new antennas). If still in doubt, users should contact their equipment provider for the required antenna information.

If the antenna height was not measured directly and vertically to the ARP in the field, e.g. when using a vertical height hook measurement or a slant measurement to the bumper or the Slant Height Measurement Mark (SHMM) on the instrument, then it must be converted to the vertical distance between the ground mark and the ARP using the offsets and method (generally applying Pythagoras in conjunction with a vertical offset) specified in the GNSS equipment manual or provided by the manufacturer – see Janssen and McElroy (2022) for examples. The correctness of antenna height and antenna type is crucial to allow the correct antenna model to be applied correctly in processing. An incorrect antenna type can introduce significant bias (more than 10 cm in the vertical component) and noise into the computed coordinates. An error in the antenna height will directly translate into an error in the resulting GNSS-derived ellipsoidal height and thus the derived Australian Height Datum (AHD) height.

If session length is critical to contractual arrangements and/or data acceptance by a third party, it is recommended to always extend session lengths by a few minutes. The start and end of the GNSS observation section in the RINEX file should be visually inspected, particularly to ensure that the first and last few epochs contain reasonably complete data blocks. If epochs at the start/end of the observation are deleted, the time of the first/last observation in the RINEX header should be modified accordingly. Frequent dropouts of satellite signals from epoch to epoch in the RINEX file may indicate bad data quality due to poor sky view conditions (e.g. tree cover or other obstructions). Note that the raw observation files in their native (binary) proprietary format collected by the GNSS receiver are compact and should always be permanently archived – they can be re-converted to RINEX and edited again if required.

5 CONTRIBUTING GNSS DATA FOR NSW DATUM MODERNISATION

5.1 The GDA2020 State Adjustment

The Geocentric Datum of Australia 2020 (GDA2020) is Australia's national datum, which is defined in the ITRF2014 (Altamimi et al., 2016) at epoch 2020.0 and based on a single, nationwide least squares network adjustment that rigorously propagates uncertainty (ICSM, 2021b; Harrison et al., 2023).

In NSW, as of November 2023, the growing GDA2020 state adjustment consists of approximately 1,250,000 measurements between 177,000 stations, translating into about 150,000 SCIMS marks and making it the largest Jurisdictional Data Archive (JDA) in Australia. It was computed with DynAdjust (version 1.2.7) using a phased-adjustment least squares methodology that provides rigorous uncertainty across the entire network (Fraser et al., 2023, 2024). The GDA2020 state adjustment includes about 120,000 GNSS baselines, 22,000 baselines originating from 14,000 AUSPOS sessions, 325,000 directions and 340,000 distances.

To achieve this, DCS Spatial Services has developed and implemented several innovative, highly automated tools and workflows to prepare, process and ingest existing and new GNSS baseline data, AUSPOS datasets and street-corner traversing data. Over several years, efforts have been undertaken to source, harvest, clean and utilise legacy geodetic measurements (Haasdyk and Watson, 2013), build state-of-the-art GNSS CORS network infrastructure (Janssen et al., 2016), observe new high-quality GNSS measurements to connect the existing survey network to CORS (Gowans and Grinter, 2013), include static Network Real-Time Kinematic (NRTK) observations and their uncertainties (Bernstein and Janssen, 2022), and systematically rationalise, maintain, upgrade and collect AUSPOS datasets at key sites across the NSW survey control network, including trigonometrical (trig) stations and AHD spirit-levelled marks (Gowans et al., 2015; Janssen and McElroy, 2021). The desired end state is that a network of fundamental AUSPOS-observed survey marks is established at a 10 km density across the eastern and central divisions of the state, ensuring users are always within 5 km (as the crow flies), and often much less, of a fundamental AUSPOS point. Current efforts also focus on densifying the NSW survey control network via secondary adjustments based on connections between survey marks sourced from Deposited Plans through the LandXML to SCIMS (LX2S) pilot project (Hine et al., 2024).

AUSPOS data of at least 6 hours duration is used to propagate the datum in NSW (via inclusion in the National GNSS Campaign Archive, NGCA, hosted by Geoscience Australia), while AUSPOS data of less than 6 hours duration strengthens the datum (via inclusion in the state's Jurisdictional Data Archive, JDA). To date, more than 15,000 AUSPOS solutions have been used to help maintain and improve the NSW survey control network.

Key components of these datum modernisation efforts have been the preservation and upgrade of survey infrastructure, including physical maintenance of permanent survey marks (including but not limited to TS, PM and SS), and the update of metadata such as survey mark information in SCIMS and survey mark photographs. This will enable future users to achieve DCS Spatial Services' vision of a Positional Uncertainty (PU) of 20 mm in the horizontal and 50 mm in the vertical (ellipsoidal height) component anywhere in the state. It will also allow for the future realisation and propagation of the Australian Vertical Working Surface (AVWS – see ICSM, 2021a) at a later date and to easily apply transformation tools to move between current, future and various historical datums and local working surfaces.

5.2 Contributing Industry-Observed GNSS Data

The profession is encouraged to contribute to the maintenance of the NSW survey control network and the timely update of survey information in SCIMS by submitting suitable industry-observed AUSPOS datasets of at least 2 hours duration and related metadata via the DCS Spatial Services Customer Hub on our website (DCS Spatial Services, 2024b). The Customer Hub is a new, user-friendly online platform providing a central contact point to interact with DCS Spatial Services. It is now the primary way for customers to make enquiries, submit data requests and provide feedback. Survey Operations can be contacted through the Customer Hub to submit AUSPOS datasets, Locality Sketch Plans (LSPs), survey mark status reports, Preservation of Survey Infrastructure (POSI) applications, trig station approvals, exemption applications and regulation approvals. Access to the Customer Hub is free and simple, after creating a one-time username and password. Through a ticketed system, customers can track the status of their requests at any point in time, which enables DCS Spatial Services to manage these more efficiently and effectively.

A practical guide to AUSPOS, including the requirements for successful AUSPOS datasets to be submitted to DCS Spatial Services, can be found in Janssen and McElroy (2022). In summary, AUSPOS data submissions to DCS Spatial Services must include the following:

- RINEX observation file of at least 2 hours duration. Also including the raw binary file in the manufacturer's native (proprietary) format is optional but strongly recommended.
- Completed log sheet or field notes, clearly indicating observation date/time, mark observed, receiver and antenna type and serial number used, and antenna height measured vertically to the ARP.
- AUSPOS processing report (using rapid or final IGS orbits).
- Locality Sketch Plan for any new mark placed (submitted separately to the AUSPOS data).
- Photographs of the mark, indicating mark type and sky view conditions (optional but recommended).

6 CONCLUDING REMARKS

The widely used RINEX format is the international standard for the storage and exchange of GNSS data. It allows efficient and unambiguous archiving of GNSS data and associated metadata in one place, while also facilitating the easy transfer and distribution of such data, independent of the equipment used and the data processing software employed. Over the years, and through several versions and sub-versions, the RINEX format has continually been improved and expanded to cater for modern satellite positioning data collected by a growing number of satellite constellations and their signals.

This paper has presented a brief history of the RINEX format and explained recent RINEX format versions using examples relevant to the surveying profession. This included outlining the short and long RINEX file naming conventions and the editing of RINEX observation files to ensure correctness of the header information. It has then given an update on the growing GDA2020 state adjustment and encouraged the profession to contribute to further improvement of the NSW survey control network and the information provided in SCIMS by submitting suitable industry-observed AUSPOS datasets and related metadata to DCS Spatial Services. It is hoped that this contribution has helped the surveying profession to better understand the RINEX format, the philosophy behind it, and its benefits to users. In the words of the legendary Australian band AC/DC: "For those about to R.O.C.K. (i.e. RINEX Observation Contributor Kindness), we salute you!" (Janssen, 2019).

REFERENCES

Altamimi Z., Rebischung P., Collilieux X., Métivier L. and Chanard K. (2023) ITRF2020: An augmented reference frame refining the modeling of nonlinear station motions, *Journal of Geodesy*, 97(5), 47.

Altamimi Z., Rebischung P., Métivier L. and Collilieux X. (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, *Journal of Geophysical Research: Solid Earth*, 121(8), 6109-6131.

Bernstein T. and Janssen V. (2022) Determining Positional Uncertainty of NRTK observations for inclusion in the GDA2020 state adjustment, *Proceedings of Association of Public Authority Surveyors Conference (APAS2022)*, Leura, Australia, 21-23 March, 29-42.

DCS Spatial Services (2024a) CORSnet-NSW, http://www.corsnet.com.au/ (accessed Mar 2024).

DCS Spatial Services (2024b) DCS Spatial Services Customer Hub, https://customerhub.spatial.nsw.gov.au/servicedesk/customer/portals (accessed Mar 2024).

Fraser R.W., Leahy F.J. and Collier P.A. (2023) DynAdjust user's guide, version 1.2, https://github.com/icsm-au/DynAdjust/tree/master/resources (accessed Mar 2024).

Fraser R.W., Leahy F.J. and Collier P.A. (2024) Automatic segmentation and parallel phased least squares for highly efficient geodetic network parameter estimation, *Survey Review*, 56(394), 32-50.

GA (2024) AUSPOS – Online GPS processing service, https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos (accessed Mar 2024).

Gini F. (2023) RINEX – The Receiver Independent Exchange format version 4.01, https://files.igs.org/pub/data/format/rinex_4.01.pdf (accessed Mar 2024).

Gowans N. and Grinter T. (2013) Tying it all together: CORSnet-NSW local tie surveys, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 104-119.

Gowans N., McElroy S. and Janssen V. (2015) Survey infrastructure preservation and upgrade: Trigonometrical stations in NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2015)*, Coffs Harbour, Australia, 16-18 March, 67-84.

Gurtner W. and Estey L. (2012) RINEX: The Receiver Independent Exchange format version 2.11, https://files.igs.org/pub/data/format/rinex211.txt (accessed Mar 2024).

Gurtner W., Mader G. and McArthur D. (1989) A common exchange format for GPS data, *CSTG GPS Bulletin*, 2(3), May/June 1989, National Geodetic Survey, Rockville, Maryland.

Haasdyk J. and Watson T. (2013) Data-mining in NSW: Towards a new and improved Australian datum, *Proceedings of Association of Public Authority Surveyors Conference (APAS2012)*, Canberra, Australia, 12-14 March, 85-102.

Harrison C., Brown N., Dawson J. and Fraser R. (2023) Geocentric Datum of Australia 2020: The first Australian datum developed from a rigorous continental-scale adjustment, *Journal of Spatial Science*, https://doi.org/10.1080/14498596.2023.2184429 (accessed Mar 2024).

Hatanaka Y. (2008) A compression format and tools for GNSS observation data, *Bulletin of the Geographical Survey Institute*, 55, 21-30, https://www.gsi.go.jp/ENGLISH/Bulletin55.html (accessed Mar 2024).

Hine S., Smith J. and Janssen V. (2024) The LandXML to SCIMS (LX2S) pilot project, *Proceedings of Association of Public Authority Surveyors Conference (APAS2024)*, Canberra, Australia, 18-20 March, 58-77.

ICSM (2021a) Australian Vertical Working Surface (AVWS) technical implementation plan, version 1.6, https://www.icsm.gov.au/publications/australian-vertical-working-surface-technical-implementation-plan-v16 (accessed Mar 2024).

ICSM (2021b) Geocentric Datum of Australia 2020 technical manual, version 1.7, https://www.icsm.gov.au/gda2020-and-gda94-technical-manuals (accessed Mar 2024).

IGS (2024a) IGS formats and standards, https://www.igs.org/formats-and-standards/ (accessed Mar 2024).

IGS (2024b) IGS products, https://www.igs.org/products (accessed Mar 2024).

IGS (2024c) IGS file access for rcvr_ant.tab, antenna.gra and igs20.atx, https://files.igs.org/pub/station/general/ (accessed Mar 2024).

Janssen V. (2019) Let there be rock: The AC/DC phenomenon, *Proceedings of Association of Public Authority Surveyors Conference (APAS2019)*, Pokolbin, Australia, 1-3 Apr, 106-125.

Janssen V., Haasdyk J. and McElroy S. (2016) CORSnet-NSW: A success story, *Proceedings of Association of Public Authority Surveyors Conference (APAS2016)*, Leura, Australia, 4-6 April, 10-28.

Janssen V. and McElroy S. (2021) The Australian Height Datum turns 50: Past, present & future, *Proceedings of APAS Webinar Series 2021 (AWS2021)*, 24 March – 30 June, 3-27.

Janssen V. and McElroy S. (2022) A practical guide to AUSPOS, *Proceedings of Association of Public Authority Surveyors Conference (APAS2022)*, Leura, Australia, 21-23 March, 3-28.

NRCan (2024) CSRS-PPP, https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/tools-outils/ppp.php (accessed Mar 2024).

Romero I. (2020) RINEX – The Receiver Independent Exchange format version 3.05, https://files.igs.org/pub/data/format/rinex305.pdf (accessed Mar 2024).

Romero I. (2021) RINEX – The Receiver Independent Exchange format version 4.00, https://files.igs.org/pub/data/format/rinex_4.00.pdf (accessed Mar 2024).

Pushing the Boundaries of AUSPOS Cluster Processing

Nicholas Gowans
DCS Spatial Services
NSW Department of Customer Service
Nicholas.Gowans@customerservice.nsw.gov.au

Volker Janssen
DCS Spatial Services
NSW Department of Customer Service
Volker.Janssen@customerservice.nsw.gov.au

ABSTRACT

AUSPOS is Geoscience Australia's free online Global Positioning System (GPS) processing service. Taking advantage of the International GNSS Service (IGS) core network station data and products together with Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) in and around Australia, it provides precise coordinates and their uncertainties based on static dual-frequency GPS carrier phase and code data submitted by the user in Receiver Independent Exchange (RINEX) format. AUSPOS data can be submitted and processed either individually (mark by mark) or collectively (in groups of concurrent observations). In the first case, the data collected at one mark is processed relative to the surrounding CORS network with no direct relationship to any other rover that was operating at the same time. In the second case, the data collected at several marks is processed together in a cluster, considering that the multiple data files were observed during the same time window and are thus correlated. Processing therefore includes baselines between the user sites, in theory providing a stronger relative connection. This paper investigates the quality of user-submitted positioning results from AUSPOS when the observation data is submitted individually as single-mark sessions versus when submitted as a cluster of several concurrently observed marks. Based on AUSPOS processing of about 3,000 observation files and 900 clusters of varying size across NSW, it is found that the AUSPOS positioning results do not significantly differ between single and cluster mode. Cluster processing also does not show any significant improvement in relative uncertainty between user-submitted stations, which is likely due to the decorrelating effect of constraining the AUSPOS reference stations.

KEYWORDS: *AUSPOS, cluster processing, uncertainty, GDA2020, datum modernisation.*

1 INTRODUCTION

Geoscience Australia's free online Global Positioning System (GPS) processing service, AUSPOS, was developed to provide an online positioning service based on Continuously Operating Reference Stations (CORS) primarily for Australian users, although it can process data collected anywhere on Earth (GA, 2024a). Initially released in 2000, it remains GPS-only and has been frequently upgraded to incorporate improvements. The current version 2.4 was released in August 2020, running in the Amazon Web Services (AWS) cloud environment with scalability and reliability (rather than on physical servers) to accommodate the increasing usage of AUSPOS. It delivers results in both the Geocentric Datum of Australia 2020 (GDA2020 – see Harrison et al., 2023) and its predecessor GDA94, as well as the International Terrestrial

Reference Frame 2014 (ITRF2014 – see Altamimi et al., 2016), along with derived heights in the Australian Height Datum (AHD – see Janssen and McElroy, 2021). Following the recent release of ITRF2020 (Altamimi et al., 2023), a new version of AUSPOS is planned to be released soon.

AUSPOS takes advantage of the International GNSS Service (IGS) core network station data and products (e.g. final, rapid or ultra-rapid orbits depending on availability – see IGS, 2024a) together with CORS in and around Australia to compute precise coordinates, using static dual-frequency GPS carrier phase and code data of at least 1 hour duration (recommended minimum of 2 hours, maximum of 7 consecutive days). When submitting 30-second Receiver Independent Exchange (RINEX – see IGS, 2024b; Janssen, 2024) data, users are required to specify the antenna type (using the IGS naming convention) and the vertically measured antenna height from the ground mark to the Antenna Reference Point (ARP). Following processing, an AUSPOS report (pdf) is emailed to the user (generally within a few minutes), which includes the computed coordinates and their uncertainties, ambiguity resolution statistics, and an overview of the GPS processing strategy applied. For advanced users, Solution Independent Exchange (SINEX) files (IERS, 2006) containing more detailed information are also available for download. A practical guide to AUSPOS can be found in Janssen and McElroy (2022).

DCS Spatial Services, a unit of the NSW Department of Customer Service (DCS), is responsible for the maintenance and improvement of the state's survey control network, which comprises more than 250,000 survey marks on public record made available via the Survey Control Information Management System (SCIMS). The backbone of the NSW survey control network is delivered by CORSnet-NSW, Australia's largest state-owned and operated Global Navigation Satellite System (GNSS) CORS network. CORSnet-NSW currently consists of 209 stations, providing fundamental positioning infrastructure that is authoritative, accurate, reliable and easy-to-use for a wide range of applications (e.g. Janssen et al., 2016; DCS Spatial Services, 2024a), thereby also representing a fundamental, high-density and long-term component of AUSPOS infrastructure. All CORSnet-NSW sites are part of the Asia-Pacific Reference Frame (APREF – see GA, 2024b), including 13 concrete-pillared NSW stations incorporated in the IGS network, and subject to the Regulation 13 certification process providing legal traceability with respect to the Recognised-Value Standard (RVS) of measurement of position in Australia (Hu and Dawson, 2020).

AUSPOS data can be submitted and processed either individually (mark by mark) or collectively (in groups of concurrent observations). In the first case, the data collected at one mark is processed relative to the surrounding CORS network with no direct relationship to any other rover that was operating at the same time. In the second case, the data collected at several marks is processed together in a cluster, considering that the multiple data files were observed during the same time window and are thus correlated. Processing therefore includes shorter baselines between the user sites, in theory providing a stronger relative connection. However, the effect of AUSPOS cluster processing has not yet been thoroughly tested and quantified.

This paper aims to fill this knowledge gap by leveraging the extensive GNSS observation datasets held by DCS Spatial Services. Based on about 3,000 observation files and 900 clusters of varying size across NSW, it evaluates any performance benefit offered by cluster processing through AUSPOS.

2 BACKGROUND

2.1 Using AUSPOS for Datum Modernisation in NSW

Datum modernisation and further improvement of survey infrastructure is required to accommodate the increasing accuracy and improved spatial and temporal resolution available from modern positioning technologies to an ever-broadening user base. With all CORSnet-NSW stations contributing to the AUSPOS service, it delivers high-quality positioning results even for shorter observation sessions of at least 2 hours across NSW, provided sky view conditions are reasonable (Janssen and McElroy, 2020). Consequently, in some situations, the use of AUSPOS campaigns has developed into a capable and reliable alternative to conducting traditional static GNSS baseline surveys, simplifying field work logistics and providing significant time savings in processing, adjustment and survey report writing. AUSPOS also forms a new and fundamental component of vertical datum modernisation across the state and enables propagation of the Australian Vertical Working Surface (AVWS – see ICSM, 2021; Janssen and McElroy, 2021) via its GDA2020 ellipsoidal heights.

Over recent years, DCS Spatial Services has observed new high-quality GNSS measurements to connect the existing survey network to CORS (Gowans and Grinter, 2013) and systematically rationalised, maintained, upgraded and collected AUSPOS datasets at key sites across the NSW survey control network, including trigonometrical (trig) stations and AHD spirit-levelled marks (Gowans et al., 2015; Janssen and McElroy, 2021). The desired end state is that a network of fundamental AUSPOS-observed survey marks is established at a 10 km density across the eastern and central divisions of the state, ensuring users are always within 5 km (as the crow flies), and often much less, of a fundamental AUSPOS point providing a direct link to datum.

While traditional GNSS baseline surveys continue to be performed and adjusted by DCS Spatial Services, AUSPOS is also increasingly employed to improve the state's survey infrastructure. To this end, AUSPOS data of at least 6 hours duration is used to propagate the datum in NSW via the National GNSS Campaign Archive (NGCA) hosted by Geoscience Australia, while AUSPOS data of 2-6 hours duration strengthens the datum via the state's Jurisdictional Data Archive (JDA). To date, more than 15,000 AUSPOS solutions have been processed to help maintain and improve the NSW survey control network.

The surveying profession is encouraged to contribute to the maintenance of the NSW survey control network and the timely update of survey information in SCIMS by submitting suitable industry-observed AUSPOS datasets of at least 2 hours duration and related metadata via the DCS Spatial Services Customer Hub on our website (DCS Spatial Services, 2024b).

2.2 AUSPOS Cluster Processing

Simply put, AUSPOS data can be submitted and processed either individually (mark by mark) or collectively (in groups of concurrent observations). Individual, single-mark AUSPOS processing refers to the data collected at one mark being processed relative to the surrounding CORS network with no direct relationship to any other rover that was operating at the same time.

AUSPOS cluster processing considers that the multiple data files were collected during the same time window and are therefore correlated. Rather than individually connecting each user site to the surrounding CORS network, processing includes baselines between the user sites, which in theory provides a stronger relative connection, provided all user sites are observed in a similar time window and the baselines formed between user sites are less than 20 km in length (Figure 1). AUSPOS first detects which rover observed the longest, and this becomes the hub for the user data (regardless of the relative geometry of all user stations and CORS). In the ideal scenario, baselines are then formed between the hub and the surrounding CORS, while all other rovers are connected to the hub (provided there is sufficient data overlap).

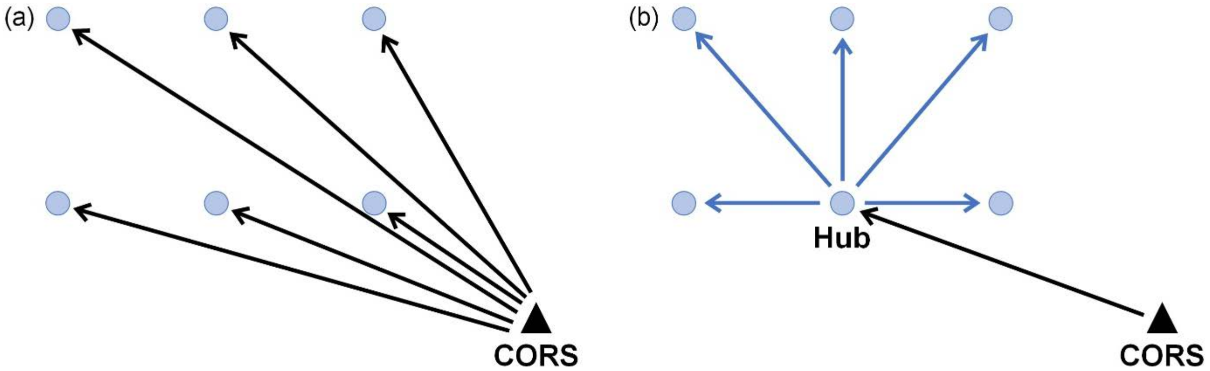


Figure 1: AUSPOS baselines in (a) single mode versus (b) the ideal scenario of cluster mode.

AUSPOS accepts submissions of up to 20 RINEX files in one job, which are then processed together as a cluster, using an observation window that contains the collected data at all sites (between earliest start time and latest end time). Individual observation sessions should overlap by at least 1 hour with respect to the hub, as this overlap is used to compute the baselines between user sites (and the direct L1/L2 ambiguity resolution strategy applied for short baselines is more reliable for data exceeding 1 hour). The baselines in the cluster are formed based on the maximum number of single-difference observations available. If the data overlap of a particular user site with respect to the hub is too short, AUSPOS attempts to compute a baseline to another user site instead (Figure 2a). If this is unsuccessful, a baseline to a CORS is formed, thereby losing the desired relative connection (Figure 2b).

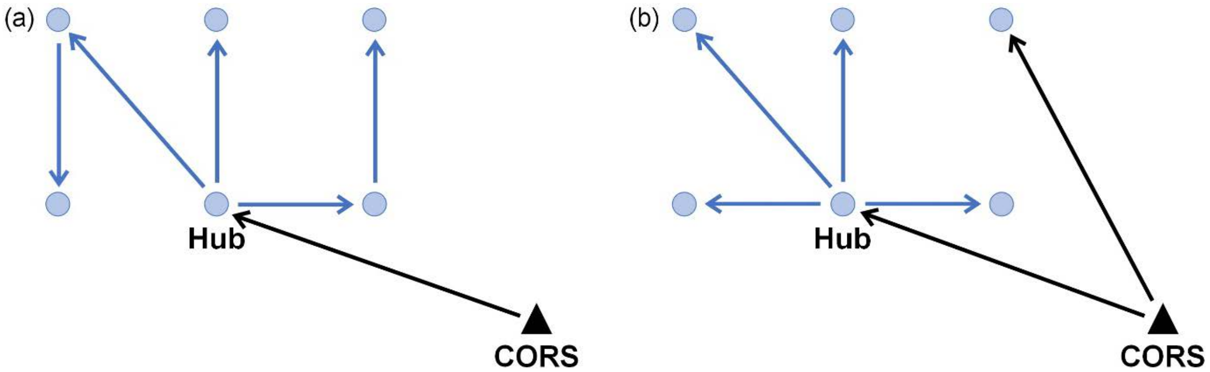


Figure 2: AUSPOS cluster processing with insufficient data overlap relative to the hub, resulting in (a) baselines between user sites not involving the hub and (b) a baseline to a CORS instead.

Figure 3 indicates the strategy used by AUSPOS to estimate the coordinates of the submitted user sites (C. Wang, pers. comm.). It is important to note that AUSPOS performs simultaneous multi-baseline processing, i.e. it combines GPS baseline processing of data collected at several sites in the same time window with a 3D least squares network adjustment before the results are delivered to the user. Commercial off-the-shelf software packages routinely used by industry, including DCS Spatial Services, only mimic this ideal, requiring a 2-step process of single-baseline processing followed by a network adjustment. Even if the user only submits one

RINEX file, AUSPOS still performs simultaneous multi-baseline processing because it uses data from up to 15 CORS. While the traditional 2-step process tends to focus on the delivery of coordinates, simultaneous multi-baseline processing delivers both coordinates and uncertainties, thereby providing better and more realistic uncertainty values.

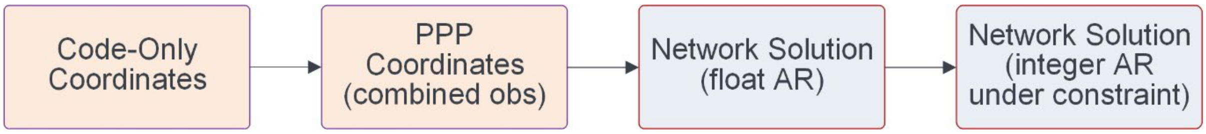


Figure 3: Strategy used by AUSPOS to estimate user coordinates.

Positional Uncertainty (PU) is defined as the uncertainty of the horizontal and/or vertical coordinates of a point, at the 95% confidence level, with respect to the datum. It can be separated into Horizontal PU (HPU) for horizontal position and Vertical PU (VPU) for ellipsoidal height. HPU is expressed as the radius of a 95% circle of uncertainty, generally calculated from the standard error ellipse produced by a least squares network adjustment. VPU is a linear quantity and obtained by scaling the standard deviation by 1.96 to convert it to 95% confidence.

AUSPOS calculates PU based on the East, North and ellipsoidal height coordinate uncertainties according to the Guideline for Adjustment and Evaluation of Survey Control, which is part of ICSM's Standard for the Australian Survey Control Network (SP1), version 2.2 (ICSM, 2020). The coordinate uncertainties of the East, North and ellipsoidal height components are scaled using an empirically derived model, which is a function of duration, data quality and geographical location (latitude and CORS density), and expressed at the 95% confidence level (Jia et al., 2016).

3 DATA AND METHODS

3.1 NSW GNSS Data Holdings

As the government agency responsible for the maintenance of the NSW survey control network under the Surveying and Spatial Information Act 2002, DCS Spatial Services maintains a repository of GNSS observation data, known as the NSW GNSS Observation Archive (NGOA). This study leverages such data where the observation duration is at least 2 hours, and the observation has successfully processed through AUSPOS version 2.4 (submitted as RINEX version 2.11).

3.2 Cluster Formation Strategy

Using in-house generated Python code, the NGOA has been interrogated to automatically form clusters based on the following criteria:

- Each observation must have been processed through AUSPOS version 2.4 submitted in single user station mode.
- Each observation may only be used in a single cluster and must not be re-used across separate clusters.
- Each observation within a cluster must have a minimum overlap of at least 2 hours with the longest observation (hub) in the cluster. No minimum overlap between all sessions in the cluster is set.

- Each station within a cluster must be located no further than 10 km (a distance nominated by the authors) from the nearest user-submitted station.
- Clusters must not contain more than 20 user-submitted observations.

This strategy resulted in the formation of 909 clusters of two or more observations using 3,124 of the 5,959 GNSS observation files that met the selection criteria (Table 1).

Table 1: Summary of clusters formed from the NSW GNSS Observation Archive.

Cluster Size	Count	Percentage	Cumulative Percentage
2	465	51.2	51.2
3	173	19.0	70.2
4	102	11.2	81.4
5	42	4.6	86.0
6	40	4.4	90.4
7	19	2.1	92.5
8	21	2.3	94.8
9	14	1.5	96.4
10	7	0.8	97.1
11	10	1.1	98.2
12	8	0.9	99.1
13	4	0.4	99.6
14	1	0.1	99.7
15	1	0.1	99.8
16	1	0.1	99.9
17	1	0.1	100.0
18-20	0	0.0	100.0

3.3 AUSPOS Processing Strategy

Each cluster was processed through AUSPOS, with the resulting AUSPOS report (pdf) and SINEX results being stored for analysis. Of the 909 clusters identified, 5 (0.6%) failed to process through AUSPOS and 199 observations (6.4%) across 131 clusters processed through AUSPOS with warnings of large PU. The failed clusters were discarded without further review, and the observations with large uncertainties were removed from the analysis. This resulted in 2,879 observation files that produced results through single and cluster processing that could be validly compared. Observations receiving large-uncertainty warnings were tallied according to the processing strategy applied and visualised in Venn diagram format, illustrating when a station observation received a warning for large PU: in single mode processing, cluster processing, both, or one and not the other (Figure 4).

This simple analysis shows that clustered solutions are more prone to resulting in large-uncertainty warnings, particularly at user stations with less-than-ideal observing conditions (e.g. poor sky view due to tree cover or other obstructions). This may be due in part to a different ambiguity resolution strategy adopted by AUSPOS with multiple submitted user stations as the baseline lengths within the cluster are shorter than those to the surrounding CORS. The short-distance, direct L1/L2 strategy applied for 0-20 km baselines may not perform as well in tough observing environments as the long-distance Quasi-Ionosphere-Free (QIF) strategy applied for 20-2,000 km baselines.

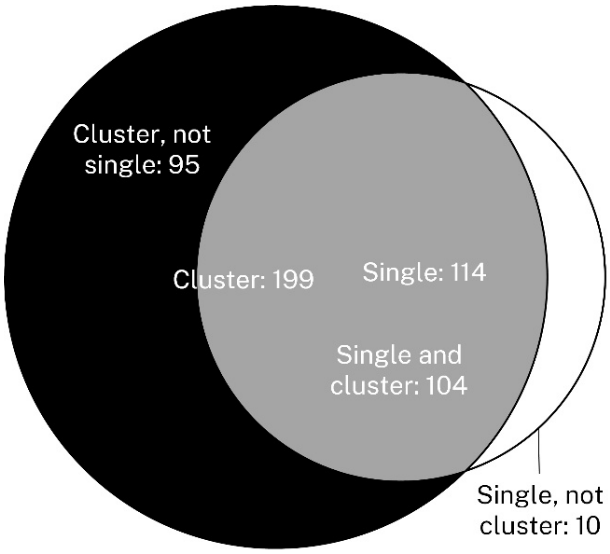


Figure 4: Venn diagram illustrating the number of observations producing warnings for each processing strategy.

Acknowledging the number of observations containing warnings in the AUSPOS report, it is worth noting that even though these observations do not produce centimetre-level positions, they may still be useful for sub-metre applications, e.g. to upgrade survey marks from Class U to Class E coordinates (DCS Spatial Services, 2021; Janssen and McElroy, 2022). Alternatively, the large-uncertainty warning may only be attached to the vertical component of the solution (generally due to a relatively short observation session affected by tree cover), while the horizontal component can still be considered fit-for-purpose. Results of this nature are routinely assessed by DCS Spatial Services on a case-by-case basis. There is further utility in storing such observation data, considering that a result that fails (or produces warnings) today may become acceptable in the future as processing strategies are refined over time.

3.4 Analysis Strategy

Following AUSPOS processing, the quality of results from single-processing and cluster-processing solutions was examined in terms of coordinate changes, derived baselines between user-submitted stations, Positional Uncertainty (PU) and Relative Uncertainty (RU). RU is calculated for a pair of survey marks (based on their PU) and can be separated into Horizontal RU (HRU) for horizontal position and Vertical RU (VRU) for ellipsoidal height.

All coordinates and quality values analysed were adopted from the GDA2020 SINEX files. PU and RU were computed from the variance-covariance matrix and expressed at the 95% confidence level. Horizontal uncertainties were computed as horizontal circular confidence regions according to the Guideline for Adjustment and Evaluation of Survey Control (ICSM, 2020), and vertical uncertainties were multiplied from their one-sigma level by expansion factor 1.96. These computations were performed using the GeodePy Python library (GA, 2024c).

Baselines between user stations were derived through coordinate differences from the SINEX files. Single-solution results were taken from their respective, discrete SINEX files and assumed uncorrelated (i.e. all covariances between stations are zero), while cluster-solution results adopted the relevant inter-station covariances as reported in the SINEX file.

4 RESULTS AND DISCUSSION

The four primary areas of interest (coordinates, derived baselines, PU and RU) show no significant change or improvement when AUSPOS cluster processing is employed. While there are some changes in the extremities of the distributions, these are not considered for further review because this study is looking for a clear trend.

Indeed, the mean and median changes for all coordinate components are less than one millimetre and well within the standard deviation of the distributions (Figure 5). This alone is sufficient to demonstrate that no significant difference is detectable between the two processing strategies based on the data available.

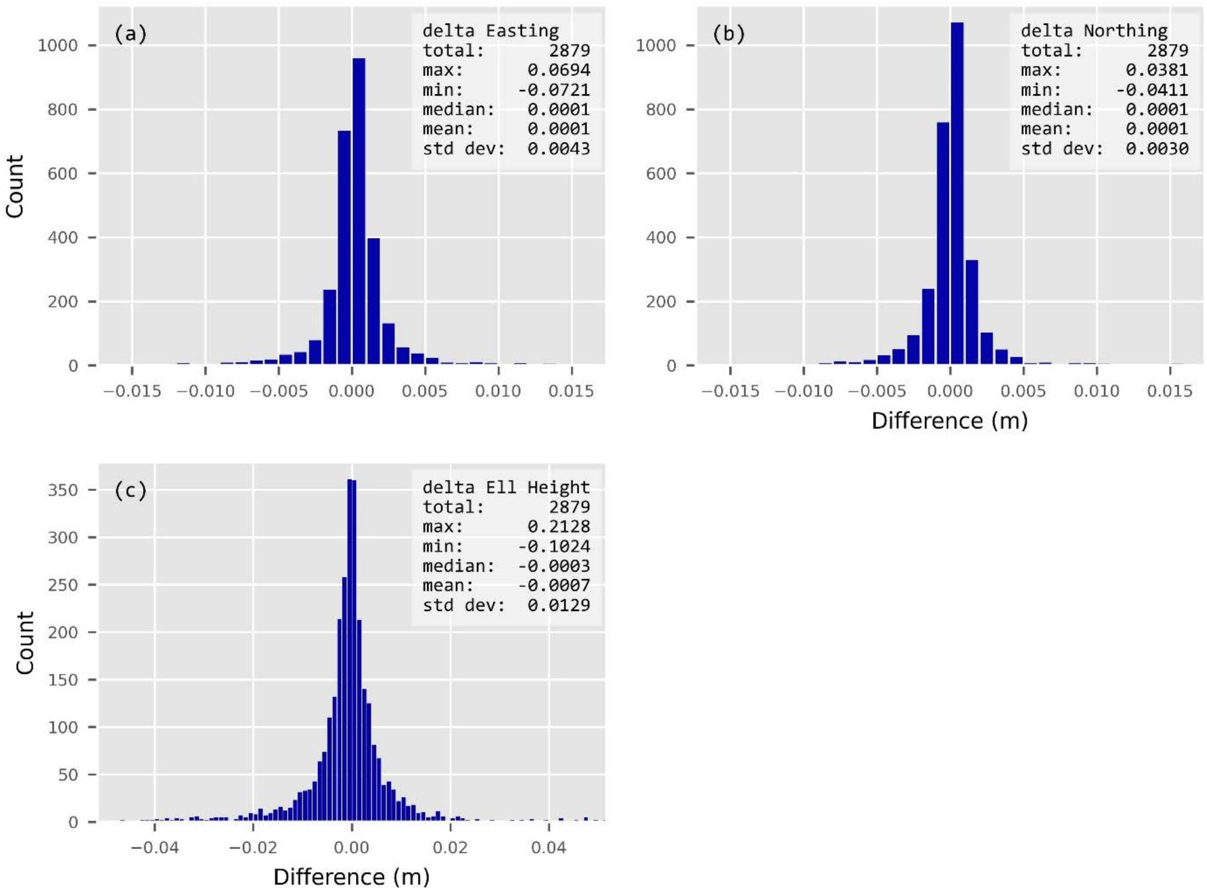


Figure 5: Histograms of GDA2020 coordinate changes in (a) Easting, (b) Northing and (c) ellipsoidal height for each observation. Differences are computed as cluster-solution coordinate minus single-solution coordinate.

Similarly, when baselines are derived between AUSPOS user-submitted stations, the average changes in baseline components are sub-millimetric (Figure 6), showing that even if a clustered solution might have a theoretically superior RU, no appreciable difference is evident in the actual relative positions.

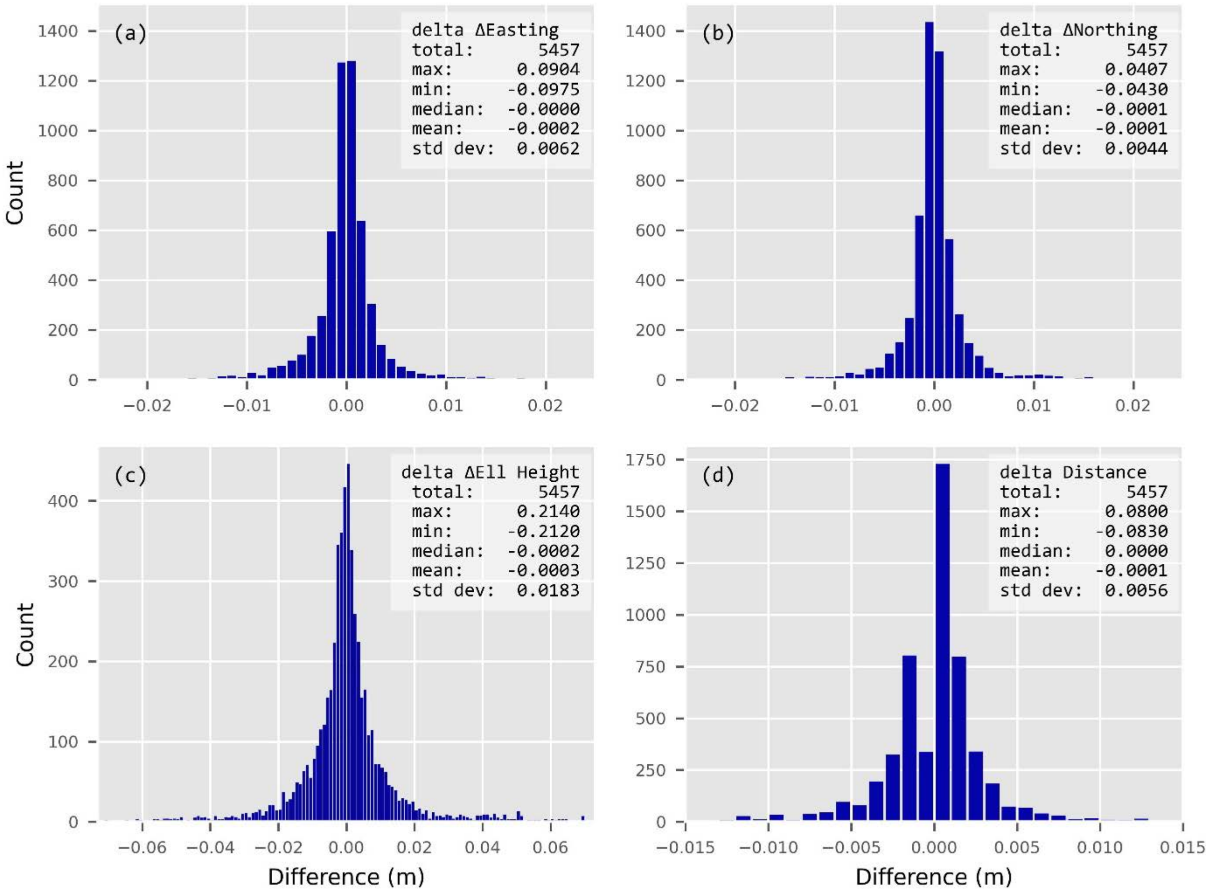


Figure 6: Histograms of derived GDA2020 baseline component changes in (a) Easting, (b) Northing, (c) ellipsoidal height and (d) geodesic distance. Differences are computed as cluster-solution baseline minus single-solution baseline.

For completeness and to quantify the distribution of uncertainty in the datasets investigated, histograms of the obtained GDA2020 PU and RU values for single and cluster solutions are presented in Figures 7 & 8. Inspection confirms the high quality of AUSPOS solutions, and that little change is present between the two processing modes.

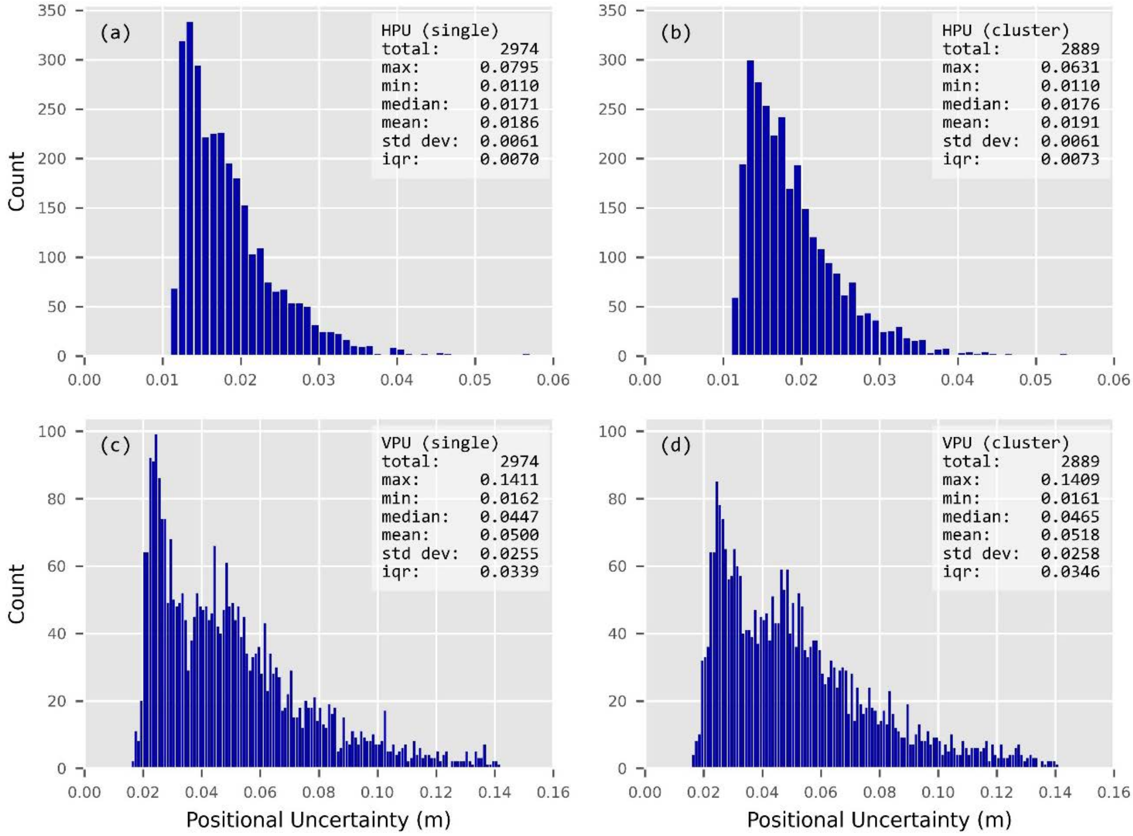


Figure 7: Histograms of GDA2020 (a) HPU in single mode, (b) HPU in cluster mode, (c) VPU in single mode and (d) VPU in cluster mode.

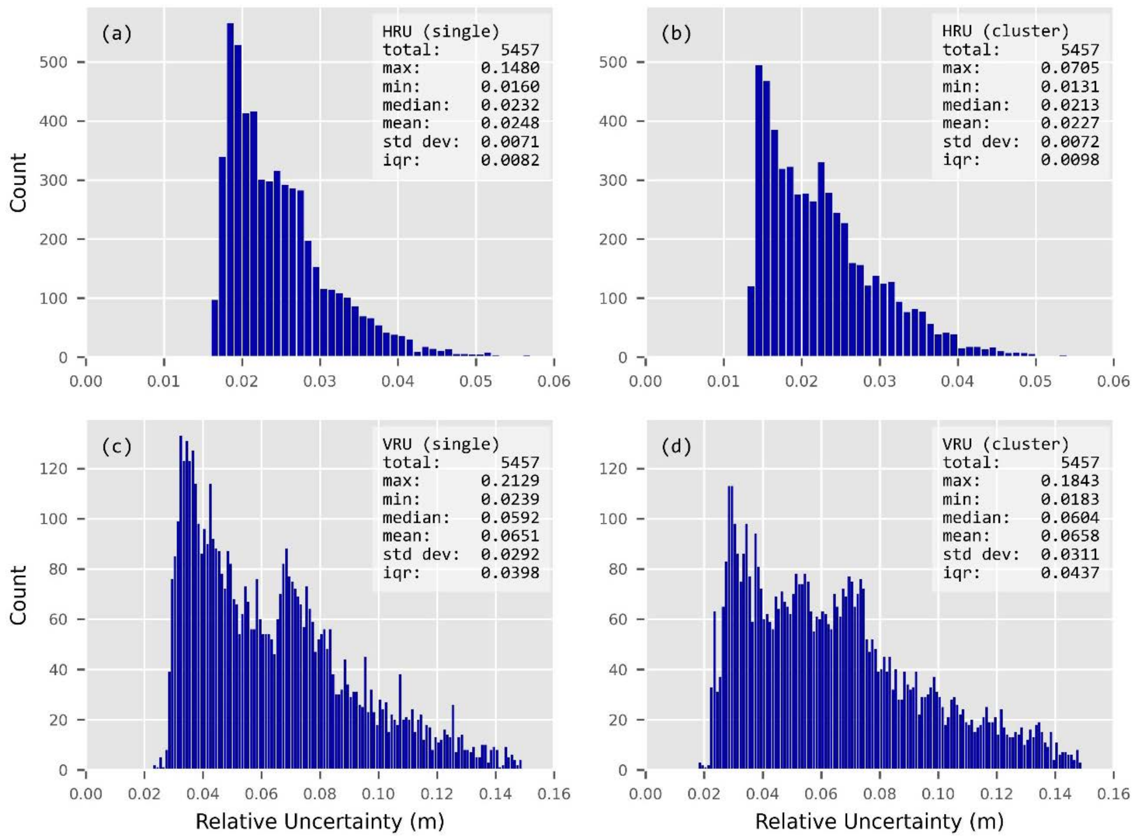


Figure 8: Histograms of GDA2020 (a) HRU in single mode, (b) HRU in cluster mode, (c) VRU in single mode and (d) VRU in cluster mode.

However, investigating the changes in uncertainty presented more mixed results (Figure 9). Cluster processing, on average, saw a very small degradation in horizontal and vertical PU while small improvements were observed in horizontal and vertical RU. Neither of these changes exceeded one-sigma of their distributions and therefore these changes are also considered statistically insignificant. The most notable uncertainty improvement using cluster processing was a median change of 0.0028 m in HRU, falling comfortably within the one-sigma level of 0.0038 m. However, it should be noted that the improvement to RU is computed from uncertainties expressed at the 95% confidence level. When converted back to the one-sigma level, the difference is closer to 1 mm, which is an improvement of questionable value to any surveyor, for any application.

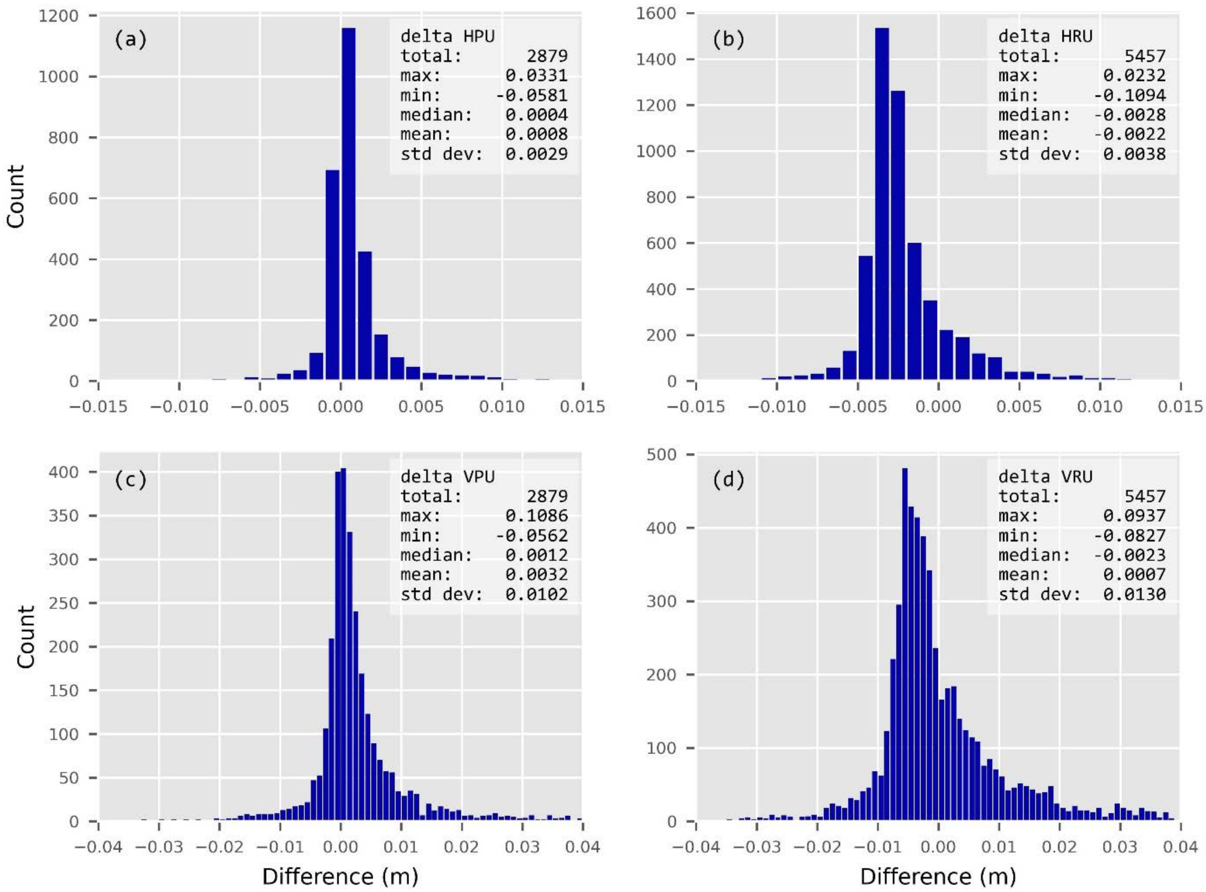


Figure 9: Histograms of changes in GDA2020 (a) HPU, (b) HRU, (c) VPU and (d) VRU. Differences are computed as cluster-solution uncertainty minus single-solution uncertainty.

Such small improvement in RU may come as a surprise. On first consideration, one would expect that stations observed concurrently and processed together should have a more precisely determined relative position, which would yield improved RU. However, the variance-covariance matrix provided by AUSPOS may not be well suited to RU computations due to the large number of constraints employed by AUSPOS, which are constrained at 1 mm horizontally and 2 mm vertically (IGS stations) or 3 mm horizontally and 6 mm vertically (other CORS). This likely decorrelates the uncertainty estimates at the user stations, resulting in RU values that are almost indistinguishable from those obtained when the observations are processed as discrete single solutions. This effect is readily seen in least squares network adjustments with very good connection to datum where the precision of the constraints ‘overpowers’ the measurements between stations. Even if this is the case, the minimal change in coordinates still supports the conclusion that AUSPOS cluster processing, in its current form, offers no real advantage over single processing.

On the other hand, the high quality of results in single mode across NSW may be in part due to the dense CORS network contributing to AUSPOS (Figure 10). The bar may be set so high that little benefit is gained with the supply of additional observations between user stations.

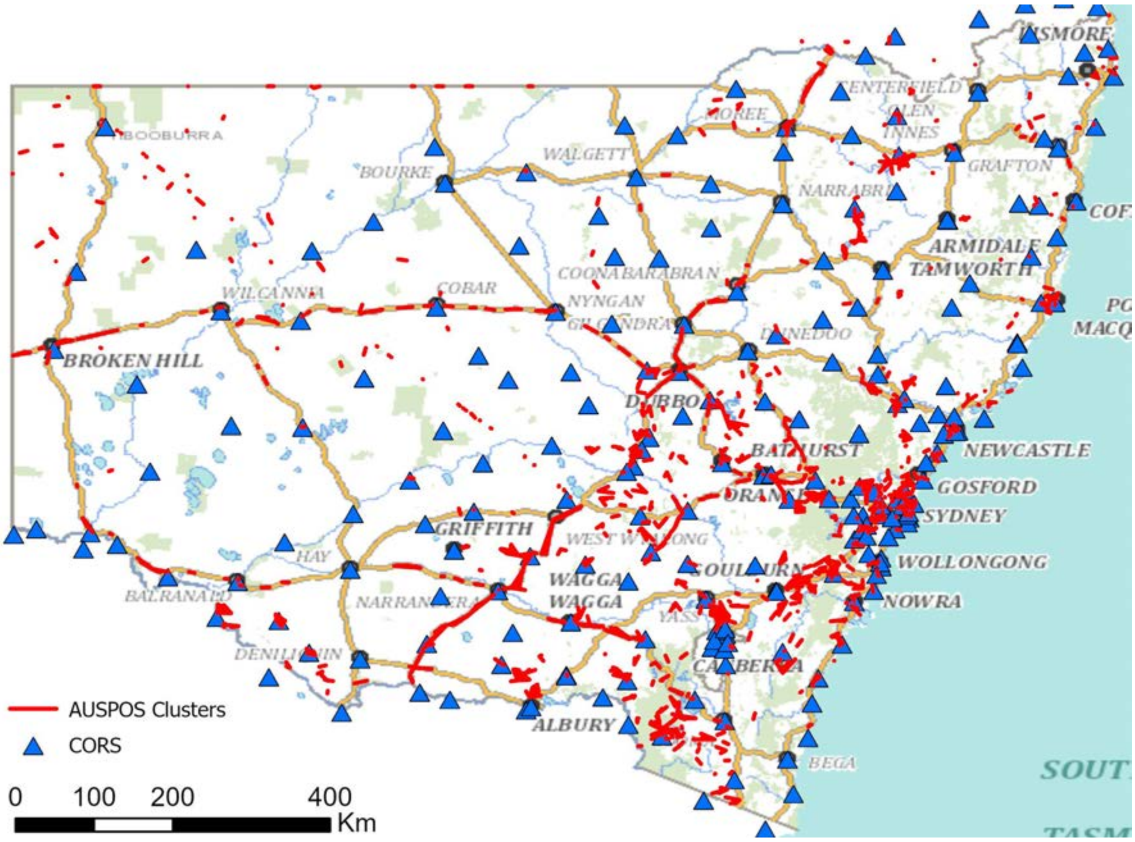


Figure 10: Baselines between user-submitted cluster stations with respect to the CORSnet-NSW network.

With no clear trend in RU between single-solution and cluster-solution, the change in RU was examined with respect to the distance between stations (Figure 11a). Additionally, it is noted that the full duration of each observation may not be utilised by AUSPOS depending on the observation overlap between stations which form a baseline. Such baselines are used by AUSPOS for ambiguity resolution, and therefore any section of observation which falls outside the overlapping window cannot be used by AUSPOS for this purpose. As such, the RU for each pair of stations was examined with respect to the overlapping observation time reported in the SINEX file (Figure 11b). In both cases, no discernible correlation was evident. This supports our earlier assertion that the large number of CORS constraints can cause a decorrelation of the uncertainty estimates at the user stations.

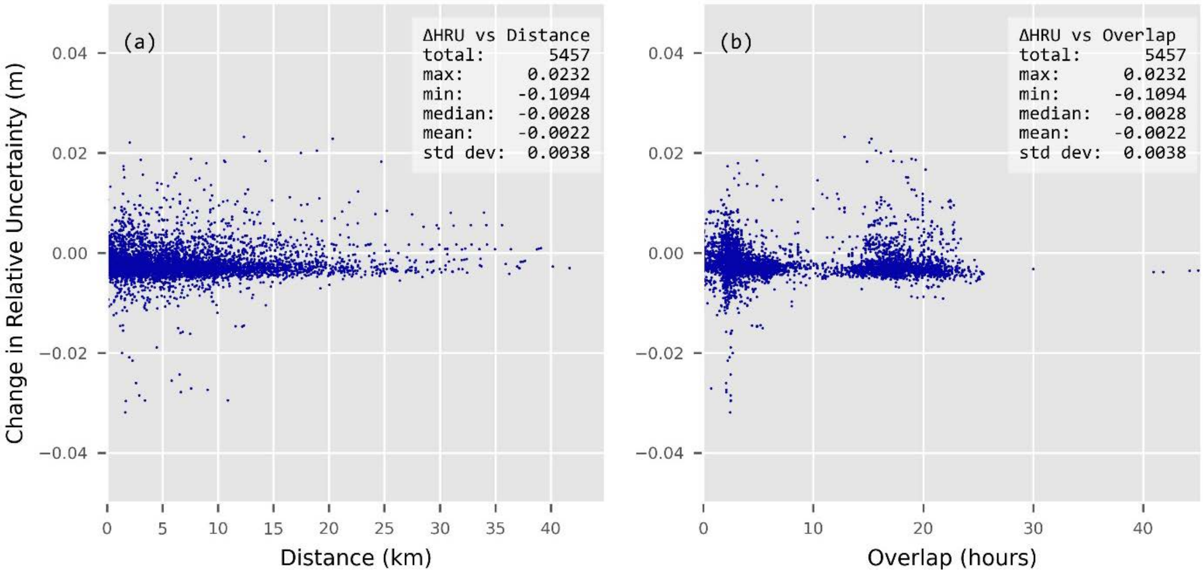


Figure 11: Scatter plot of changes in RU and their (a) station separation distance and (b) observation session overlap. Differences are computed by cluster-solution uncertainty minus single-solution uncertainty.

Similarly, no significant correlation was found between the change in RU and the cluster size (Figure 12). The decrease in standard deviation at the upper end should be weighed against the smaller sample sizes of available clusters. It should also be noted that the number of clusters stated here differs from those in Table 1 due to the large-uncertainty warnings encountered (see Figure 4). Affected stations were removed and the clusters then 're-sized' accordingly.

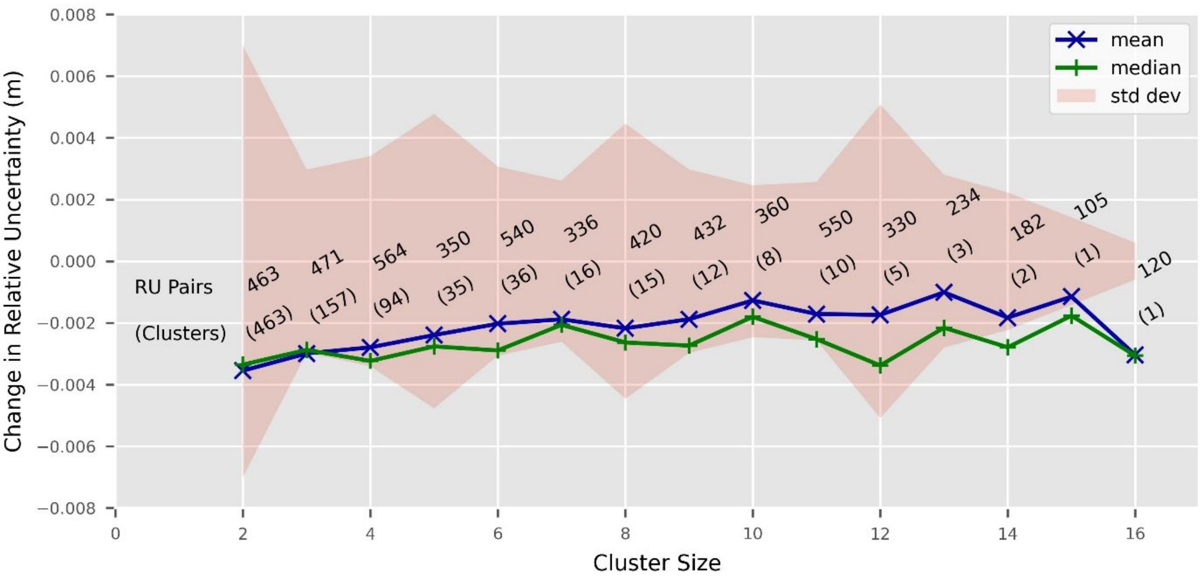


Figure 12: Changes in RU categorised by cluster size. Differences are computed by cluster-solution uncertainty minus single-solution uncertainty.

Finally, the experiment was rerun with the RU analysis restricted to only include pairs of stations where AUSPOS reported that a baseline had been formed during processing. With this constraint, 1,455 pairs of stations could have their RU analysed (Figure 13). These results were not significantly different to the full analysis (see Figures 9b & 9d).

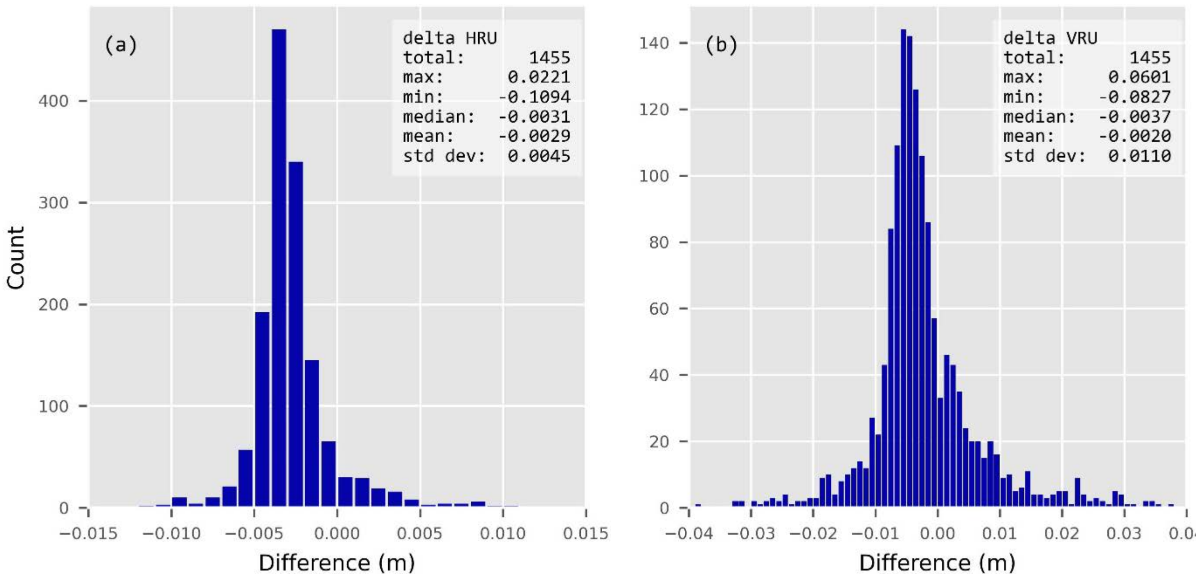


Figure 13: Histograms of changes in (a) HRU and (b) VRU between pairs of stations where AUSPOS has reported a baseline. Differences are computed by cluster-solution uncertainty minus single-solution uncertainty.

It should be noted that while the coordinates and uncertainties analysed here are based on the AUSPOS GDA2020 SINEX results, the AUSPOS ITRF2014 SINEX results were also reviewed and similarly showed little change between single and cluster processing. In the initial design of the study, we sought to additionally process observations from a purposely observed cluster campaign (i.e. a cluster as it would be planned and observed in surveying practice, see Figure 1b) through a traditional baseline processing engine in the event a ‘deciding vote’ was required. Given the results encountered here are statistically indistinguishable, this was abandoned.

Based on the results presented here, it can be concluded that AUSPOS positioning results do not significantly differ between single and cluster mode. Considering the additional effort required for field work planning and logistics, purpose-designed cluster networks offer little benefit, at least in regions covered by a dense CORS network such as NSW. Furthermore, in some instances, AUSPOS users may encounter more frequent large-uncertainty warnings where cluster-processing is employed (see Figure 4), especially at sites with challenging sky view conditions. If such problems are encountered, the user is advised to try single mode AUSPOS processing.

However, AUSPOS clustering may be more convenient for some users and applications because concurrently observed RINEX files can be submitted together in one job and the processing results are received in a single AUSPOS report. This is a decision of convenience rather than performance and will depend on the user’s preferences and the task at hand. In any case, AUSPOS continues to deliver high-quality positioning results via a sophisticated but convenient online service.

5 CONCLUDING REMARKS

This study has leveraged the extensive NSW GNSS Observation Archive to automatically form concurrently observed clusters and investigate the quality of results produced by AUSPOS in single-processing and cluster-processing modes. It incorporated AUSPOS processing of about 3,000 observation files and 900 clusters of varying size across the state.

Based on an analysis of absolute and relative coordinate changes, Positional Uncertainty and Relative Uncertainty, no significant change is detected between the single and cluster processing strategies. A slight improvement in RU may exist, but this is not apparent in the SINEX variance-covariance matrix, likely due to the decorrelating effect of tightly constraining the reference stations. Even if a variance-covariance matrix based on a minimally constrained AUSPOS solution could provide a theoretical improvement to the estimate of RU, the average changes to absolute and relative positions are all below one millimetre and are virtually undetectable, thereby making no difference in real-world applications. For sites with challenging sky view conditions due to tree cover or other obstructions, using the single-processing mode may be more robust than processing observations as a cluster. In practice, utilising AUSPOS in single or cluster mode is a decision of convenience rather than performance, at least in NSW.

REFERENCES

Altamimi Z., Rebischung P., Collilieux X., Métivier L. and Chanard K. (2023) ITRF2020: An augmented reference frame refining the modeling of nonlinear station motions, *Journal of Geodesy*, 97(5), 47.

Altamimi Z., Rebischung P., Métivier L. and Collilieux X. (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, *Journal of Geophysical Research: Solid Earth*, 121(8), 6109-6131.

DCS Spatial Services (2021) Surveyor-General's Direction No. 12: Control Surveys and SCIMS, https://www.spatial.nsw.gov.au/surveying/surveyor_generals_directions (accessed Mar 2024).

DCS Spatial Services (2024a) CORSnet-NSW, http://www.corsnet.com.au/ (accessed Mar 2024).

DCS Spatial Services (2024b) DCS Spatial Services Customer Hub, https://customerhub.spatial.nsw.gov.au/servicedesk/customer/portals (accessed Mar 2024).

GA (2024a) AUSPOS – Online GPS processing service, http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos (accessed Mar 2024).

GA (2024b) Asia-Pacific Reference Frame (APREF), https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/asia-pacific-reference-frame (accessed Mar 2024).

GA (2024c) GeodePy – A toolkit for geodesy and surveying in Python, https://github.com/GeoscienceAustralia/GeodePy (accessed Mar 2024).

Gowans N. and Grinter T. (2013) Tying it all together: CORSnet-NSW local tie surveys, *Proceedings of Association of Public Authority Surveyors Conference (APAS2013)*, Canberra, Australia, 12-14 March, 104-119.

Gowans N., McElroy S. and Janssen V. (2015) Survey infrastructure preservation and upgrade: Trigonometrical stations in NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2015)*, Coffs Harbour, Australia, 16-18 March, 67-84.

Harrison C., Brown N., Dawson J. and Fraser R. (2023) Geocentric Datum of Australia 2020: The first Australian datum developed from a rigorous continental-scale adjustment, *Journal of Spatial Science*, https://doi.org/10.1080/14498596.2023.2184429 (accessed Mar 2024).

Hu G. and Dawson J. (2020) Overview of legal traceability of GPS positioning in Australia, *Satellite Navigation*, 1, 25, https://doi.org/10.1186/s43020-020-00026-8.

ICSM (2020) Standard for the Australian survey control network (SP1), version 2.2, https://www.icsm.gov.au/publications/standard-australian-survey-control-network-special-publication-1-sp1 (accessed Mar 2024).

ICSM (2021) Australian Vertical Working Surface (AVWS) technical implementation plan, version 1.6, https://www.icsm.gov.au/publications/australian-vertical-working-surface-technical-implementation-plan-v16 (accessed Mar 2024).

IGS (2024a) International GNSS Service products, https://www.igs.org/products (accessed Mar 2024).

IGS (2024b) IGS formats and standards, https://www.igs.org/formats-and-standards/ (accessed Mar 2024).

IERS (2006) SINEX – Solution Independent Exchange format, version 2.02, https://www.iers.org/IERS/EN/Organization/AnalysisCoordinator/SinexFormat/sinex.html (accessed Mar 2024).

Janssen V. (2024) Understanding the RINEX format, *Proceedings of Association of Public Authority Surveyors Conference (APAS2024)*, Canberra, Australia, 18-20 March, 3-18.

Janssen V., Haasdyk J. and McElroy S. (2016) CORSnet-NSW: A success story, *Proceedings of Association of Public Authority Surveyors Conference (APAS2016)*, Leura, Australia, 4-6 April, 10-28.

Janssen V. and McElroy S. (2020) Assessment of AUSPOS performance in New South Wales, Australia, *Proceedings of IGNSS Symposium 2020 (IGNSS2020)*, Sydney, Australia, 5-7 February, 17pp.

Janssen V. and McElroy S. (2021) The Australian Height Datum turns 50: Past, present & future, *Proceedings of APAS Webinar Series 2021 (AWS2021)*, 24 March – 30 June, 3-27.

Janssen V. and McElroy S. (2022) A practical guide to AUSPOS, *Proceedings of Association of Public Authority Surveyors Conference (APAS2022)*, Leura, Australia, 21-23 March, 3-28.

Jia M., Dawson J. and Moore M. (2016) Upgraded AUSPOS and refined solution uncertainty, presented at IGNSS Symposium 2016 (IGNSS2016), Sydney, Australia, 6-8 December.

The Realisation of AUSPOS Based on ITRF2020/IGS20

Carl Wang
GNSS Analysis Section, Geoscience Australia
Carl.Wang@ga.gov.au

Anna Riddell
GNSS Analysis Section, Geoscience Australia
Anna.Riddell@ga.gov.au

Umma Zannat
GNSS Analysis Section, Geoscience Australia
Umma.Zannat@ga.gov.au

Salim Masoumi
GNSS Analysis Section, Geoscience Australia
Salim.Masoumi@ga.gov.au

ABSTRACT

A new global reference frame, the International Terrestrial Reference Frame 2020 (ITRF2020), was released in October 2022 by the International Earth Rotation and Reference Systems Service (IERS), which was followed by the International GNSS Service (IGS) realisation using modernised products and analysis, called IGS20. This presentation outlines the adoption of ITRF2020/IGS20 across Geoscience Australia's GNSS Analysis products and services, including the introduction of a 2-step transformation strategy deployed in AUSPOS to provide access to the national datum, the Geocentric Datum of Australia 2020 (GDA2020). AUSPOS is a free online GPS data processing service provided by Geoscience Australia and recommended by the Intergovernmental Committee on Surveying and Mapping (ICSM) for control surveys by GNSS in the Australian region. To align with the best available global reference frame available, AUSPOS is being updated from ITRF2014/IGb14 to ITRF2020/IGS20. We are committed to being the trusted provider of analytic products and services by enhancing the accuracy and reliability of positioning in Australia. In the Australian region, GDA2020 is the commonly used datum for a diverse range of positioning applications. AUSPOS provides access to the national datum by providing GDA2020 coordinates if the user's data is collected in the Australian region. By definition, GDA2020 is aligned to ITRF2014/IGb14. With the upgrade of AUSPOS to be ITRF2020/IGS20 compatible, a transformation from ITRF2020/IGS20 to ITRF2014/IGb14 is needed in order to provide GDA2020 coordinates.

KEYWORDS: *AUSPOS, GDA2020, ITRF2020, datum modernisation, transformation.*

Hierarchy of Evidence in Rural Cadastral Surveying: Pushing the Boundaries at Carmel Lane, Baradine

Thomas Casey
Casey Surveying and Design
thomas@csad.com.au

ABSTRACT

According to the well-established hierarchy of evidence for cadastral surveying in NSW, marks placed in Crown surveys lie only second to natural features. But what happens if a surveyor finds Crown marks from more than one survey, and the evidence from one survey differs considerably from another? What takes precedence, and where is the boundary? In order to show a boundary not agreeing with Crown marks, a surveyor must make extra sure they have conducted a complete search of the public record and of the available field evidence. This was the dilemma facing the author as he progressed through the definition of the boundaries involved in a 7 km rail corridor survey at Carmel Lane, west of Baradine in north-western NSW as part of the land acquisition and dedication process for the Narromine to Narrabri section of the Australian Rail Track Corporation (ARTC) Inland Rail Project between Brisbane and Melbourne. This presentation outlines the survey project, which received the 2023 Excellence in Surveying and Spatial Information (EISSI) award in the 'Rural Cadastral Surveying & Land Titling' category. The survey defined the land for the new rail corridor through five large rural portions and across the Baradine to Coonamble Road. Two plans of survey were to be prepared, along with a subdivision plan for the privately owned portions and an acquisition plan for where the rail corridor affected the road. Pre-survey analysis of the plan search revealed several concerns not only with the original 1895 surveys, but also with the differences between them and the subsequent surveys of 1912 and 1919. Searching for the original 1895 reference trees, corner marks and iron pipes was crucial to the correct definition of Carmel Lane, while reference to the original 1895 field notes was also required to investigate the concerns raised. Following a thorough search, several of the original pegs and reference trees were found in the field, providing the required evidence to move the boundary definition from a Crown survey. In the end, it was a combination of the surveyor's field ability and experience, along with the dogged determination to leave no stone unturned to re-establish the boundary and find the best or 'correct' result that ended solving the Carmel Lane problem.

KEYWORDS: *Cadastral surveying, hierarchy of evidence, Crown marks, Inland Rail.*

Using SAR and Coherent Change Detection to Map Erosion in the Quilpie Region, Queensland

Kyran Cook
School of Surveying and Built Environment
University of Southern Queensland
Kyran.Cook@unisq.edu.au

ABSTRACT

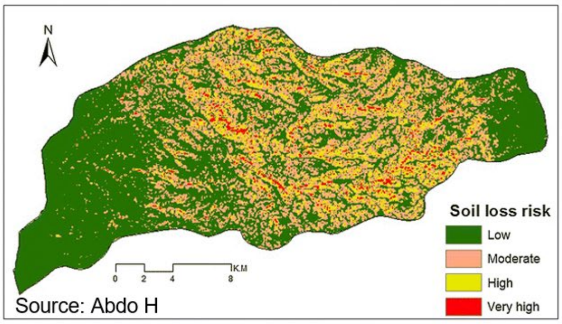
Erosion is a powerful force that has moulded the Earth ever since water has been present on its rocky surface. In its seemingly harmless pursuit, erosion threatens ecosystems, reduces agricultural production and impacts water quality. When trying to investigate erosion, there is no easy way to identify hotspots, only leaving the possibility of predicting where erosion should be occurring. This study aimed to develop a method to identify erosion using Synthetic Aperture Radar (SAR) images in a process called Coherent Change Detection (CCD) and was conducted in the Quilpie region, Queensland. It was found that CCD can be used to positively identify erosion due to rain events but also has false positives due to soil moisture changes. This study used a unique method for removing soil moisture that did limit the false positives, but more work is required to ensure soil moisture does not interfere with the results. Nevertheless, with the results from this study, it is still possible to create a near real-time erosion analysis system for arid regions. This presentation is based on the author's undergraduate Honours research project at the University of Southern Queensland (UniSQ), which was awarded the APAS UniSQ Student Project Prize 2023. The results are reported in a paper entitled 'Mapping Erosion Hotspots: Coherent Change Detection Study in the Quilpie Region', which has been submitted to the journal Remote Sensing.

KEYWORDS: *Erosion, Synthetic Aperture Radar (SAR), Coherent Change Detection (CCD).*

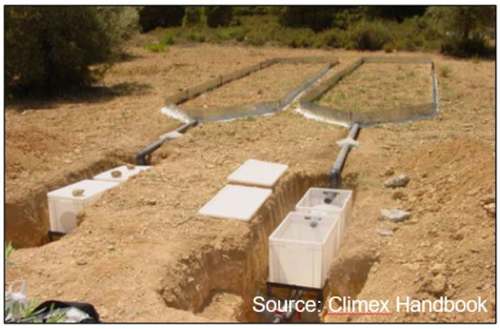
Erosion

Ways to Measure to Erosion

Predictive Models



Observation Analysis



SAR and Coherence

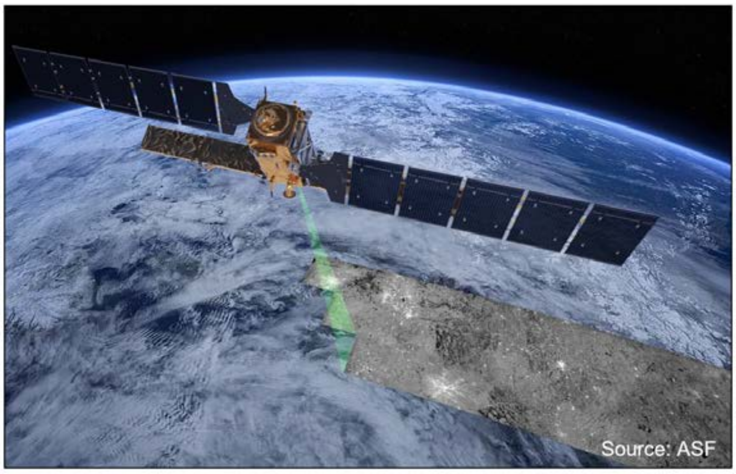
$$\text{Coherence} = \Upsilon_{geometric} \cdot \Upsilon_{volume} \cdot \Upsilon_{thermal} \cdot \Upsilon_{temporal}$$

Advantages
- Active Sensor
- Can be used in all weather conditions
- Large amounts of data
- Can detect small changes

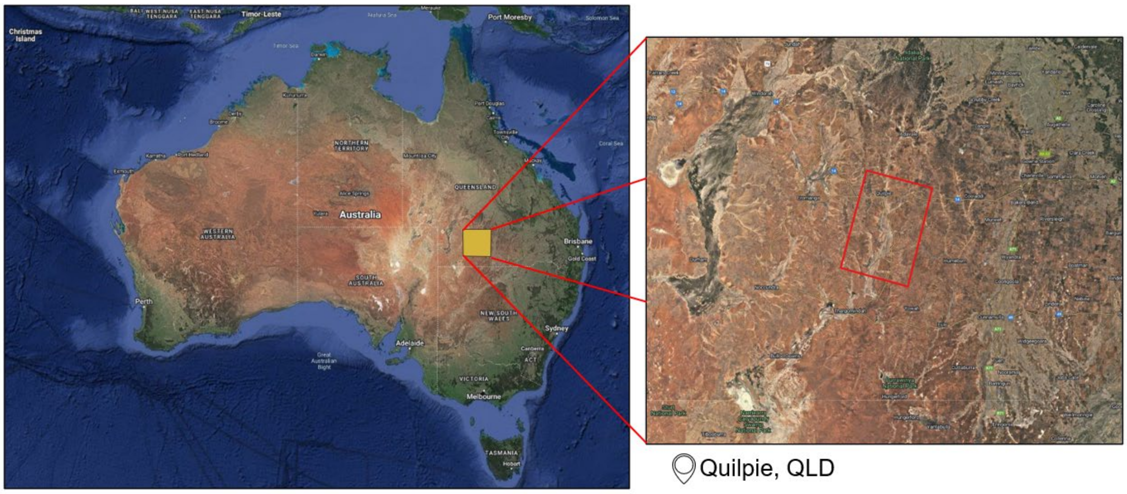
Data

Sentinel-1
- Resolution: 20m by 5m

Sentinel-2
- Resolution: 20m by 20m
- Band 5 – VNIR
- Band 11 – SWIR



Study Area

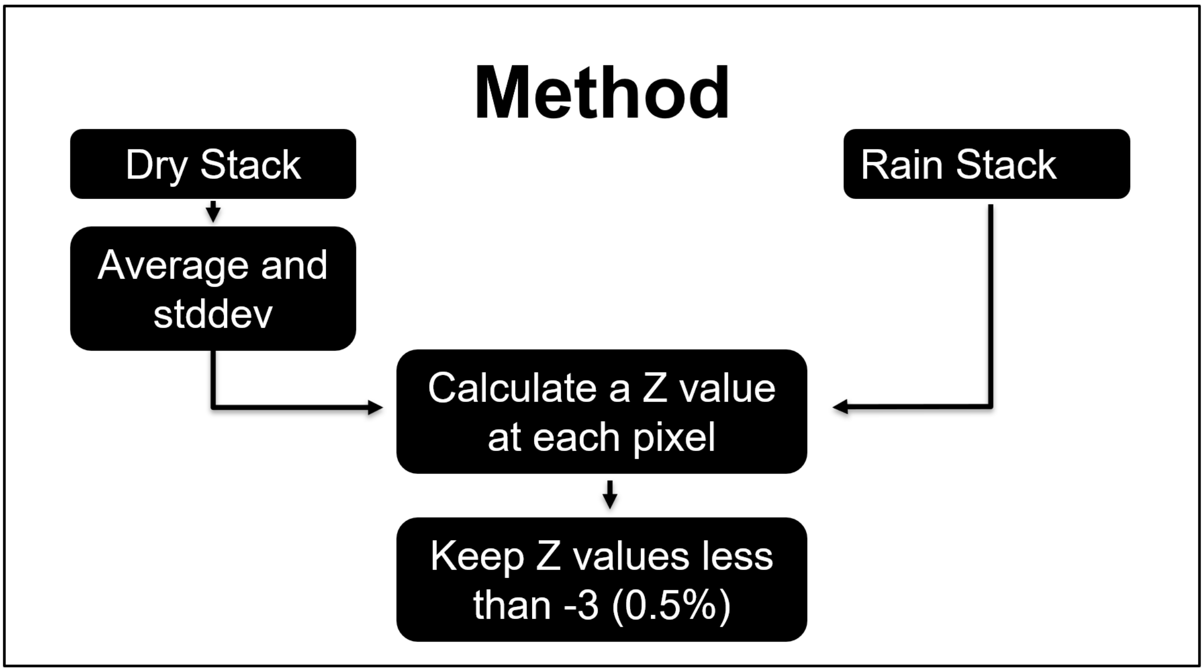


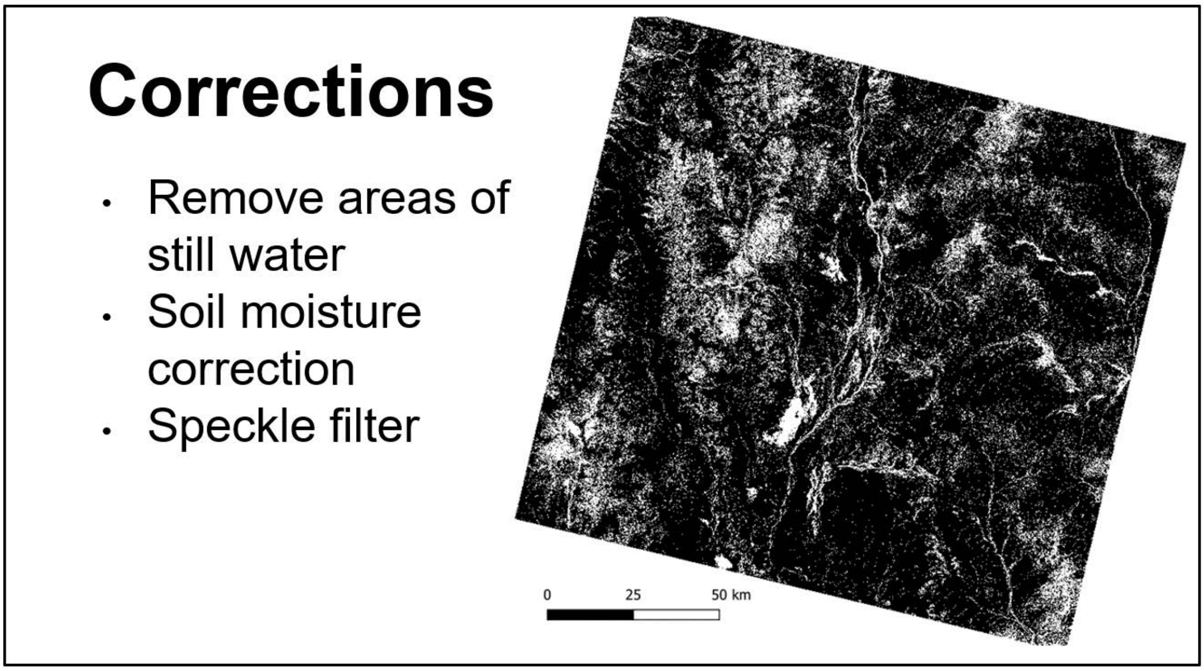
Method

Phase 1: Erosion Identification

Phase 2: Field Study

Phase 3: Time Series Analysis

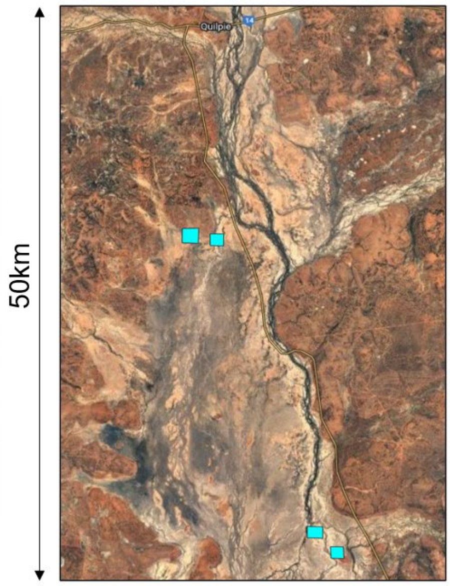

Method
Dry Stack
Rain Stack
Average and stddev
Calculate a Z value at each pixel
Keep Z values less than -3 (0.5%)


Corrections
• Remove areas of still water
• Soil moisture correction
• Speckle filter
0
25
50 km

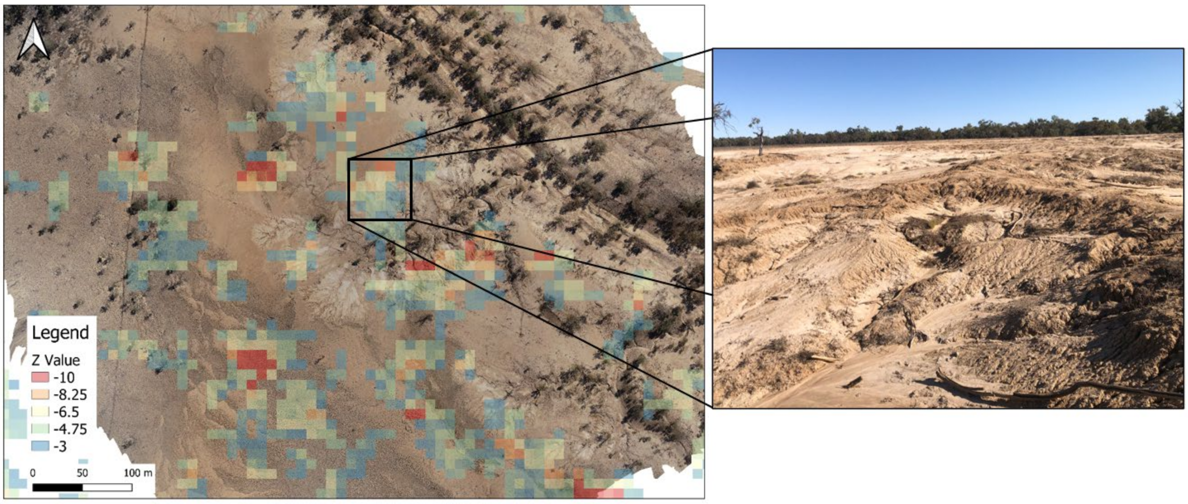
Field Work

Soil Samples
Shear Strength

Site	kPa
1	29.15
2	25.43
3	27.14
4	27.67



Results



Validation

$$\text{Coherence} = \cancel{\Upsilon_{geometric}} \cdot \cancel{\Upsilon_{thermal}} \cdot \Upsilon_{volume} \cdot \Upsilon_{temporal}$$

Geometric

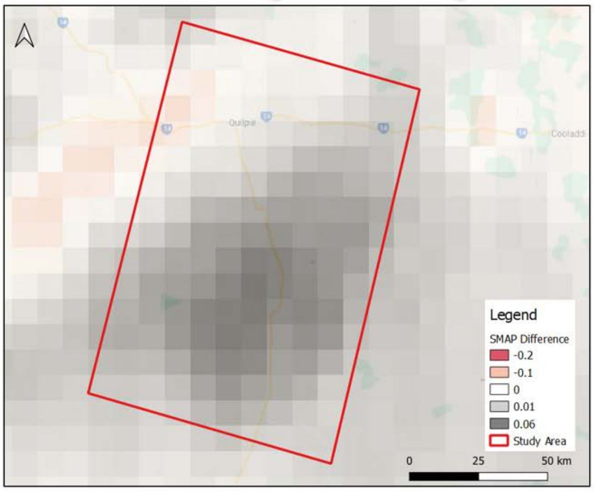
Number	Baseline (m)
SAR 1	81.54
SAR 2	31.47
SAR 3	29.73
SAR 4	32.82
SAR 14	147.65
SAR 15	36.22
SAR 16 Reference	0
SAR 17	58.13
SAR 18	25.01
SAR 32	43.04
SAR 33	23.89
SAR 34	46.06

Thermal

- Thermal factors are difficult to correct for
- Averaging
- Filtering

Validation - Volume

$$\text{Coherence} = \cancel{\Upsilon_{geometric}} \cdot \cancel{\Upsilon_{thermal}} \cdot \cancel{\Upsilon_{volume}} \cdot \Upsilon_{temporal}$$



Time Series Analysis

Implications

- More efficient observational erosion analysis
- Possibility of real-time erosion analysis

Adjusting to GDA2020: SCIMS, the NSW State Adjustment and You

Joel Haasdyk
DCS Spatial Services
NSW Department of Customer Service
Joel.Haasdyk@customerservice.nsw.gov.au

Nicholas Gowans
DCS Spatial Services
NSW Department of Customer Service
Nicholas.Gowans@customerservice.nsw.gov.au

Simon McElroy
DCS Spatial Services
NSW Department of Customer Service
Simon.McElroy@customerservice.nsw.gov.au

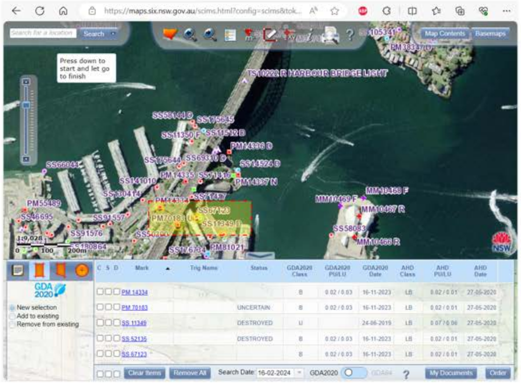
ABSTRACT

This presentation provides an update on the status of the Geocentric Datum of Australia 2020 (GDA2020) in the Survey Control Information Management System (SCIMS) and our progress towards bringing GDA2020 adjusted coordinates with a calculated accuracy to a street-corner near you. SCIMS is currently 'refreshed' every 6 months based on an immense (and ever-growing) 3D least squares network adjustment of more than a million geodetic and survey observations across NSW. This adjustment now underpins the GDA2020 realisation of the NSW survey control network and directly connects local survey marks to the Australian Fiducial Network (AFN), which defines GDA2020. This connection allows the rigorous calculation of Positional Uncertainty (PU) and Local Uncertainty (LU) with respect to datum. Significant automation developed in-house has supported a much faster-than-anticipated re-adjustment of our historic survey data archives from GDA94 to GDA2020, including the majority of street-corner control in urban areas. This feat, originally expected to require 10-20 years, has been largely completed in the 6 years since GDA2020 was defined. We also acknowledge additional process improvements that aim to facilitate the quick turn-around of new data and make SCIMS metadata-rich, leveraging all contributions from the wider survey community. These include improved business-as-usual data flows, a monthly ingestion of AUSPOS submissions, metadata archaeology from our hardcopy archives, and the much-anticipated 'LandXML to SCIMS' project. An added benefit of this 'big picture' perspective has been the easier identification of issues such as stand-point (mis)naming and discontinuities. Currently, SCIMS contains more than 309,000 survey marks (including witness marks and destroyed marks), 69% of which are now 'established' in GDA2020 and of those 72% have Horizontal Positional Uncertainty (HPU). In terms of height, 41% are 'accurate' in the Australian Height Datum (AHD) and of those 64% have an AHD Positional Uncertainty (AHD-PU). Approximately 20% of SCIMS are 'witness' marks or have a status of 'destroyed', 'uncertain' or 'subsidence', but omitting these marks does not significantly alter the statistics reported above.

KEYWORDS: *GDA2020, SCIMS, adjustment, Positional Uncertainty, datum modernisation.*

SCIMS Survey Control Information Management System
What is it?

SIX Maps - SCIMS Online
https://six.nsw.gov.au



Delivers GDA2020 (from July 2019)
Delivers GDA94 (for historic data)

- GDA2020 (3D) and AHD coordinates
- Class, PU, LU (more on this later)
- other useful metadata...

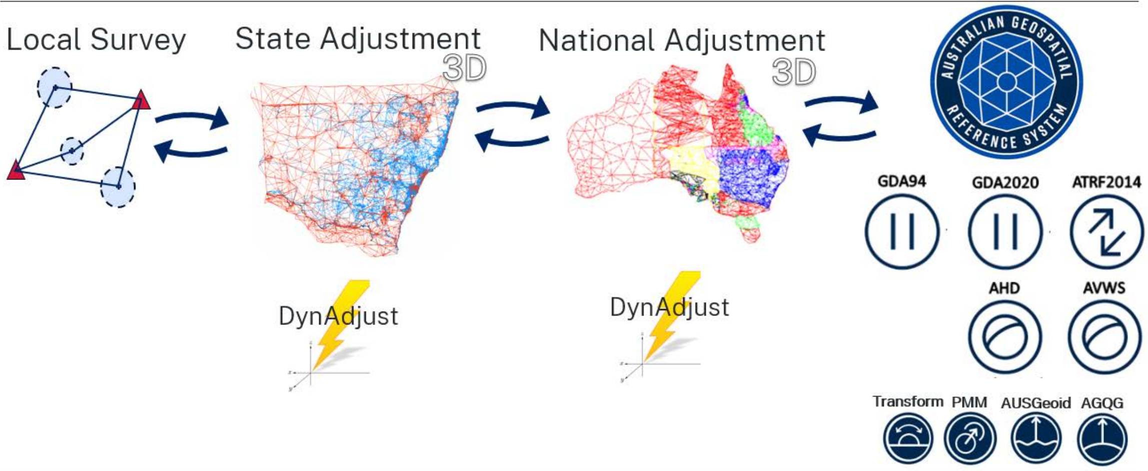
SCIMS SURVEY MARK REPORT AS AT: 16-FEB-2024

Your Reference: null Search Number: 1137137

MARK NAME STATUS	COORDINATES AND HEIGHTS				CLASS	PU	LU	SOURCE	CSF CONVERGENCE AUSGEOID2020
PM 70947	Horizontal coordinates are adjusted (or initialised) in GDA2020								
	MGA2020	308439.445	6183122.367	56	C	0.02	0.03	301416	1.000048
	GDA2020	-34° 28' 32.54033"	150° 54' 50.86549"						-1° 10' 51.89"
FOUND INTACT	GDA2020	Ellipsoidal Height		27.	U			300777	
	AHD71	Normal-Orthometric		6.625	L2A			216391	20.601
TS 12067	Horizontal coordinates are adjusted (or initialised) in GDA2020								
PORT KEMBLA CORS [P]	MGA2020	308399.664	6183139.724	56	3A	0.01	0.02	301416	1.000047
	GDA2020	-34° 28' 31.95059"	150° 54' 49.32102"						-1° 10' 52.75"
RESTRICTED ACCESS	GDA2020	Ellipsoidal Height		34.446	2A	0.02	0.03	301416	
	AHD71	Normal-Orthometric		13.836	A			234136	20.603

Department of Customer Service 2

NSW State adjustment
Part of the bigger picture



Department of Customer Service 3

NSW State adjustment
A few novel ideas

NSW GOVERNMENT

No HIERCARCHY of control; No primary, secondary, tertiary control
- Control is NOT FIXED, but CONSTRAINED
- Control is allowed to move (within uncertainty)

A single adjustment across NSW
- all available survey measurements are used
- with estimate of accuracy / uncertainty
- rejecting measurements is a last resort; review and re-weight (where appropriate)

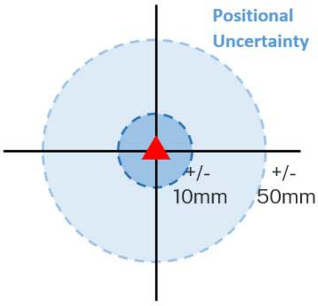
Observations have time-stamps
- station movement can be accounted for (with 'discontinuities')

Re-compute as required
- currently run monthly, for internal review
- ~16 hours to crunch the numbers

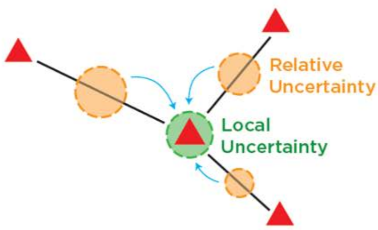
Department of Customer Service 4

NSW State adjustment
Uncertainty and Class (reported from SCIMS)

NSW GOVERNMENT



Positional Uncertainty (PU)
describes the accuracy of a point with respect to the datum (e.g. GDA2020 or AHD) (95% confidence)



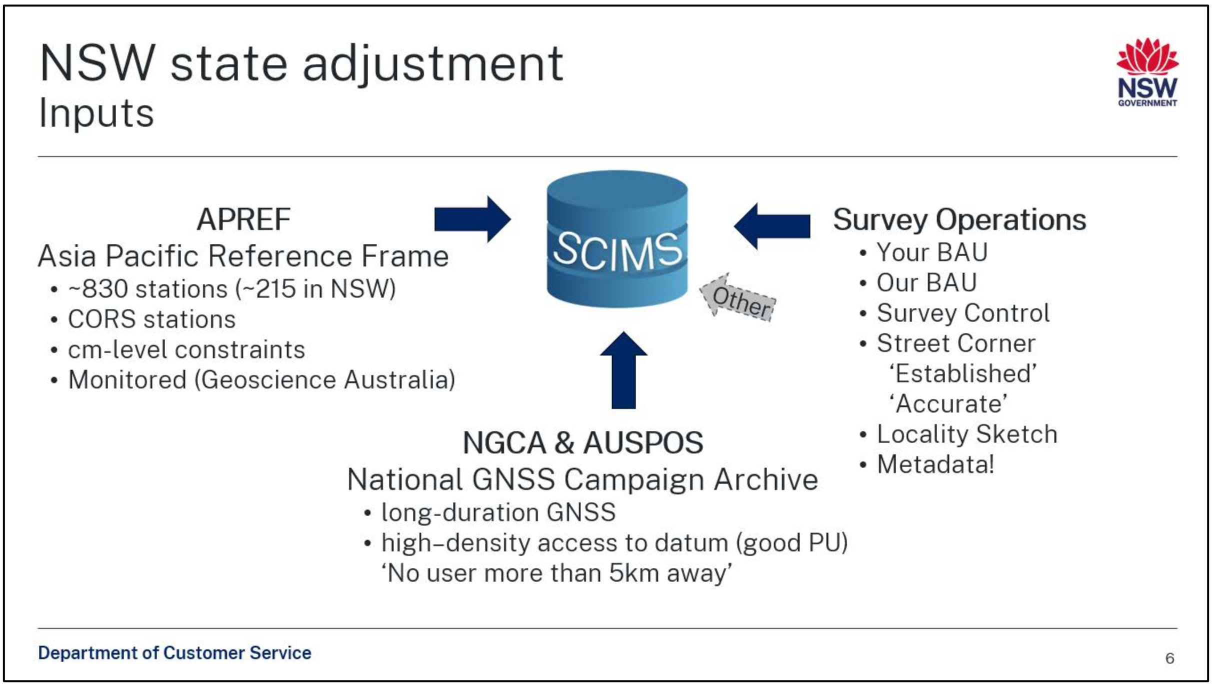
Local Uncertainty (LU)
describes the relative accuracy of a point derived from the survey connections to adjacent points

Class	Typical Application
3A	Special High Precision
2A	National Geodetic
A	State Geodetic
B	State Survey Control
C	Cadastral Survey Control
...	

Table, after SG_Direction_4

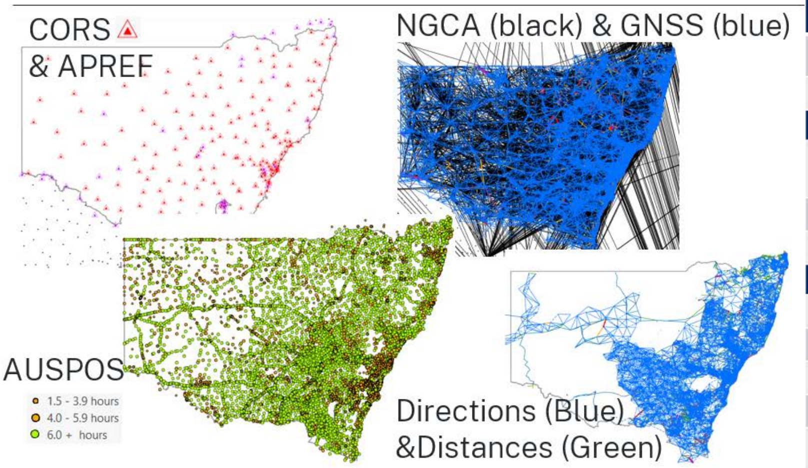
Class
describes the planned and achieved precision of a (local) survey network, incl: network design, survey method, equipment, Class of control, intent, mark type ...

Department of Customer Service 5



NSW state adjustment – Inputs

More data than ever before



How many, did you say?!

Item	Count
Total stations	**177,000**
Total MSR	**1,250,000**
Stations	
APREF / CORS	830 (~215 in NSW)
NGCA stns	~8,000
AUSPOS stns	~4,400
Measurements	
Xmsr (~NGCA)	71,000 (x, y, z)
Gmsr	360,000 (x, y, z)
Directions	325,000
Distances	340,000
Height (h)	130,000

Department of Customer Service

7

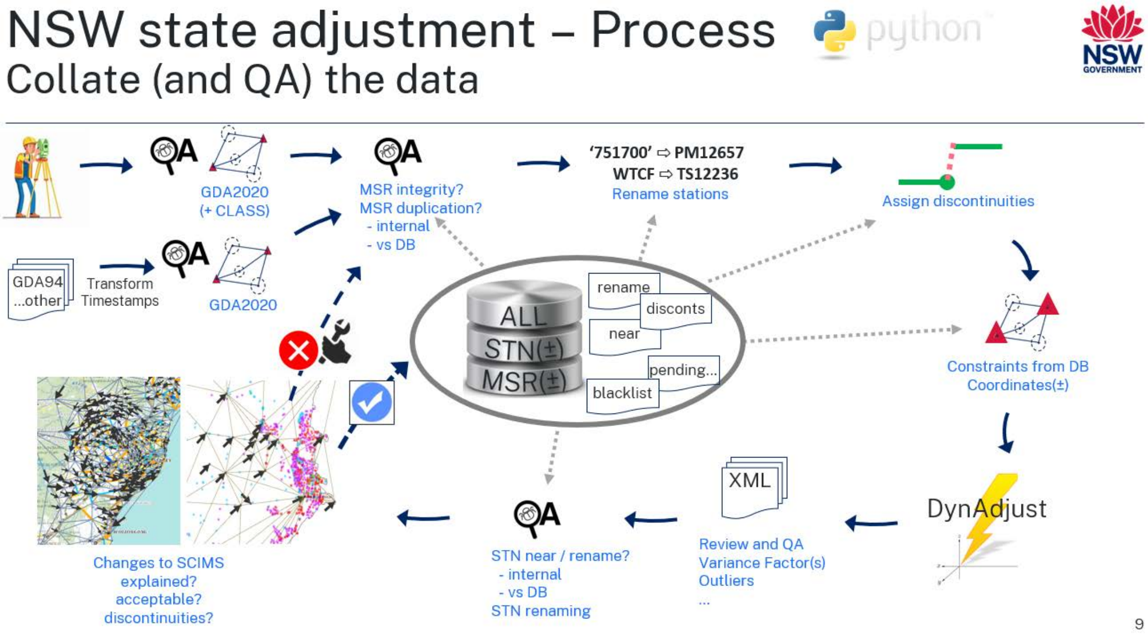
NSW state adjustment
What's NOT included?

- Not levelling (this is worthy of its own project)
- Not Airborne gravity
- Not LandXML data – **see S. Hine & J. Smith presentation this week!**
- Not for SCIMS marks without survey measures
  - e.g. Dept Main Roads (DMR) plans. Class B, but just GDA94 coords off a plan.
  - Some AGD66 > Tf GDA94 > Tf GDA2020, without data.
- Not (yet) our smaller historical data (e.g. < 10 marks in an adjustment)
- Emerging techniques (e.g. InSAR for deformation) – **see M. Bates presentation this week!**

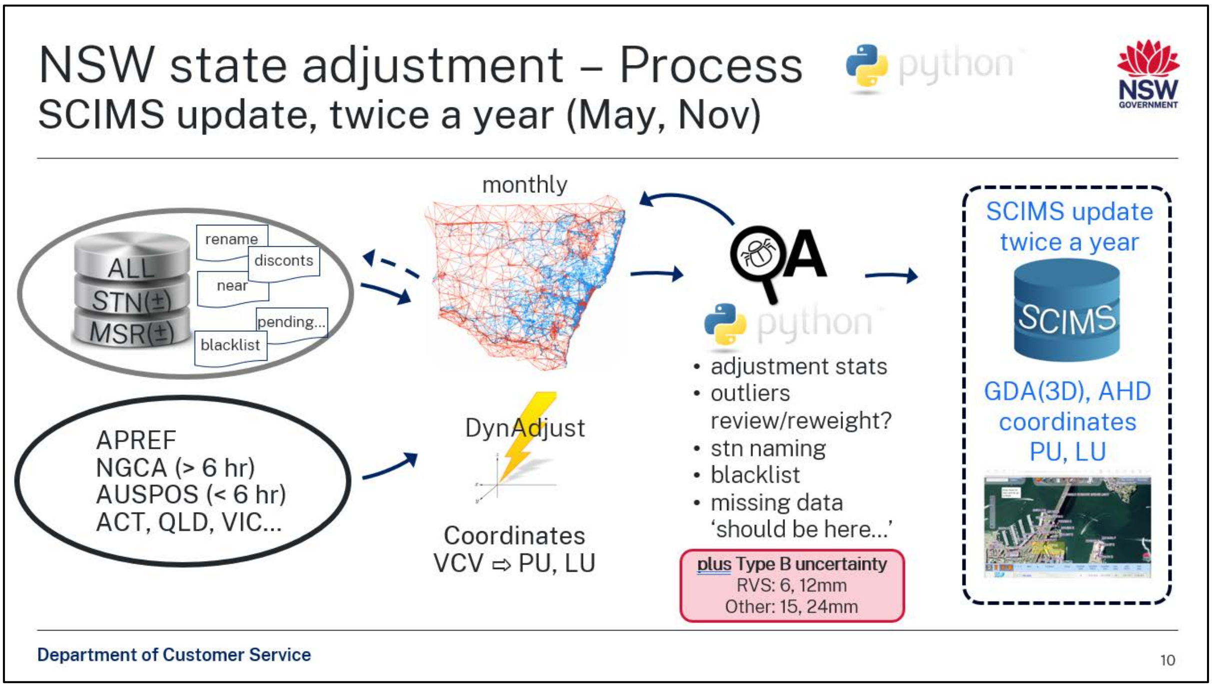
Department of Customer Service

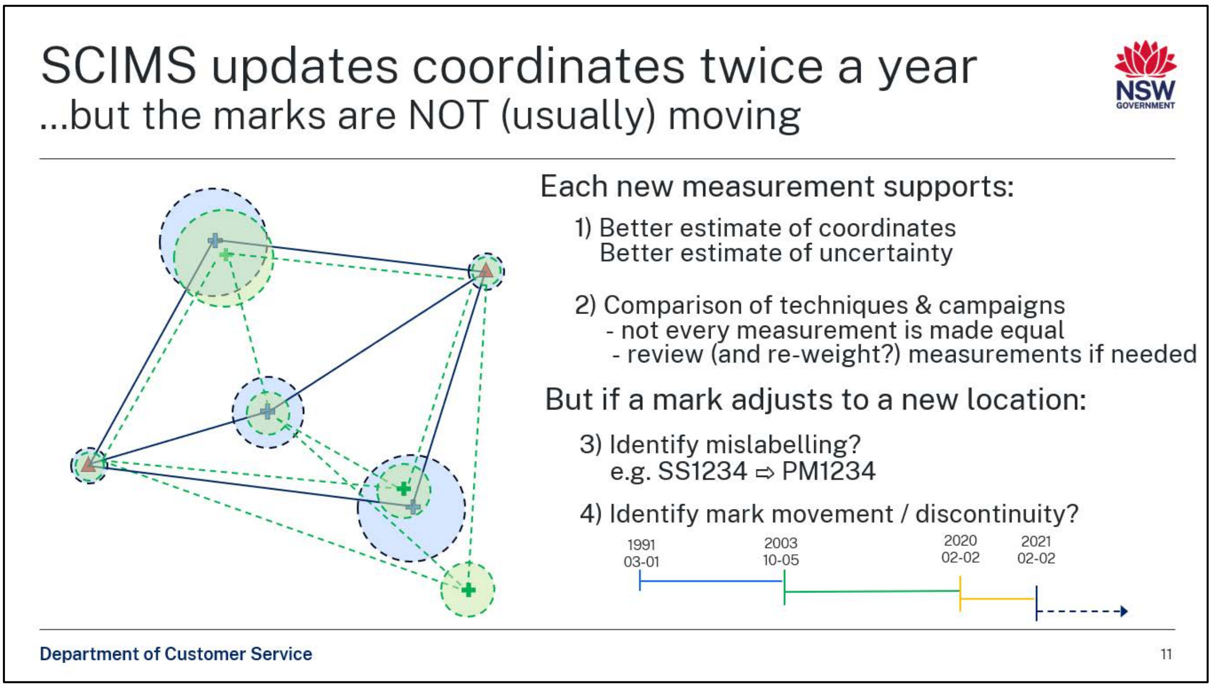
8

NSW state adjustment – Process
Collate (and QA) the data



9


NSW state adjustment – Process
SCIMS update, twice a year (May, Nov)
python
NSW GOVERNMENT
monthly
ALL
STN(±)
MSR(±)
rename
disconts
near
pending...
blacklist
APREF
NGCA (> 6 hr)
AUSPOS (< 6 hr)
ACT, QLD, VIC...
DynAdjust
Coordinates
VCV ⇨ PU, LU
QA
python
• adjustment stats
• outliers review/reweight?
• stn naming
• blacklist
• missing data 'should be here...'
plus Type B uncertainty
RVS: 6, 12mm
Other: 15, 24mm
SCIMS update twice a year
SCIMS
GDA(3D), AHD coordinates PU, LU
Department of Customer Service
10


SCIMS updates coordinates twice a year
...but the marks are NOT (usually) moving
NSW GOVERNMENT
Each new measurement supports:
1) Better estimate of coordinates
Better estimate of uncertainty
2) Comparison of techniques & campaigns
- not every measurement is made equal
- review (and re-weight?) measurements if needed
But if a mark adjusts to a new location:
3) Identify mislabelling?
e.g. SS1234 ⇨ PM1234
4) Identify mark movement / discontinuity?
1991 03-01
2003 10-05
2020 02-02
2021 02-02
Department of Customer Service
11

SCIMS updates
NSW State Adjustment, twice a year (May, Nov)

State Adjustment (May, Nov)
(* where we have measurements; ½ of SCIMS)

- Coordinates (rigorous, adj)
- PU, LU
- 'One' SourceID (for ½ of SCIMS)
  - e.g. 301416 GDA2020 3D
  - e.g. 301417 AHD (derived from EHGT)
- Does NOT change Class!
  - Except if Class E or U
  - ⇨ Class D (PU < 0.1m)
  - ⇨ Class E (PU < 1.0m)
- Does NOT touch Accurate AHD

SURVEY MARK

Mark	Name	Alias
TS 12067	PORT KEMBLA CORS [P]	PTKL

Status	Date	Comments
RESTRICTED ACCESS	21-NOV-2011	

Location	Monument	Date Placed	Placed By
GROUND LEVEL	CONC PILLAR	16-SEP-2009	LAND & PROPERTY INFORMATION -

MGA2020/GDA2020

Horizontal coordinates are adjusted (or initialised) in GDA2020

MGA2020 Easting	MGA2020 Northing	Zone	GDA2020 Latitude	GDA2020 Longitude
308399.664	6183139.724	56	-34° 28' 31.95059"	150° 54' 49.32102"

Class	Positional Uncertainty	Local Uncertainty	GDA2020 Updated
3A	0.01	0.02	16-NOV-2023

Source	Type	Method	Date issued	Issued By
301416	ADJUSTMENT	DYNADJUST	6-NOV-2023	JOEL HAASDYK

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

Comments
GDA2020 STATE ADJUSTMENT NOV 2023

... and similar for GDA2020 EHGT, and AHD71

Department of Customer Service

12

SCIMS updates
from all mechanisms

State Adjustment (May, Nov)
(* where we have measurements; ½ of SCIMS)

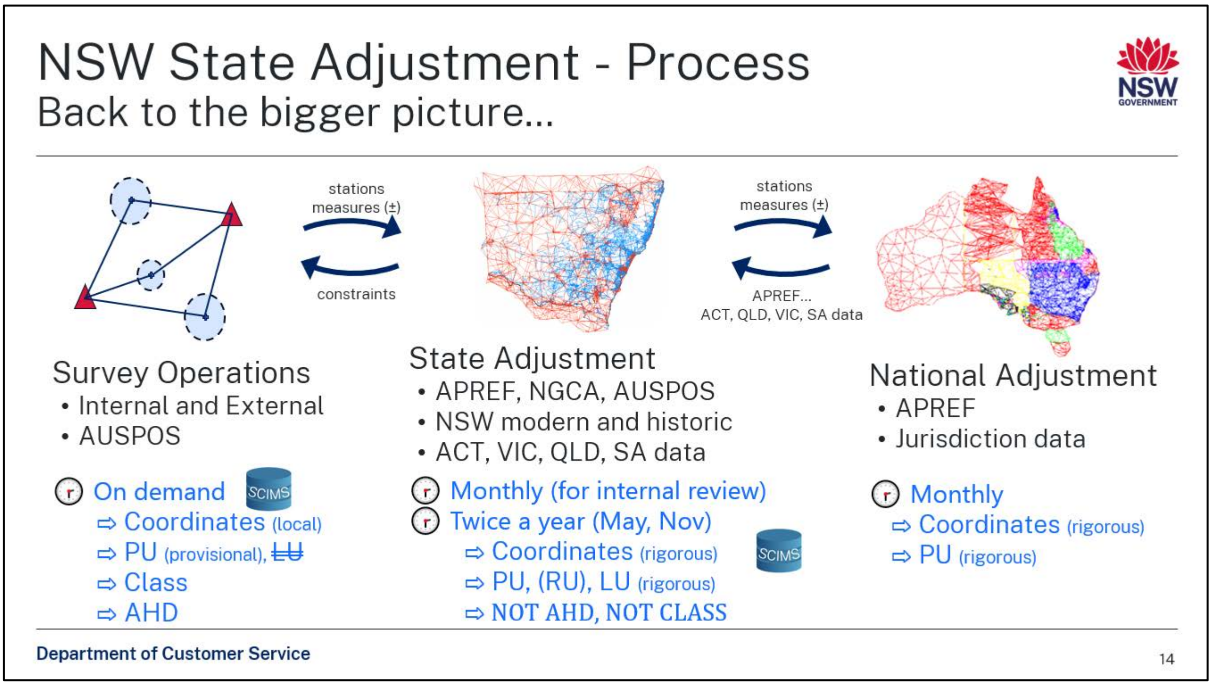
- Coordinates (rigorous, adj)
- PU, LU
- 'One' SourceID (for ½ of SCIMS)
  - e.g. 301416 GDA2020 3D
  - e.g. 301417 AHD (derived from EHGT)
- Does NOT change Class!
  - Except if Class E or U
  - ⇨ Class D (PU < 0.1m)
  - ⇨ Class E (PU < 1.0m)
- Does NOT touch Accurate AHD

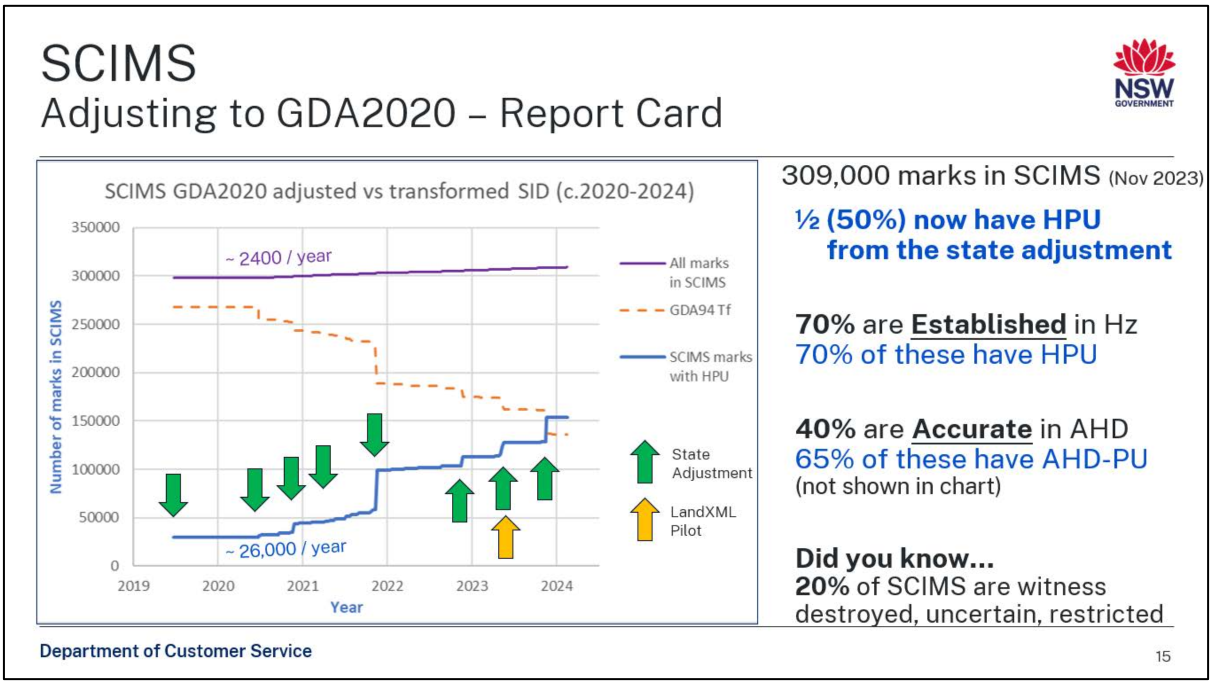
Other SCIMS update methods

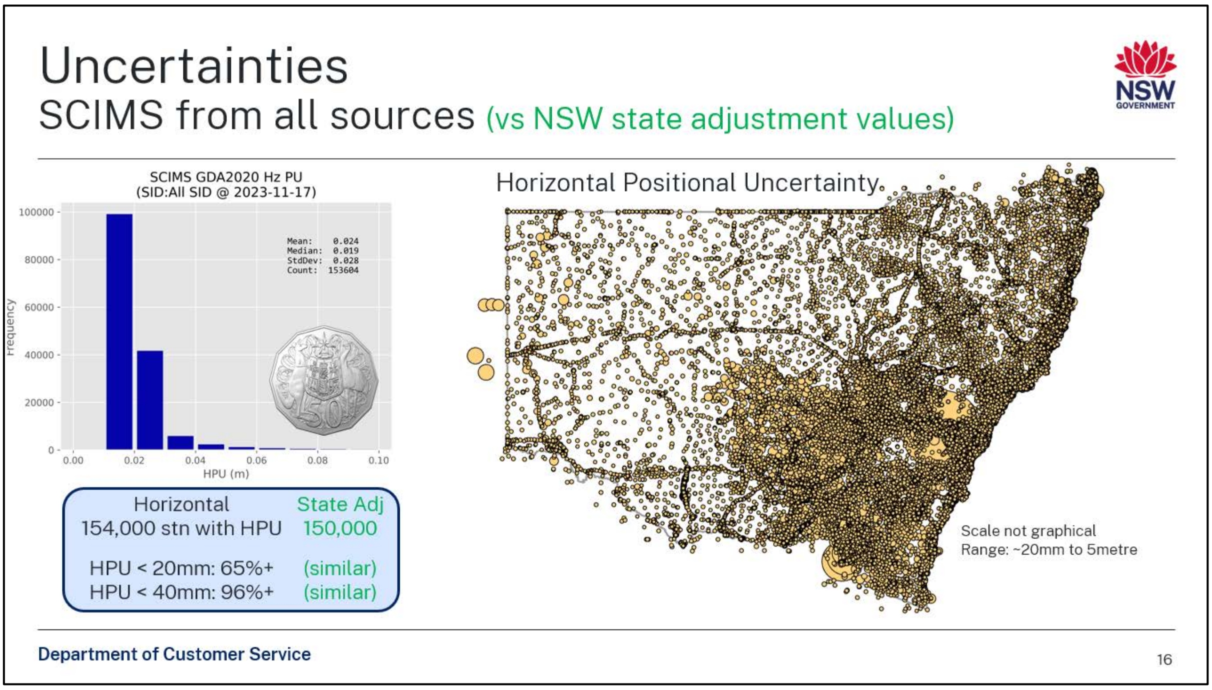
- SurveyOps (on demand, business as usual)
- AUSPOS (monthly; internal & external data)
- Edmark (new stations from LSPs; station updates)
- Missing heights: (twice a year: May, Nov)
  - AHD & EHGT from Surface Model (new marks)
  - AHD ⇔ EHGT
- Metadata
  - from digital logsheets
  - from photos
  - from LSP (data mine old LSP [pending])
  - from *NSW Survey Marks* app
- [and in Future: LandXML?... so much data!]

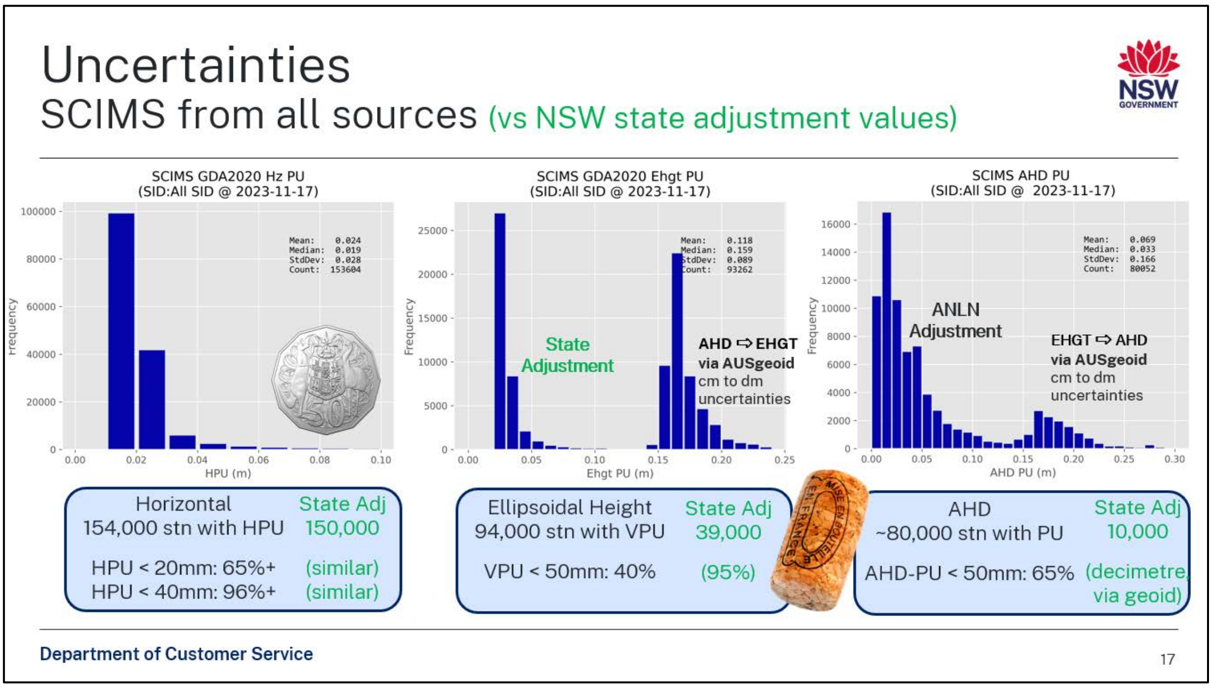
Department of Customer Service

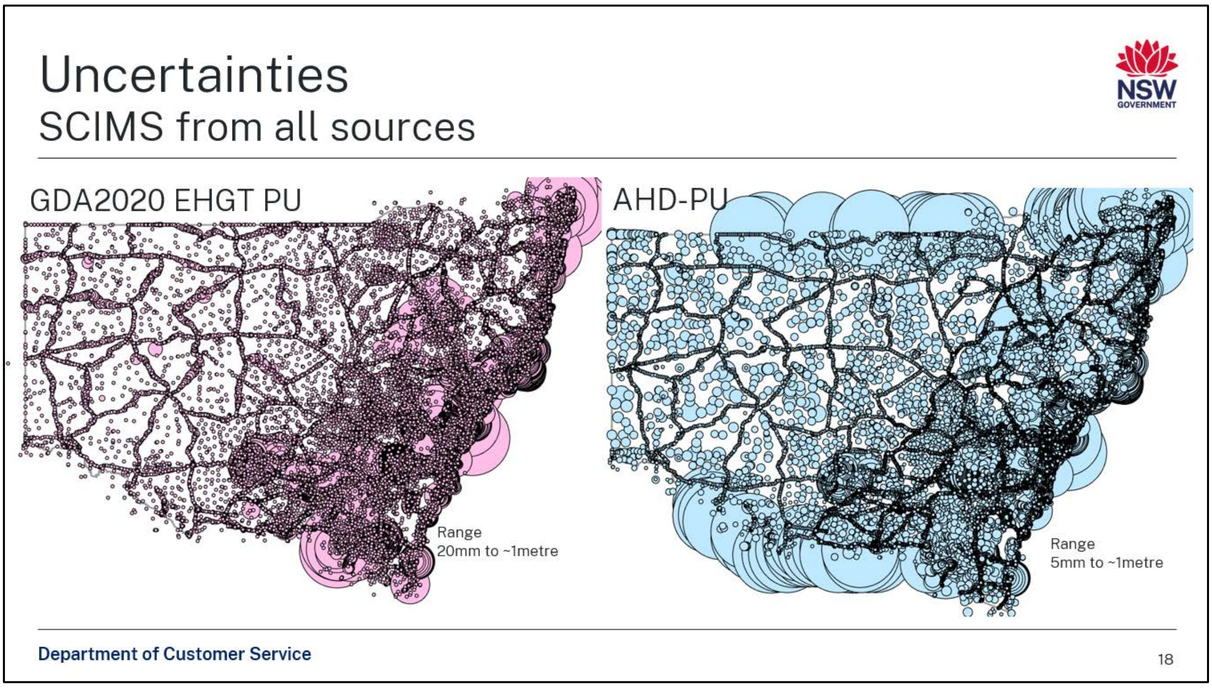
13

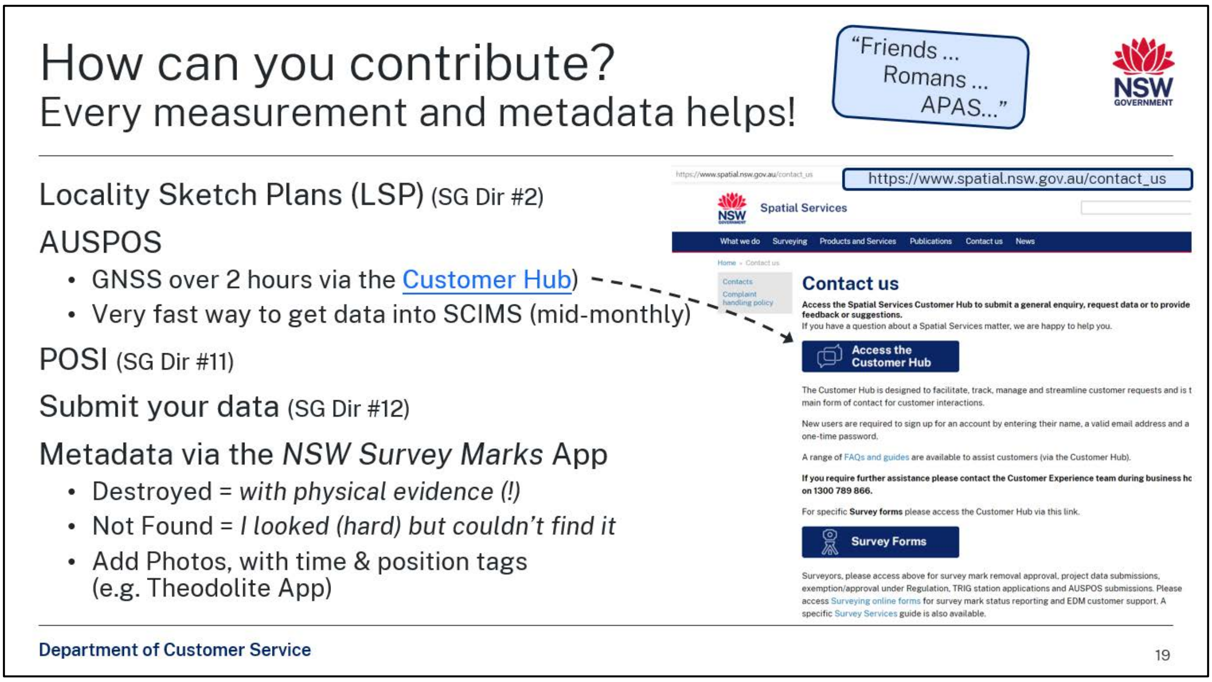

NSW State Adjustment - Process
Back to the bigger picture...
NSW GOVERNMENT
stations
measures (±)
constraints
stations
measures (±)
APREF...
ACT, QLD, VIC, SA data
Survey Operations
• Internal and External
• AUSPOS
On demand
SCIMS
⇨ Coordinates (local)
⇨ PU (provisional), LU
⇨ Class
⇨ AHD
State Adjustment
• APREF, NGCA, AUSPOS
• NSW modern and historic
• ACT, VIC, QLD, SA data
Monthly (for internal review)
Twice a year (May, Nov)
⇨ Coordinates (rigorous)
⇨ PU, (RU), LU (rigorous)
⇨ NOT AHD, NOT CLASS
SCIMS
National Adjustment
• APREF
• Jurisdiction data
Monthly
⇨ Coordinates (rigorous)
⇨ PU (rigorous)
Department of Customer Service
14


SCIMS
Adjusting to GDA2020 – Report Card
NSW GOVERNMENT
SCIMS GDA2020 adjusted vs transformed SID (c.2020-2024)
Number of marks in SCIMS
350000
300000
250000
200000
150000
100000
50000
0
2019
2020
2021
2022
2023
2024
Year
~ 2400 / year
~ 26,000 / year
All marks in SCIMS
GDA94 Tf
SCIMS marks with HPU
State Adjustment
LandXML Pilot
309,000 marks in SCIMS (Nov 2023)
½ (50%) now have HPU from the state adjustment
70% are Established in Hz
70% of these have HPU
40% are Accurate in AHD
65% of these have AHD-PU
(not shown in chart)
Did you know...
20% of SCIMS are witness destroyed, uncertain, restricted
Department of Customer Service
15


Uncertainties
SCIMS from all sources (vs NSW state adjustment values)
SCIMS GDA2020 Hz PU
(SID:All SID @ 2023-11-17)
Mean: 0.024
Median: 0.019
StdDev: 0.028
Count: 153604
Frequency
HPU (m)
Horizontal Positional Uncertainty
Horizontal
154,000 stn with HPU
HPU < 20mm: 65%+
HPU < 40mm: 96%+
State Adj
150,000
(similar)
(similar)
Scale not graphical
Range: ~20mm to 5metre
Department of Customer Service
16


Uncertainties
SCIMS from all sources (vs NSW state adjustment values)
SCIMS GDA2020 Hz PU
(SID:All SID @ 2023-11-17)
Mean: 0.024
Median: 0.019
StdDev: 0.028
Count: 153604
HPU (m)
SCIMS GDA2020 Ehgt PU
(SID:All SID @ 2023-11-17)
Mean: 0.118
Median: 0.159
StdDev: 0.089
Count: 93262
State Adjustment
AHD ⇨ EHGT
via AUSgeoid
cm to dm
uncertainties
Ehgt PU (m)
SCIMS AHD PU
(SID:All SID @ 2023-11-17)
Mean: 0.069
Median: 0.033
StdDev: 0.166
Count: 80052
ANLN
Adjustment
EHGT ⇨ AHD
via AUSgeoid
cm to dm
uncertainties
AHD PU (m)
Horizontal
154,000 stn with HPU
HPU < 20mm: 65%+
HPU < 40mm: 96%+
State Adj
150,000
(similar)
(similar)
Ellipsoidal Height
94,000 stn with VPU
VPU < 50mm: 40%
State Adj
39,000
(95%)
AHD
~80,000 stn with PU
AHD-PU < 50mm: 65%
State Adj
10,000
(decimetre,
via geoid)
Department of Customer Service
17


Uncertainties
SCIMS from all sources
GDA2020 EHGT PU
AHD-PU
Range
20mm to ~1metre
Range
5mm to ~1metre
NSW GOVERNMENT
Department of Customer Service
18


How can you contribute?
Every measurement and metadata helps!
"Friends ... Romans ... APAS..."
NSW GOVERNMENT
Locality Sketch Plans (LSP) (SG Dir #2)
AUSPOS
• GNSS over 2 hours via the Customer Hub)
• Very fast way to get data into SCIMS (mid-monthly)
POSI (SG Dir #11)
Submit your data (SG Dir #12)
Metadata via the NSW Survey Marks App
• Destroyed = with physical evidence (!)
• Not Found = I looked (hard) but couldn't find it
• Add Photos, with time & position tags (e.g. Theodolite App)
https://www.spatial.nsw.gov.au/contact_us
Spatial Services
Contact us
Access the Customer Hub
Survey Forms
Department of Customer Service
19

Take home
What does this mean for you?

½ SCIMS coordinates change (improve) twice a year (May, November)

At a street-corner near you…

- Sydney metro area largely complete by Nov2023, May2024
- POSI and BAU work are expected to become more efficient
- Metadata! Report what you find: *NSW Survey Marks* App

Coordinates with "Known Uncertainty"

- PU, LU
- PU 20mm easily fits proposed Regulations ('40mm + 175ppm')
- You can measure across the road, at the given PU
- You can measure to marks by others at the given PU (e.g. Transport, SurveyorABC)

Marks without PU are transformed from GDA94…

+/- 0.2 metres
Use with caution.

All on the same datum – GDA2020 3D!

- CORS, AUSPOS, SCIMS…   NSW, VIC, ACT, QLD, SA…

Department of Customer Service 20

An Introduction to SouthPAN

Vincent Rooke
Geoscience Australia
Vincent.Rooke@ga.gov.au

ABSTRACT

As part of the Positioning Australia program, Geoscience Australia is progressing with the delivery and operations of SouthPAN, the Southern Positioning Augmentation Network. SouthPAN is a Satellite-Based Augmentation System (SBAS), which includes a system of space and ground infrastructure that augments positioning signals provided by the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS) to significantly improve positioning accuracy and reliability. SouthPAN delivers positioning data to users via satellite and is a partnership between Geoscience Australia and Toitū Te Whenua Land Information New Zealand (LINZ) under the Australia New Zealand Science, Research and Innovation Cooperation Agreement. SouthPAN is a 'next-generation SBAS', currently delivering the following open services: (1) L1 SBAS augmenting the GPS L1-C/A navigation signal, (2) L5 Dual-Frequency Multi-Constellation (DFMC) augmenting the GPS L1-C/A and L5 navigation signals as well as the Galileo E1 and E5a navigation signals, and (3) L5 Precise Point Positioning (PPP) via SouthPAN. The SouthPAN broadcast signals went live on 26 September 2022 and will operate for 19 years with Safety of Life SBAS services commencing in 2028. We are providing Australia and New Zealand world-class access to positioning services that will improve accuracy from 5-10 metres to as little as 10 centimetres on land and sea without the need for mobile or internet coverage. SouthPAN is the first SBAS service in the southern hemisphere and estimated to generate at least $7.6 billion in benefits to the Australian and New Zealand economies over 30 years. This presentation provides an introduction to SouthPAN, along with a progress update of project and service delivery and the benefits to users.

KEYWORDS: *Positioning Australia, SouthPAN, SBAS, PPP.*

Dam Monitoring of Regional Dams

Jarad Cannings
NSW Public Works
Department of Regional NSW
jarad.cannings@pwa.nsw.gov.au

Lachlan Anderson
NSW Public Works
Department of Regional NSW
lachlan.anderson@pwa.nsw.gov.au

ABSTRACT

This presentation delves into the essential role of dam monitoring within the context of dam safety requirements for local governments in New South Wales. NSW Public Works takes a pivotal role in conducting dam monitoring surveys for many regional councils across the state. The discussion centres on the approach adopted by NSW Public Works in monitoring dams, giving an overview of methodologies applied in dam monitoring with emphasis on technological advancements and considerations in network design. Drawing upon recent examples of network designs implemented at various dams, the presentation aims to provide valuable insights into the effective strategies employed by NSW Public Works to help ensure the safety of many dams across NSW.

KEYWORDS: *Dams, deformation monitoring, least squares, dam safety.*

The LandXML to SCIMS (LX2S) Pilot Project

Simon Hine
DCS Spatial Services
NSW Department of Customer Service
Simon.Hine@customerservice.nsw.gov.au

Jonathon Smith
DCS Spatial Services
NSW Department of Customer Service
Jonathon.Smith@customerservice.nsw.gov.au

Volker Janssen
DCS Spatial Services
NSW Department of Customer Service
Volker.Janssen@customerservice.nsw.gov.au

ABSTRACT

LandXML is an international data standard for exchanging geospatial information. Since 2015, DCS Spatial Services has captured and stored registered Deposited Plans (DPs) in the LandXML format. To date, this has resulted in the capture of more than 1 million DPs including over 4.4 million land parcels. The DP LandXML files are stored in Cadastre NSW, a system to centrally store, index and track the lifecycle of cadastre-specific data assets (including LandXML files). Constituting the NSW State Control Survey, the Survey Control Information Management System (SCIMS) is the state's database containing more than 250,000 survey marks on public record, including coordinates, heights, accuracy classifications and other metadata. This paper outlines the innovative LandXML to SCIMS (LX2S) pilot project, which was initiated by DCS Spatial Services to automate the harvesting of State Control Survey observations from registered DPs, adjust the 'islands' of harvested observations, and publish the adjusted GDA2020 coordinates and their quality in SCIMS. The automated harvesting and adjustment for the LX2S pilot project was executed using Python code developed in-house to retrieve, test and process DP LandXML files from Cadastre NSW. This initiative supports industry and community growth by extending the state's fundamental positioning framework, the State Control Survey, with a greater density of survey marks with GDA2020 coordinates of known quality. It also demonstrates to industry customers the clear benefit and outcomes of the regulatory requirement for survey plans to connect to the State Control Survey. In recognition of its innovative design and the enormous benefits it provides, the LX2S pilot project was awarded joint winner of the 'Extra Dimension & Innovation' category at the 2023 Excellence in Surveying and Spatial Information (EISSI) awards.

KEYWORDS: *Innovation, LandXML, SCIMS, densification, harvesting, adjustment.*

1 INTRODUCTION

The NSW regulatory requirement for survey plans to connect to Permanent Survey Marks (PSMs) has the long-recognised potential to assist in the densification of the State Control Survey. On behalf of the Surveyor-General, DCS Spatial Services, a unit of the NSW Department of Customer Service (DCS), is responsible for the establishment, maintenance and improvement of the State Control Survey, which is made available to users via the Survey Control Information Management System (SCIMS). SCIMS is the state's database containing more than 250,000 survey marks on public record, including coordinates, heights, accuracy classifications and other metadata, provided in the Geocentric Datum of Australia 2020 (GDA2020 – see Harrison et al., 2023), its predecessor GDA94 (ICSM, 2024) and the Australian Height Datum (AHD – see Roelse et al., 1971; Janssen and McElroy, 2021). The basic concept of the SCIMS database is illustrated in Figure 1.

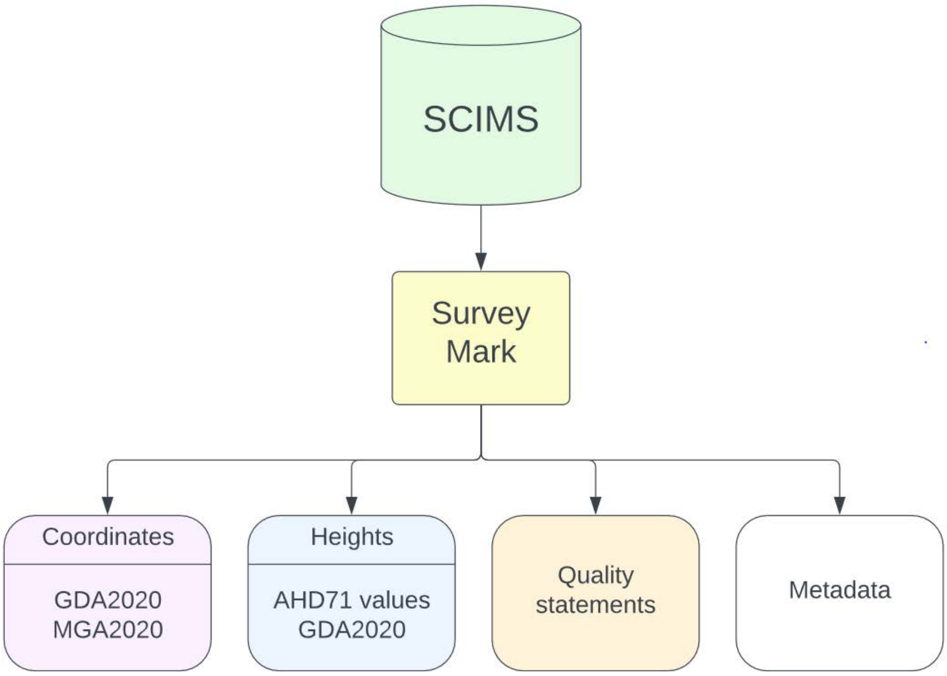


Figure 1: Simplified SCIMS database concept.

LandXML is an international data standard for exchanging geospatial information. The Intergovernmental Committee on Surveying and Mapping (ICSM) has developed a national LandXML schema from which NSW has developed a subset NSW LandXML recipe. Over recent years, LandXML has become increasingly popular as a format to store survey plans in the digital age. In 2015, DCS Spatial Services initiated a project to capture and store registered Deposited Plans (DPs) in the LandXML format, which has to date captured over 1 million DPs including over 4.4 million land parcels. DPs are captured using the NSW LandXML recipe and stored in Cadastre NSW, a system to centrally store, index and track the lifecycle of cadastre-specific data assets (including LandXML files) (Figure 2).

This paper outlines, in general terms, the innovative LandXML to SCIMS (LX2S) pilot project, which was initiated by DCS Spatial Services to automate the harvesting of State Control Survey observations from registered DPs, adjust the 'islands' of harvested observations, and record the adjusted GDA2020 coordinates and their qualities (i.e. Horizontal Class and Horizontal Positional Uncertainty, HPU) in SCIMS. Automated harvesting and adjustment for the pilot project was executed using sophisticated Python code developed in-house that retrieved registered DP LandXML files conforming to the NSW LandXML recipe from Cadastre NSW (Figure 3).

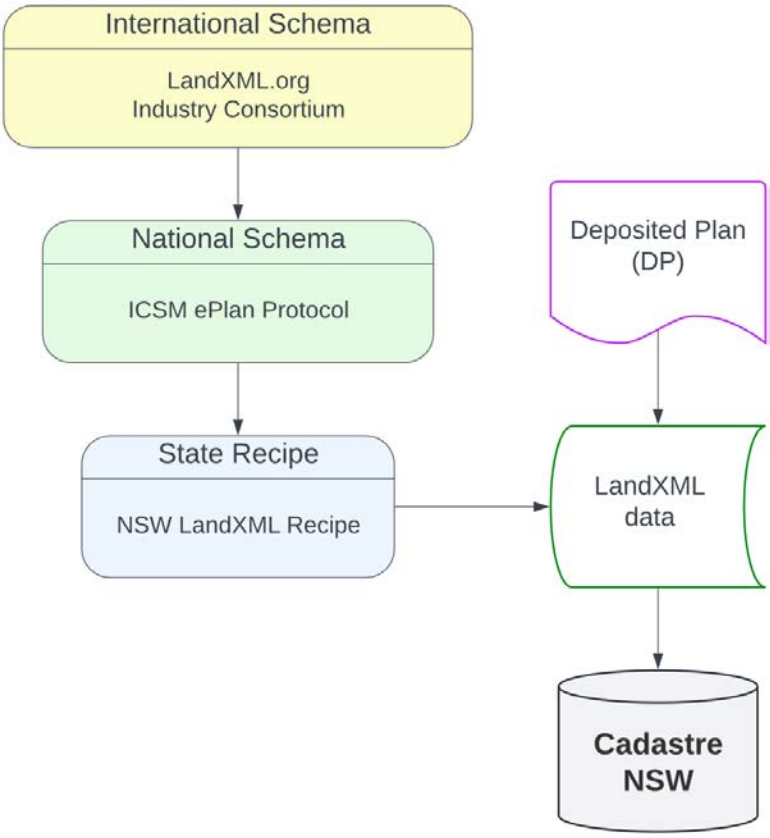


Figure 2: Structural concept of LandXML, Deposited Plans and Cadastre NSW.

Figure 3: Concept of harvesting LandXML control data to update SCIMS.

2 NEW SPATIAL APPLICATIONS REQUIRED

The LX2S pilot project required several new spatial applications to be generated in order to support the automated workflow design. This was critical to enable the desired automated harvesting, Quality Assurance (QA), adjustment and SCIMS update for vast amounts of data.

2.1 Python Code Base

DCS Spatial Services has been developing in-house utilities to automate and streamline its unique workflows for more than 50 years. The in-house utilities support the maintenance and extension of the State Control Survey and the cadastre, both being legislative requirements of the Surveyor-General under the Surveying and Spatial Information Act 2002. The development of in-house utilities also directly supports the digital business initiatives of Digital.NSW (e.g. the harvesting of DP LandXML data) to support our industry customers and stakeholders. To this end, a closed-source code repository called SurvPy (within a ‘Git’ distributed version control system) has been developed to facilitate fulfilment of the Surveyor-General's legislative requirements using the interpreted, dynamically typed programming language Python.

The LX2S pilot project utilises innovative data structures and algorithms. As no off-the-shelf software existed for the project requirements, the small project team had to develop a custom-built code base to further extend the SurvPy library (calling many of the unique functions within SurvPy). Python was chosen to develop the LX2S code base in the current digital framework, as the existing SurvPy library could be directly used with no translation required. Python is also compatible with major platforms and systems, has a large standard library and is cost-effective to use and maintain. Python is considered one of the most globally popular programming languages and used by organisations such as Geoscience Australia and ICSM.

A commercial Integrated Development Environment (IDE) was used to develop the LX2S Python code base. An IDE is software that facilitates code development and provides a code editing interface with productivity tools that substantially increase the efficiency, standardisation and integration of code development. LX2S adopted an Object-Oriented Programming (OOP) model, as this was considered the only viable option for a project of this size. The LX2S code base greatly increases the scope of the existing SurvPy library, with additions for the LX2S pilot project totalling approximately 25,000 lines of Python code. This number continually increases as processes are refined, expanded and optimised into the future.

2.2 SQLite Database

In order to store, perform QA, query and output the relevant State Control Survey observations from registered DPs, a customised SQLite relational database was built to fulfil the project requirements. SQLite was chosen as the database format for its ease of use, lightweight structure, read-write performance and reliability. Customised LX2S database tables were configured for the storing of observations and metadata pertinent to each observation, including its parent DP, observation weightings, QA assessments and overrides (both automatic and manual). For example, the extract of the LX2S database shown in Figure 4 includes columns detailing the survey mark name/number as harvested from the DP, its verification, override option and relevant comments. The customised LX2S database is the project-critical data structure in the transition from DP LandXML files to the production of least squares adjustment input files.

id	plan_id	pntref	name	name_verified	name_manual	name_comment
Filter	Filter	Filter	Filter	Filter	Filter	Filter
113	27	3	SS185957	SS185957	NULL	Coordinates match SCIMS
114	28	860	PM50232	PM50232	NULL	Near stations check, exact match - 1.544 m
115	28	861	SS17266	SS17266	NULL	Near stations check, exact match - 1.438 m
116	28	862	SS144731	SS144731	NULL	Near stations check, exact match - 1.492 m
117	28	863	SS208127	SS208127	NULL	Coordinates match SCIMS

Figure 4: Extract of a customised LX2S database table.

2.3 Adjustment Software

The open-source DynAdjust least squares network adjustment software distributed by ICSM (Fraser et al., 2023, 2024) was used to adjust the LX2S output data. DynAdjust was chosen due to the high performance of both its simultaneous and phased adjustment modes and for consistency and compatibility with the GDA2020 state and national adjustments, which also use DynAdjust. It should also be noted that LX2S team members have made contributions to improve the DynAdjust GitHub code repository. Customised LX2S Python modules allow the automated sequential execution of each auto-generated DynAdjust input file comprising the LX2S adjustment islands. Figure 5 shows a DynAdjust input file extract, detailing the ellipsoidal distance measurement and its standard deviation between SS69512 and SS69517, harvested from DP1254738 dated 30 October 2019.

```
<!-- Type E Ellipsoidal Distance -->
<!-- StdDev from: Constant=0.010, PPM=50, C.L.=95% -->
<!-- Source legislation: Surveying and Spatial Information Regulation, 2017 -->
<DnaMeasurement>
  <Type>E</Type>
  <Source>CadNSW_dp1254738.xml_LANDXML_SUPP_v9_2020-12-23T22:44:49</Source>
  <Epoch>30.10.2019</Epoch>
  <Ignore/>
  <First>SS69512</First>
  <Second>SS69517</Second>
  <Value>79.9131</Value>
  <StdDev>0.0071</StdDev>
  <MeasurementID>103000025</MeasurementID>
</DnaMeasurement>
```

Figure 5: Extract of a DynAdjust input file.

2.4 Mathematical Integrity Report

The Mathematical Integrity Report (MIR) was developed to speed up the examination of individual DP LandXML files when testing code development and manually assessing individual LX2S island adjustments. The report has large spin-off benefits to DCS Spatial Services as it reduces manual close-checking time from hours/days to minutes and empowers the NSW Surveyor-General with better tools to uphold legislative responsibilities. The MIR also has potential to be of significant benefit to industry stakeholders external to DCS Spatial Services.

The MIR is an attention-focuser that highlights mathematical integrity problems within a DP LandXML file via the use of juxtaposed textual and graphical reports. The MIR converts a DP LandXML file from data to meaningful diagrams and analytical reports of the many survey closures within the LandXML file in a manner fit for human interpretation. At a fundamental level, it checks the closes in a plan in the same manner that a professional surveyor would manually check them with a hand-held calculator, whilst also detecting and highlighting potential problem observations.

The report is delivered as a colour pdf with navigational bookmarks for ease of use. Summary tables (Figure 6) and graphics (Figures 7 & 8) explicitly show those closes which exhibit a misclose outside the relevant legislative tolerances. Details of each close are reported (Figures 9 & 10).

Possible error edges (measured edges - edge dimensions as quoted in XML)

(from, to)	Bearing	Chord	Arc	Radius	Rot.	Meas.	Type
(86, 87)	32° 03' 45"	16.9				True	Connection
(324, 87)	343° 38' 38"	13.777				True	Reference

Cycles with Misclose Weight Ratio < 1 (non-compliant)

Cycle	Misclose Weight Ratio	Misclose	Nom. tolerance
PSM_cad_cycle_8	0.08	0.401	0.031
PSM_cad_cycle_19	0.08	0.403	0.034
PSM_cad_cycle_13	0.09	0.399	0.034

Figure 6: MIR summary extract, detailing possible error edges and cycles with misclose problems.

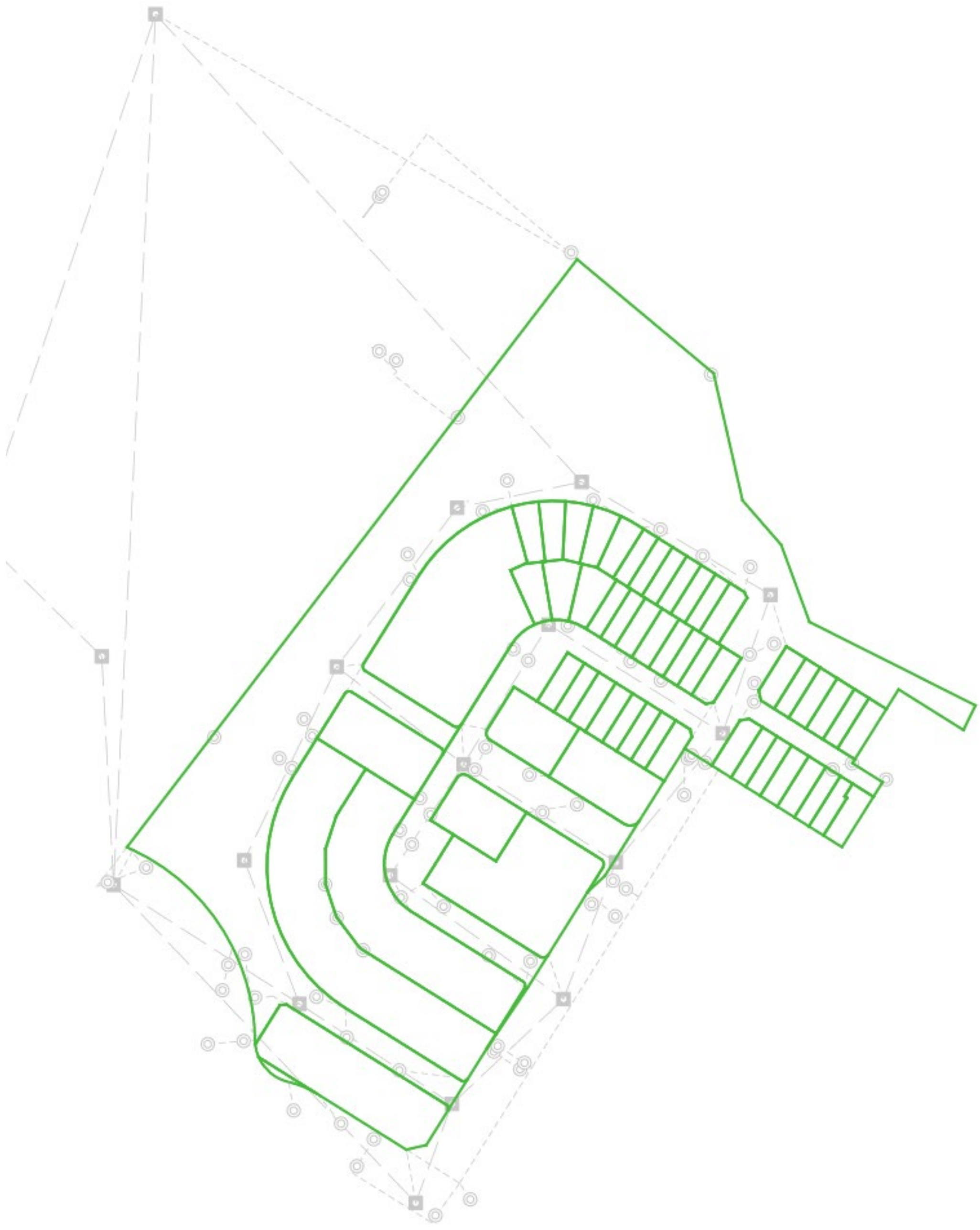


Figure 7: MIR parcels health diagram example, indicating no misclose problems (green = good).

Figure 8: MIR extracted cycles health diagram example, indicating problematic cycles (orange = suspect, red = possible error).

Misclose

M/C dist.	M/C bearing	MWR	Prop (1:)	PPM	Nom. tolerance
0.004	76° 42' 57"	19.2	158943	6.3	0.086

Cycle vectors

(from, to)	Bearing	Chord	Arc	Radius	Rot.	Meas.	Type
(212, 213)	268° 08'	27.415				True	Boundary
(213, 215)	6° 37' 40"	7.581	7.585	67.7	CCW	True	Road
(215, 216)	88° 08'	27.41				True	Boundary

Figure 9: MIR parcel report extract, detailing the misclose and cycle vectors.

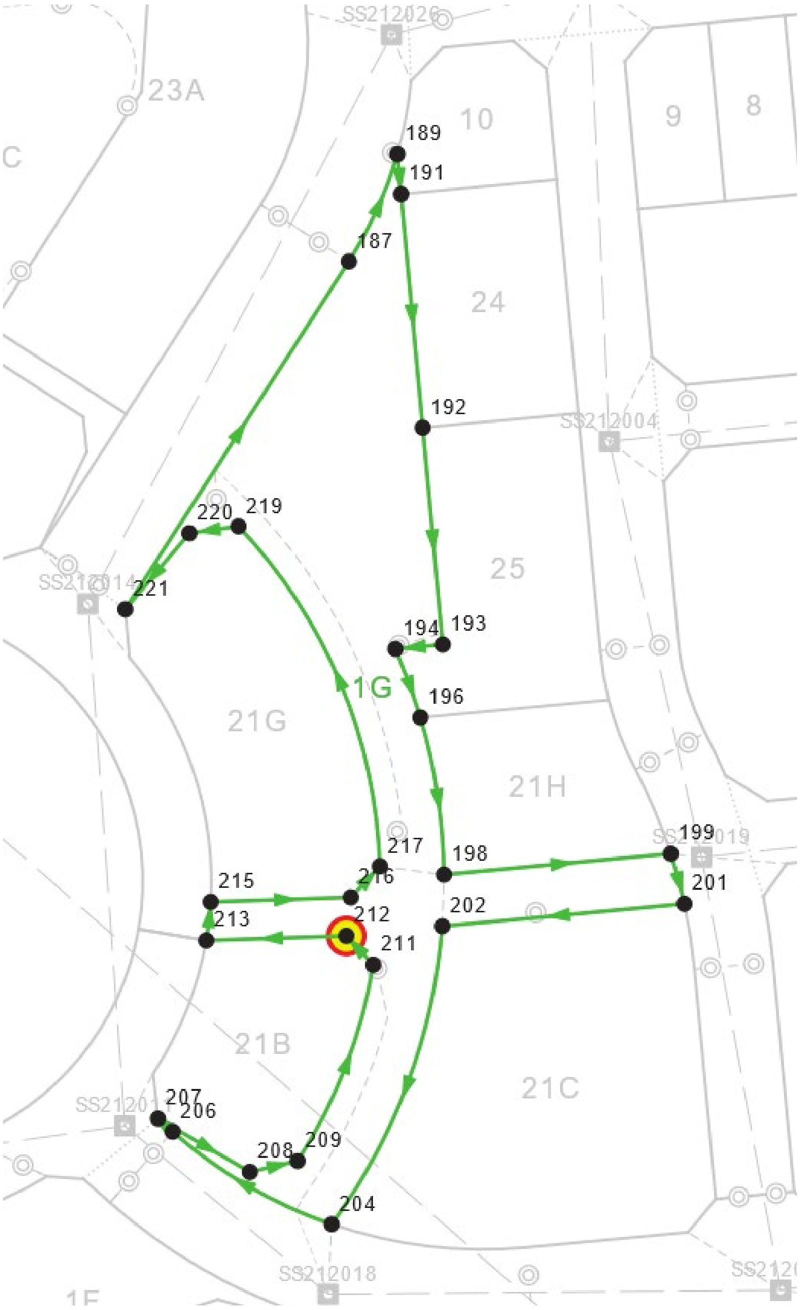


Figure 10: MIR parcel diagram example, indicating 212 as the start/end point of the cycle for manual examination purposes.

3 INNOVATIVE METHOLOGY

The scale of the LX2S project vision required innovative approaches to each stage of the project workflow. The project workflow can be broken into four broad categories (Figure 11). The following sections briefly discuss each part of this workflow.

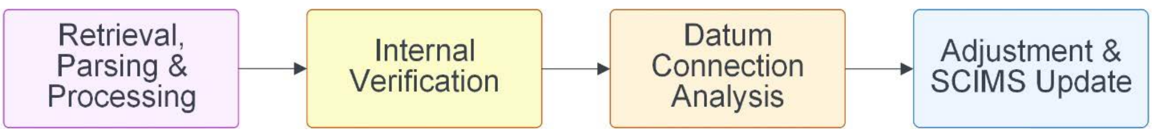


Figure 11: Workflow overview.

3.1 Retrieval, Parsing and Processing

The LX2S methodology for retrieving bulk quantities of DP LandXML files from Cadastre NSW requires a focused balance between retrieval speed and hardware capacity limitations. To achieve the desired balance, a strategy of chunked asynchronous retrieval using ‘Elasticsearch’ queries was adopted (Figure 12), where the overall query is, if required, broken into smaller chunks so that hardware capacity limits are not breached in downstream processing. Each chunk is then submitted asynchronously to maximise the speed of retrieval of each Cadastre NSW DP bundle. Bundles are assessed to determine the best available LandXML file for each DP.

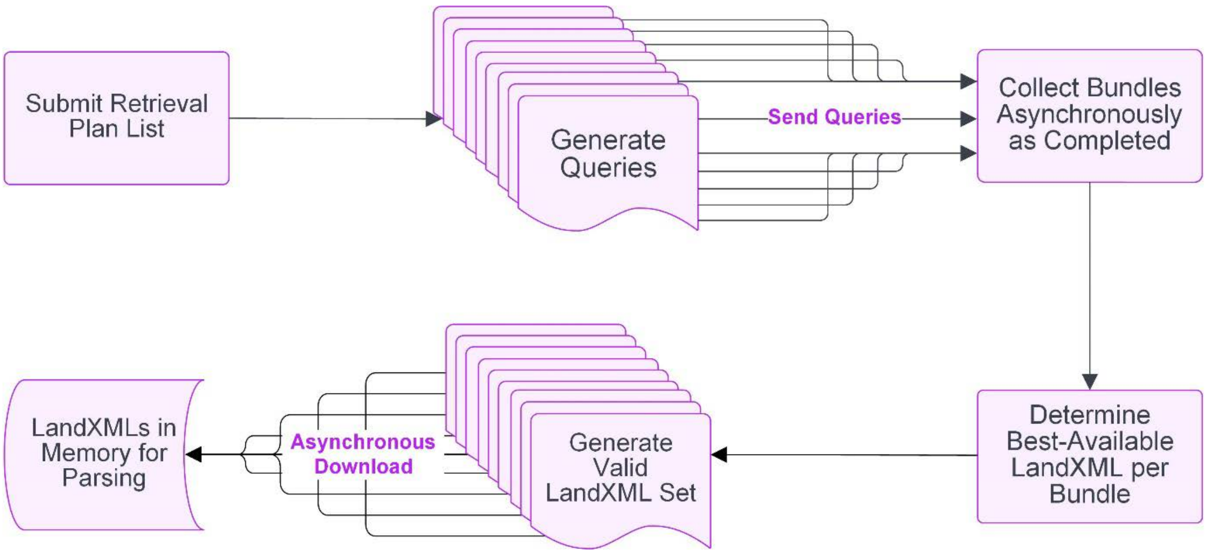


Figure 12: Retrieval overview.

The process of parsing (breaking up the LandXML file into its components) and storing required the LX2S team to custom-build a complete object-oriented data structure to fulfil current and future processing requirements of DP data from LandXML sources, other existing sources as well as sources and formats yet to be defined. LX2S parses retrieved LandXML data and places the parsed data into ‘DepositedPlan’ Python objects (Figure 13). The DepositedPlan Python object contains attributes, some of which themselves can be objects with attributes (think of a set of drawers where a drawer can itself be broken into a set of drawers). It is into these compartments and sub-compartments that the parsed data is stored.

```
class DepositedPlan:
    """
    Contains attributes & methods pertinent to a range of applications requiring analysis of a registered
    Deposited Plan as captured into an appropriate data format.

    :cvar scims_marktypes: Set containing all valid SCIMS mark types
    :type scims_marktypes: set
    """

    scims_marktypes = {'PM', 'SS', 'TS', 'CR', 'CP', 'GB', 'MM'}
```

Figure 13: Code extract of the DepositedPlan object.

LX2S processing passes the DepositedPlan object to custom-built Python processing objects. The processing objects populate the component objects and attributes within the DepositedPlan object and calculate any attributes required in the downstream load flow. One of the main priorities in processing is assessment of the mathematical integrity of the DepositedPlan object, as this comprises the critical pre-QA assessment. This is essentially a misclose check of the LandXML data for the subject DP and leverages sophisticated applications of mathematical graph theory. Simply put, graph theory examines the relationships of graphs, which are mathematical objects consisting of vertices (or nodes) connected pairwise by edges (or lines). It is a branch of mathematics used to represent relations and networks and is widely used in network analysis.

As a result of the mathematical integrity assessment, each observation is given a weighting, the Misclose Weight Ratio (MWR) (Equation 1), which is applied downstream in adjustment weighting. Observations involved in closes outside legislative tolerances are down-weighted unless the MWR value is below a floor value, at which point they are discarded. Observations only involved in closes that meet legislative tolerances are given a ceiling MWR value.

$$MWR_n = \frac{legislative\ misclose\ tolerance_n}{misclose_n} \quad (1)$$

Once processing is complete, the relevant data is extracted from the processed DepositedPlan objects and written to the custom-built LX2S SQLite database.

3.2 Internal Verification

Sophisticated, highly detailed internal verification objects form the bulk of the automated LX2S QA processes, whose broad categories can be summarised as follows:

1) A-priori coordinate generation: The LandXML CgPoint attributes stored in the DepositedPlan object are transformed to the best approximation of datum via sequential transformation method attempts, including a Euclidian least squares transform method.
2) Permanent Survey Mark (PSM) label verification: The PSM labels are verified using a range of techniques, including string matching (exact and combination matching), progressive radial searching for near stations, mark type switching, mark number integer substitution and Trigonometrical Station (TS) name matching.
3) Measurement QA: The validity of each PSM-to-PSM observation is assessed against multiple criteria, including MWR threshold testing, self-looping observations, compiled status and mark status.
4) PSM heights: It is ensured that all PSMs have a valid ellipsoidal or orthometric height for reduction of ground distances to the ellipsoid. PSMs without a height are given an orthometric (AHD71) height interpolated from the NSW Digital Elevation Model (DEM) (Smith and Janssen, 2022).
5) Measurement reduction: All observations are rigorously reduced to the ellipsoid surface in preparation for the adjustment step.
6) Measurement outlier detection: Outliers are detected and removed using a range of detection techniques, including modified z-score distribution analysis and comparison with SCIMS values (Figure 14).

primary_edge	qa_status	qa_comment	adj_island	adj_status
Filter	Filter	Filter	Filter	Filter
True	active	MWR passed|||SINGLE MSR - no internal distribution test performed|||...	1	active
True	active	MWR passed|||LARGE DATASET - passes internal edge distribution test|||...	2	active
True	active	MWR passed|||LARGE DATASET - passes internal edge distribution test|||...	2	active
True	active	MWR passed|||SMALL DATASET - passes internal edge distribution test|||...	3	active
True	active	MWR passed|||SMALL DATASET - passes internal edge distribution test|||...	3	active
True	inactive	MWR rejection	NULL	inactive
True	active	MWR passed|||LARGE DATASET - passes internal edge distribution test|||...	1	active
True	active	MWR passed|||LARGE DATASET - passes internal edge distribution test|||...	1	active
True	active	MWR passed|||LARGE DATASET - passes internal edge distribution test|||...	1	active
True	active	MWR passed|||LARGE DATASET - passes internal edge distribution test|||...	1	active
True	inactive	MWR rejection	NULL	inactive
True	inactive	MWR rejection	NULL	inactive

Figure 14: Automated QA results in the LX2S database.

3.3 Datum Connection Analysis

Datum connection paths are regressively determined for all PSMs and adjustment islands generated (where datum connection is available) using mathematical graph theory. To be classified as ‘connected to datum’, an island must be connected to two or more established PSMs with HPU in SCIMS.

3.4 Adjustment and SCIMS Update

The adjustment files are written from the LX2S database to the DynAdjust input files using the LX2S PlanAdjustmentWriter object. The input observations are collated into the islands formed in the datum connection step (see section 3.3) and written to separate adjustment input files. The PSMs with HPU in SCIMS (as determined during the datum connection analysis) are used as the constraints for each island adjustment. Observations that retain an active status in the LX2S database are sent to the input files with a-priori weightings calculated from a combination of legislative tolerances and the MWR.

Once the automated adjustment process and a report of the adjustment outcomes (including convergence status, number of outliers, etc.) is complete, the outcomes are examined for any adjustments requiring manual intervention (Figure 15). Where manual intervention is required, staff assessment is carried out and the required data fields in the LX2S database are manually edited (e.g. mark name changed or observation de-activated) (Figure 16) and the adjustment files re-generated.

```
may_2023_pilot_island_18.simult.adj     : CONVERGED   - NO OUTLIERS

may_2023_pilot_island_19.simult.adj     : OUTLIER COUNT > 0
                                          Outlier Count = 1
                                          Outliers within accepted tolerance (N -stat < 3.0) --> ACCEPTED
```

Figure 15: Extract of adjustment processing log.

manual_status ▲1	comments
Filter	Filter
use	MIR analysis indicates OK
use	MIR analysis indicates OK
use	MIR analysis indicates OK
ignore	Adjustment outlier
ignore	Adjustment outlier
ignore	Adjustment outlier
ignore	Adjustment outlier
ignore	Adjustment outlier
ignore	Adjustment outlier
ignore	Adjustment outlier
ignore	Adjustment outlier
ignore	Gross error in bearing
ignore	Gross error in ground distance

Figure 16: Example of manual overrides in the LX2S database.

The results of all successful island adjustments are collated into a single SCIMS bulk update file. The strategy for the SCIMS update required detailed attention from the LX2S team so that survey mark coordinates of superior quality were not accidentally overwritten (Figure 17).

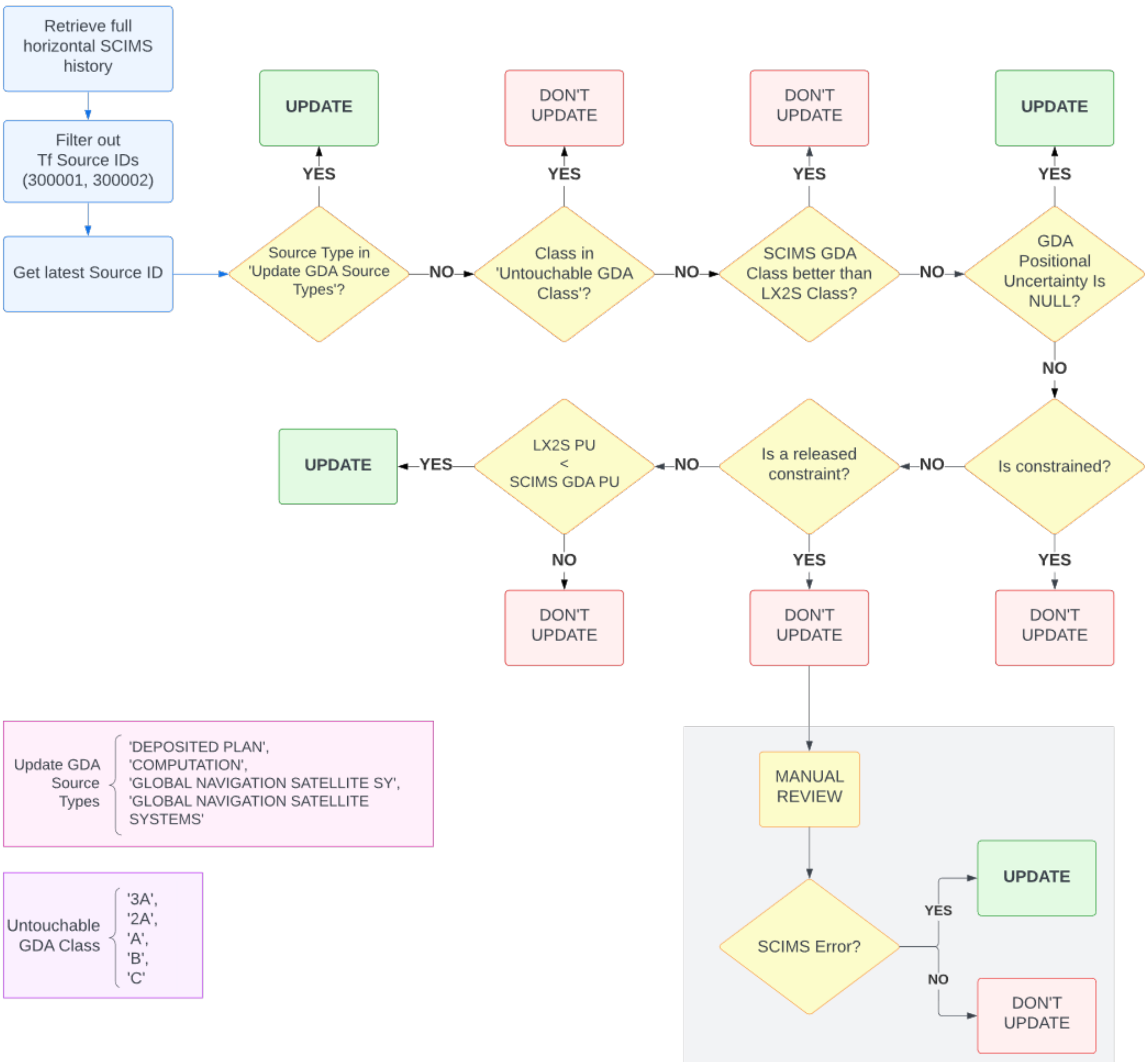


Figure 17: SCIMS update strategy.

A major strategic decision made was not to update hanging communities of survey marks. Extensive analysis of the pilot project areas showed that the veracity of the observations downstream from the articulation point (pivot) could not be ascertained (Figure 18). For all other survey marks, SCIMS is updated with GDA2020 coordinates, HPU and Horizontal Class according to the strategy shown in Figure 17. The minimum HPU that can be attained by a mark being updated is that of the smallest constraint HPU in the subject adjustment island. Horizontal Class is rigorously assessed using horizontal relative uncertainties, and the best Horizontal Class that can be obtained is Class D.

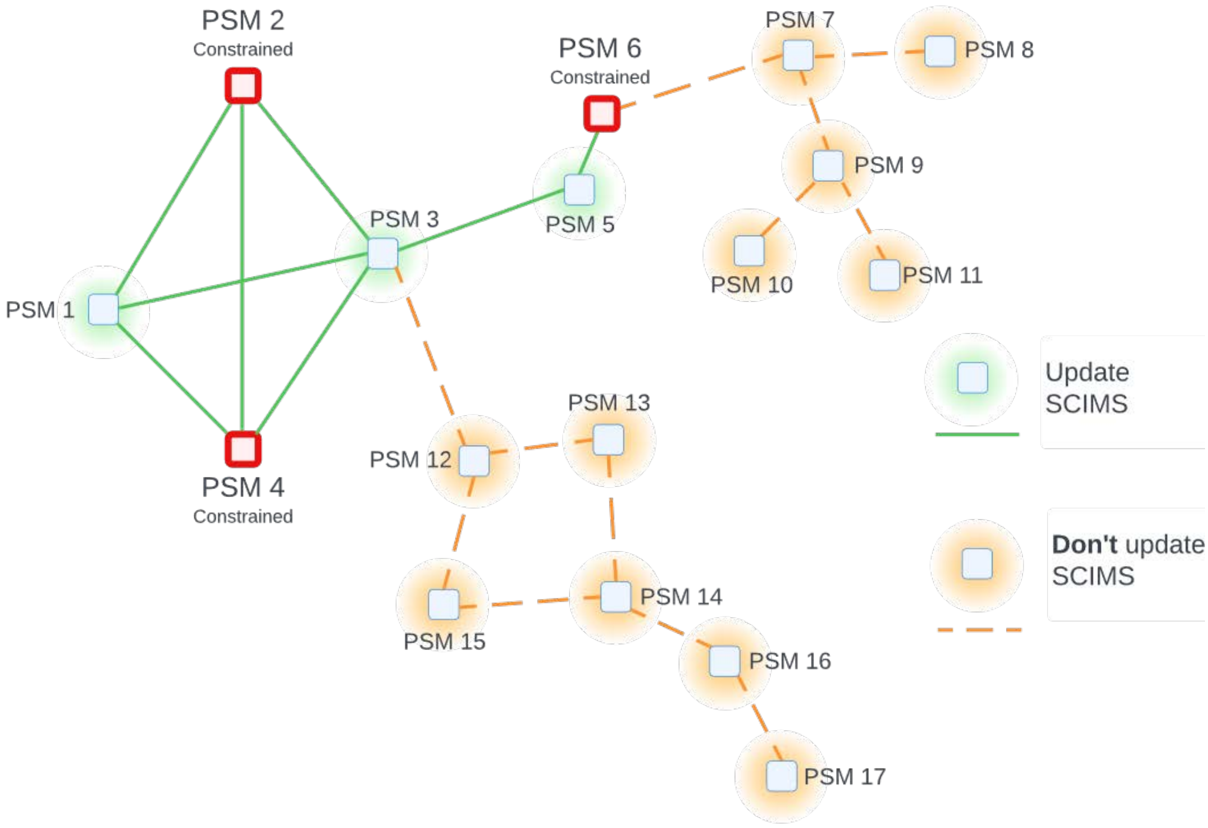


Figure 18: Hanging community strategy.

4 PILOT PROJECT AREAS AND RESULTS

Eleven major pilot areas were chosen, covering a diverse range of geographical areas in NSW with the intention of including areas in proximity of each Survey Operations office (Figure 19). Overall, across the 11 test areas (and the suburbs within these), the LX2S pilot project retrieved 7,099 DPs, extracted and analysed 33,981 measurements from these DPs, and updated 4,188 survey marks in SCIMS. Of these, 2,059 survey marks (49%) were newly established with Horizontal Class D:

- 1,367 survey marks were upgraded from Horizontal Class U.
- 692 survey marks were upgraded from Horizontal Class E.

A breakdown of the pilot area results is given in Table 1, listing the total number of survey marks updated and how many of those were established or newly established by the LX2S pilot. The distribution of HPU for the upgraded survey marks is impressive, with a median value of 0.035 m and a standard deviation of 0.024 m (Figure 20).

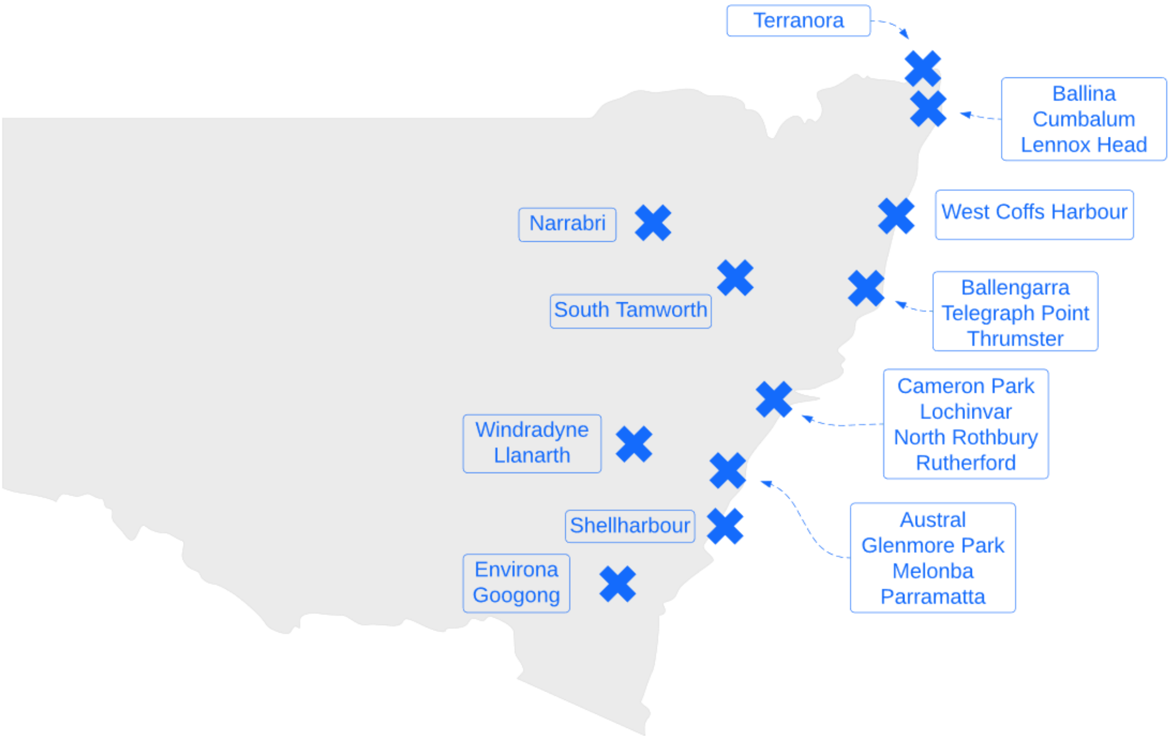


Figure 19: Location of the LX2S pilot areas and their suburbs.

Table 1: Breakdown of pilot area results according to Survey Operations office location and suburb.

Survey Operations Office	Total	Established	Newly Established
Bathurst	**803**	**793**	**349**
Windradyne / Llanarth	148	148	44
Googong	264	264	95
Environa	61	61	61
Narrabri	73	71	51
South Tamworth	257	249	98
Sydney Metro	**1482**	**1470**	**823**
Glenmore Park	461	455	38
Austral	359	355	326
Melonba	479	479	307
Parramatta	183	181	152
Newcastle / Hunter	**967**	**963**	**525**
Cameron Park / Edgeworth	382	380	218
North Rothbury / Greta	156	156	146
Lochinvar	78	78	69
Rutherford	351	349	92
Coffs Harbour	**281**	**281**	**116**
West Coffs Harbour	67	67	23
Telegraph Point / Ballengarra	10	10	8
Thrumster	204	204	85
Lismore	**289**	**289**	**135**
Ballina	60	60	25
Cumbalum	76	76	34
Lennox Head / Skennars Head	80	80	49
Terranora	73	73	27
Nowra	**366**	**361**	**111**
Shellharbour	366	361	111
Total	**4188**	**4157**	**2059**

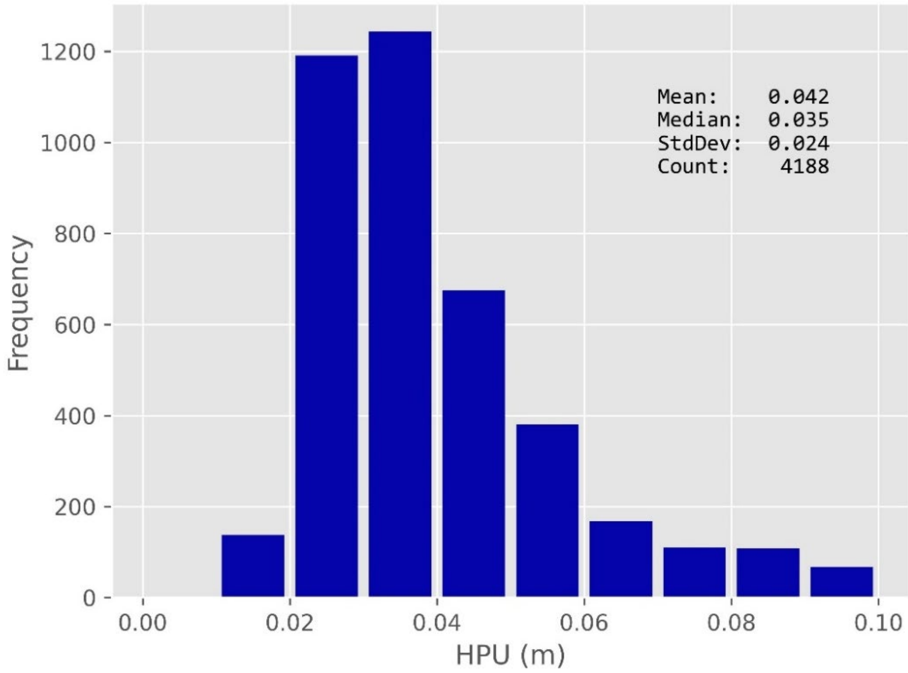


Figure 20: Distribution of Horizontal Positional Uncertainty (HPU) across the LX2S pilot areas.

As an example, Figures 21-23 illustrate the results for three pilot areas (Cameron Park / Edgeworth, Googong and Shellharbour), showing the horizontal constraints, the measurements between marks and the resulting Horizontal Class after the SCIMS update. The vastly increased density of established survey marks in each area is clearly evident, indicating the immense improvement made to the NSW State Control Survey through the LX2S pilot project.

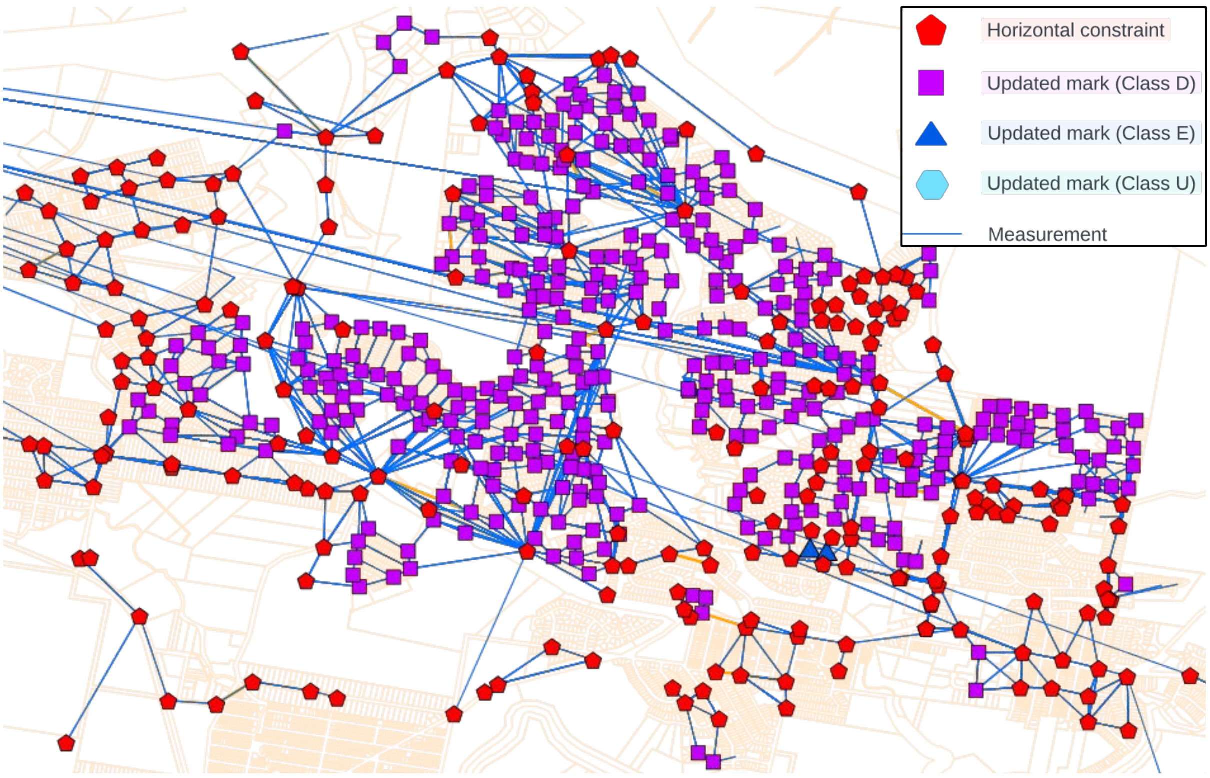


Figure 21: Resulting survey mark updates in the Cameron Park / Edgeworth pilot area – 380 marks established, of which 218 were newly established.

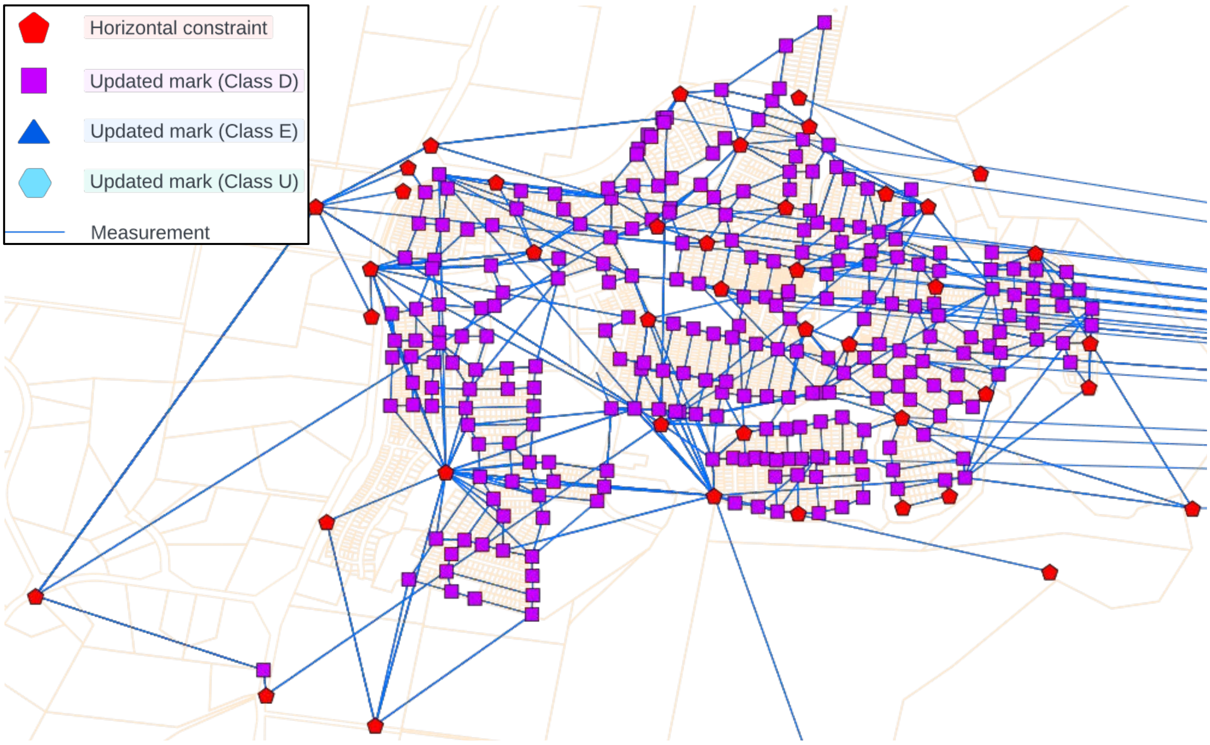


Figure 22: Resulting survey mark updates in the Googong pilot area – 264 marks established, of which 95 were newly established.

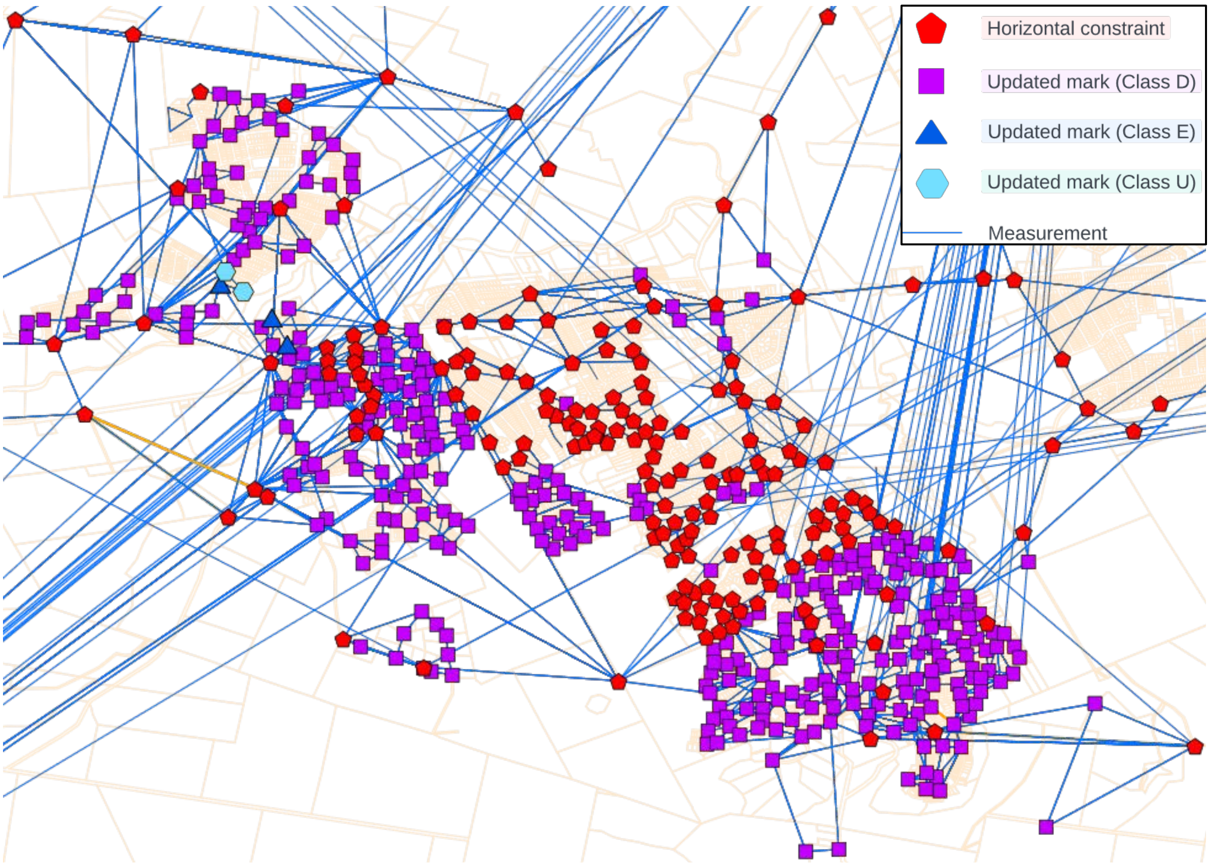


Figure 23: Resulting survey mark updates in the Shellharbour pilot area – 361 marks established, of which 111 were newly established.

5 FUTURE DIRECTION

The vision for the future of the LX2S initiative is a fully automated incremental feed of registered DPs updating the State Control Survey on a regular basis, with only minor manual intervention when required. The intent of the LX2S pilot project was to develop the base code structures and workflows necessary to realise this vision for the future, demonstrate the very substantial productivity gains for DCS Spatial Services as well as for internal and external stakeholders and to determine areas of refinement required for the production environment.

The pilot project has identified the next steps required to realise the LX2S vision (Figure 24):

- Realise an area-based (e.g. town or suburb) harvesting model prior to an incremental-feed workflow.
- Refine the automatic QA process.
- Augment reporting to focus the targeting of future field work by DCS Spatial Services surveyors.
- Investigate the potential for access to tools:
    - Mathematical Integrity Report.
    - Visualisation of LX2S networks.
    - Provision of metadata.
    - Awareness, training and education of DCS Spatial Services staff and customers.

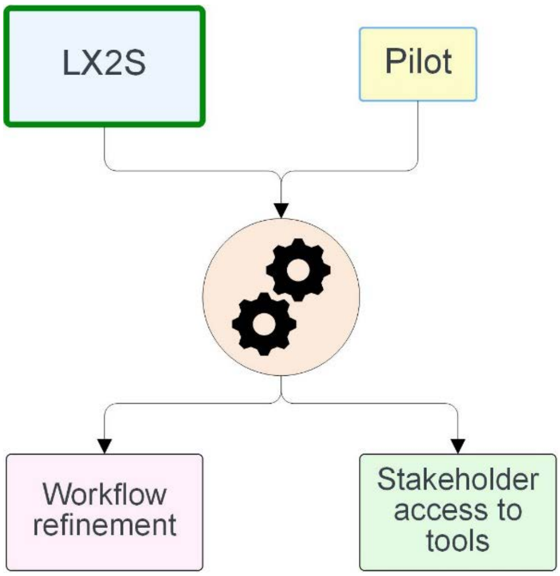


Figure 24: LX2S future direction.

6 ECONOMIC AND COMMUNITY BENEFITS

The LX2S pilot project provides substantial benefits to the surveying profession in particular and the people of NSW in general, including industry and community growth, economic benefits, regulatory benefits and increased community awareness. Based on the pilot project, it is anticipated that LX2S will have the greatest benefit in urban areas, as the active nature of development in those areas engenders a higher density of PSMs with viable paths to datum.

It supports industry and community growth by extending the state's fundamental positioning framework, the State Control Survey, with a greater density of survey marks with GDA2020 coordinates of known quality. Such densification of survey marks with GDA2020 coordinates generates several industry and community benefits:

- Improved positional accuracy of the NSW cadastre, hence improved positional accuracy of the Foundation Spatial Data Framework (FSDF) and the Digital Cadastral Database (DCDB).
- Enablement of infrastructure development (large and small).
- Improved positioning of utilities and underground services.
- Enablement of emerging technologies reliant on positioning.
- Contribution to ICSM's Cadastre 2034 vision.

Densification of geodetic networks, being the fundamental outcome of the LX2S pilot project, has long-recognised economic benefits to a nation and state (United Nations, 2015), including:

- Interoperability and standardisation of disparate spatial datasets across a wide range of applications.
- Improved integration of digital mapping, planning and infrastructure management.
- Improved natural hazard and disaster management.
- Sea level and climate change monitoring.
- Further enablement of digital government outcomes.

In addition, the LX2S pilot project realises specific economic gains for NSW, including:

- Enablement of easier compliance with the Surveying and Spatial Information Regulation 2017, thus reducing time and cost of acquiring datum for preparation of DPs, in turn reducing cost to the general community.
- Enablement of faster turn-around-time harvesting DPs to densify the State Control Survey.
- Faster ingestion of DPs into the DCDB, enabling faster state and local government outcomes.
- Associated tools for efficiency gains in spatial processing:
  - Mathematical Integrity Report – reducing plan checking from hours/days to minutes.
  - Targeting activities of DCS Spatial Services field teams to realise the best gains for government, industry and the general community.
- Greater integrity of the State Control Survey densification from DPs (larger redundancy), reducing time loss due to outlier resolution reported by industry customers.

The LX2S pilot project uses the State Control Survey information required to be shown on DPs by the Surveying and Spatial Information Regulation 2017 and does so in a timely manner. This demonstrates to industry customers the clear benefit and outcomes of the regulatory requirement for DPs to connect to the State Control Survey (Figure 25).

The economic and time-saving benefits stemming from the LX2S pilot project provide real-world gains in deliverables to the community from the surveying industry and all levels of government. This will foster an increased awareness and appreciation of the innovative, practically focused nature of the surveying profession.

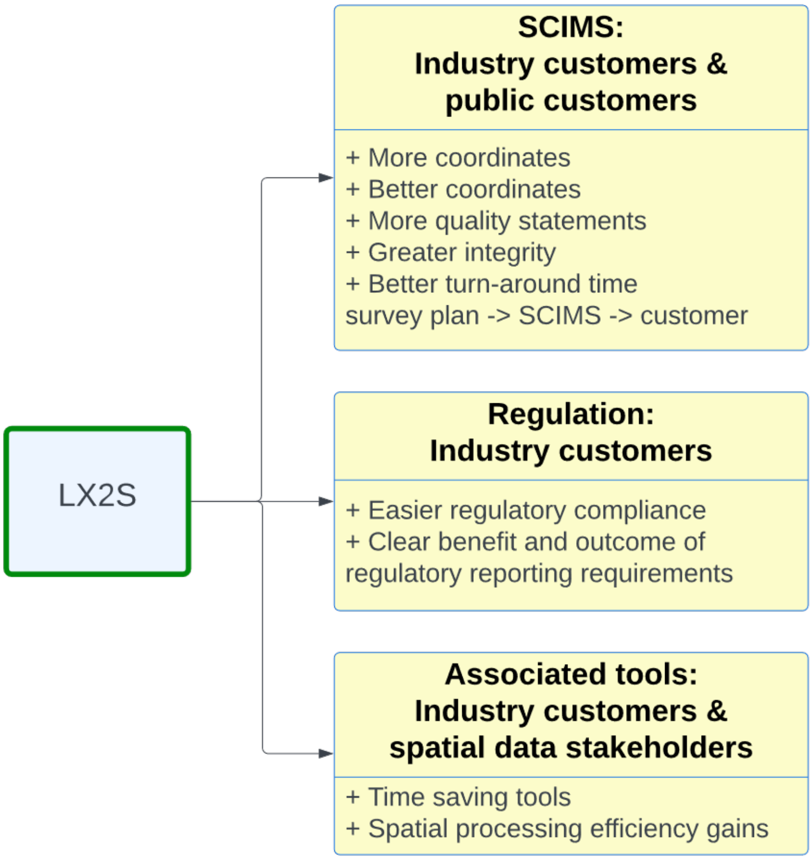


Figure 25: LX2S benefits.

7 CONCLUDING REMARKS

On behalf of the Surveyor-General, DCS Spatial Services is responsible for the establishment, maintenance and improvement of the NSW State Control Survey, which is made available to users via SCIMS. To this end, this paper has presented, in general terms, the innovative LandXML to SCIMS (LX2S) pilot project, which was initiated by DCS Spatial Services to automate the harvesting of State Control Survey observations from registered DPs, adjust the 'islands' of harvested observations, and publish the adjusted GDA2020 coordinates and their quality in SCIMS. The automated harvesting and adjustment was executed using sophisticated Python code and innovative workflows developed in-house to retrieve, test and process DP LandXML files from Cadastre NSW.

Across 11 pilot areas incorporating several suburbs distributed across eastern NSW, the LX2S pilot project successfully retrieved 7,099 DPs, extracted and analysed 33,981 measurements from these DPs, and updated 4,188 survey marks in SCIMS, resulting in 49% of these being newly established with Horizontal Class D. The distribution of HPU for the upgraded survey marks is impressive, with a median value of 0.035 m and a standard deviation of 0.024 m.

The LX2S pilot project has successfully developed the base code structures and workflows necessary (and identified the required refinements for the production environment) to realise the vision of a fully automated incremental feed of registered DPs updating the State Control Survey on a regular basis, with only minor manual intervention when required. It has also demonstrated the substantial productivity gains for DCS Spatial Services, its stakeholders and customers once this vision is realised. This includes the clear benefit and outcomes of the regulatory requirement for survey plans to connect to the State Control Survey. It is anticipated that LX2S will realise the greatest benefit in urban areas, due to the higher density of PSMs with viable paths to datum. In recognition of its innovative design and the enormous benefits it provides, the LX2S pilot project was awarded joint winner of the 'Extra Dimension & Innovation' category at the 2023 Excellence in Surveying and Spatial Information (EISSI) awards.

REFERENCES

Fraser R.W., Leahy F.J. and Collier P.A. (2023) DynAdjust user's guide, version 1.2, https://github.com/icsm-au/DynAdjust/tree/master/resources (accessed Mar 2024).

Fraser R.W., Leahy F.J. and Collier P.A. (2024) Automatic segmentation and parallel phased least squares for highly efficient geodetic network parameter estimation, *Survey Review*, 56(394), 32-50.

Harrison C., Brown N., Dawson J. and Fraser R. (2023) Geocentric Datum of Australia 2020: The first Australian datum developed from a rigorous continental-scale adjustment, *Journal of Spatial Science*, https://doi.org/10.1080/14498596.2023.2184429 (accessed Mar 2024).

ICSM (2024) GDA2020 and GDA94 technical manuals, https://www.icsm.gov.au/gda2020-and-gda94-technical-manuals (accessed Mar 2024).

Janssen V. and McElroy S. (2021) The Australian Height Datum turns 50: Past, present & future, *Proceedings of APAS Webinar Series 2021 (AWS2021)*, 24 March – 30 June, 3-27.

Roelse A., Granger H.W. and Graham J.W. (1971) The adjustment of the Australian levelling survey 1970-1971, *Technical Report 12*, Division of National Mapping, Canberra, Australia, 81pp.

Smith J. and Janssen V. (2022) Updating SCIMS with DEM-sourced AHD heights across NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2022)*, Leura, Australia, 21-23 March, 43-52.

United Nations (2015) A global geodetic reference frame for sustainable development, General Assembly Resolution 69/266, https://ggim.un.org/documents/a_res_69_266_e.pdf (accessed Mar 2024).

The Future of Surveying Education in Australia

Craig Roberts
School of Civil and Environmental Engineering
University of New South Wales
c.roberts@unsw.edu.au

ABSTRACT

Surveying is a practical profession. The Council of Reciprocating Surveyors Boards for Australia and New Zealand (CRSBANZ) sets standards for the curriculums of the nine surveying programs offered in Australia and New Zealand that are pre-requisite for a professional qualification of registered or licensed land surveyors in the corresponding jurisdictions. A significant professional and vocational element must be embedded into the curriculum. This professional need clashes with the motivations of modern universities who are driven by rankings to elevate their status in the eyes of future paying students. Academic staff hires are therefore favoured towards those that can enhance the rankings, with a strong emphasis on research excellence. Industry and teaching experience comes a distant second. The cohort of teachers within a surveying program should combine a spectrum of teachers with industry experience and researchers with academic experience. In recent years, new staff hires have favoured the latter, threatening the ongoing relevance of university education to the wider surveying profession. However, there is a way forward. Over the last two decades, the School of Civil and Environmental Engineering at the University of New South Wales (UNSW) has supported several academic staff members as half industry funded. Industry donors cover half the cost of employing teaching or combined track staff and in return have some influence over the curriculum and receive access to top students. Building on this experience, the surveying program has negotiated a consortium of five industry donors to half-fund a so-called Industry Senior Lecturer in Surveying position to support teaching and bring a wealth of industry experience and connections into the BE(Surveying) program at UNSW. This presentation elaborates on this model and the benefits to the consortium members and the wider profession. New initiatives such as program enhancement, iSTEM curriculum support and a new TAFE pathway are also presented.

KEYWORDS: *Education, CRSBANZ, university, curriculum, UNSW.*

Proceedings of the 27th Association of Public Authority Surveyors Conference (APAS2024)
Canberra, Australian Capital Territory, Australia, 18-20 March 2024

A View From Above: Using InSAR to Eliminate the Uncertainty of Mark Movement

Matthew Bates
DCS Spatial Services
NSW Department of Customer Service
Matthew.Bates@customerservice.nsw.gov.au

Craig Roberts
School of Civil and Environmental Engineering
University of New South Wales
c.roberts@unsw.edu.au

ABSTRACT

Advancements in measurement technologies and improvements in Australia's national datums have exposed the need to monitor ground surface movements previously thought to be insignificant. Ground surface deformation directly impacts physical survey marks and monuments, in turn causing problems for surveyors trying to determine their position. The uncertainty surrounding mark movement has long plagued the surveying and geospatial industries, with a reliable yet accessible solution being needed. This paper is based on the first author's undergraduate honours research thesis at the University of New South Wales (UNSW), which received the 2023 Excellence in Surveying and Spatial Information (EISSI) University Student of the Year award. It investigates modern measurement techniques and determines their effectiveness and suitability for large-scale ground monitoring across Australia. Specifically, the accuracy and suitability of publicly available Interferometric Synthetic Aperture Radar (InSAR) data is examined by comparing it against trusted ground-based survey methods, i.e. Global Navigation Satellite System (GNSS) positioning and differential levelling. Horizontal and vertical ground velocities determined by InSAR missions in NSW's Southern Coalfield are contrasted against velocities derived using static and Real-Time Kinematic (RTK) GNSS, and differential levelling, to identify the effects of mine subsidence in the region. The results indicate that although the InSAR data could be used to quickly identify areas of concern, the magnitude of the velocity values greatly varies to those derived by ground-based methods. In most instances, InSAR is effective at determining the direction of the ground movement (being either up or down, or east or west). However, the rate of movement not only differs from the ground-based results but also between each individual InSAR mission. Whilst little correlation is evident, the poor spatial resolution of the InSAR data coupled with an assumption of linear velocity rates from the ground-based data are both significant limiting factors of this study. Nevertheless, it is obvious that InSAR has the potential to be an extremely useful tool for surveyors and could finally reduce the uncertainty when establishing reliable survey control following surface deformation.

KEYWORDS: *Deformation, survey mark movement, uncertainty, surveying, InSAR.*

1 INTRODUCTION

Although the need for large-scale deformation monitoring in Australia has long been regarded as unessential, significant advancements in measurement technologies coupled with pronounced improvements in the country's national datums have unearthed the need for a more robust approach to be adopted. With smaller uncertainties in measured values, small changes in the topography of the land can be identified with greater confidence, in turn uncovering their potential impact on the infrastructure upon the land. The impact of this deformation can be directly seen in survey marks and monuments, whose positions are closely monitored and maintained by surveyors across the country.

Presently, a nationwide strategy for managing ground deformation is yet to be established in Australia. A key reason for this is due to the country's vastness and low population density, making it unfeasible and unjustifiable to cover the continent with traditional surveying methods. In addition, the difficulty in reliably determining the true nature and extent of deformation events has led to it being assessed on a case-by-case basis. However, emerging technologies such as Interferometric Synthetic Aperture Radar (InSAR) promise to provide a unique solution to the problem, with many countries around the world already implementing such instruments.

Survey marks and monuments play a vital role in the management of land and infrastructure in Australia. Their primary purpose is to provide a physical reference to an intangible entity, such as the cadastre or an underlying reference frame, i.e. the Geocentric Datum of Australia 2020 (GDA2020). In the case of the cadastre, for most practical applications, property boundaries need to be located on the ground for them to be useful. In the New Zealand Supreme Court case of Equitable Building and Investment Co. Ltd. v. Ross (1886), Judge Richmond states "*Neither the words of a deed, nor the lines and figures of a plan, can absolutely speak for themselves. They must, in some way or other, be applied to the ground.*" In this statement, Richmond implies that for property boundaries to be useful, they must be administered to the physical world. From this vein stems the notion of a 'monumented cadastre', whereby physical features are the sole means of identifying the location of property boundaries.

The benefit of using marks and monuments over measurements and descriptions is that they are far less ambiguous. Whilst a boundary dimension or a coordinate may be stated to an accuracy at the millimetre level, errors in measurement mean there is almost always a degree of uncertainty in the values. This notion is explored by Richmond (1886), when he remarked: "*Land-surveying is a practical art; which is as much to say that it is not capable of the ideal precision of the mathematics*."

However, this presents the controversial predicament where figures on a plan or stated coordinates of marks disagree with what a surveyor may deem to be their real-world position. In such a situation, an investigation may be required in order to answer the following questions:

- Are the stated figures or coordinates correct? Were they incorrectly stated when established?
- Have new errors been introduced into the survey? Are the new measurements correct?
- Have the positions of any of the marks or monuments changed between surveys?

These questions can be very difficult and sometimes impossible to answer. As such, drawing the conclusion that a value *is* incorrect or a monument *has* moved requires a substantial amount of evidence. If not enough proof can be found, the point of truth will often reside with the original features. That said, in the instance where a mark has likely changed position (i.e. there are no errors in the survey work), it is important to determine the true nature of the movement as it is probable that future surveys will also discover the same discrepancies.

This paper investigates modern measurement techniques and determines their effectiveness and practicality for large-scale ground deformation monitoring across Australia. Specifically, the accuracy and suitability of publicly available InSAR data is examined by comparing it against trusted ground-based survey methods, namely Global Navigation Satellite System (GNSS) positioning and differential levelling. Using publicly available data, this paper tests the validity of InSAR data from the point of view of an ordinary cadastral surveyor. In particular, the gap between geodesy and cadastral surveying will be bridged using this public data, providing new strategies that can be applied to modern-day surveying tasks.

2 GROUND DEFORMATION IN AUSTRALIA

From a climate and environmental standpoint, Australia is an extremely diverse country that leads to a landscape with a vast array of characteristics. As a result, the landscape must adapt to suit changing weather patterns and tectonic anomalies. Furthermore, it is also exceptionally rich in natural resources, which form a key part of the nation's economy. Tapping into these resources can put great strain on the landscape and in turn lead to human-induced (anthropogenic) deformation. As such, it is useful to differentiate between the causes of ground deformation based on the level of human influence.

2.1 Natural Deformation

The Australian continent sits entirely within the Indo-Australian tectonic plate, and hence no major fault lines run through or near the landmass. Interactions between plate boundaries are the main cause of large earthquakes around the globe, thus Australia is not subject to such events. However, intraplate earthquakes – earthquakes occurring within the interior of a tectonic plate – have been recorded in the past and some have been known to noticeably shift the Earth's surface. The 1988 Tennant Creek earthquake in the Northern Territory is the largest ever recorded in Australia. The event comprised a series of three earthquakes, with approximate magnitudes of 6.3, 6.4 and 6.7 (Bowman et al., 1990). The authors reported that the quakes caused deformation of 0.5-1.5 m by low-angle thrusts and 1.0-1.5 m by horizontal thrusts. Even in a rural setting, this amount of movement is enough to severely affect survey infrastructure and property boundaries. That said, this event is a significant outlier in the history of earthquakes in Australia, with most events not large enough to cause surface rupture. Nevertheless, earthquake deformation is still very possible across the continent, and so it should be treated as a noteworthy threat to survey infrastructure, albeit infrequent.

Another source of natural ground deformation in Australia is soil type and structure. The two main types in this category are reactive soils and soil creep. Reactive soils are fairly common in Australia and are typically associated with the moisture content of clay-based soil. These soils will swell when large amounts of water are present and alternatively shrink during dry spells. This can lead to a somewhat cyclic motion where the surface level of the area rises and falls. In the NSW Land & Environment Court (NSW LEC) case of Mine Subsidence Board v. Maria Vervoorn (2008) (see section 2.3), reactive soils were examined to determine if they were the cause of structural building damage in the area of Lithgow. Expert witnesses in the case determined that much of the area was undergoing cyclic movements in the range of ±20 mm and attributed this movement to reactive soils.

Soil creep is the gradual movement of volumes of soil due to gravity. Conducting an extensive study in the Northern Territory and NSW, Clarke et al. (1999) found that annual creep rates could be up to almost 8 cm^3/cm. This unit indicates the volume of a column of soil with 1 cm width moving past a given contour. Figure 1 illustrates a method for measuring volumetric creep and highlights the resultant volumetric units. However, Clarke et al. (1999) found that rates were highly unpredictable, and few correlations could be seen between the rates and the characteristics of the landscape. Nonetheless, this evidence proclaims that soil factors may indeed offer sufficient movement to have a detrimental effect on the accuracy of survey marks.

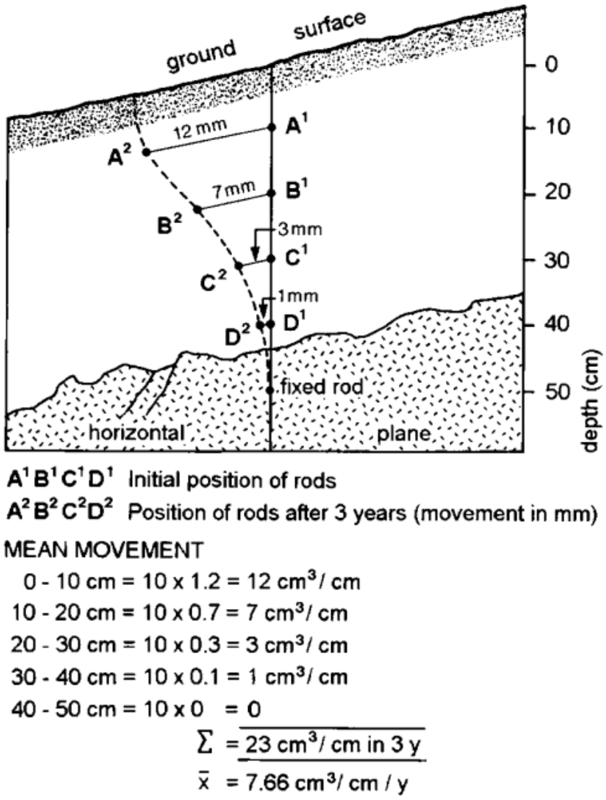


Figure 1: A method for determining volumetric creep (Clarke et al., 1999).

A source of natural deformation closely linked to soil properties are landslides. It is worth noting that landslides are also often the result of human interference through excavation and demolition, but for the purpose of this paper they will be treated as a natural source of deformation. Landslides are typically seen after extreme weather events possessing excess volumes of rain. This aberrant amount of water may weaken the structure of the soil and, if coupled with a significant slope, can cause the land to give way. Depending on the scale of the landslide, many if not all the survey marks and structures in the immediate zone will be disturbed or destroyed. Additionally, marks surrounding the event may be more subtly affected as the land settles and subsides. Although devastating, these incidents are often localised and only affect small areas at a time. As a result, it may be easier to identify which marks may or may not have moved after a landslide than it would for an event of larger scale.

2.2 Anthropogenic Deformation

Australia's abundance of natural resources has led to a prolific mining industry. Many mining operations extract enormous quantities of material from the ground to harvest the precious deposits, leaving behind large voids in or beneath the Earth's surface. Whilst ground deformation can still be seen around open-pit mines, the most significant surface distortions are caused by underground mines. When volumes of earth are mined using techniques such as longwall mining, the surface above the void may tend to subside under its own weight. Mine subsidence is particularly common in the coal-rich regions along the east coast of Australia, particularly in central-eastern NSW. Figure 2 illustrates the locations of recent mining operations in Australia.

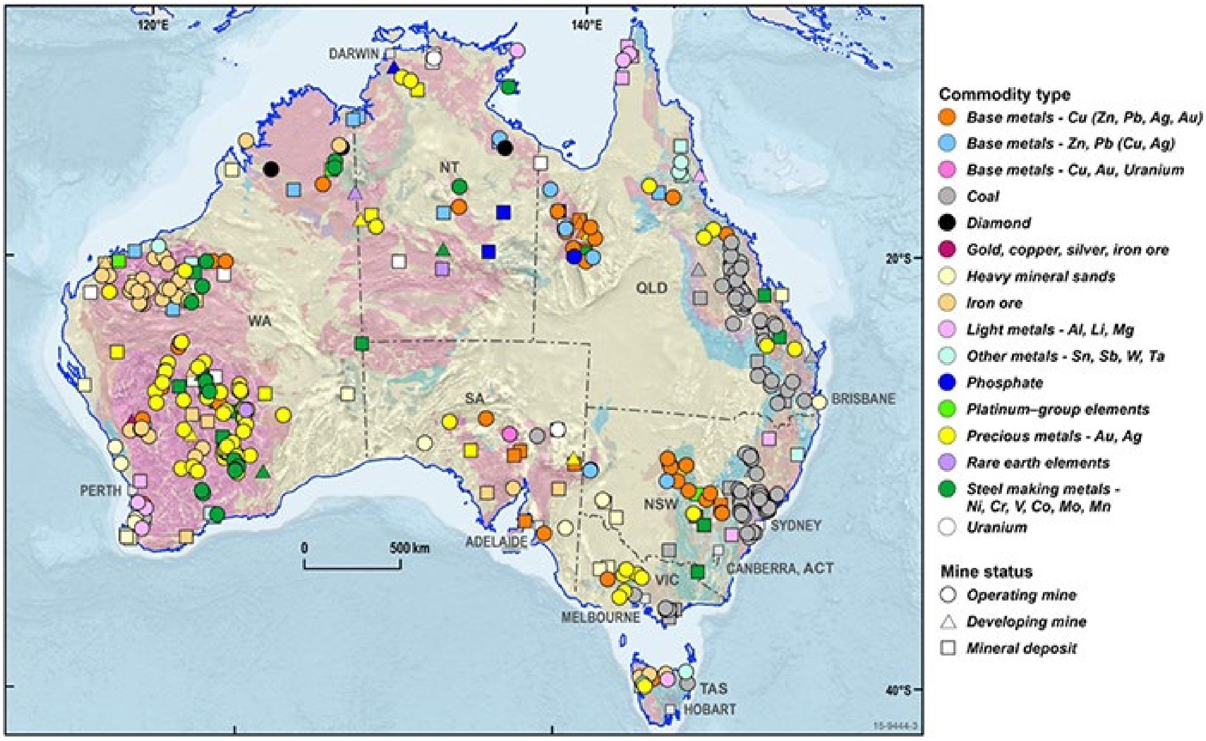


Figure 2: Major mining operations and mineral deposits as of 2016 (GA, 2017).

Other sources of ‘man-made’ ground deformation are groundwater extraction and poor landfill compaction. In some regions of Australia, groundwater is a primary source of usable drinking water and is extracted from the ground in enormous quantities. When water is extracted from underground aquifers via bores, the ground above the aquifer may sink under its own weight in a similar process to mine subsidence. Conversely, deformation due to poor landfill compaction occurs when voids in the ground are inadequately filled. When large weight forces are exerted on the surface above these voids (due to construction), the ground can compress and cause a sinking effect. This emphasises the fact that ground deformation can occur in both urbanised and regional areas, making it a significant threat to survey infrastructure across the entire country. Fortunately, these specific examples generally affect a concentrated area and can therefore be easily identified in most cases.

2.3 Case Study: Mine Subsidence Board v. Maria Vervoorn

There have been several court disputes involving damage to residencies where surveyors have played a key role in determining the cause and extent of the damage. In the case of Mine Subsidence Board v. Maria Vervoorn (2008), surveyors placed monitoring points to determine the movements of a damaged structure and measured to distant survey marks to act as a point of reference. The permanent survey marks were situated around 400-500 m from the site at locations determined to be unaffected by the proposed subsidence. However, the results confirmed that the survey marks were also moving in a similar fashion to the damaged structure. Experts in the case disagreed on the cause of the movements, and specifically whether the marks and the structure were being moved by the same forces. This highlights the fact that (as with all measurements) establishing a rigid datum is critically important.

According to the court proceedings, the survey marks were originally placed in 1995. Mrs Vervoorn made an initial complaint about cracking in 1991, and then again in 1998. After the latter complaint, the Mine Subsidence Board began monitoring of the structure. It is unclear how many (and at what time) surveys were completed between 1998 and the final survey in 2007. However, the following statement from Prof. Galvin reveals the inconsistencies in the measurements: "*In absolute terms comparing 1998 to March 07 the points are down, they're lower than 1998. In terms of trends the trends are up, down, up, down, and who knows how many more because of the frequency of the surveys*." This assertion highlights the importance of the temporal aspect of monitoring surveys in gaining a true understanding of how a landscape is behaving.

In an ideal world, around-the-clock monitoring of the features in question would provide the most certainty when ascertaining the relative mark movements in this case. This, however, is unfeasible for virtually all traditional surveying methods, as they are far too reliant on human operation. Although proven to be highly accurate, instruments such as GNSS receivers, total stations and automatic or digital levels all require considerable human operation in order to function. This dilemma has unearthed the need for an efficient and cost-effective method to actively monitor large expanses of land, at an accuracy level comparative to that of traditional surveying methods.

3 INTERFEROMETRIC SYNTHETIC APERTURE RADAR (INSAR)

InSAR presents a modern alternative to geodetic monitoring with capabilities beyond the realm of most traditional methods. Using its own pulses of microwave energy emitted from a sensor onboard a radar satellite, Synthetic Aperture Radar (SAR) is an *active* remote sensing technique that can operate day and night and in all weather conditions. A SAR image is created using the amplitude and phase of the returned signal, which has been 'scattered' off the Earth's surface, providing information about the slope and nature of the terrain.

InSAR uses the SAR images acquired at different epochs to map ground movement and changes in the topography. Specifically referred to as Differential InSAR (DInSAR), where two images have been taken over the same area with the same imaging geometry at different epochs, a phase shift will occur if the ground has undergone deformation (Garthwaite and Fuhrmann, 2020). The authors explain that this technique allows for maps to be produced with metre-level spatial resolution and precision at the centimetre level. Figure 3 illustrates the principles of DInSAR and the resultant phase shift after two passes over the same area.

As previously mentioned, image geometry is an important factor when generating a DInSAR image. It specifically refers to what phase of its orbit a satellite is in when an image is captured. When the satellite is travelling from north to south, it is said to be in a *descending* pass, and contrarily when the satellite is travelling from south to north, it is said to be in an *ascending* pass (Figure 4).

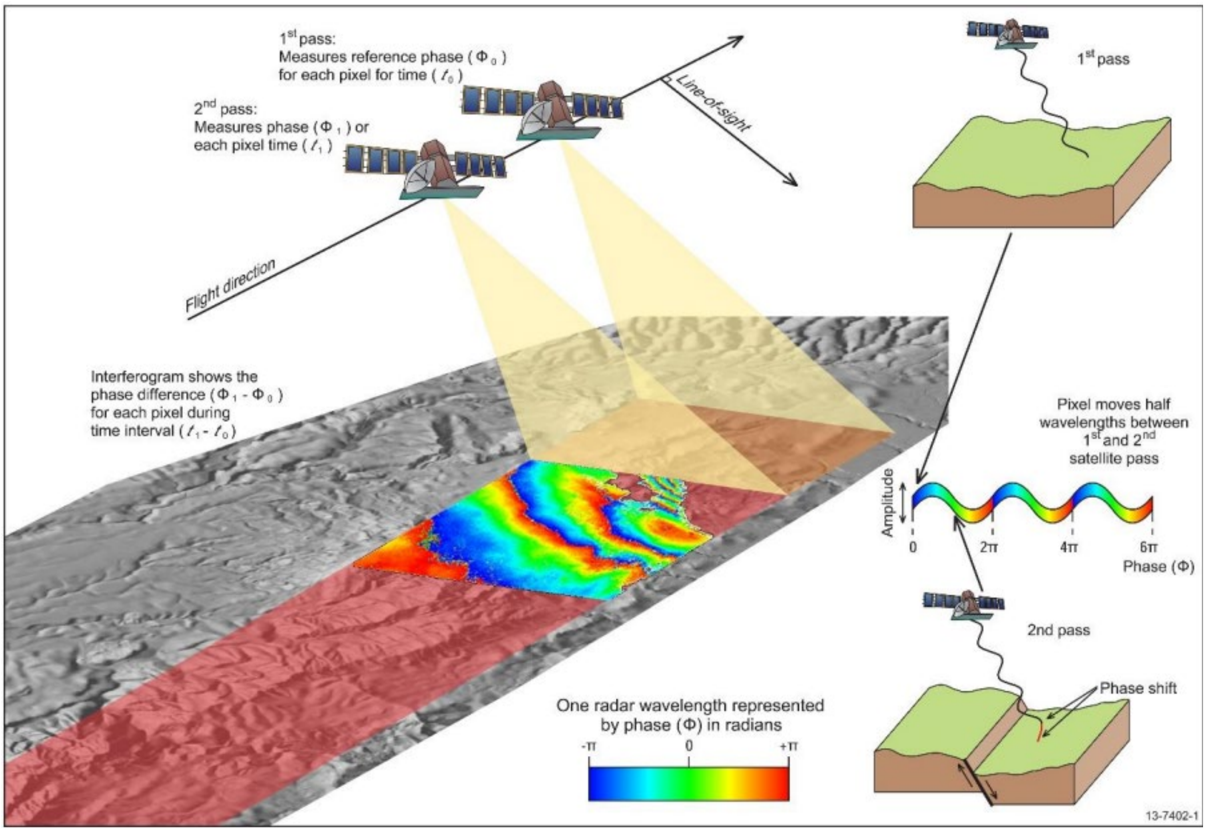


Figure 3: Illustration of the concepts of DInSAR and the principle of a phase shift that has occurred due to ground deformation (Garthwaite and Fuhrmann, 2020).

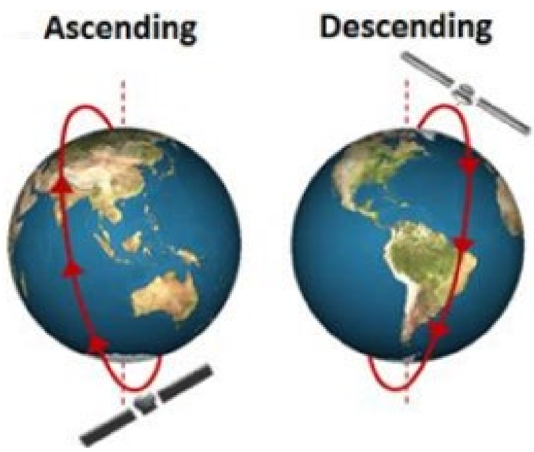


Figure 4: Diagrammatic representation of an ascending and a descending orbital pass (Garthwaite and Fuhrmann, 2020).

This distinction is important because SAR is a side-looking system whereby the sensor is orientated perpendicular to the direction of flight (Macchiarulo et al., 2023). This creates a 'slanted style' image (see Figure 3) that is only representative from this particular viewing angle. In other words, a SAR image captured on an ascending pass can only be used to create a DInSAR image with other ascending images, and vice versa for descending passes. However, if an ascending and descending pass both capture the same area on the ground, the two resultant DInSAR signals can be used to validate and improve the accuracy of the final image as they are both independent representations of the same area. Furthermore, this combination can greatly help to distinguish the true vertical and horizontal ground displacements as the singular 'slanted' images can generate misleading results. The typical 'revisit time' (i.e. the time taken for a satellite to return to the same viewing location) per viewing geometry is around 24 days, meaning that an ascending and descending image is captured around every 12 days.

With the ability to cover widths of several to hundreds of kilometres in a single pass and achieve centimetre-level precision on the ground, it is clear to see how InSAR is an extremely valuable tool in geodetic monitoring. That said, the technique is not without its limitations, which at times, can greatly hinder its performance. The most obvious restriction of many current InSAR techniques is that it is generally noticeably weaker in the horizontal direction than in the vertical. This is primarily due to the viewing geometry of the sensor, and the fact that radar satellites have a typical orbital altitude of around 800 km. This is not to say that the horizontal component of InSAR scans is unusable, but rather that it should simply be treated with a degree of caution.

Another significant limitation of InSAR (and most other space-borne monitoring systems) is due to atmospheric effects. Specifically, the troposphere has the most considerable impact on the SAR signals, with the water vapour in the wet part of the layer causing variability of up to several centimetres (Klees and Massonnet, 1998). The authors also explain that an additional factor affecting the suitability of InSAR is temporal decorrelation, whereby the environment or climate may change but the ground surface does not. This is an issue because the changing environment may indicate a phase shift that is misinterpreted as a shift due to ground deformation. For example, 'environmentally dynamic' areas such as forests and vegetated areas suffer from significant decorrelation, whereas arid areas such as deserts are typically unaffected. As a result, InSAR cannot be utilised over the ocean because the decorrelation is too great.

Whilst InSAR has already promised to be an extremely useful tool to identify and measure areas of deformation, there are still doubts over the precision of the technique, and if it could ever be used as the primary method for re-establishing and updating survey infrastructure affected by an event.

4 SUBSIDENCE IN THE NSW SOUTHERN COALFIELD

Making up the southern portion of the Sydney Basin, the Southern Coalfield of NSW produces premium-quality hard coking coals typically used in the production of steel. There are several operating mines within the Southern Coalfield, with one of the largest operations located approximately 80 km south-west of Sydney, near the township of Tahmoor.

The Tahmoor Coking Mine commenced underground mining operations in 1980, by means of bord and pillar extraction. After 1987, longwall mining was implemented, and remains the primary method of coal extraction. The Tahmoor Coking Mine has consent to produce up to 3 million tonnes of coal per annum (SIMEC, 2024). Removing this amount of material from the ground exerts enormous strain on the overlying surface and has inevitably led to significant subsidence in the area. As part of the mine extends under the Tahmoor township, many survey marks have been affected by the subsidence, with a large portion requiring regular checks and upgrading. Private surveyors in the area notified DCS Spatial Services about the potential deformation and requested that an investigation be undertaken to determine its severity and re-establish survey control.

5 GROUND-BASED SURVEY STRATEGY

DCS Spatial Services, a unit of the NSW Department of Customer Service (DCS), conducted thorough ground-based surveys in March and May 2018, throughout the town of Tahmoor and surrounding suburbs. Before the majority of affected marks could be updated, accurate survey control had to be re-established throughout the area to confirm and validate the future results. Specifically, stable marks (i.e. marks unaffected by the subsidence) had to be found and measured using static GNSS in order to add a level of redundancy to the survey. After achieving this, the accurate information of these marks could be used to help update the coordinates and heights of a subset of the affected marks, which also had been measured using static GNSS. Although static GNSS is one of the most accurate variants of the GNSS technique, it is rather time consuming, with each mark possibly needing to be occupied for a minimum of up to 60 minutes per occupation. As a result, static GNSS was in this case only used to re-establish a horizontal and vertical datum throughout the area, so that more time-efficient techniques could be utilised later. The final product of this survey is a dispersion of marks across the affected area with new, accurate coordinates and heights. The location of selected control marks in relation to the approximate area of interest around Tahmoor is shown in Figure 5.

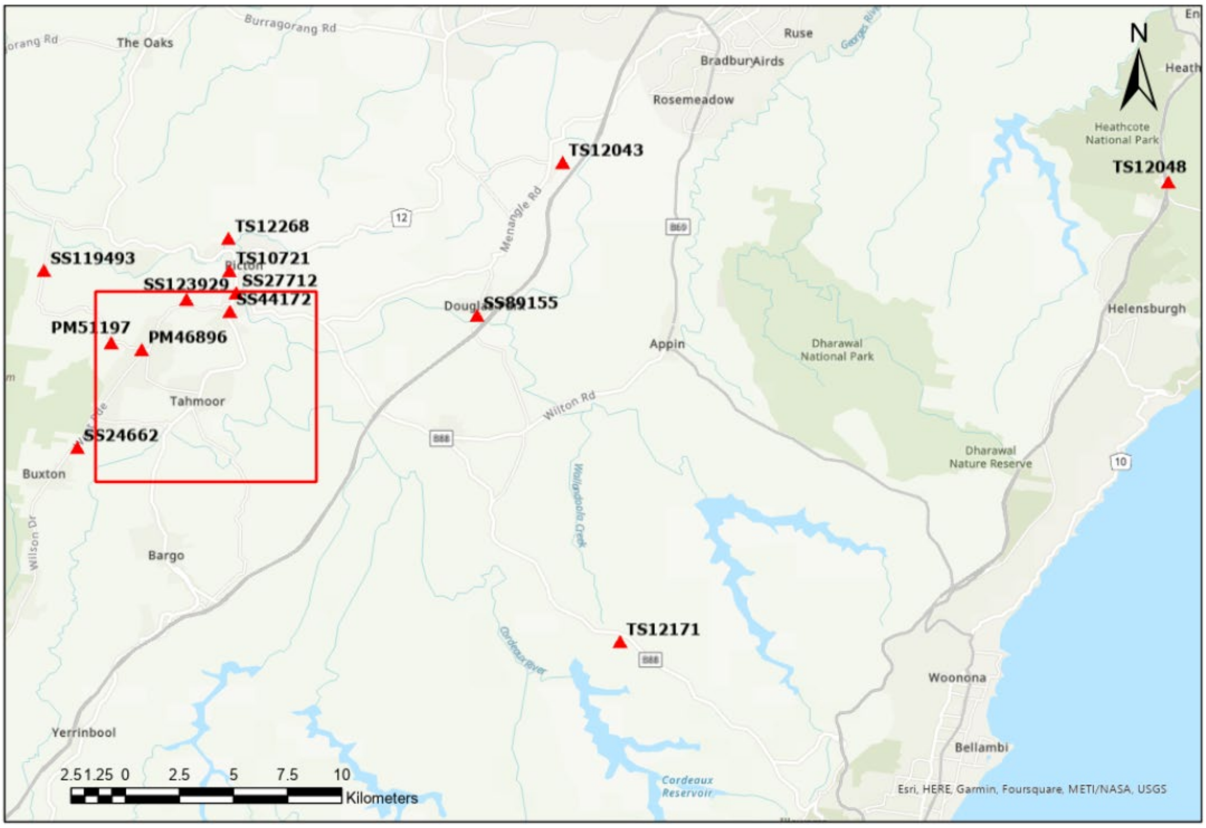


Figure 5: Location of selected control marks in relation to the approximate area of interest.

As expected, Figure 5 shows that many of the chosen control marks reside outside the potential subsidence zone. There is a good coverage of marks encompassing the area of interest, with a denser coverage closer to the suspected area of deformation. It is also evident that the distance between many of the marks is quite large, which greatly inflates the time spent in the field. The three eastern-most marks (TS12043 MENANGLE CORS, TS12048 WATERFALL CORS and TS12171 CORDEAUX CORS) are existing GNSS Continuously Operation Reference Stations (CORS) belonging to CORSnet-NSW (Janssen et al., 2016; DCS Spatial Services, 2024), and were included in the survey to improve the redundancy and geometry, without the need to occupy them. In total, 6 days were spent performing the initial static GNSS control survey, highlighting how time-exhausting the process is to re-establish survey control over a large area.

In total, the information of 36 survey marks was updated as part of this initial control survey, resulting in a localised network of marks with current and high-quality coordinates to be used to help improve surrounding marks in the immediate area. Densification of the improved survey network was conducted using the Real-Time Kinematic (RTK) GNSS technique due to the time-efficiency and economical gains it provides. Whilst it is known that RTK does not have the accuracy capabilities of static GNSS, it can still achieve levels of ±0.025 m (Mekik and Arslanoglu, 2009), which is sufficient for identifying areas of deformation and in some cases can still be used to update survey mark information. As a high-quality local control network had been newly established, it was deemed acceptable to use RTK observations to update the coordinates and heights of many additional survey marks in the area, although any marks updated using this technique would only achieve a maximum Class D. The purpose of this RTK densification survey was not only to increase the number of marks with current, good-quality information, but to also determine the general severity of the ground deformation in the area.

The final step in the overall campaign was to verify and update a series of accurately levelled marks in Tahmoor. In order to best preserve the accuracy of the Class LB marks, 2-way differential levelling was chosen due to its high accuracy, efficiency and the fact that the marks were quite close together.

Adjustment and analysis of these surveys revealed that many marks had moved horizontally, vertically or both. Although the results are reliable, the time and human resources exhausted to achieve these results were very significant. Moreover, as the physical ground deformation cannot be seen with the naked eye, all survey marks in the suspected area of interest need to be individually checked to see if they have been affected. There is also no guarantee that the marks will have finished moving after the surveys have been completed, thus further checking may be required until the movement has ceased.

6 INSAR DATA COMPILATION

InSAR data was used to compare against the ground-based survey methods described above. This data was obtained through Geoscience Australia’s NationalMap platform (GA, 2024), a publicly available online tool providing spatial data acquired by Australian government agencies through a map-based platform. The relevant dataset in this case is the Camden Environmental Monitoring Project (CEMP) InSAR, which contains horizontal and vertical ground surface displacements and velocities derived from radar satellites. Together with their respective uncertainties, the values obtained using this method were thoroughly examined to determine the effectiveness of InSAR as a frontline management tool for ground deformation. Detailed information about this campaign can be found in Garthwaite and Fuhrmann (2020).

The CEMP utilised data from three satellite radar missions: ALOS, Envisat and Radarsat-2. Using combined ascending and descending viewing geometries, values have been derived in the vertical (up-down) and horizontal (east-west) directions for each mission. Due to the nature of slanted line-of-sight InSAR, values in the north-south direction cannot be obtained, thus the horizontal values are strictly limited to east-west. Figure 6 provides an example of a product available via NationalMap, displaying up-down velocities derived from ALOS. It is apparent that there are areas that appear sparse, with very little data available. This typically occurs in densely vegetated areas where the radar signals are heavily obstructed. As a result, these areas produce a large amount of signal noise and as such have not been included in the resultant product. In general, ALOS products have a spatial coverage that is denser than Envisat and Radarsat-2, due to ALOS having a longer wavelength (~24 cm as opposed to ~6 cm) which gives it greater penetrability.

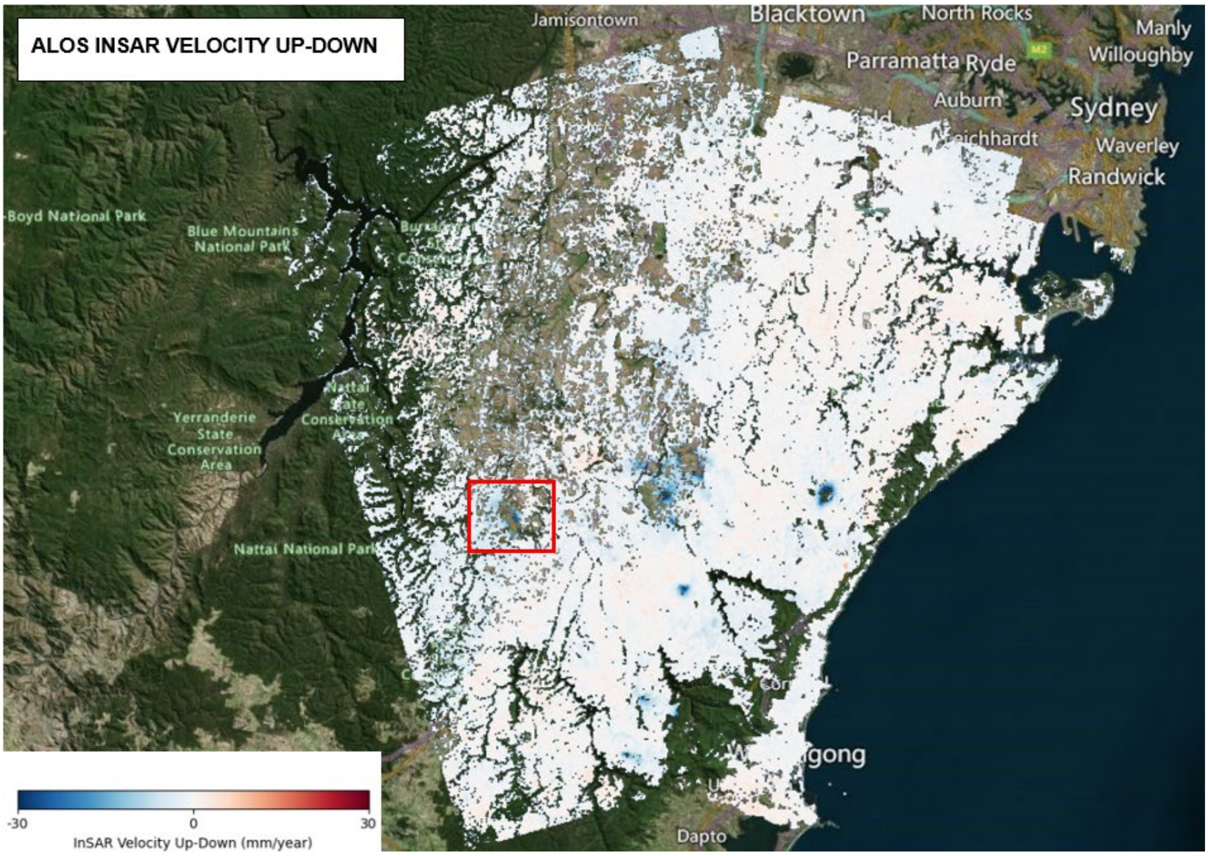


Figure 6: NationalMap product, displaying up-down velocities determined by the ALOS mission, with the addition of the approximate area of interest.

For each mission's final products, the data has been interpolated to 50 m pixel spacing. For an in-depth explanation of the processing techniques and methods employed by Geoscience Australia to produce the final InSAR products, the reader is referred to Garthwaite and Fuhrmann (2020). Both a displacement and a velocity product has been determined for each mission, showing the magnitude (in millimetres) and the linear rate (in millimetres per year) of ground movement, respectively. The time period used to calculate the velocity for each product is approximately 4 years (Table 1). For each interpolated pixel in the displacement and velocity products, an uncertainty has also been calculated for both the up-down and east-west components. Garthwaite and Fuhrmann (2020) explain that these uncertainties arise from error propagation when different viewing geometries are combined during the initial processing phase.

Table 1: Time period used to determine the velocity of each product.

Mission	Start Date	End Date
ALOS	16/05/2006	07/01/2011
Envisat	02/06/2006	25/09/2010
Radarsat-2	15/07/2015	31/05/2019

As the epochs of the InSAR products do not align with the ground-based survey epochs, it was decided to use the average yearly velocity values for a comparison between the techniques, as the displacement values are entirely dependent on the time period at which they were observed. As such, the displacements (mark movement) determined in the ground-based surveys have been converted to velocities (in millimetres per year) to be in keeping with the InSAR values. Although these results may be more generic and approximate, they should be able to adequately identify trends in the ground movement that can be more closely compared to the ground-based survey results. Furthermore, this decision means it is assumed that ground movement occurs linearly, which is certainly not always true.

Figure 7 shows the survey marks selected to act as control for the campaign, overlayed onto the ALOS, Envisat and Radarsat-2 velocity product layers. Although it has already been stated and explained that these marks were selected as control for the survey because they were deemed to be stable and unmoving, the figure provides immediate justification for this selection. It is instantly clear that all control marks are situated in or around yellow-coloured regions of the map, indicating they are in areas of little to no ground movement.

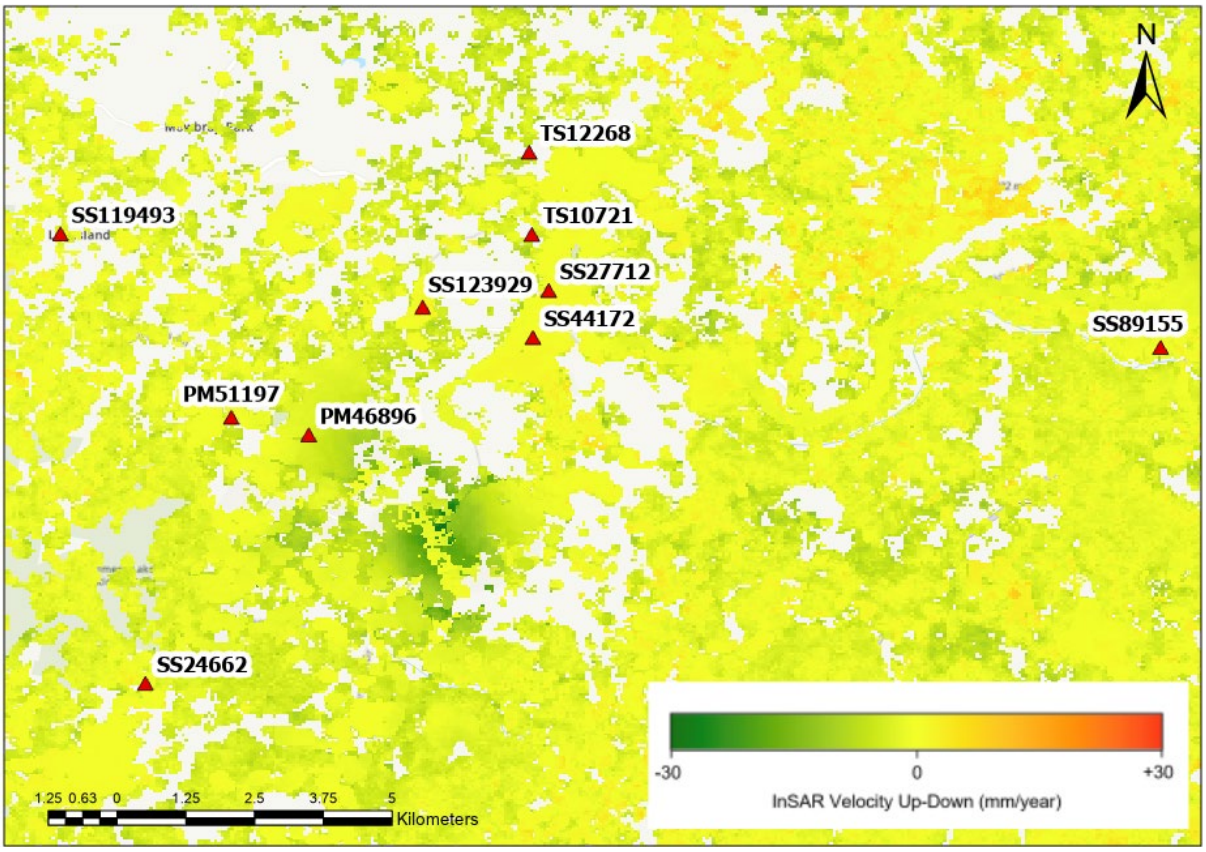


Figure 7: Survey marks selected to act as the initial control of the survey campaign, overlayed onto the ALOS, Envisat and Radarsat-2 velocity products.

Tables 2-5 summarise the values extracted from the NationalMap products for all established survey marks used in the ground-based campaign. To determine these values, the positions of the survey marks were intersected with each InSAR product, and the resultant pixel was adopted to represent the position of a mark. In some instances, no InSAR data was available, due to the issue of sparseness detailed previously. For horizontal (east-west) results, negative velocities indicate westward movement and positive velocities signify eastward movement. Similarly, for vertical (up-down) data, negative velocities indicate downward movement whilst positive velocities suggest upward movement.

Tables 2 & 3 state the velocities and uncertainties (standard deviations) derived by each radar mission for the established survey marks used in the static GNSS control survey. It is immediately evident that there is a large disparity in the velocity values between each mission for the same pixel. Additionally, the standard deviations of the ALOS values are significantly higher than for the other two missions. Specifically, the ALOS standard deviations are around four times larger than Envisat and Radarsat-2, which can be attributed to ALOS having a wavelength that is also approximately four times longer than the other missions. As mentioned previously, the longer wavelength allows ALOS signals to penetrate vegetation more easily, but this comes at the cost of larger uncertainty. Figure 8 illustrates the positions of the established marks in relation to the three InSAR products.

Table 2: Horizontal (east-west) InSAR velocities and standard deviations (mm/yr) for marks used in the static GNSS survey.

Mark	ALOS Vel.	ALOS Std.	Envisat Vel.	Envisat Std.	Radarsat-2 Vel.	Radarsat-2 Std.
PM46911	-	-	18.6	1.4	0.4	1.0
PM82399	-8.1	7.5	-9.3	2.1	0.0	0.8
SS123929	-1.9	19.5	-1.7	1.3	13.6	1.0
PM46896	3.1	3.5	7.6	1.9	3.5	0.7
PM46910	7.8	1.3	-	-	-	-
PM46932	1.4	6.5	1.8	1.3	-	-
PM46899	2.9	3.5	4.3	1.9	6.1	0.7
PM46929	-1.6	1.5	2.4	2.0	-	-
PM46937	11.1	12.3	3.9	0.1	-	-
PM46912	-13.8	21.5	2.3	2.1	-2.0	1.2

Table 3: Vertical (up-down) InSAR velocities and standard deviations (mm/yr) for marks used in the static GNSS survey.

Mark	ALOS Vel.	ALOS Std.	Envisat Vel.	Envisat Std.	Radarsat-2 Vel.	Radarsat-2 Std.
PM46911	-	-	-17.8	0.7	-0.5	0.8
PM82399	-6.1	6.3	-5.1	1.1	-5.4	0.6
PM46910	-6.5	1.0	-	-	-	-
PM46899	-8.6	3.0	-5.4	1.0	1.4	0.5
PM46929	-5.5	0.5	-1.5	0.9	-	-
PM46937	-21.5	10.4	-8.4	0.0	-	-
PM46912	-22.5	21.5	-18.0	1.1	-2.3	0.9

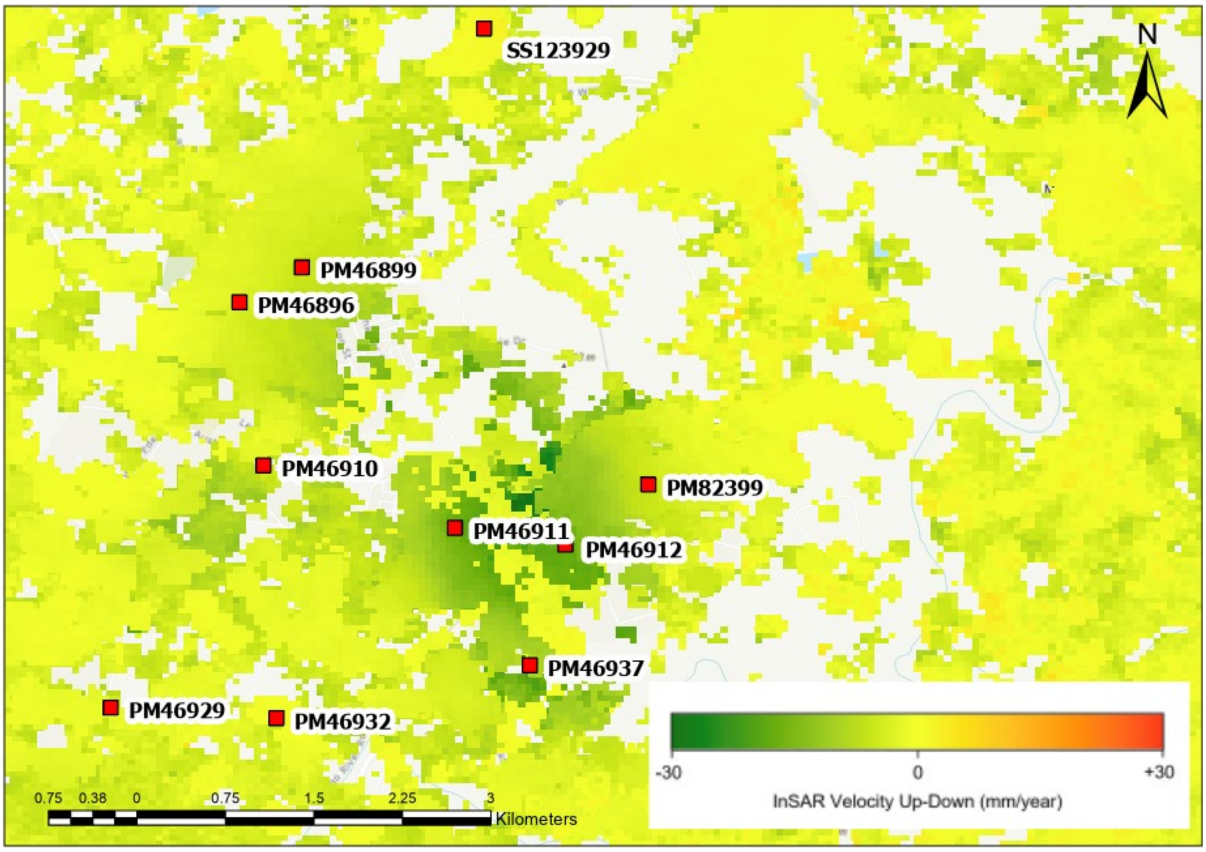


Figure 8: Survey marks measured using static GNSS, overlayed onto the vertical ALOS, Envisat and Radarsat-2 velocity products.

Tables 4 & 5 provide the InSAR values for the established survey marks included in the RTK GNSS and differential levelling surveys. Again, large variation is seen between the InSAR missions for coincident pixels. Unfortunately, this area includes concentrated patches of no available radar data for one or more missions at the locations of some survey marks. Particularly ALOS exhibits very poor spatial coverage over the southern portion of this area, hence no velocities are available for most of the marks in the south-eastern corner of Figure 9.

Table 4: Horizontal (east-west) InSAR velocities and standard deviations (mm/yr) for marks used in the RTK GNSS survey.

Mark	ALOS Vel.	ALOS Std.	Envisat Vel.	Envisat Std.	Radarsat-2 Vel.	Radarsat-2 Std.
PM46936	-	-	7.8	4.3	-0.9	0.9
SS41450	-	-	-	-	-1.6	0.9
PM60507	-	-	-	-	0.2	1.0
PM46900	3.1	10.1	3.2	0.9	8.6	0.7
SS72197	-1.5	11.4	2.1	0.8	7.5	0.6
SS49906	7.7	3.3	10.1	1.9	4.8	0.8
SS72198	-2.1	13.3	2.6	1.3	6.9	0.6
SS91897	10.6	2.0	13.5	4.3	3.5	0.6
SS58699	4.5	3.3	6.9	1.7	-	-
PM66406	2.6	8.4	4.1	4.3	-	-
PM51195	1.4	12.0	-	-	-	-

Table 5: Vertical (up-down) InSAR velocities and standard deviations (mm/yr) for marks used in the RTK GNSS and differential levelling surveys.

Mark	ALOS Vel.	ALOS Std.	Envisat Vel.	Envisat Std.	Radarsat-2 Vel.	Radarsat-2 Std.
PM46900	-4.8	9.1	-3.5	0.5	1.5	0.5
SS41451	-	-	-	-	-0.7	0.8
SS41450	-	-	-	-	-0.5	0.7
SS41447	-	-	-	-	-1.4	0.8
PM60507	-	-	-	-	-2.1	0.8
SS54834	-22.8	21.5	-18.0	1.1	-1.6	0.8
PM46936	-	-	-16.8	2.2	-0.2	0.7
SS54839	-	-	-17.3	1.9	-1.4	0.8

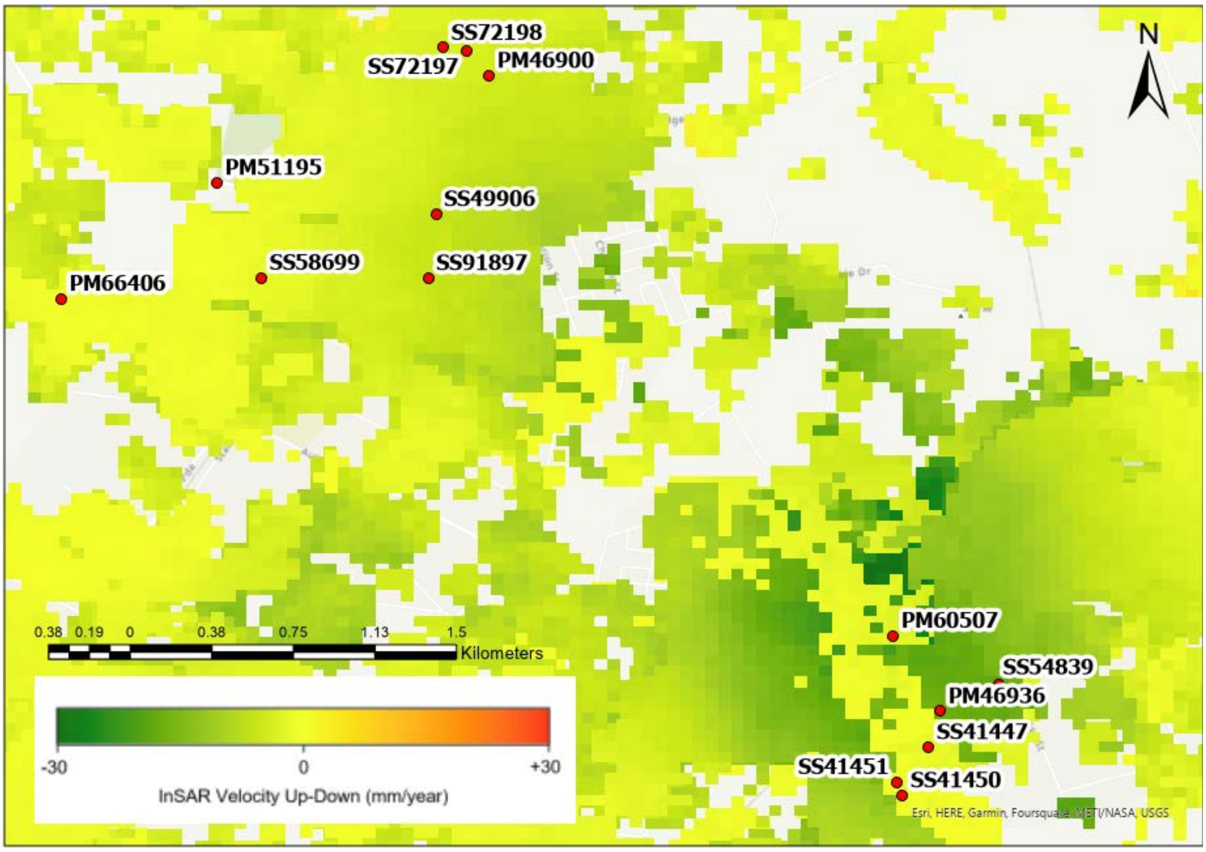


Figure 9: Survey marks measured using RTK GNSS and differential levelling, overlayed onto the vertical ALOS, Envisat and Radarsat-2 velocity products.

After examining the values in the tables above, three factors are apparent. The first is that values for the same pixel between missions are highly inconsistent. Not only do ALOS, Envisat and Radarsat-2 velocities differ in magnitude for the same pixel, but occasionally they also differ in direction. This means that whilst the values from one mission may be indicating downward vertical movement (subsidence), another may be suggesting upward vertical movement (uplift). Without any prior knowledge of the site, these conflicting results make it extremely difficult to decipher how the landscape is actually moving, and in turn how best to deal with the deformation. The second factor is that the standard deviations are typically larger for the horizontal values than for the vertical. This reinforces the fact that InSAR is generally weaker in the horizontal direction as a result of the viewing geometry and orbiting altitude. The third factor is the significant lack of data for many of the marks in the area. For the 25 established marks used from the ground-based survey, there should be 63 horizontal velocities (a value from each mission for 21 horizontally established marks) and 45 vertical velocities (a value from each mission for 15 vertically accurate marks). However, only 48 of the possible 63 horizontal velocities are available, and only 30 of the possible 45 vertical velocities are present. Again, this absence is likely due to overhead obstructions impeding the radar signals, thus creating ‘noisy’ pixels that have been removed from the NationalMap dataset.

7 COMPARISON OF GROUND-BASED AND INSAR RESULTS

This section details the differences between the deformation results derived via the ground-based survey methods (static GNSS, RTK GNSS and differential levelling) and by InSAR. Before these comparisons can be made, the units of the ground movement need to be made consistent between all techniques. Results determined by ground-based methods are expressed as a total magnitude in metres (difference in coordinates or height), and the InSAR results are represented as velocities in millimetres per year. As previously stated, the starting and ending epochs of the ground-based surveys do not align with those of the InSAR missions, so all results should be expressed as average linear velocities in millimetres per year. Thus, the displacements determined in the ground-based surveys must be converted to velocities using a starting epoch.

To convert the coordinate shifts in the ground-based surveys to velocities, the shift is divided by the number of years between the current survey by DCS Spatial Services and the most recent previous survey. However, if the previous date occurs prior to the commencement of mining activity, the velocities will be skewed as ground movement will only materialise after the underground extraction has begun. As such, the date of each longwall commencement should be found and compared to the date of the initial survey value to determine which should be used as the starting epoch for the velocity calculation. Figure 10 provides an indication of the positions of the underground workings of the Tahmoor mine. Figure 10a was scaled, georeferenced and digitised to create Figure 10b, which shows the approximate locations of the longwalls in relation to the survey marks. Whilst the positions of the longwalls are only roughly known, the accuracy is considered adequate to decipher their probable influence on the ground movement.

To determine the most likely point at which an area of land first began subsiding, the oldest longwall within a mark’s vicinity must be identified. Jankowski and Spies (2007) state that other studies in the NSW Southern Coalfield have detected significant subsidence up to 1.5 km from mining panels. With this estimate in mind, a 1.5 km buffer was placed around each survey mark and the oldest longwall it intersected was adopted as the time that ground movement began at that location.

Figure 11 illustrates an example of this process, specifically highlighting the buffer around PM46899. In this case, the oldest intersected longwall is LW21, and so the time at which this longwall commenced is taken as the start of ground movement at the position of that mark. This method is approximate and does not consider the geological nature of the area, but it is the only means available for retrospectively predicting the onset of the ground deformation.

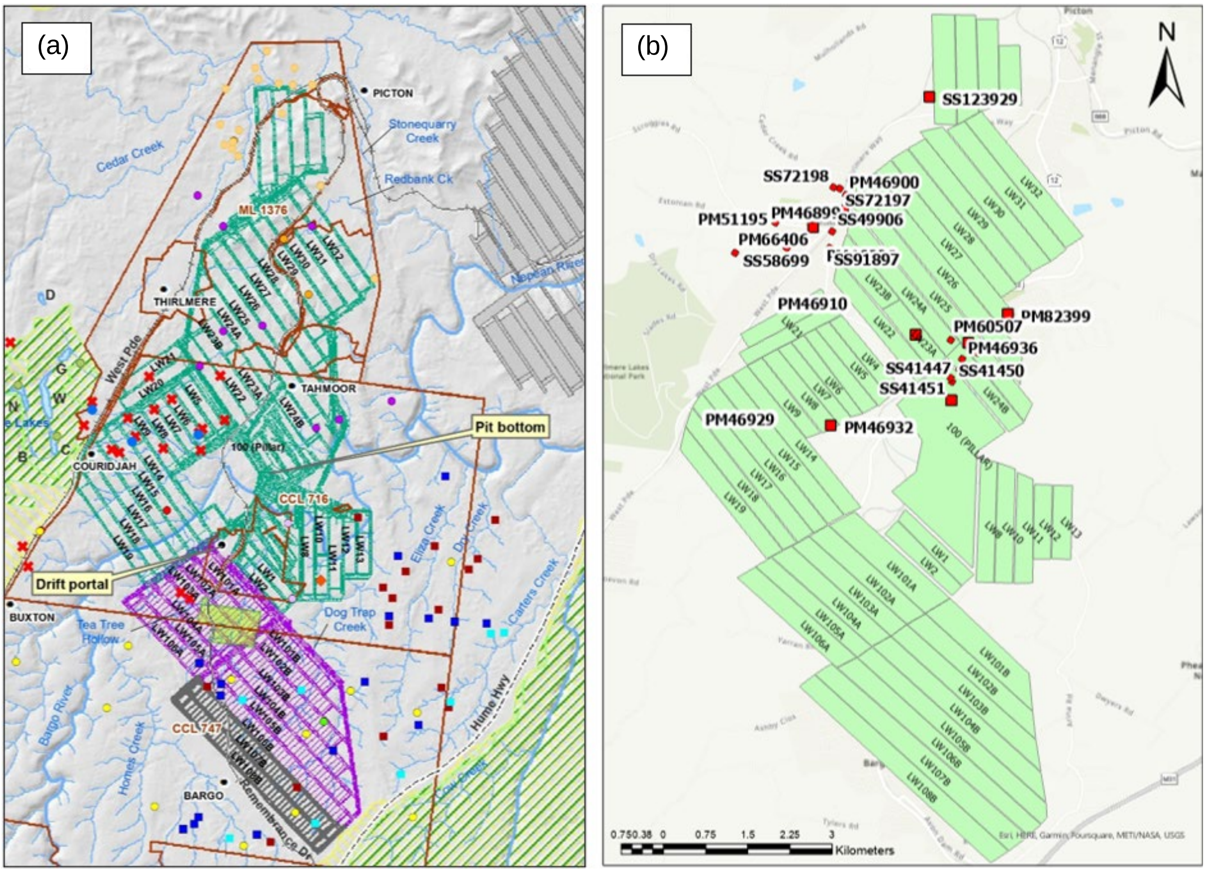


Figure 10: (a) Overlay of the underground workings of Tahmoor mine (SLR Consulting, 2020), and (b) base image after digitisation and georeferencing in relation to the survey marks.

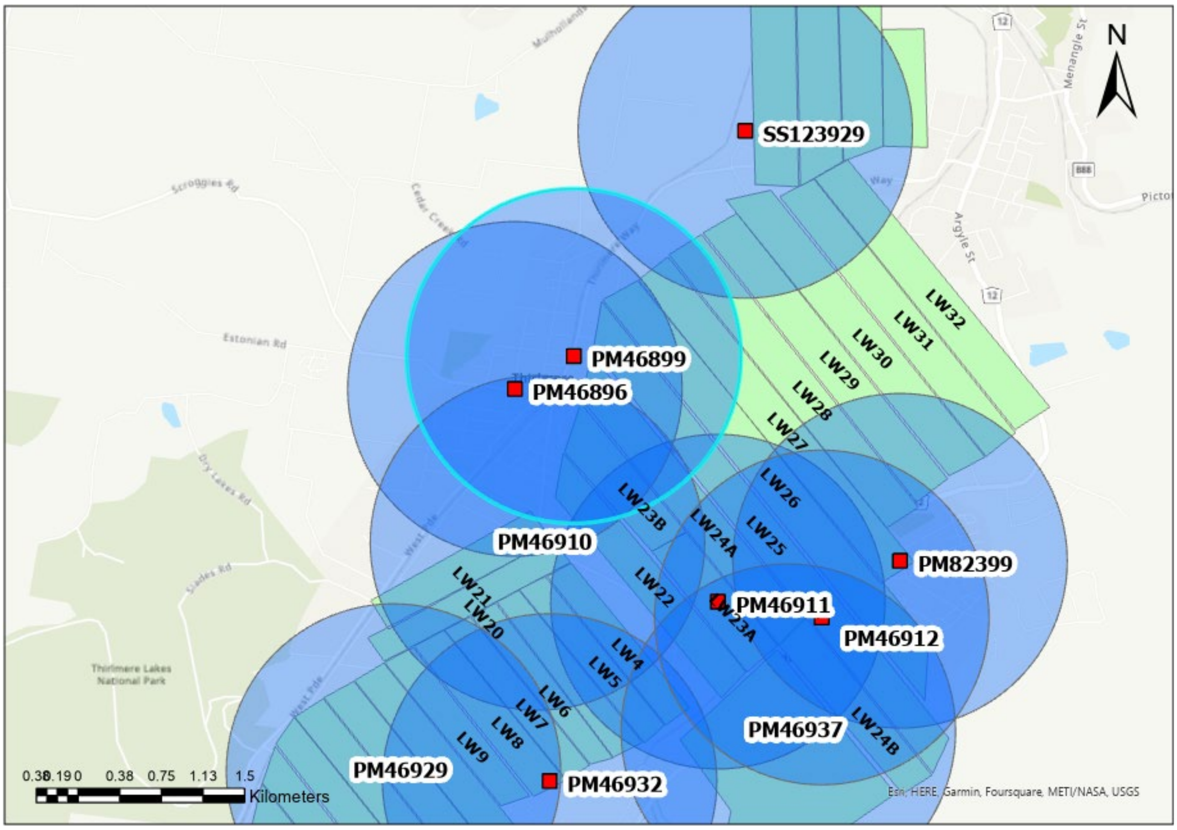


Figure 11: The oldest longwall that a 1.5 km buffer around PM46899 intersects, is LW21.

This process was carried out for all marks, with dates sourced from Ainsworth (2017) and by interpolation. If the date of the longwall succeeds the initial survey date, it is adopted as the initial epoch for the velocity calculation. These velocities can then be directly contrasted against the InSAR values. Figures 12-16 illustrate the differences between the velocities derived by ground-based survey methods and by InSAR for each mark. In these charts, each survey mark has four unique bars (one for the ground-based survey and one for each InSAR mission), indicating the derived direction and magnitude of movement at the site. Ideally, the bars for each mark should be in the same direction and be of a similar length.

Figure 12 highlights the immense disparities between the horizontal velocities obtained by static GNSS and those by each InSAR mission. Only three values appear to closely align, with most disagreeing by more than ±6 mm/yr. For the most part, the derived direction (being either positive or negative) of the ground movement for each mark tends to be consistent between each method with only a few isolated noteworthy variations. One such variation can be seen in the velocities for PM46912, where the ALOS value completely differs in direction to the static GNSS value. The magnitude of horizontal velocities differs considerably for most marks.

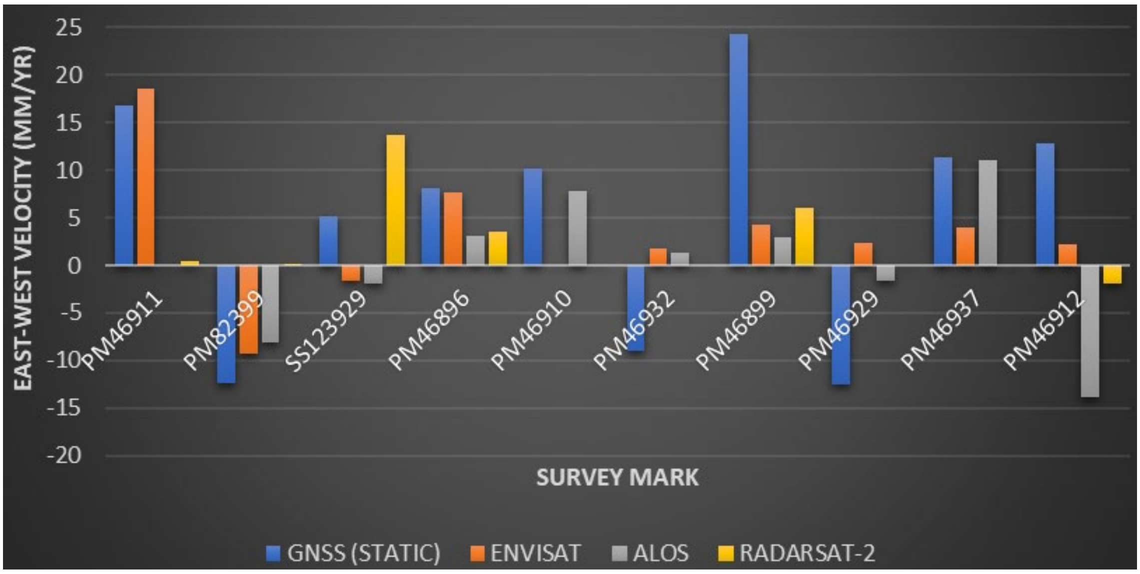


Figure 12: Horizontal (east-west) velocities (mm/yr) determined by static GNSS and each InSAR mission.

The differences between the vertical velocities from static GNSS and the InSAR missions are shown in Figure 13. Again, very little correlation can be seen amongst the ground-based and InSAR results, with several differences exceeding ±20 mm/yr. It is apparent that all but one velocity value has been derived as negative, which supports the already known fact that the area is subsiding. However, as with the horizontal case, the magnitude of the velocities is highly variable between methods with very little correlation seen.

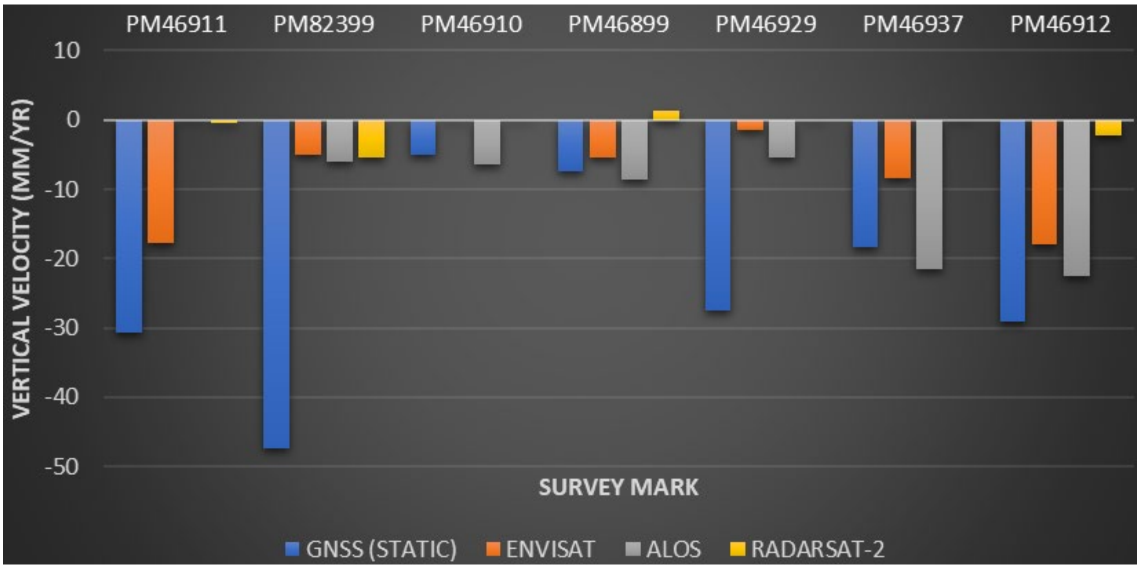


Figure 13: Vertical (up-down) velocities (mm/yr) determined by static GNSS and each InSAR mission.

Figure 14 shows the differences in horizontal velocities derived by RTK GNSS and each InSAR mission. Here, the discrepancies are slightly better than in the static GNSS case, with around an even split between differences above and below ±6 mm/yr. The largest differences are also noticeably less than in the previous case, and overall a closer correlation can be seen. It is once again evident that the derived directions of movement tend to align between methods for most marks in the study, with only five values disagreeing in direction.

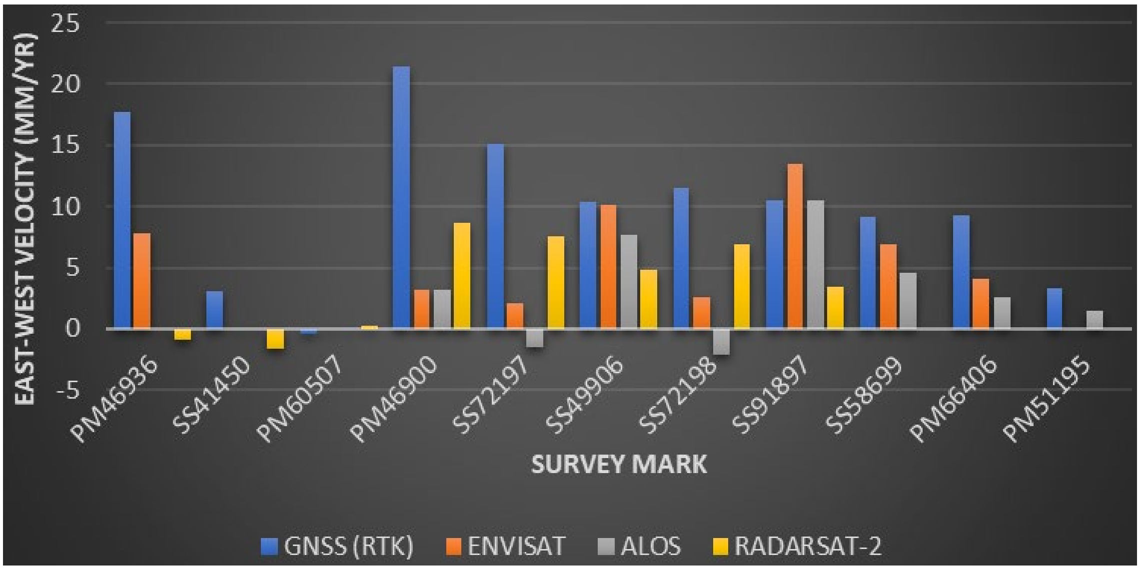


Figure 14: Horizontal (east-west) velocities (mm/yr) determined by RTK GNSS and each InSAR mission.

The differences in vertical velocities between RTK GNSS and each InSAR mission are illustrated in Figure 15. Very little correlation is seen in this dataset, with all but one difference exceeding ±6 mm/yr. Also apparent is a significant lack of data from the ALOS and Envisat missions in this area, which further hinders the analysis. Nevertheless, once more the derived direction of the velocities is mostly consistent between all methods.

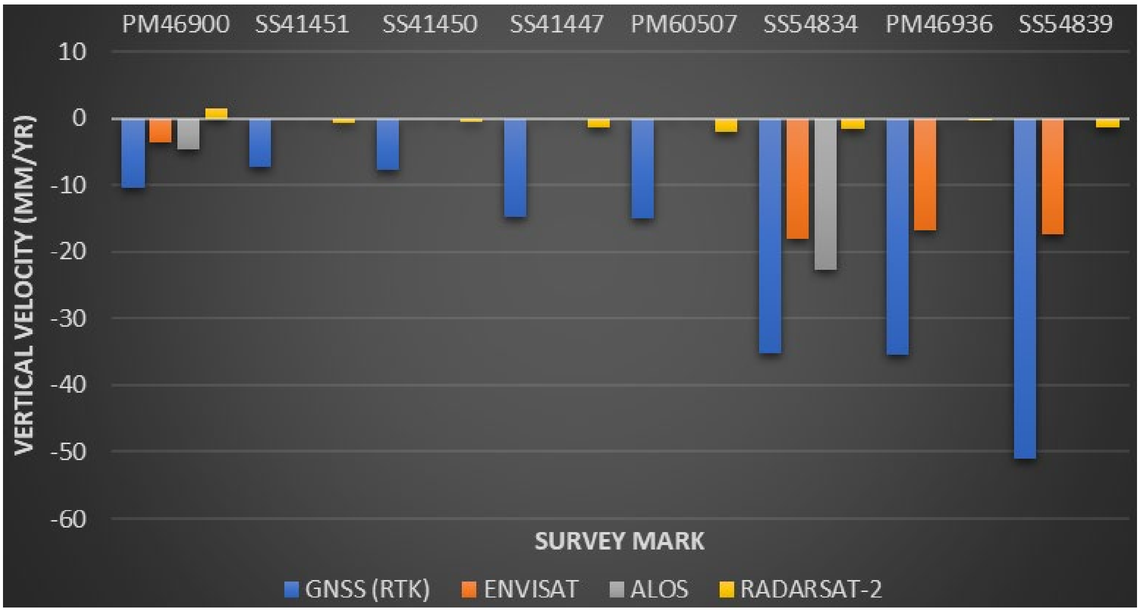


Figure 15: Vertical (up-down) velocities (mm/yr) determined by RTK GNSS and each InSAR mission.

Finally, Figure 16 highlights the differences in vertical velocities determined by differential levelling and each InSAR mission. As with the vertical RTK GNSS results, large variations are evident between each method. Again, there is a lack of data from the ALOS and Envisat missions at the locations of these marks. While the figure highlights the similarities in derived direction between the methods, it is difficult to adequately compare the techniques with almost half of the possible data unavailable.

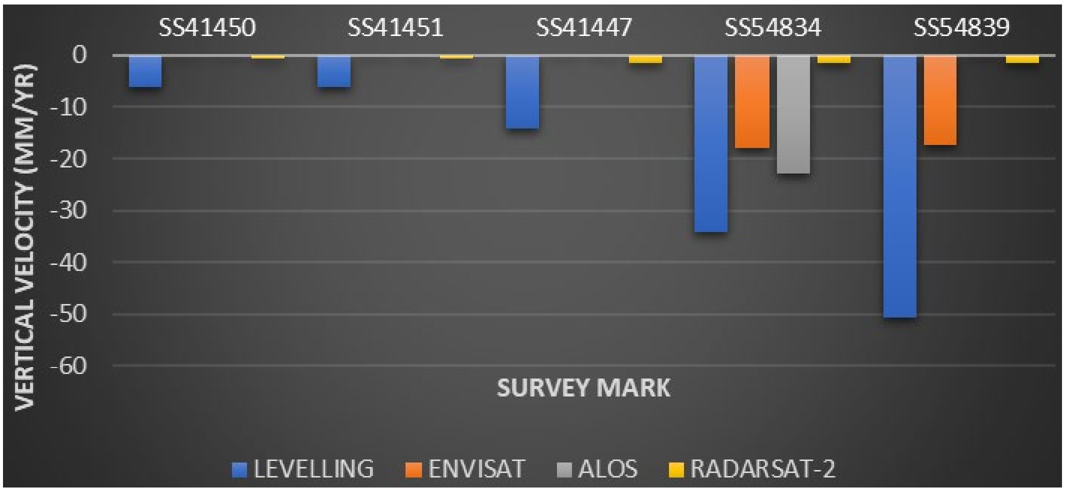


Figure 16: Vertical (up-down) velocities (mm/yr) determined by differential levelling and each InSAR mission.

The results of this study clearly indicate a great dispersion between the InSAR and ground-based velocities, and amongst the InSAR missions themselves. For the most part, the velocity directions derived by all methods tended to agree, but the magnitude of the velocities was highly variable. In other words, all methods were sufficient in determining whether the horizontal movement was either easterly or westerly, and whether the vertical movement was upward or downward, but the amount of movement was highly contentious. Given the standard deviations of the InSAR velocities (see Tables 2-5) were at times as large as the velocity values themselves, it is no surprise that these large discrepancies are present. The ALOS and Envisat values generally showed greater correlation to the ground-based values than Radarsat-2, but they both had large areas of no data. In contrast, Radarsat-2 had the densest covering of data, but the magnitude of the velocities was typically very different from the other two missions. Due to the lack of data, it is difficult to determine with certainty whether InSAR performed better in the vertical or horizontal direction, although the available data suggests that it generally performed equally in both. This is somewhat surprising given that the standard deviations for the horizontal velocities were significantly larger than those for the vertical.

Several factors can be attributed to the variation in results. The first and perhaps most obvious is the large uncertainties derived for the InSAR velocities. Garthwaite and Fuhrmann (2020) explain that areas of large surface displacement (such as above the Tahmoor mine) require a different processing strategy that only uses consecutive interferograms rather than the 'persistent scatter' method, which utilises a selection algorithm to determine pixels with slowly decorrelating phase characteristics. This results in much noisier displacement values, which in turn leads to greater uncertainties being assigned to them. Another limiting factor of the study relates to the interpolation of the InSAR data and the resultant pixel sizes. The 50-metre pixel spacing means that a single displacement and velocity value is assigned to each 50 m by 50 m area. These values have been adopted in this study to represent a singular point (being the location of the survey mark) and compared against ground-based values that have been acquired specifically at that point. It is highly unlikely that the value assigned to a pixel will be truly representative of any singular point within that pixel, and so it is unrealistic to expect that the ground-based and InSAR values will closely align.

Other limiting factors contributing to the discrepancies in velocity values arise from assumptions made in the design of the study. To determine the velocities of the ground-based survey displacements, an assumption was made that ground deformation would most likely begin when mining activity in the immediate vicinity has commenced. This means that if the initial survey date of a mark occurred before mining initiated, the date of mining commencement was adopted to calculate the velocities of the ground-based values. When this occurred, an approximate date of each respective longwall was used for the velocity calculation. Of course, it is impossible to know with certainty whether or not a nearby longwall has had any influence on the timing of localised ground movement. However, no other options were available to adequately perform the calculation. Furthermore, an equally significant assumption made was that ground deformation has occurred linearly between the initial and final epochs. This assumption is not entirely accurate as ground deformation is dependent on a range of factors, and movement may be more or less pronounced from one year to the next. For many of the survey marks in this study, the time range used for the ground-based velocities does not match those of the InSAR missions, and so there is a possibility that the rate of ground movement was different in each period. This means that the discrepancies between methods may be indicating the different rates of ground movement in each respective time period.

These limitations highlight the difficulties associated with retrospectively determining the presence and rate of ground movement. Whilst ground-based methods such as GNSS can provide very accurate positioning results, these results are limited to singular points on the ground. Furthermore, with the exception of CORS, a great deal of time and energy must be spent occupying marks at various epochs in order to determine a representative rate of ground movement because deformation does not always occur linearly. Conversely, while InSAR on its own may not provide positioning information at the level of ground-based methods, it has far superior spatial resolution, with the ability to cover far more land with greater ease. It is evident there is certainly a place for InSAR, allowing for the emergence of several new research areas.

8 NEW NATIONWIDE DATASETS

The InSAR data used in this study was processed and made available by Geoscience Australia specifically for use in the Camden Environmental Management Project. As such, the data is only available over a limited area relevant to the project (see Figure 6). However, nationwide subsidence monitoring is possible, and has already begun, in Australia. Through the Sentinel-1 mission, the entire Australian landmass can be covered at a far greater frequency than previously considered possible. Made available via the Copernicus Australasia Regional Data Hub, data from Sentinel-1 is openly available to the public, albeit in a largely unprocessed state.

The Sentinel-1 mission uses a pair of twin polar orbiting satellites, orbiting at an altitude of around 700 km (ESA, 2024). The platform utilises a range of imaging modes that vary the resolution and swath width of the final images. The modes that enable a full coverage of Australia are the Interferometric Wide (IW) swath mode, and the Extra Wide (EW) swath mode. The IW mode can achieve a swath width of 250 km at a geometric ground resolution of around 5 m x 20 m, whereas the EW mode can achieve a swath width of 400 km but at a lower resolution of around 20 m x 40 m. Both modes use Terrain Observation with Progressive Scans SAR (TOPSAR), which ensures higher quality throughout the image.

Figure 17 shows Sentinel-1's coverage across Australia, while Figure 18 indicates its subsidence management potential, illustrating ground deformation in the NSW Southern Coalfield. In this figure, the Tahmoor coal mine can be seen in the south-western corner of the image. Data from the Sentinel-1 mission therefore has the potential to greatly improve the detection of ground deformation in the study area.

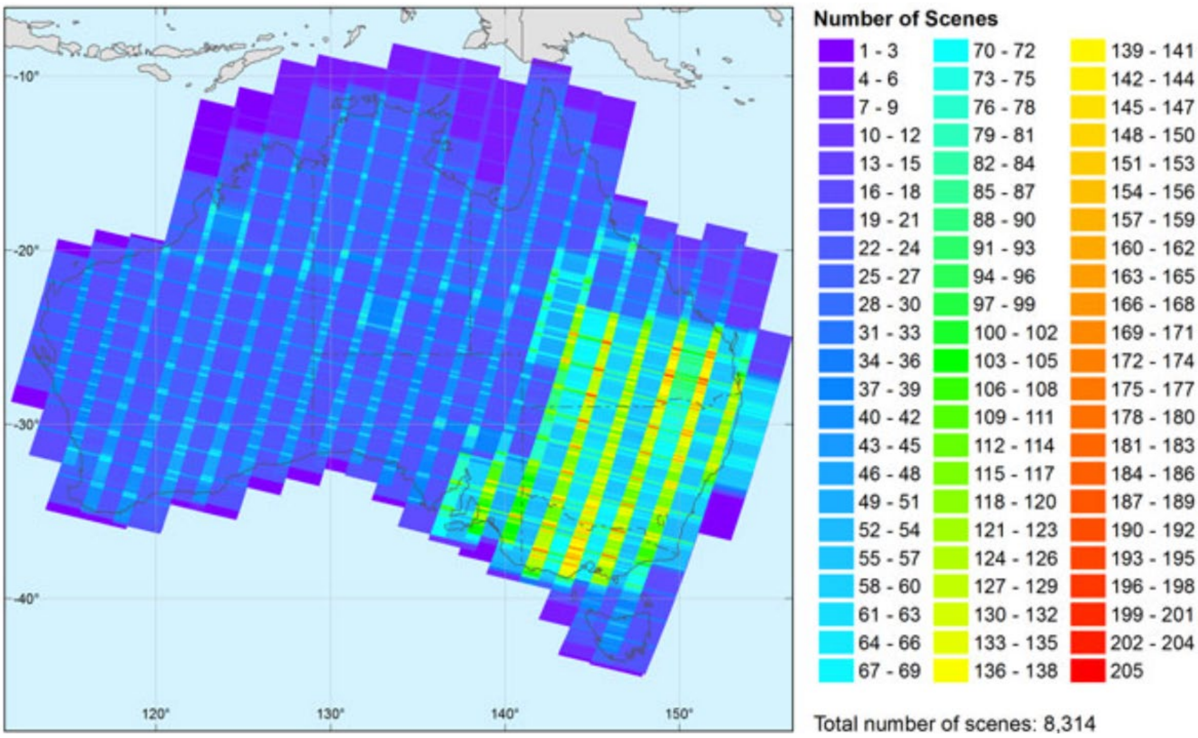


Figure 17: Sentinel-1 data coverage across Australia as of 30 April 2017 (GA, 2017).

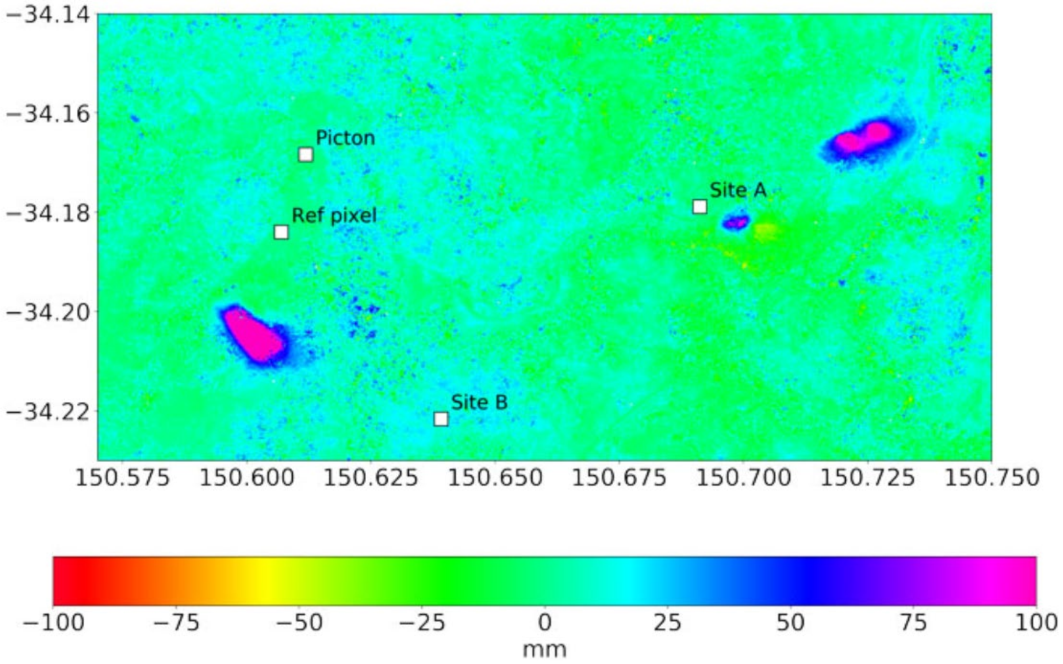


Figure 18: Areas of subsidence in the NSW Southern Coalfield determined using the Sentinel-1 mission. The Tahmoor mine is located in the south-western corner of the image (GA, 2017).

9 CONCLUDING REMARKS

The aim of this study was to compare the accuracy and practicality of modern geodetic measurement technologies for the application of large-scale ground deformation monitoring in Australia. It is desired to find methods that could be implemented to reduce or perhaps eliminate the uncertainty around survey mark movement and ground deformation. Specifically, publicly available InSAR data was examined and contrasted against traditional ground-based survey methods to test the validity of currently accessible techniques that could be utilised by surveyors and geospatial experts.

Following the comparison of ground-based and InSAR velocity results, it was evident that the public InSAR data was highly variable and not capable of providing results accurate enough to be considered as a primary means of re-establishing coordinates of survey marks. That said, the InSAR data used in this study was not designed to be used as a precise positioning tool, which is reflected by the 50-metre pixel spacing of each dataset. In addition, the aim of the study was not to test the most accurate InSAR data available, but instead to use publicly available data that any practising surveyor could access. With this in mind, it is unsurprising and perhaps unrealistic to expect near-perfect results from the public platform. Nevertheless, the InSAR data still proved to be a valuable tool for quickly detecting areas of ground movement and correctly determining its direction. This in itself could greatly benefit surveyors who suspect ground deformation has taken place but are unable to make a decisive judgement. In this case, the public InSAR data would serve as a point of verification to support a surveyor's claim. Furthermore, the use of InSAR would eliminate a lot of the guess work involved with re-establishing survey control after (or during) a deformation event. Using InSAR, areas unaffected by ground movement can be swiftly identified, providing a surveyor with a more certain location to begin their survey.

Although this study was not successful in finding a new frontline solution for managing ground deformation across Australia, it did succeed in uncovering new tools for practising surveyors to utilise. The accuracy and suitability of various geodetic measurement technologies was sufficiently tested in order to make a valid judgement on their practicality. Whilst there were obvious limitations in the design of this study, many of these were unavoidable and the product of compromise. Nonetheless, it proves that InSAR could be used in conjunction with ground-based technologies to monitor the movement of survey monuments and thus work to create greater certainty when determining the extent of ground deformation events. This study has proven to be a stepping-stone in the pursuit of a nationwide strategy to handle ground deformation.

ACKNOWLEDGEMENTS

This paper is based on the first author's undergraduate honours research thesis at the University of New South Wales (UNSW), which received the 2023 Excellence in Surveying and Spatial Information (EISSI) University Student of the Year award. Dr Matthew Garthwaite and Patrick Du at Geoscience Australia are thanked for their support, guidance, clarifications and datasets.

REFERENCES

Ainsworth Z. (2020) Mine operations plan, Tahmoor Coking Coal Operations - SIMEC Mining, https://www.tahmoorcolliery.com.au/wp-content/uploads/sites/8/2022/10/20079_tahmoor-colliery-mop-2020-24_rev-b_20200828.pdf (accessed Mar 2024).

Bowman J.R., Gibson G. and Jones T. (1990) Aftershocks of the 1988 January 22 Tennant Creek, Australia intraplate earthquakes: Evidence for a complex thrust-fault geometry, *Geophysical Journal International*, 100(1), 87-97.

Clarke M.F., Williams M.A.J. and Stokes T. (1999) Soil creep: Problems raised by a 23 year study in Australia, *Earth Surface Processes and Landforms*, 24(2), 151-175.

DCS Spatial Services (2024) CORSnet-NSW, http://www.corsnet.com.au/ (accessed Mar 2024).

Equitable Building & Investment Co. Ltd. v. Ross (1886), 5 NZLR (SC) 229.

ESA (2024) Sentinel-1, https://sentinel.esa.int/web/sentinel/missions/sentinel-1 (accessed Mar 2024).

GA (2017) New open-source software enhances satellite geodesy capability, https://www.ga.gov.au/news-events/news/latest-news/new-open-source-software-enhances-satellite-geodesy-capability (accessed Mar 2024).

GA (2024) NationalMap, https://www.ga.gov.au/scientific-topics/national-location-information/nationalmap (accessed Mar 2024).

Garthwaite M.C. and Fuhrmann T. (2020) Subsidence monitoring in the Sydney Basin, New South Wales: Results of the Camden Environmental Monitoring Project, Geoscience Australia, http://dx.doi.org/10.11636/Record.2020.016 (accessed Mar 2024).

Jankowski J. and Spies B. (2007) Impact of longwall mining on surface water-ground water interaction and changes in chemical composition of creek water, *Proceedings of XXXV IAH Congress*, Lisbon, Portugal, 17-21 Sep, 10pp, https://www.ipcn.nsw.gov.au/resources/pac/media/files/pac/projects/2019/05/ulan-coal-mod-4/comments-received-after-26-june-2019/ibrahim-farag/1-impact-of-longwall-mining-on-surface-waterground-water-interaction.pdf (accessed Mar 2024).

Janssen V., Haasdyk J. and McElroy S. (2016) CORSnet-NSW: A success story, *Proceedings of Association of Public Authority Surveyors Conference (APAS2016)*, Leura, Australia, 4-6 April, 10-28.

Klees R. and Massonnet D. (1998) Deformation measurements using SAR interferometry: Potential and limitations, *Geologie en Mijnbouw*, 77(2), 161-176.

Macchiarulo V., Milillo P., Blenkinsopp C., Reale C. and Giardina G. (2023) Multi-temporal InSAR for transport infrastructure monitoring: Recent trends and challenges, *Proceedings of the Institution of Civil Engineers – Bridge Engineering*, 176(2), 92-117.

Mekik C. and Arslanoglu M. (2009) Investigation on accuracies of Real Time Kinematic GPS for GIS applications, *Remote Sensing*, 1(1), 22-35.

Mine Subsidence Board v. Maria Vervoorn (2008), NSWCA 280.

SIMEC (2024) Tahmoor Colliery, https://www.tahmoorcolliery.com.au/ (accessed Mar 2024).

SLR Consulting (2020) Tahmoor Mine groundwater modelling plan, version 2.0, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-8445%2120200803T055828.848%20GMT (accessed Mar 2024).

Terrestrial Laser Scanning in Cadastral Surveying: The ACT Experiment

Greg Ledwidge
ACT Office of the Surveyor-General and Land Information
Greg.Ledwidge@act.gov.au

Matt Stevenson
Lonergan Surveying
matt@lonergansurveying.com

ABSTRACT

Remote sensing in cadastral surveying is in its infancy in the ACT as in other jurisdictions. There is an increasing need to measure stratum subdivisions (and in 3D more generally), and it is likely that Unit Titles (Strata) will follow suit soon. Recognising this development, the former ACT Surveyor-General, Jeff Brown, in an agreement with the NSW Board of Surveying & Spatial Information (BOSSI) Land and Mining Surveyor Committee, gave dispensation for a pilot stratum cadastral survey to be completed using Terrestrial Laser Scanning (TLS) techniques. The lucky registered land surveyor who undertook the task was Matt Stevenson from Lonergan Surveying. The objective of this presentation is to investigate the TLS technique and its applicability in cadastral surveying. It outlines the NSW standards that were applied in the pilot project and the learnings in relation to using TLS and what changes may be needed in future guidelines or regulations. The BOSSI guideline 'Terrestrial Laser Scanning (TLS) for Cadastral Surveys' was the framework adopted for conducting the survey. The ACT Office of the Surveyor-General and Land Information worked with registered surveyor Matt Stevenson in adapting the guideline for use with the ACT Surveyors Practice Directions at the time. The survey was for a stratum subdivision of a parcel of land. TLS was applied as a measuring technique to both the external and internal structures in relation to the existing and proposed boundaries. There were critical learnings from the pilot project in relation to the application of accepted TLS methods, survey validation, best practice guidelines and managing errors. The result of the survey was a successfully examined and then registered Deposited Plan. As a technique, TLS offers considerable promise but, like any measurement method, there are limitations. While the pilot project was a success, additional work needs to be done to refine standards, techniques and related guidelines for the future.

KEYWORDS: *Terrestrial Laser Scanning, cadastral surveys, standards.*

Pushing the Planning Boundaries: A Case of Forensic Surveying

Mike Stapleton
Lovell Property Consultants
mikestapleton65@gmail.com

ABSTRACT

Legislation plays a vital role in cadastral surveying and town planning, and on occasion surveyors are asked to give evidence at court. This paper outlines the case of a Canberra homeowner and their architect stretching the planning rules beyond the limits and a surveyor's critical role in a court case relating to the rules for home construction. In Deakin, an old and prestigious suburb of Canberra, 2-storey dwellings are the maximum size permitted. However, what constitutes a 'storey' and 'basement' are critical to the extent one can build. In this case, a dwelling was erected. The owner, their architect, a certifier and the Government Planning Authority believed that the dwelling satisfied the planning rules. A neighbour disagreed and took the matter to the ACT Civil & Administrative Tribunal. Critical to the case was the determination of the 'datum ground level' and the position of the contour a metre below the floor level above the lowest level. This paper describes the investigation to determine the datum ground level, involving research of contour plans dating back as far as 1910 and aerial imagery dating back to 1951. The datum ground level determination required ascertaining the levels at the time of operational acceptance for subdivision, which in this case was 1951. The methodology used to determine the datum ground level and its location involved the following 9-step process: (1) Analyse the definition, (2) determine the time stamp required for datum ground level, (3) plan the research, (4) locate the site on the contour plan, (5) determine a consistent datum, (6) search and analyse aerial imagery, (7) trace locations into a Computer-Aided Design (CAD) file, (8) interpolate the data, and (9) decide on the best solution for the datum ground level and its location. It was concluded that the critical datum ground level contour passed through the bedroom on the upper level, meaning that the dwelling should be deemed to be a 3-storey building and not permitted on the site.

KEYWORDS: *Legislation, cadastral surveying, town planning, datum ground level, basement.*

1 INTRODUCTION

Legislation plays a vital role in cadastral surveying and town planning, and on occasion surveyors are asked to give evidence at court. This paper provides an example by outlining the case of a Canberra homeowner and their architect stretching the planning rules beyond the limits and the surveyor's critical role in a court case relating to the rules for home construction.

A new residence has been constructed on Block 5 Section 9 at 8 Gawler Crescent in Deakin, Australian Capital Territory (ACT) (Figure 1). A dispute has arisen as to whether the building is a 2-storey or 3-storey building. On visual inspection, the building clearly has three levels. However, the owner and the architects who designed the building contend that part of the lower level is a basement and that the third level is constructed over the basement. If the third level is constructed over a basement, the building can be considered as a 2-storey building.

Basement means a space within a building where the floor level of the space is predominantly below datum ground level and where the finished floor level of the level immediately above the space is less than 1.0 m above datum ground level. Whether part of the lower level is a basement and, if it is, where that part of the basement is located with respect to the upper level is dependent on the position of datum ground level. This paper examines the issue of datum ground level and makes a determination as to its location.

Figure 1: New residence constructed in Deakin.

2 DEFINITION OF DATUM GROUND LEVEL

The Territory Plan defines datum ground level as the surface ground level as determined in a field survey authorised by a registered surveyor (ACT Government, 2024a):

a) at the time of operational acceptance for subdivision, or
b) if a) is not available, provided no new earthworks have occurred, or
c) at the date of grant of the lease of the block,

whichever is the earliest.

Where a), b) or c) is not available, datum ground level is the best estimate of the surface ground level determined in a field survey, considering the levels of the immediate surrounding area and authorised by a registered surveyor.

The author believes that a) and c) in this instance will be the same. Option b) does not apply as earthworks have occurred. The options a) or c) can be deduced from old plans or databases before or after the date and confirmed by comparing recent surveys of undisturbed areas in proximity of the site.

The following assumptions are made:

- Datum ground level means the existing level of a site at any point. It is not a single level.
- A registered surveyor includes the equivalent status utilised at the time of the survey. (Charles Scrivener was a licensed surveyor.) Government departments with registered/licensed surveyors are included in the definition.
- A field survey includes photogrammetric or Light Detection and Ranging (LiDAR) surveys conducted by aircraft or drones.

It should be noted that the Surveyor-General of the ACT has issued a guideline in 2013 relating to the determination of datum ground level. As it is inconsistent with the Territory Plan (ACT Government, 2024a) and National Capital Plan (Australian Government, 2020), the Territory Plan definition is considered to be that which should be used in the determination. Unfortunately, due to its existence, confusion exists as to the definition to be adopted and thus the value of datum ground level.

The definition in the guideline states (ACT Government, 2013): "Datum ground level means the level of the surface of the ground as defined in a field survey and authorised by a qualified surveyor at the time of operational acceptance for greenfield development or prior to any new earthworks having occurred after that time."

The key difference between the definitions is that the Territory Plan provides three options and specifically states that if available the earliest should be adopted. The guideline definition requires that for non-Greenfields developments the level is that level prior to any new earthworks having occurred after that time. Thus under the Territory Plan definition, the datum ground level is the level before construction in 1955, while under the guideline the level is that level of the ground before construction commenced for the new dwelling, which is the level defined in the plan produced by Capital Surveys in 2020 (see section 4.7).

A second difference is that the Territory Plan requires the authorisation of a registered surveyor, whilst the guideline requires the authorisation of a 'qualified surveyor', whose definition includes surveyors other than registered surveyors.

3 HISTORY OF THE SITE

Deposited Plan (DP) 316 was signed by the licensed surveyor on 14/05/1951 and certified by the Acting Surveyor-General on 01/08/1951 (Figure 2). It is likely that 'operational acceptance' occurred earlier in 1951 or late 1950. The date of survey was 10/10/1950. The lease of Block 5 Section 9 was granted on 14/07/1951.

Over the years, several aerial images were collected over the site (Figure 3). Older aerial imagery revealed the following:

- 1951: Only scattered tracks crossed the site. No significant earthworks had occurred.
- 1952: Works appeared to have commenced with the construction of Westminster House on the adjacent Block 4 south-east of the site.
- 1955: Dwellings had been constructed on adjacent Blocks 4 and 18, while earthworks had commenced on the subject site.
- 1958: The dwellings on Blocks 5 and 6 appeared to have been constructed.
- 1962: Extensions were added to 8 Gawler Crescent (at the rear of the existing building).

Recent history included:

- May 2021: Environment, Planning and Sustainable Development (EPSD) consideration.
- September 2021: Certifier approval for the proposed dwelling.
- May 2023: Certifier approval of amendments.

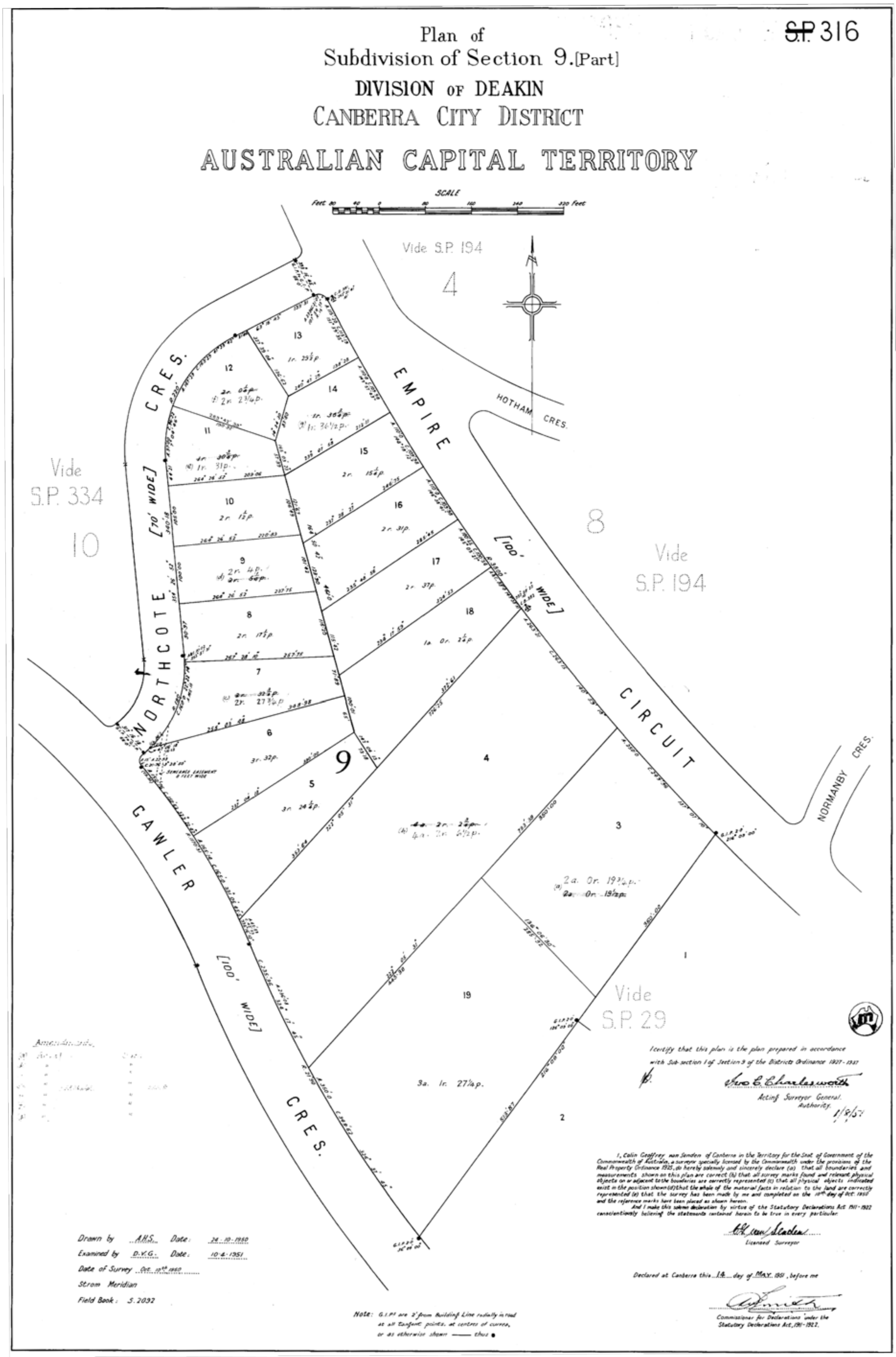


Figure 2: DP316.

Recent aerial imagery indicated:
- 2004 & 2015: Original home with access driveway. Apparent undisturbed areas around a regulated tree south of the dwelling on Block 6 and in the rear of Block 18.
- 2022: Original home demolished, construction of new dwelling underway with extensive earthworks, but undisturbed areas remain under the tree on Block 6 and in the rear of Block 18.

Figure 3: Aerial imagery collected over the site in 1951, 1955, 2021 and 2022.

4 CONTOUR PLANS

The following contour plans indicating levels have been found relating to the site:
- 1910 contour map of Canberra – Charles Scrivener (1910).
- Site plan 10 Gawler Crescent – Unknown (1955-1958).
- Site plan 8 Gawler Crescent – Unknown (1955).
- ACT Contour Series (7C) – Department of the Interior (1960).
- ACT Contour Series (8A2) – Department of the Interior (1960).
- Canberra-by-Suburbs – ACT Survey Office (pre-2000).
- ACTmapi 2015 contours – ACT Survey Office (2015).
- 2015 LiDAR data – ACT Survey Office / Geoscience Australia (2015).
- Contour and detail surveys – Capital Surveys (2020).

The following sections describe these contour plans in more detail.

4.1 Contour Map of Canberra (1910)

The only comprehensive source of heights (levels) found prior to 1951 was the 1910 contour map of Canberra prepared under the supervision of Charles Scrivener (Scrivener, 1912) (Figure 4). As existing trigonometrical (trig) stations were shown on the plan, it is possible to 'locate' the subject site on the plan and hence use the contours from the plan. These contours would be indicative of the levels at the time of issue of the lease and commencement of the subdivision in 1951. The contour intervals are 5 ft, indicating a reasonably high level of accuracy.

Figure 4: Contour map of Canberra (1910).

The levels are given in feet and thus can be converted to metres. However, the height datum for levels has changed over the years with the ACT adopting the Australian Height Datum (AHD) in 1971 (Daly, 1972; Evans, 2022). To relate the Scrivener and 1964 levels to the current levels would thus require adaptation. On the other hand, the Canberra-by-Suburbs levels and current surveys relate to the AHD. The adaption may normally involve comparing level values of bench marks from early surveys to what they are and adjusting contours accordingly. For example 'West of School' trig is shown on the Scrivener plan as having a level of 1,978 ft, which converts to 602.894 m, whilst its level now provided in the ACTmapi database (ACT Government, 2024b) is 602.265 m.

A more realistic approach was to adopt areas close by, which do not appear to have been affected by earthworks and compare levels shown on the various level sources to determine an appropriate datum. The ACTmapi contours appear to have been based on the 2015 LiDAR data, so could be used as a source for comparison with the 1910 survey.

In summary, this 1910 plan provides an early indication of the levels of the site. However, the accuracy is questionable due to:

- The distortion in creating the image.
- The scale of the plan relative to the site.
- The methodology for determining heights was less accurate than the methods used today.
- The levels of bench marks have changed over time, and the height datum has been changed to AHD.

Nevertheless, the 1910 contours do give an indication of the even slope over the site.

4.2 Site Plan 10 Gawler Crescent (1955-1958)

This site plan was obtained from an image of the house design provided by Berkely Real Estate on the allhomes website. Unfortunately, the image is not clear and as a result neither the contour values nor the responsible surveyor's name can be read. Values for the contour intervals can be gauged by comparing the contours on recent plans (either Capital Surveys or ACTmapi contours), thus providing an indication of the levels along the boundary between Blocks 5 and 6.

4.3 Site Plan 8 Gawler Crescent (1955)

This site plan forms part of building plans submitted by Ancher, Mortlock and Murray, Architects. The plan is rough, with boundaries not scaling to match the dimensions of the block (Figure 5). No indication is provided as to the derivation of the contours, or whether the survey was authorised by a registered surveyor. Contours are provided at 2 ft intervals based on a local datum. However, the floor level of the dwelling is provided as 92 ft.

As the later survey by Capital Surveys determined a height of the floor level, it was possible to derive contour values based on the Capital Surveys floor level (average of 618.8 m). Thus, whilst the plan appears to be rough and the accuracy may be queried, the plan does provide the most direct indication of datum floor level.

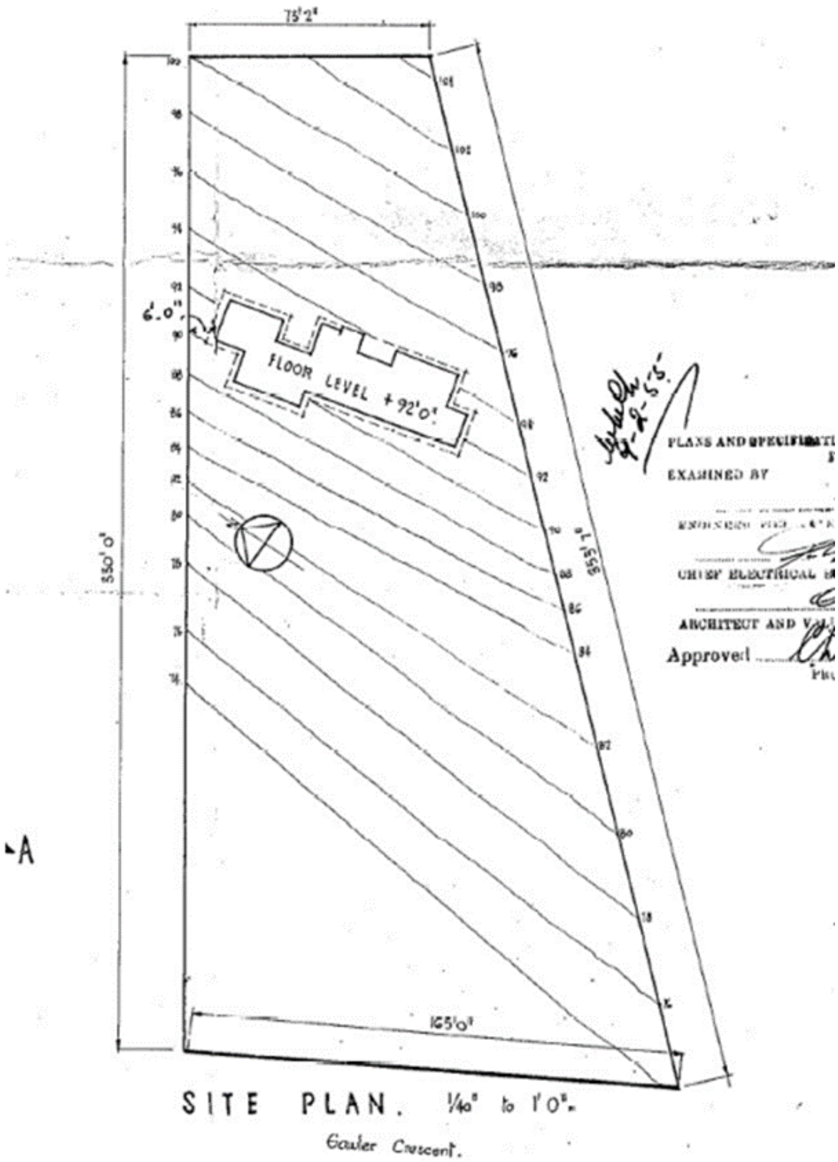


Figure 5: Site Plan 8 Gawler Crescent (1955).

4.4 ACT Contour Series (7C and 8A2) (1960)

Plan 7C indicates contours and also that a dwelling had been constructed on the site before that time. Hence earthworks would have occurred around the site of the dwelling, which is also the approximate location of the existing dwelling. Plan 7C has 5 ft contour intervals, while Plan 8A2 (which extends into Block 4 south-east of the site) has 1 ft contour intervals. Plan 7C indicates fencing on or close to the boundaries, so a good indication of the relative position of the boundaries and contours can be plotted. Plan 8A2 shows the boundaries as opposed to boundary fences, thus providing greater accuracy. Plan 8A2 also again illustrates the even gradient of the land near the subject site. As these plans were prepared after the construction of the dwellings and as the conversion to AHD occurred after 1960, these plans have not been used.

4.5 Canberra-by-Suburbs Contour Set (Pre-2000)

A Computer-Aided Design (CAD) file dataset of boundaries, contours, building outlines and other features was provided by the ACT government before the commencement of ACTmapi.

The origin of the contours is unknown, but it is known to have been provided before 2000. The contours were not used as they were determined after construction work was undertaken and have been superseded by the LiDAR survey of 2015.

4.6 ACTmapi Contours and LiDAR Levels (2015)

The ACTmapi contour database is based on 2015 LiDAR survey data and provides a good indication of the levels on the site and surrounding areas before construction began on the newly constructed dwelling (Figures 6 & 7). It also enables the determination of level values of apparently undisturbed land close to the site of the residence (at the rear of Blocks 5 and 14, and around the regulated tree near the boundary adjacent to the residence at 10 Gawler Crescent). The ACTmapi contours are a smoothed version of the contours from the Geoscience Australia point cloud.

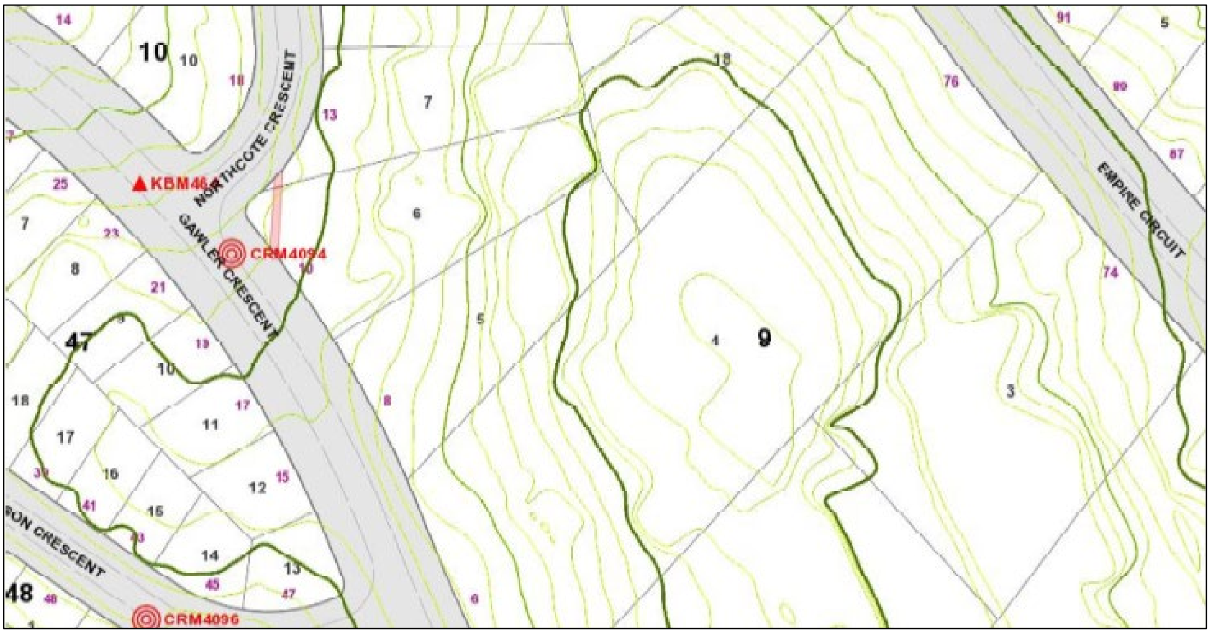


Figure 6: ACTmapi contours (2015) derived from LiDAR data.

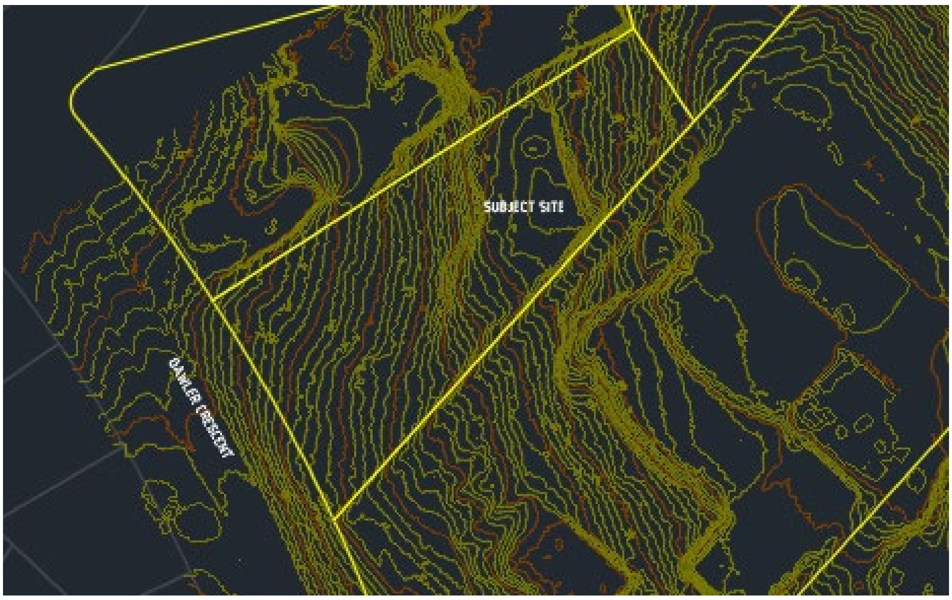


Figure 7: LiDAR contours (2015) from Geosciences Australia.

4.7 Contour and Detail Plan of Block 5 by Capital Surveys (2020)

This survey covers the area on which the new dwelling has been built (Figure 8). It is referred to AHD and largely consistent with the ACTmapi 2015 contours. The survey was undertaken before the old dwelling was demolished and one can determine contours through apparently undisturbed areas. The plan was certified by a registered surveyor.

Thus it was possible to suggest that the contours at the rear (north-east) of Block 5 (621 m) and the contour running close to the regulated trees (615 m) are largely undisturbed. Assuming the even slope shown in the Scrivener and other plans, a justifiable datum ground level for the site could be interpolated between the 615 m and 621 m contours.

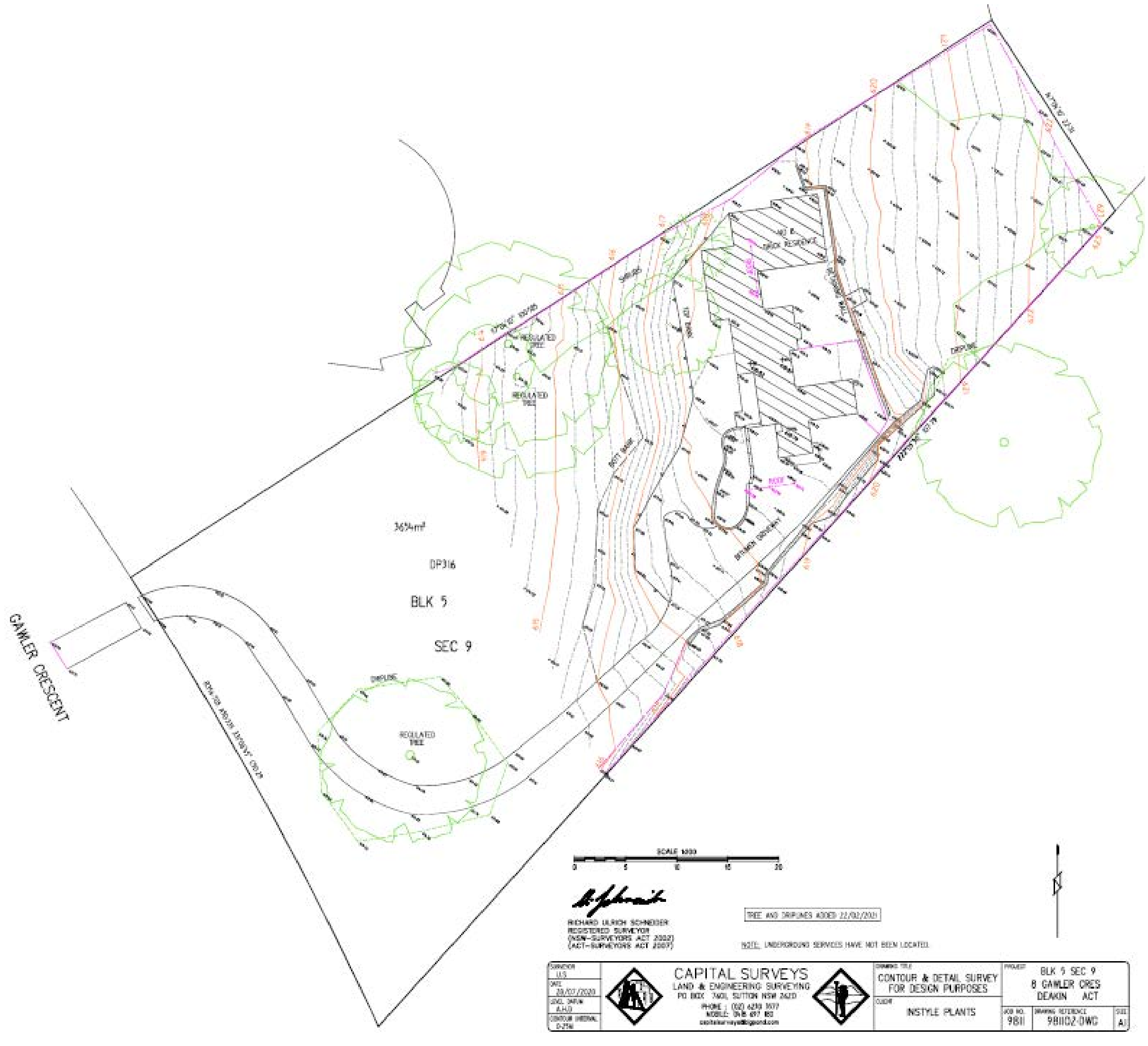


Figure 8: Contour and detail plan of Block 5 by Capital Surveys (2020).

5 METHODOLOGY

Following the decision to use the Territory Plan definition, the methodology used to determine the datum ground level and its location involved the following process: (1) Determine the time stamp required for datum ground level, (2) plan the research, (3) locate the site on the contour plan, (4) determine a consistent datum, (5) search and analyse the aerial imagery, (6) trace locations into a CAD file, (7) interpolate the data, and (8) decide on the best solution for the datum ground level and its location.

5.1 Determine the Time Stamp Required for Datum Ground Level

The Crown Lease and Deposited Plan (DP316) were examined to determine the date of operational acceptance for subdivision and the date of grant of the lease of the block. This was determined to be between October 1950 and August 1951.

5.2 Plan the Research

A thorough investigation was made of sources of levels, encompassing 90 years between Scrivener's original contour survey in 1910 and the survey of the subject site by Capital Surveys in 2020. The acquired contour plans have already been discussed in section 4.

5.3 Locate the Site on the Contour Plan

The locations of the Scrivener contours could be approximately determined using trig stations and survey marks shown on the plan that either still exist today or for which coordinates are still available (Figure 9). Some versions of the Scrivener maps also included grids and street overlays. The ACTmapi historical plans website provides an overlay of the cadastral boundaries over old maps.

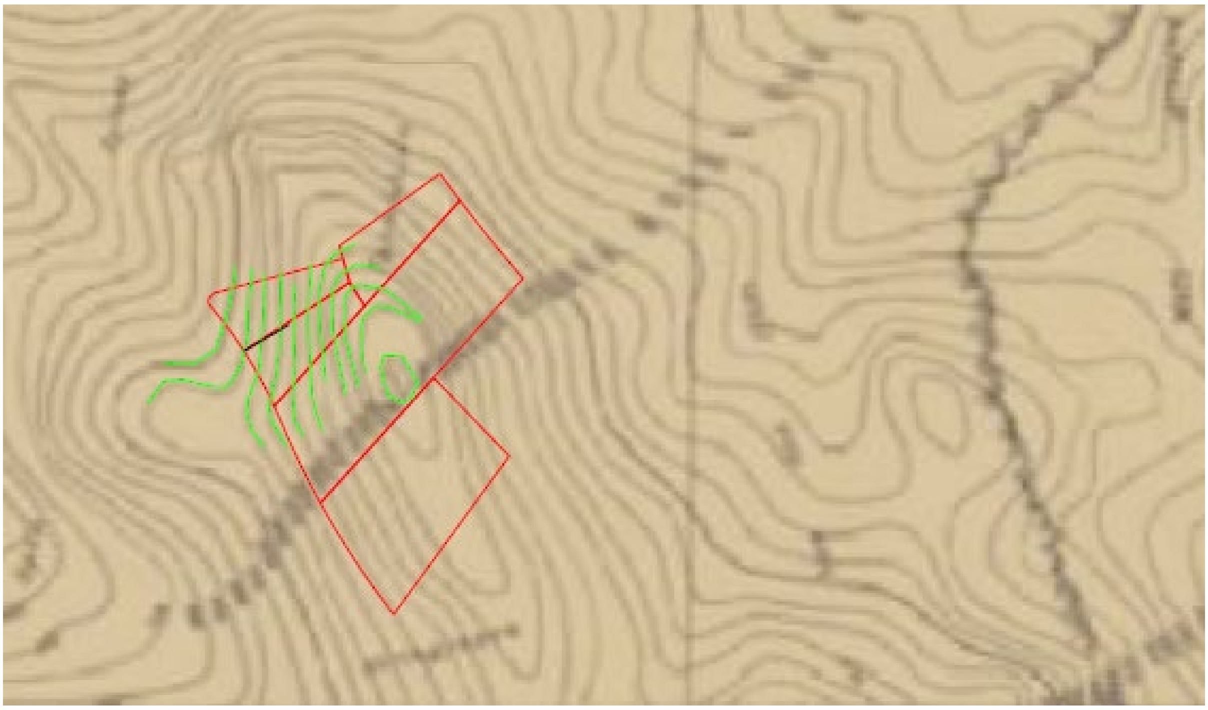


Figure 9: Location of the subject site overlayed on Scrivener's contour plan.

5.4 Determine a Consistent Datum

The acquired plans had varying coordinate and level datums. These datums needed to be correlated to ensure consistent comparisons could be made and the site analysed.

5.5 Search and Analyse the Aerial Imagery

It was necessary to determine when construction began and the extend of excavations on the site and neighbouring properties. ACTmapi provides historical aerial imagery dating back to the early 1950s (see Figure 3). From these images, it was possible to determine the extent and year of excavation, along with identifying unexcavated areas. Based on this information, contours shown within the excavated areas on plans prepared after the date of excavation were discounted. Modern imagery is available via ACTmapi as well as other sources such as Nearmap. By comparing the recent imagery with the imagery from the 1950s one could determine areas on or close to the site where little or no excavation had taken place. Levels in those areas could thus be used as an indication of the datum ground level.

5.6 Trace Locations into a CAD File

Based on the information provided on the site plan of the architects, Collins Pennington, and the survey report plan of Kleven Spain, it was not possible to accurately plot the position of the new dwelling. Unfortunately, CAD data was not provided. However, modern CAD packages such as AutoCAD allow the user to import other files (including images) into the CAD file.

The site and floor plans of the dwelling were thus scanned as jpg files and imported into the CAD file. As these drawings showed the location of the dwelling as well as the boundaries, it was possible to scale and rotate the images to reflect the scale and orientation of the CAD file. The ACTmapi database includes accurate cadastral information, allowing the site coordinates to be determined on the required grid. The now scaled and rotated images were then overlaid with the boundaries obtained from the ACTmapi database, and the positions of the dwelling and associated floors were traced into the CAD file.

In a similar way, contours shown on acquired plans could be traced into the CAD file and used to determine the datum ground level. Thus, datum ground levels for strategic points of the new dwelling could be interpolated from this data.

5.7 Interpolate the Data

Contours are not a precise determination of heights surveyed. The denser the survey of heighted points, the more accurate is the resulting contour. Contours are determined by interpolating on a straight line between points for which a height has been surveyed. This process is repeated multiple times between the points surveyed to obtain the contour on which datum ground level can be based. Modern software does this process very quickly using a triangular mesh over the points surveyed.

Similarly to determining the contour by interpolation, heights associated with various parts of a building can be determined by interpolating either between surveyed points (if available) or by interpolating between the contours.

In order to determine the datum ground level, the following two interpolation processes were applied:

- Interpolation between adopted contour lines (in unexcavated areas) to approximate the contours over areas which had been excavated.
- Interpolation of datum ground levels from the contours adopted or interpolated for positions of the dwelling.

5.8 Decide on the Best Solution for Datum Ground Level

Based on this interpolation, the following two result options were determined:

1) The contours obtained from the recent surveys (Capital Surveys confirmed by ACTmapi contours), being the 615 m and 621 m contours, were interpolated evenly to obtain the contours between these values. This approach is justified due to the even distribution of contours shown on earlier plans, and it can be shown that the plans used were produced under the authorisation of a registered surveyor. The results are shown in Figure 10.
2) The contours were determined using the site plan in the building plans of the dwelling constructed in the 1950s and shown relative to the floor level. Capital Surveys surveyed three floor levels in the old dwelling with very consistent results. A rounded average of 618.8 m was adopted, and the contour values of the building plans were then converted to this datum. It is likely that the Capital Surveys plan was the contour survey used by the architects for the design of the new dwelling. Thus using the building site plan to reflect datum ground level before excavation began, the datum ground levels for positions of the new dwelling were determined. This method is more direct and positively reflects levels at the time relative to the building floor level. However, option 1 was also provided as the origin of the levels used in option 2 is uncertain, and it is further unknown if the survey was conducted under the authority of a registered or licensed surveyor. The results are shown in Figure 11.

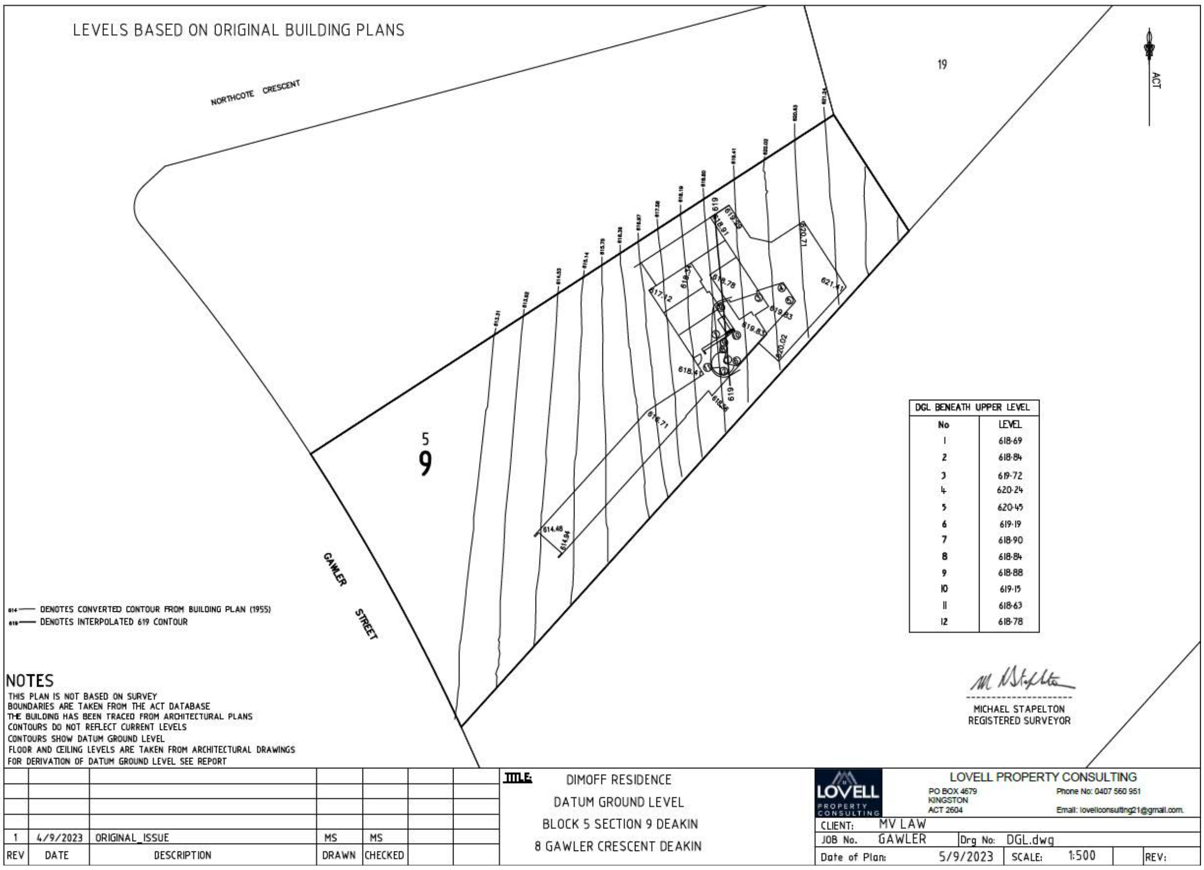


Figure 10: Datum ground level determination based on option 1.

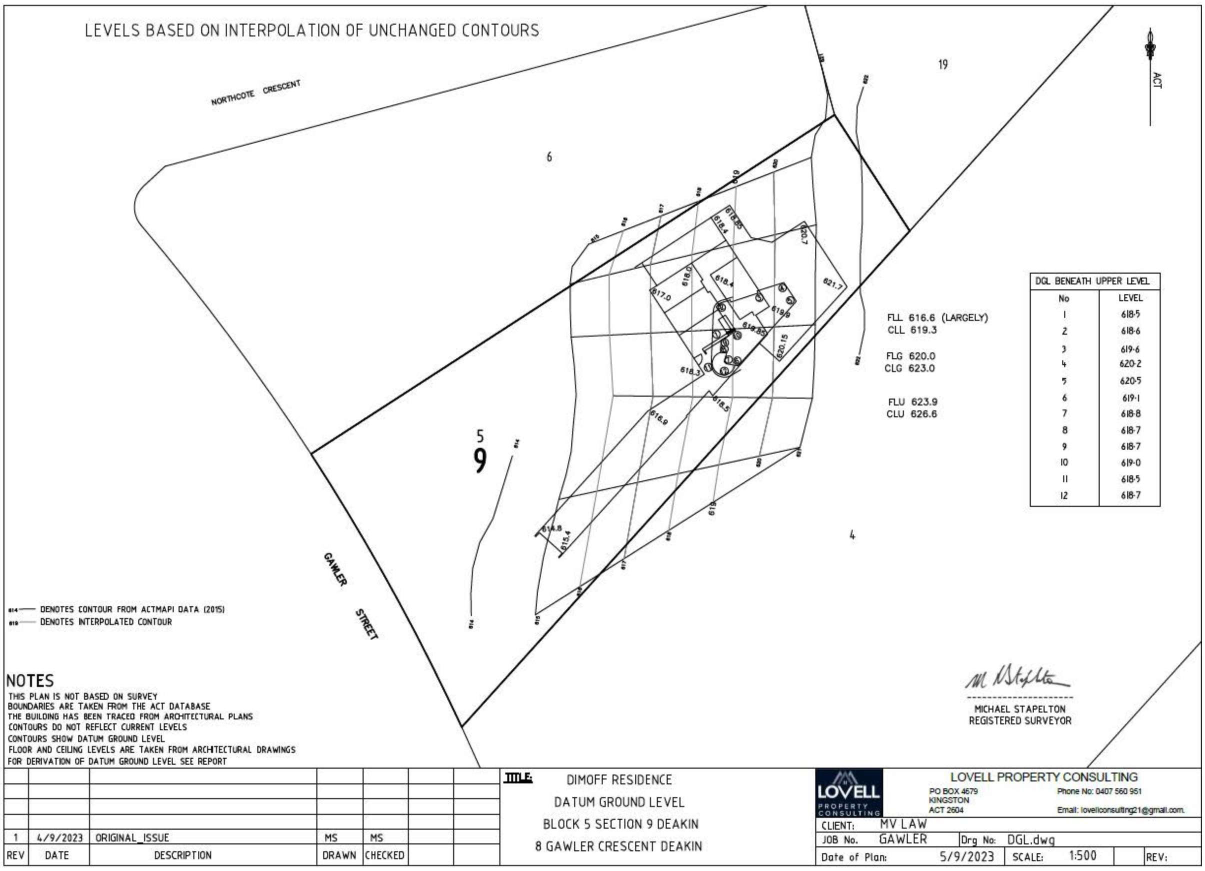


Figure 11: Datum ground level determination based on option 2.

In the author's opinion, option 2 should be adopted. The two options produced reasonably consistent results for the datum ground level. Importantly, both options determined the critical 619 m contour further to the east from that adopted in the design of the new dwelling. The location of the 619 m contour (from both options) passes through the bedroom located on the upper level of the new dwelling. Consequently, the dwelling should be considered to have three storeys and is therefore in contravention of the building code for the area.

On the provision of the author's report as evidence for the case, the 'other side' produced reports from surveyors expressing their views and rebutting the evidence provided. As a consequence of these reports, further investigation was required into the views expressed therein and the author was asked to address queries raised and provide his own rebuttals. One of the issues which arose was the creation of contours from a triangular mesh and how different critical contours could be portrayed if alternative contours were adopted.

6 THE DESIGN AND THE CONTENTION ENABLING THE UPPER FLOOR

The architect made a determination that the lowest contour relevant to enabling part of the lowest floor to be considered as basement was the 619 m contour. The floor level of the middle level was thus designed as 620 m, and all of the lower level built on land with a datum ground level above 619 m should be considered as basement. This would enable an additional storey to be constructed above that part of the lowest level considered a basement. In the design, the 619 m contour passed through a balcony on the upper level. The architect did not consider the balcony to be part of the building for the determination of the number of storeys. The building certifier and the ACT government authorities agreed with the architect's view. The design is illustrated in Figure 12. The determination of the location of the 619 m contour in the datum ground level investigation could thus be critical to whether the dwelling has two or three storeys.

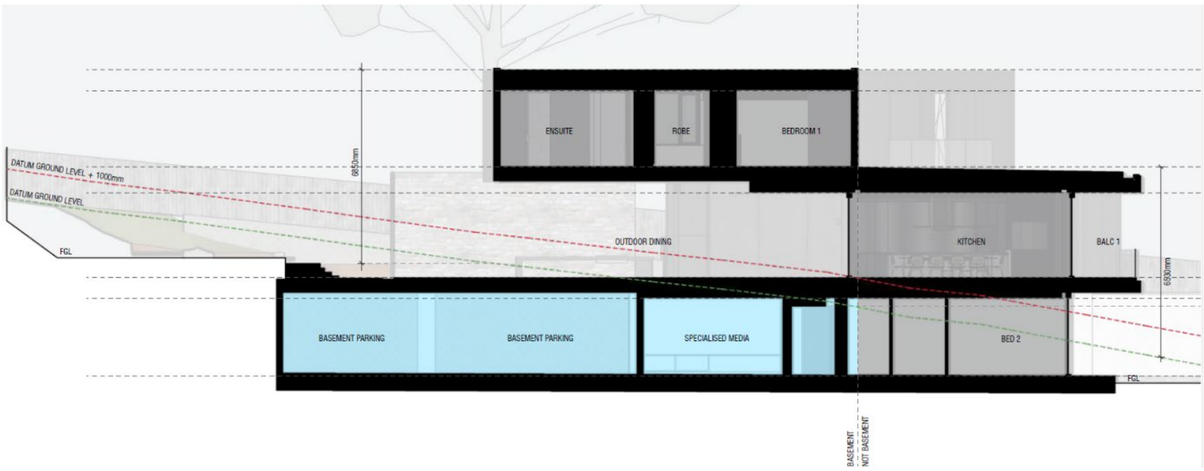


Figure 12: Example of the architect's design drawing.

7 CONCLUDING REMARKS

The dispute went to court, the ACT Administrative Appeals Tribunal. Most of the initial evidence was provided by surveyors: the author for the neighbour, another surveyor for the ACT government and a third for the homeowner.

The evidence presented by the author was largely as described in this paper. Questions were raised regarding:

- The use of LiDAR and photogrammetry intended for macro use in a micro use individual block scenario.
- The accuracy of old data.
- The use of plans not signed by a registered surveyor.
- The interpolation of contours where levels had clearly been disturbed.
- The identification of which areas were disturbed and which areas were not.
- The definitions of datum ground level.

From the start, the Senior Member presiding over the case made it clear that in his mind, based on a site inspection, the building consisted of three stories and was hence illegal. He suggested that if others thought otherwise, they would need to change his mind, and suggested further that the parties may wish to liaise and seek a compromise. Before the end of presenting the evidence, a compromise was reached, where the dwelling would be allowed to stand, regardless of whether legal or not, but all windows facing the neighbour were to be bricked in and a covenant inserted in the lease to the effect that no windows were to be permitted to be inserted in the wall facing the neighbour.

Unfortunately, as a consequence of the compromise, it is possible that no judgement will be made regarding the survey issues raised in the case. It seems that in the Senior Member's view, the planning boundaries were pushed a little too far. In this case, it was shown that a Canberra homeowner and their architect were possibly stretching the planning rules beyond their legal limits and the surveyor was critical in providing an expert opinion in this regard.

REFERENCES

ACT Government (2013) Surveyor-General of the Australian Capital Territory Guideline 12 – Datum Ground Level, https://www.planning.act.gov.au/professionals/resources (accessed Mar 2024).

ACT Government (2024a) Territory Plan, https://www.planning.act.gov.au/professionals/our-planning-system/the-territory-plan (accessed Mar 2024).

ACT Government (2024b) ACTmapi, https://www.actmapi.act.gov.au/ (accessed Mar 2024).

Australian Government (2020) National Capital Plan 1990 (December 1990), https://www.legislation.gov.au/Details/F2020C01103 (accessed Mar 2024).

Daly P.B. (1972) Conversion of ACT level datums to Australian Height Datum, Survey Branch, Department of the Interior, Canberra.

Evans G. (2022) A short history of heights in the ACT, Office of the Surveyor-General and Land Information, Environment Planning and Sustainable Development Directorate, Canberra, https://www.planning.act.gov.au/__data/assets/pdf_file/0011/2329454/a-short-history-of-heights.pdf (accessed Mar 2024).

Scrivener C.R. (1912) The contour survey of the federal capital site, *The Surveyor*, 26(5), 92-103.

Holdsworth Avenue: The City of Sydney’s “Road to Nowhere”

Don Urquhart
City of Sydney
durquhart@cityofsydney.nsw.gov.au

ABSTRACT

This paper outlines the cadastral history of Holdsworth Avenue, Rushcutters Bay, in the City of Sydney. It includes an investigation into its status as a road, some interesting challenges that we encountered with the neighbours, and the ultimate resolution of those challenges, providing the best possible solution for the City of Sydney and its residents. Holdsworth Avenue is a short (approximately 100 m long) road section linking Elizabeth Bay Road with Rushcutters Bay Park. In 2016, it was the focus of a ‘David vs. Goliath’ battle between the City of Sydney Council and an adjoining landowner, who was attempting to claim a portion of the road via adverse possession. The matter was highly political, with councillors, residents and local media getting involved, so a sensitive approach was required by City of Sydney staff. The main question we had to resolve was whether the contested portion was actually part of a road or not. The solution involved a variety of professionals at the City of Sydney, including legal, property and survey people, and incorporated investigating the history of the land, an extensive survey investigation and ultimately the registration of a formal plan of dedication to end all doubt. Ultimately, the claim of adverse possession was refuted, and the land was ‘returned’ to the people of the City of Sydney. Subsequent landscaping works have enhanced the amenity and use of the space, providing benefit for ‘the many’, not just ‘the few’.

KEYWORDS: *Road definition, road dedication, adverse possession, cadastral, history*.

1 INTRODUCTION

Roads in the City of Sydney local government area have a long history and, because of this, have been dedicated or modified by many different methods, including:

- By acceptance under common law.
- Under Act 4 William 4.
- Under the Sydney Corporation Act 1879.
- Under the Local Government Act 1919.
- Under the Roads Act 1993.

Establishing the ownership of roads can be complicated. There are numerous road owners and operators, including:

- The City of Sydney.
- Transport for NSW.
- Place Management NSW.
- Transurban.
- Centennial Park & Moore Park Trust.

In addition to the main road owners, there are many private roads, dunny lanes etc. that are either formed and privately operated (e.g. within newer industrial or residential estates) or are legacy items from private subdivisions, often part of a deceased estate. The City of Sydney even has an 'underwater' road (Harber Street, Alexandria) and a caged, underground carpark road (Griffin Place, Glebe) (Figures 1 & 2).

Figure 1: Harber Street, Alexandria – Sydney's 'underwater' road.

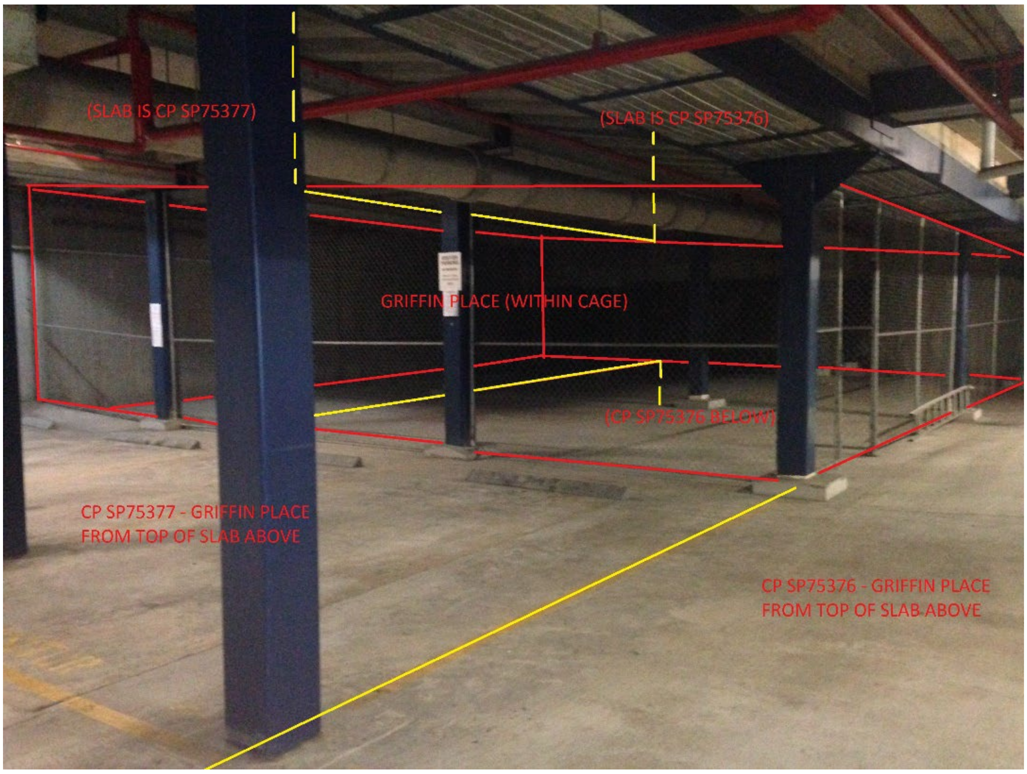


Figure 2: Part of Griffin Place, Glebe.

The subject of this paper is Holdsworth Avenue in Rushcutters Bay – the City of Sydney's "road to nowhere". It presents the history of the road, how and why we got involved, the survey investigation and the ultimate resolution.

2 HOLDSWORTH AVENUE – A ROAD IS BORN

Holdsworth Avenue is in the harbourside suburb of Rushcutters Bay. It is short (under 100 m end-to-end) and consists of 70 m of formed bitumen carriageway running south from Elizabeth Bay Road before terminating at Rushcutters Bay Park in an old, steep flight of stairs.

The land on which it sits is part of an original grant of 54 acres to Alexander McLeay (also spelt Macleay or MacLeay – see Australian Dictionary of Biography, 1967) dated 19 October 1831 (Figure 3). McLeay was an influential early public servant, at one time holding the post of Colonial Secretary of New South Wales, and later nominated to the NSW Legislative and Executive Council. He was also a notable entomologist, and his scientific collection still forms part of the University of Sydney's Chau Chak Wing Museum (Macleay Collection). He also built and lived in Elizabeth Bay House (which is also now a museum) on the granted land.

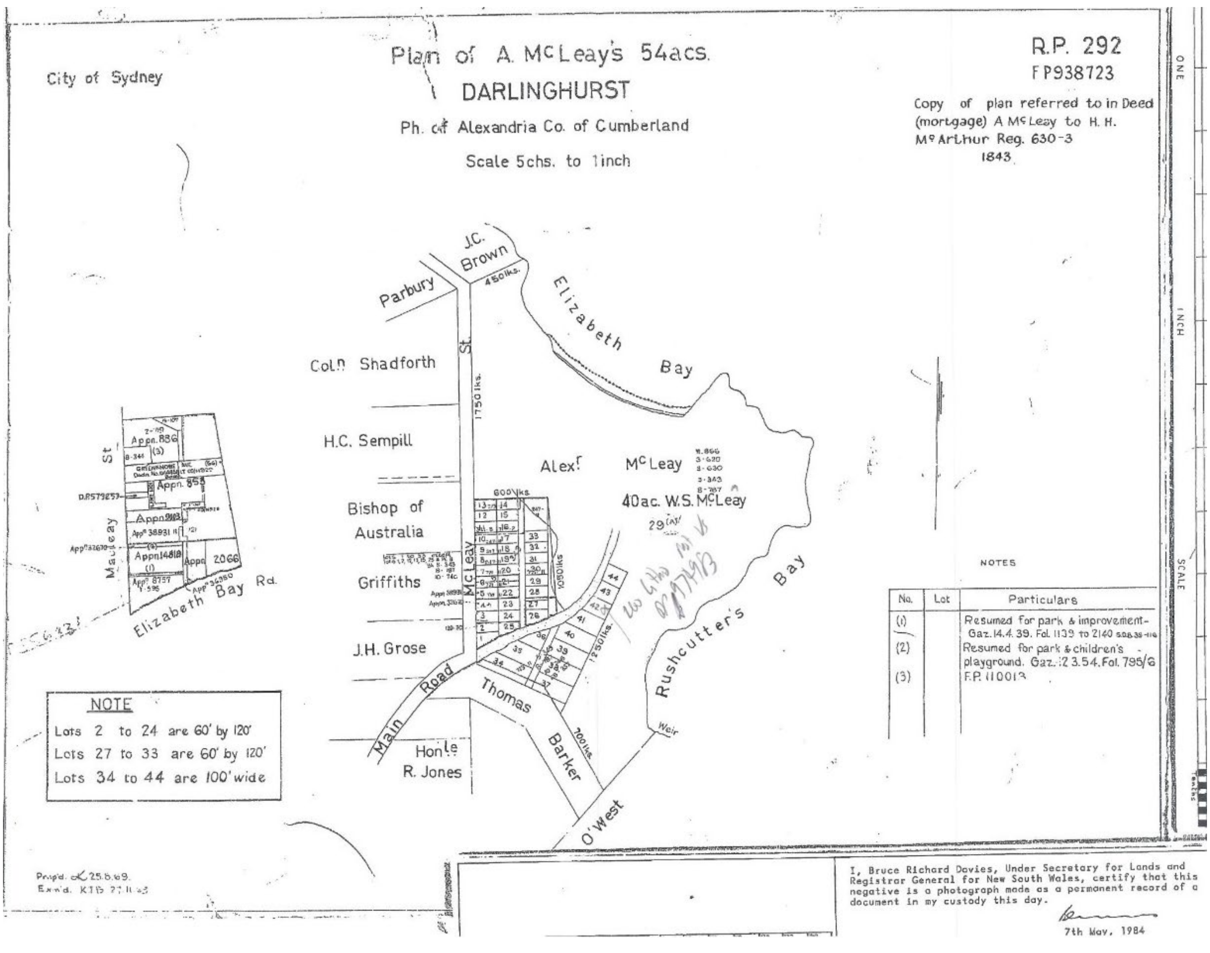


Figure 3: DP928723 showing McLeay's 54 acres.

As happens, the original grant was subdivided and sold off or leased over the years. The first hard evidence of the existence of Holdsworth Avenue appeared in early 1876, where it was noted on a dealing as "Reserved Road" (Figure 4). This date is important, as will be discussed in the next section.

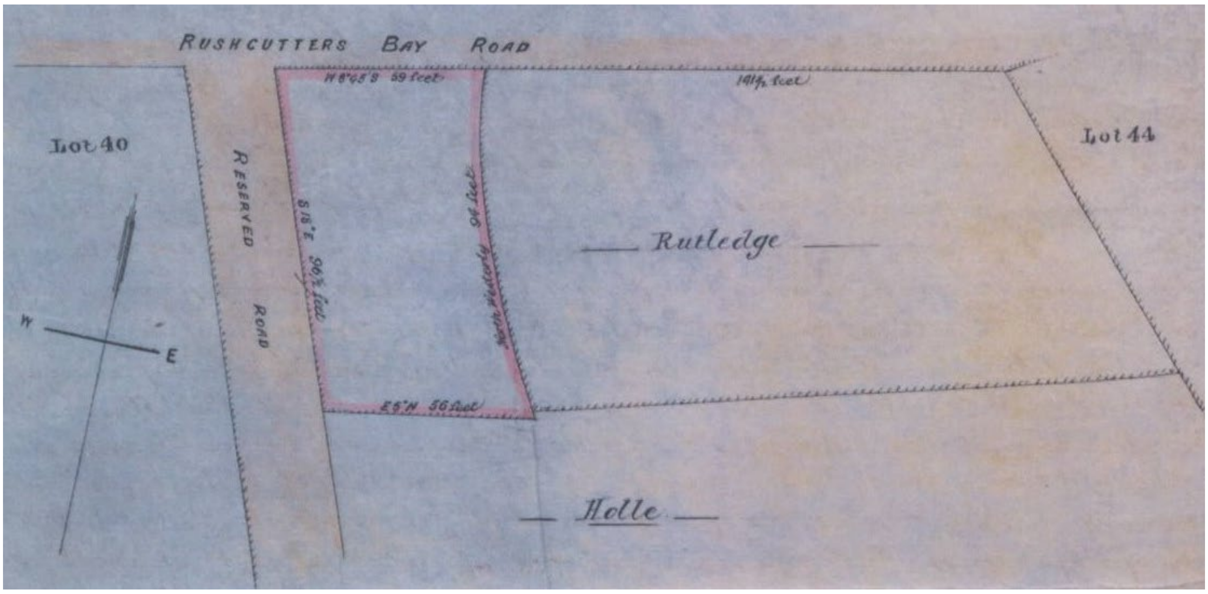


Figure 4: Plan attached to dealing Book 156 No. 791.

3 THE SYDNEY CORPORATION ACT 1879 NO. 27A

3.1 History

By the early 1800s, the City of Sydney was expanding rapidly, but development was not occurring in an orderly manner. To introduce a degree of control, the government passed several acts to regulate building, water reticulation and drainage, lighting, the police force, use of public land, and so on.

Many of these acts also specifically addressed matters related to surveying, roads and property boundary matters, including:

- Alignment of Sydney Streets Act 1834 No. 25A.
- Sydney Streets Alignment Act 1835 No. 14A.
- Sydney Surveyor Act 1837 No. 2A.
- Sydney City Incorporation Act 1842 No. 10A.
- Several incarnations of the Sydney Corporation Act (and amendments) between 1846 and 1940.

All of these are accessible online and are an interesting insight into the development of planning controls in Sydney.

3.2 Why is the Sydney Corporation Act 1879 so Important to Surveyors?

The Sydney Corporation Act 1879 No. 27A (NSW Legislation, 2024a) addressed many aspects of the functions of the council, including the constitution of the council, appointment of council officers, roads, water, health, sewerage and revenue – all the things you would expect of local government.

Although it was not the first act to regulate the use and formation of roads, for surveyors working in the City of Sydney, Part V (relating to the regulation of public ways) was significant and included several notable clauses:

- Clause 69 – mandating a minimum road width of 66’ and minimum lane or alley width of 20’.
- Clause 88 – outlining specifications for new roads, including the need to gazette the footpath and carriageway widths. This clause also allowed the council to declare a footpath width from “the curb-stone or exterior edge of the footpath”, within which it was unlawful to erect any building.
- Clause 89 – stating that, in relation to any building line in Sydney, every curb-stone as laid down at the date of the act, was lawfully laid. This is the clause that effectively aligned many of the city streets that existed at that time.

But the most important clause in relation to this project was (Figure 5):

- Clause 67 – vesting all public ways “now or hereafter formed” in the council, together with full power to widen, level, divert, extend, construct, improve, maintain, repair and order them.

PART V.

Powers of Council for regulation of Public Ways.

Public ways vested in Council.

67. All public ways in the City of Sydney now or hereafter formed shall be vested in the Council who shall have full power to alter widen level divert extend construct improve maintain repair and order such public ways and the footpaths thereof and to carry off any water mud or filth therefrom by means of sewers channels or drains or otherwise subject to the provisions of this Act and any by-laws made by the Council in that behalf But no public way shall be opened altered widened diverted or extended or the width or the footpath thereof fixed or altered until the approval thereto of the Governor shall have been obtained and notice of such approval shall have been published in the *Gazette*.

Figure 5: Part V clause 67 of the Sydney Corporation Act 1879 No. 27A (NSW Legislation, 2024a).

4 OLD LAWS AND A NEW PROBLEM

4.1 Background

As mentioned earlier, the northern part of Holdsworth Avenue is a fully formed and functioning carriageway, whilst the southern part is steep and ends in a set of stairs, rock outcroppings and vegetation that had been largely left to its own devices. During the 2000s, the owners of 10 Evans Road (SP6849) had several building applications approved for additions and modifications to the property, noting that all three units were in the one ownership. At some point in time they also decided to improve the amenity of the common property backyard, by adding some paving, terraced gardens and new fencing. The only problem was that they were not authorised to do so, and a large part of their improvements (approximately 50%) was built over Holdsworth Avenue.

In 2009, a survey contracted by the City of Sydney as part of a planned upgrade to Rushcutters Bay Park identified the encroachment, and on 24 December 2009 the City issued a ‘Notice of Intention to Give an Order’ under section 132 of the Local Government Act for the removal of the encroachment. In 2011, Byrne & Associates were contracted to provide an identification and detail survey of the stair area, revealing that the encroachment encompassed approximately

25 m^2 of Holdsworth Avenue (Figure 6). This was estimated to be worth between $200,000 and $275,000 based on the 2015 land values as published by the Valuer General.

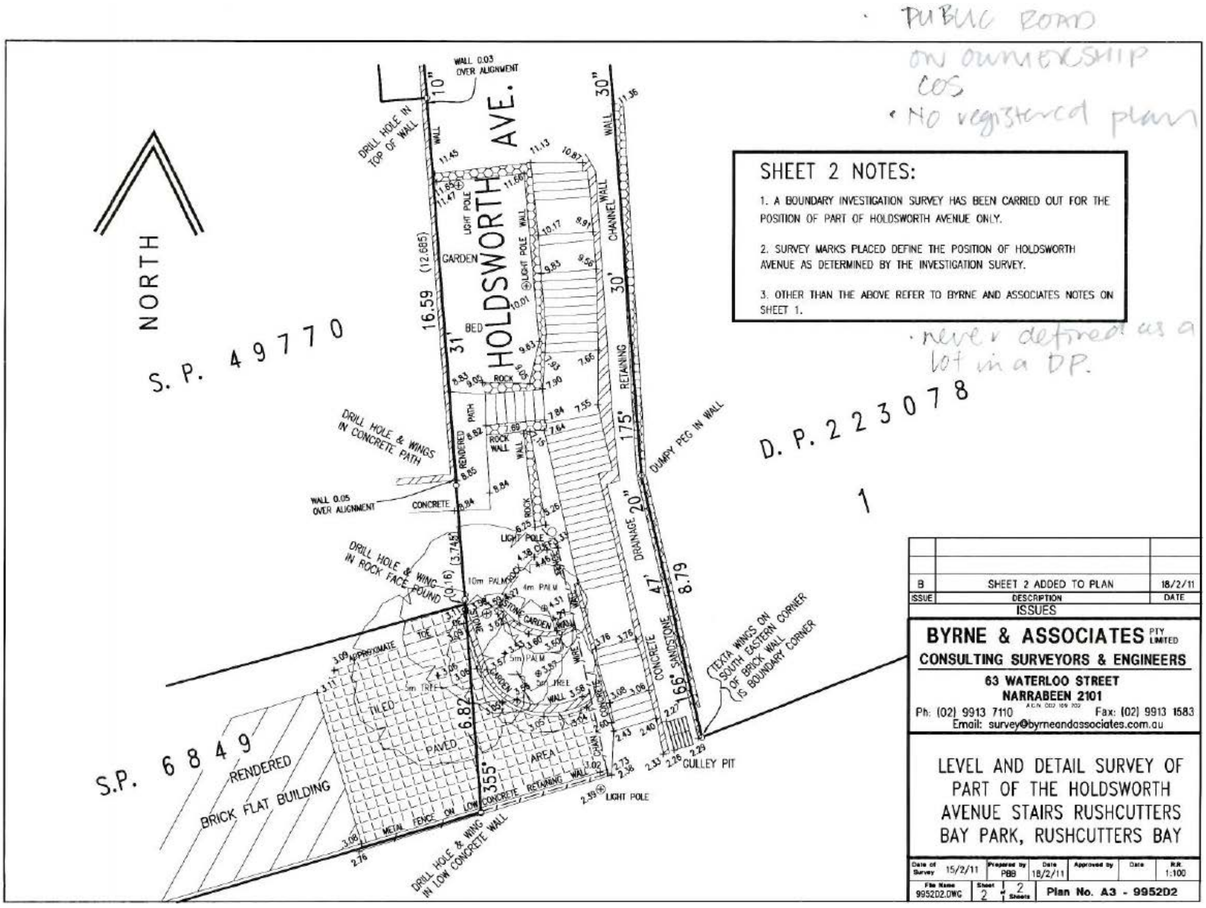


Figure 6: Identification and detail survey by Byrne & Associates (used with permission).

4.2 So, How Did We Get Involved?

Over the following years, there were numerous actions, counteractions and correspondence back and forth over the encroachment. Meanwhile, the City of Sydney continued with plans to upgrade this portion of Holdsworth Avenue. Finally, in 2015, the City of Sydney served notice on the owners of 10 Evans Road for them to completely remove and dispose of the encroaching structures. In response to this notice, the owners engaged a solicitor and, on their advice, proceeded with an application for adverse possession with Land and Property Information (LPI, now DCS Spatial Services), claiming that they and previous owners had continuously occupied the site since the 1950s.

It now got hot politically, with pressure from residents, lawyers, councillors and even the local media, who portrayed it as a ‘David vs. Goliath’ battle and likened it to the plight of the Kerrigan family in the movie ‘The Castle’. All work on the project was stopped, pending the resolution of this new complication. The City of Sydney was compelled to respond rapidly, and so a working group consisting of legal, property and survey professionals was assembled to formulate a response.

4.3 Where to Start?

Under NSW law, adverse possession is not permitted against the Crown (this includes Local Government Authorities) in cases of land "*set out as road under any Act*" or "*dedicated under any Act for a public purpose*" (NSW Land Registry Services, 2024).

As the City of Sydney believed that the disputed land was part of Holdsworth Avenue, the first step was clearly to establish its status, to which end we engaged an external title search. The search concluded that:

- Documentary title to the road was vested in James William Macarthur Onslow (deceased).
- There had been no formal resumption or dedication of the road to council.
- However, dedication may have occurred outside the control of LPI by other means, i.e. by the "spending of public monies" or "through use by the public as road".

As the search results were inconclusive, the task now distilled into establishing whether dedication had occurred "by other means".

4.4 Is It a Road?

This initiated a large amount of research. The City of Sydney compiled as much evidence as possible about Holdsworth Avenue, tracing the history of the site from the original grant, through the first mention of it in the aforementioned dealing (Book 156 No. 791), through numerous published maps, sales lithographs, engineering plans and so on.

The following summary details this historical timeline:

- 19/10/1831: Contained within original grant of Portion 229 (54 acres) to Alexander Macleay.
- 01/02/1848: Contained within 40 acres of the original grant conveyed to William Sharp Macleay (Conveyance Book 8 No. 277).
- Circa 1850-1870: Contained within Lot 41 of "Elizabeth Bay Estate 1st Subdivision" of William Sharp Macleay's 40-acre estate (now DP939367).
- 16/06/1873: Lot 41 included in lease to Robert Hills (Lease Book 138 No. 972).
- 07/01/1876: Northern portion of Holdsworth Avenue shown as "Reserved Road" in Lease Book 156 No. 791. Also referred to in Sub Lease Book 156 No. 595. Both deeds purport to create a "Right of Way" over a reserved road 20 feet wide, which would have expired, with the lease, in 1972.
- 01/08/1879: Under Part V of the Sydney Corporation Act 1879, all "public ways … now or hereafter formed" are vested in the council. Public way is defined as "*Any road, highway, street, square, lane, court, alley or other public thoroughfare or place, whether the same be in actual use or not.*"
- Circa 1885: Site of Holdsworth Avenue noted (unnamed) in the Atlas of the Suburbs of Sydney (Figure 7).
- 22/04/1892: The fee simple of the original grant of Portion 229 vested in James William Macarthur Onslow forever.
- 20/08/1902: Under Part VIII of the Sydney Corporation Act 1902, all "public ways … now or hereafter formed" are vested in the council. Public way is defined as "*Any road, highway, street, square, lane, court, alley or other public thoroughfare or place, whether the same be in actual use or not.*" The Sydney Corporation Act 1879 is repealed by this Act.

- 11/11/1909: Holdsworth Avenue depicted on sale lithograph (S7C-144_1). The plan shows the stairs that remain in situ today, together with the first widening of Holdsworth Lane at Rushcutters Bay Park (Figure 8).
- 30/11/1915: Holdsworth Avenue depicted on sale lithograph (S7C-144_2). The plan shows kerbing laid within the formation and a fencing encroachment. However, the stairs are omitted from this plan (Figure 9).

Figure 7: Excerpt of an 1885 map of the City of Sydney, showing Holdsworth Avenue (centre).

Figure 8: Sale lithograph (S7C-144_1).

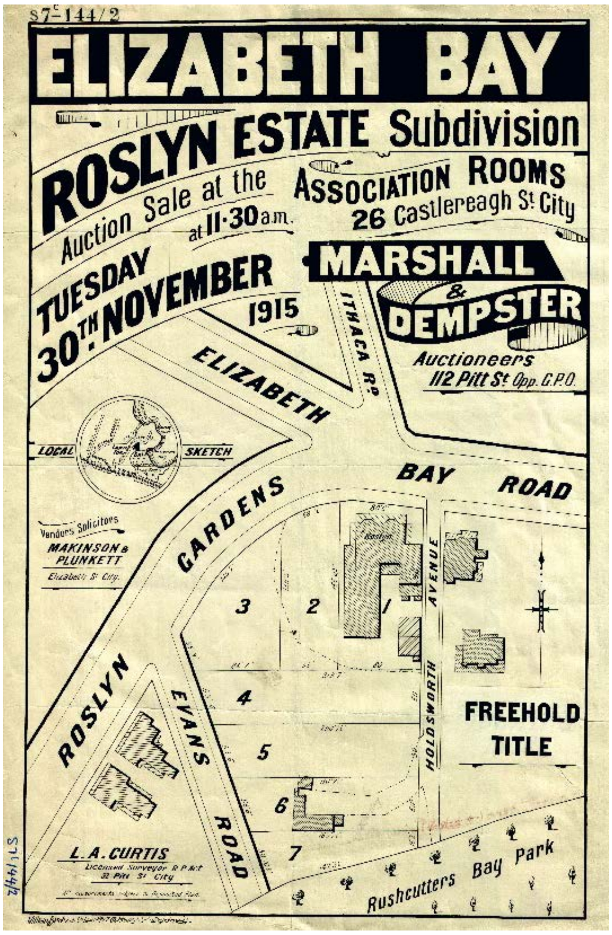


Figure 9: Sale lithograph (S7C-144_2).

- 01/07/1920: Under the Local Government Act 1919, all roads in existence at this date vested in the local council (presumed to also include the City of Sydney).
- 22/12/1932: Under Part VIII of the Sydney Corporation Act 1932 (NSW Legislation, 2024b), all "public ways … now or hereafter formed" are vested in the council. Public way is defined as "*Any road, highway, street, square, lane, court, alley or other public thoroughfare or place, whether the same be in actual use or not*." The Sydney Corporation Act 1902 is repealed by this Act.
- 03/09/1948: Sydney Corporation Act 1932 repealed by Local Government (Areas) Act 1948, save as to the status of any road.
- 1974: Variable width road widening in DP577484.
- 1980: 1.525 m road widening with splays in DP616213.
- 1994: 1.525 m road widening (in stratum) in DP848463.

This historical timeline was presented to the legal team to help them make the case with LPI that Holdsworth Avenue was indeed a road.

4.5 And the Winner Is?

The City of Sydney's case was that there was sufficient evidence that Holdsworth Avenue existed at least in part in 1876, and therefore at the time of the Sydney Corporation Act 1879. Part 7-7 of Hallmann (2007) states that "*Public roads in the City of Sydney were "vested" in the council by the 1879 Act but it was held by the Privy Council in Municipal Council of Sydney v. Young (1898) that the vesting under that statute gave the council no title to the streets beyond* *what was necessary to carry out its duties under the Act. However, an estate in fee simple was vested in Council in 1935 – see section 76B of the Sydney Corporation Act 1932*." Notably, the 1932 Act defines "public way" as "*Any road, highway, street, square, lane, court, alley or other public throughfare or place,* ***whether the same be in actual use or not***."

Ultimately, LPI agreed that Holdsworth Avenue *had* been vested in the council as road by the 1879 Act, and that subsequent additions and modifications (as shown on the historical plans) were also included as road under one or more of the subsequent acts, and the adverse possession claim was formally rejected.

5 EPILOGUE

In 2016, the City of Sydney's surveyors were asked to prepare a Deposited Plan (DP) dedicating it to the public, therefore formalising the position and status of Holdsworth Avenue as road. Due to the age of the area and the three road widenings in the latter 20th century, this became a challenging task and ultimately involved defining (in addition to Holdsworth Avenue itself):

- Elizabeth Bay Road.
- Rosyln Gardens.
- Evans Road.
- The northern boundary of Rushcutters Bay Park.

The result was DP1217417, titled a "Plan of Dedication of Holdsworth Avenue being part of the lands described in Book 489 No. 253 as public road" (Figure 10). For those that are interested in the definition, the accompanying survey report is included in the Appendix.

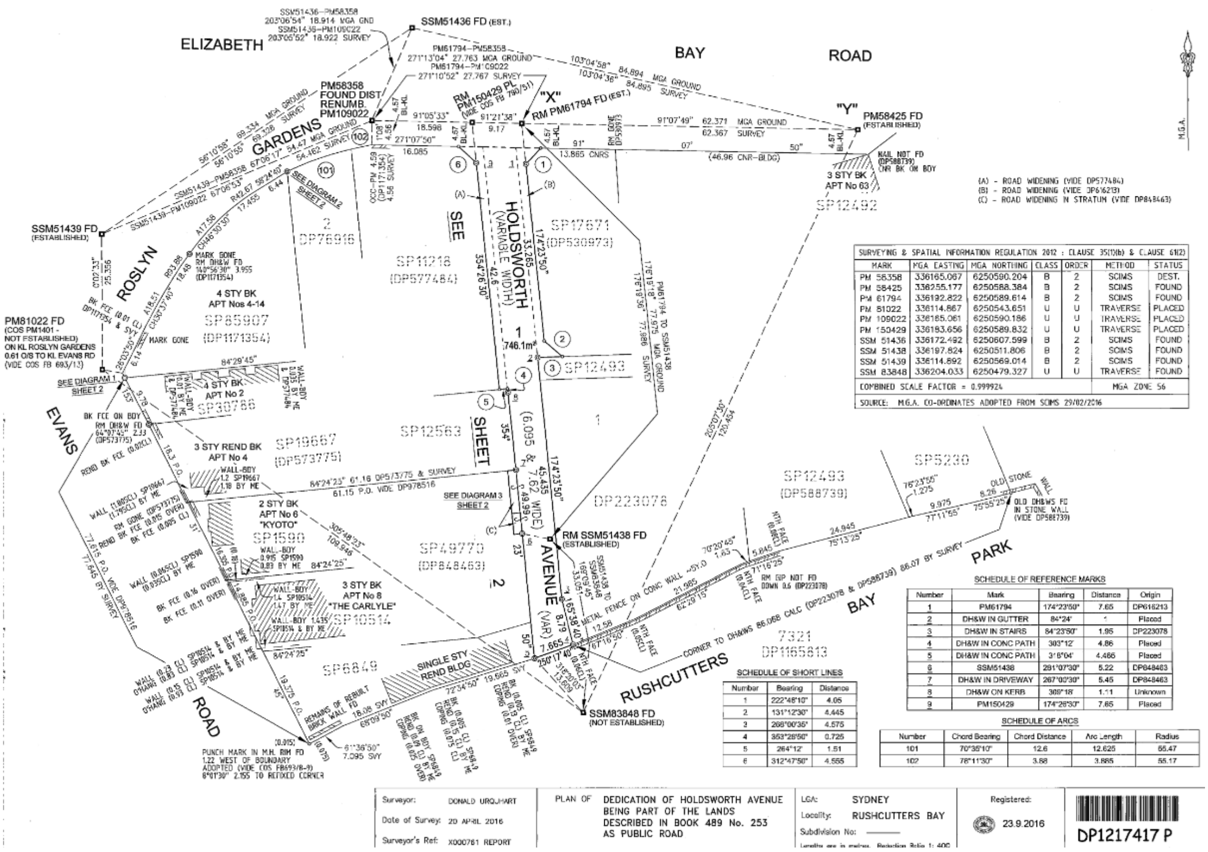


Figure 10: Sheet one of DP1217417.

The City of Sydney eventually completed the remediation and landscaping works as planned. The result is a marked improved in the safety and utility of the area (Figure 11).

Figure 11: Holdsworth Avenue stairs from Rushcutters Bay Park (2024).

6 CONCLUDING REMARKS

This paper has provided an overview of one of the many property anomalies found each year within the City of Sydney. It has outlined the cadastral history of Holdsworth Avenue, Rushcutters Bay, the investigation into its status as a road, interesting challenges encountered with the neighbours, and the ultimate resolution of those challenges, providing the best possible solution for the City of Sydney and its residents. This example reinforces the importance of undertaking solid, comprehensive research and the significance of even historical and long-since repealed legislation.

REFERENCES

Australian Dictionary of Biography (1967) Alexander McLeay (1767-1848), https://adb.anu.edu.au/biography/mcleay-alexander-2413 (accessed Mar 2024).

Hallmann F. (2007) *Legal aspects of boundary surveying as apply in New South Wales* (2nd edition), The Institution of Surveyors NSW, Australia.

NSW Land Registry Services (2024) Registrar General's Guidelines: Possessory titles, https://rg-guidelines.nswlrs.com.au/deposited_plans/conversion_os/possessory_title (accessed Mar 2024).

NSW Legislation (2024a) Sydney Corporation Act 1879 No. 27A, https://legislation.nsw.gov.au/view/pdf/asmade/act-1879-27a (accessed Mar 2024).

NSW Legislation (2024b) Sydney Corporation Act 1932 No. 58, https://legislation.nsw.gov.au/view/pdf/asmade/act-1932-58 (accessed Mar 2024).

APPENDIX: SURVEY REPORT ACCOMPANYING DP1217417

City of Sydney
Town Hall House
456 Kent Street
Sydney NSW 2000

Telephone +61 2 9265 9333
council@cityofsydney.nsw.gov.au

GPO Box 1591 Sydney NSW 2001
cityofsydney.nsw.gov.au

CITY OF SYDNEY 2030

Sydney2030/Green/Global/Connected

22 April 2016

Our Ref: X000761 Report
File No: X000761

The Plan and Title Advisor
Land and Property Information
GPO Box 15
Sydney NSW 2001

Dear Sir/Madam

Survey Report on Deposited Plan 1217417

Background

Our searchers have determined that the documentary title for Holdsworth Avenue remains comprised in disentailing deed Book 489 No. 253.

It appears to have been formed wholly within and parallel to the western boundary of Lot 41 of the Elizabeth Bay Estate plan (DP939367) and is also shown abutting the western edge of the Roslyn Estate plan (DP978516).

The intended width appears to be 6.095m (20') and variable as shown on DP223078 and by scale from DP978516. The variable portion is also reflected in DP978516.

There have been three subsequent road widenings:

- DP577484 (1974) – variable width road widening
- DP616213 (1980) – 1.525m (5') widening plus splay corner at Elizabeth Bay Road and SP12493
- DP848463 (1994) – 1.525m widening (in stratum)

Alignment of Evans Road

Marks adopted for alignment in Evans Road were City of Sydney PM1401 (now PM81022) at Roslyn Gardens (set at 0.61m (2') west of the eastern kerb line vide CoS FB693/13) and the punch mark found on a sewer manhole in Rushcutters Bay Park (set at 1.22m (4') from both the kerb line and building alignment in CoS FB693/8).

The fix is supported by the RM DH&W found at the northern boundary of Lot 4 in DP573775, occupations generally and wall to boundary offsets on Strata Plans 19667 and 10514 (as noted on the face of the plan).

I adopted the RM for the sideways fix and this was generally supported by wall to boundary offsets shown on Strata Plans in the street, most notably the southern building wall on SP10514. This left close to P.O. distance between the RM and boundary derived from this wall offset. The P.O. frontage was then used on the prolongation to refix the southwestern corner of SP6849.

city of villages

Sustainable. Made from 100% Australian recycled paper, printed with vegetable based inks.

Alignment of Elizabeth Bay Road

Marks adopted for alignment in Elizabeth Bay Road (east of Holdsworth Avenue) were PM61794 (formerly CoS PM1834 vide FB790/51) and PM58425 (formerly CoS PM1404 vide FB693/35). These marks were placed by City Surveyors for the alignment of Elizabeth Bay Road at 0.915m (3') north of the southern kerb line. The fix was supported by the offset to the corner of the old brick building at No.63 Elizabeth Bay Road and the old stone kerb as laid at Holdsworth Avenue.

It was determined that PM58538 (formerly CoS PM1403 vide FB693/34) at Roslyn Gardens had been disturbed. There have been significant kerb and footpath works in the vicinity of the mark which could have contributed to the disturbance. Supporting evidence for this assumption included discrepancies in a number of SCIMS connections (shown on the plan), the wall offset shown in DP1171354 (4.59m in the DP and 4.56m by me) together with connections to the original mark as shown in CoS FB790/51. On the advice of LPI staff, PM58538 was reported destroyed and the pin re-referenced and renumbered PM109022.

A new permanent mark (PM150429) was established at 0.915m north of the southern kerb line of Elizabeth Bay Road and on the western alignment of Holdsworth Avenue (as widened) using the geometry in CoS FB790/51. The alignment of Elizabeth Bay Road, west of Holdsworth Avenue, is as per CoS FB 790/15 and DP577484.

Alignment of Roslyn Gardens

As a result of the previously mentioned construction works, all boundary marks shown on DP1171354 have been destroyed, together with the RM DH&W in Gutter off the westernmost corner of this plan.

To determine the Roslyn Gardens alignment, the terminals of Evans Road and Elizabeth Bay Road were refixed from their respective alignments and a P.O. adjustment executed. This resulted in good agreement with wall offsets and the RM DH&W in gutter in the middle of Lot 1 DP1171354, but resulted in the re-referencing of marks at the northernmost corner of Lot 1. P.O. distance remains across the frontage of DP1171354.

Alignment of Holdsworth Avenue (Eastern alignment)

The eastern alignment of Holdsworth Avenue was determined using PM61794 (1.525m east of the original alignment as shown on DP616213) and the RM DH&W in DP223078 found on the stairs at the southern end of Holdsworth Avenue. This was supported by several occupations/offsets including the face of the old stone wall and brick unit building shown on DP223078.

The road widening between Elizabeth Bay Road and SP12493 was held as being 1.525m (5') from this line, which resulted in minor discrepancies with wall & building offsets shown on DP616213, but good agreement with the depth to the old two storey brick residence 'Kia-Ora' as shown on DP530973.

The remains of an old brick wall, believed to have been at the corner of the "concrete drainage apron" shown on DP223078 and DP848463 was found at Rushcutters Bay Park and adopted. This resulted in P.O. depth from the angle to the Park and a 0°6'20" (16mm) angular discrepancy with DP223078.

Alignment of Holdsworth Avenue (Western alignment)

The western alignment of Holdsworth Avenue was determined using the eastern alignment and a P.O. width (vide DP223078) of 6.095m (20'). This resulted in good agreement with occupations, RMs and the fixes shown on DP577484, SP11218 and DP848463. This was further supported by the discovery of a drill hole & wings at the intersection of Holdsworth Avenue with Rushcutters Bay Park when marking the boundaries, leaving P.O. frontage across SP6849 from the southern boundary of SP49770 to the Park.

The 1.525m (5') road widening from DP577484 has resulted in Holdsworth Avenue being variable width from Elizabeth Bay Road to SP12563 and this geometry has been retained in my plan.

Rushcutters Bay Park Boundary

The boundary of Rushcutters Bay Park between Evans Road and Holdsworth Avenue was determined by holding the southern terminals of Evans Road & Holdsworth Avenue fixed (see above) and executing a P.O. adjustment. This resulted in a minor shortage in the depth of SP6849 (approximately 50mm).

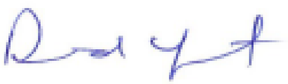
The boundary of Rushcutters Bay Park between Holdsworth Avenue and SP5230 was determined by adopting the corner of the old brick wall at Holdsworth Avenue (see above) and the drill hole and wings found at the south east corner of SP5230 (as shown on DP588739). P.O. distance (from DP223078 & DP588739) was found to exist, however there was no other supporting evidence (it is believed that the RM GIP shown at the south eastern corner of DP223078 was destroyed when the new concrete wall was built).

Conclusion

I believe the fix shown on my plan accurately reflects the original position and width of Holdsworth Avenue and subsequent road widenings.

If you have any further questions regarding the definition on my plan, please contact me on 0467 739 754 or at durquhart@cityofsydney.nsw.gov.au.

Yours faithfully,



Don Urquhart
Principal Surveyor
City of Sydney

Discussion Forum: Digital Survey Plans Program Update and the CAD Translator

Michael London
DCS Spatial Services
NSW Department of Customer Service
Michael.London@customerservice.nsw.gov.au

Daniel Griffin
Digital Plans Manager
NSW Land Registry Services
Daniel.Griffin@nswlrs.com.au

ABSTRACT

Since 2019, the NSW Government and NSW Land Registry Services have engaged in a strategic reset for the implementation of Digital Survey Plans (DSP). Engagement with industry saw the development of a DSP Delivery Plan that broke the reform into three main components: (A) Moving to an online plan creation to registration process, (B) requiring digital data to be included as part of plan lodgments, and (C) digital data to be considered the legal point of truth. With the delivery of LRS Connect Release 3 in July 2023, component A is nearing completion and work to deliver component B has begun in earnest. A solution to make data consistent and accurate is the NSW Deposited Plan Computer-Aided Design (CAD) Layering standard and the CAD to LandXML translator. This discussion forum first outlines and demonstrates the use of both these tools, along with the validation of data, interpretation of the summary report and the 'part-rendered' data ready for drafting. Open discussion then follows as a forum for feedback on enhancements that could be made to the tools and processes to progress the reform.

KEYWORDS: *Digital survey plans, cadastre, CAD, LandXML.*

Henry, Me and Philosophy

Warren Thomas
Surveyor / Infrastructure Property Officer (Retired)
siriusfour@optusnet.com.au

ABSTRACT

Forty years ago this year, in 1984, I sat with renowned surveyor, lecturer and historian Mr A.P.H. (Henry) Werner to review and edit what would be his final published work. You see... Henry was dying. I had first met Henry when he was a lecturer and I was a student at the University of New South Wales in the mid-1970s. He was a character and always made any lecture interesting. Several years after graduating, while working at the NSW Department of Public Works, I was contacted by Henry seeking my help with a paper he was preparing for publication in The Australian Surveyor, the national surveying journal of its time. Henry said he did not have much time left. We worked on the paper together over several months. He would draft his text and I would edit and fact-check against his references and other sources. The paper was published in September 1984 under the title 'The philosophy of progress: Any lessons from the history of surveying?' Henry's message in that paper is as relevant today as it was when he first wrote it. This paper outlines the life and times of Henry Werner for context, also touching on his esteemed career. However, the main objective of this paper is to highlight the words and wisdom of Henry Werner from way back in 1984. It aims to demonstrate the continued relevance of his words to today's fast-changing world, using examples such as how we are grappling with the application, potential and concerns of an unbridled Artificial Intelligence (AI). Henry's paper does not refer to AI, but it appears that he knew it was coming as he urges us to be aware "of the far-reaching consequences of progress in relation to the future of mankind."

KEYWORDS: *Henry Werner, surveyor, philosophy, knowledge, wisdom, AI.*

1 INTRODUCTION

Arthur Paul Heinz "Henry" Werner (1918-1984) is best known as a former surveying lecturer at the University of New South Wales (UNSW). Henry was born in Germany at the end of World War I. He was 15 when Adolf Hitler came to power and 21 at the outbreak of World War II. He remained conscripted in the German army until the end of the war. Henry graduated with a Diplom-Ingenieur (Verm.) from the University of Bonn in 1950 and arrived in Australia in 1951. Joining the School of Surveying at UNSW in 1960, Henry was a lecturer of legendary status to most undergraduate students during the 1960s and 1970s.

So why is Henry Werner still so relevant in 2024? As well as a lecturer, Henry was an 'historian', a 'philosopher' and a prolific contributor to surveying journals including *The Australian Surveyor*. Seen in Figure 1, aged 61, Henry received a terminal diagnosis some four years later, in 1983. Henry yearned to write one last paper. Knowing his cognitive skills were in decline, Henry sought my assistance to review and help edit his paper. I was a 28-year-old former student of Henry's, who just happened to be coordinator of a NSW Department of Public Works conference in 1982 where Henry delivered an address on the philosophy of technological progress using the historic example of surveying for the Great Pyramid of Giza. In early 1984, over a period of four to five months, Henry, with my help, converted that address into a paper for publication in *The Australian Surveyor*. The paper was published in September 1984 under the title 'The philosophy of progress: Any lessons from the history of surveying?' (Werner, 1984).

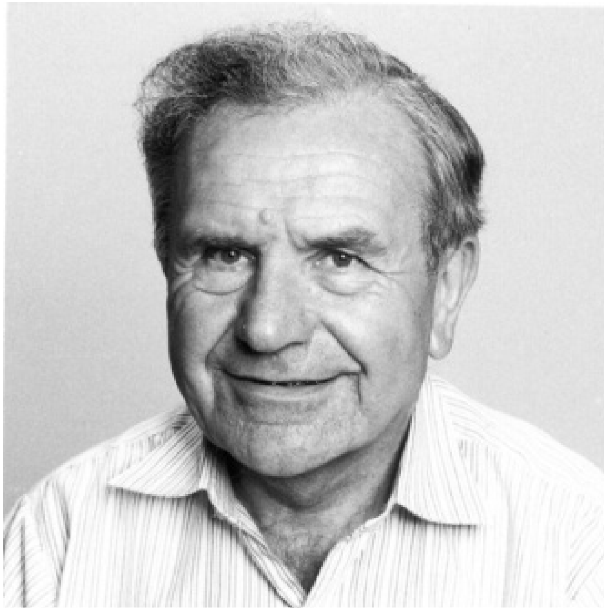


Figure 1: Henry Werner, 1979 (courtesy of UNSW).

Henry's philosophical message in the 1984 paper is as relevant today as it was when he first wrote it. In 1984, the world was in a state of cold war dealing with the ever-present threat of nuclear weapons. In 2024, the world is in a state of digital suspicion dealing with endless opportunities and potential threats posed by generative Artificial Intelligence (AI).

This paper is not intended to be a biography or a full account of Henry's life. It is, however, necessary for context to include some biographical information and relevant aspects of Henry's life and the times in which he lived. This will give insight into the possible motivations as to why a learned yet humble surveyor would have deemed it absolutely necessary to write a paper for publication in *The Australian Surveyor* in the final few months of his life.

2 LIFE AND TIMES OF HENRY WERNER

Arthur Paul Heinz "Henry" Werner was born in 1918 in the eastern German town of Lübbenau, approximately 100 km south of Berlin and halfway to Dresden. At the time, his father was a surveyor with a German army unit on the western front.

Henry received his high school education in the western German city of Essen where his father was by then a municipal surveyor. Essen was a major industrial centre. Henry believed that his social attitudes were largely moulded in his school days when he mixed with the sons of leading industrialists, lawyers, merchants, musicians and coal miners. Figure 2 shows Henry aged 12. Evident is an inquisitive mind and a yearning to understand how things work.

Figure 2: An inquisitive Henry Werner, aged 12, in Essen, 1930 (courtesy of Sibylle Werner).

Henry matriculated in 1937 and served the compulsory two years of army service. His intention was to commence studies in meteorology, but with the outbreak of war in 1939 he remained drafted in the German army and was assigned to an anti-aircraft unit until May 1945. Figure 3 shows a relaxed Henry in uniform with his parents in 1941.

Figure 3: Henry Werner with his parents in Essen, 1941 (courtesy of Sibylle Werner).

During the war years, in 1944, Henry married his ‘forever’ wife, Ruth, spending their honeymoon in East Prussia. With the rumble of artillery never far away, Henry said it “*was a change from the never ceasing entertainment provided by the Allied Air Forces over much of Germany*.” With Germany’s surrender in May 1945 and after release from a prisoner of war camp, Henry underwent pre-university training with a registered surveyor before enrolling at the University of Bonn in April 1946. Figure 4 shows Henry around this time embarking on a lifetime of study to learn, question, share knowledge and stimulate others.

Figure 4: A young Henry Werner studying hard (courtesy of Sibylle Werner).

In the book 'The Snowy: The people behind the power' (McHugh, 1995) we learn that in May 1950, Roy Robinson, a young engineer with the Snowy Mountains Hydro-Electric Authority, was dispatched to Europe with instructions to select over 600 tradesmen and as much of the top engineering and surveying talent as he could muster. They had to be healthy and politically acceptable. The Australian Military Mission arranged with the German authorities to put ads in the press and on the radio. They interviewed nearly 3,000 people, each having been assessed beforehand. Roy Robinson had to ensure that he did not recruit anyone who had Nazi sympathies or had been part of the Nazi side of politics. When the Germans surrendered, they failed to destroy their very large filing systems – they had virtually a dossier on every citizen in Germany and one of the first things done was to refer any names to an organisation run by the joint military occupiers, the Americans and British, to get a clearance before an interview.

Henry graduated with a Diplom-Ingenieur (Verm.) from the University of Bonn in 1950. About the same time he spotted an advertisement on the university noticeboard seeking suitably qualified engineers and surveyors to work on the fledgling Snowy Mountains Hydro-Electric Scheme (Snowy Scheme) in Australia. In an oral history project (Unger, 1974), Henry was interviewed by Margaret Unger and said that he "*was sick of the idea of having to go through a secondary state examination* [to become a licensed surveyor in Germany] *after having just passed his university exams.*" Another 2½ years of indenture, study and exams would have made him 34 years of age. As such the advertisement was very appealing, the wages good, and as explained by Henry, "*I thought it would be a marvellous excuse to avoid that and have a look at the other side of the world.*"

In the interview by Unger (1974), Henry recalled being visited by an "*Englishman*" in his home, essentially to be further screened. Germans in general were very successful applicants and Henry believed the assessment process may have been able to statistically forecast behaviour patterns, strong and weak points, the ability to succeed on the project and to generally fit in.

McHugh (1995) comments that in 1949 "*Australians were still xenophobic, their lifestyles a caricature of English customs, warped by time and distance, but never relinquished. Roast dinners on sweltering Christmas days, heavy serge school uniforms, carefully nurtured BBC accents on the radio, cricket and lawns and imported flowers.*" In contrast, McHugh (1995) also comments that a European 'invasion' followed after World War II: "*Soon a bewildering cacophony of accents and languages could be heard in every centre, as the unlikely looking newcomers assembled in the cities, towns and villages. Shopkeepers grappled with ridiculous-sounding ideas like sour cabbage, boiled sausages and black bread.*"

Henry arrived in Australia by plane. In the interview by Unger (1974), he said that arriving from Europe at Mascot Airport in May 1951 was like "*departing Sydney today* [in 1974] *and arriving in Cobar* [presumably as an example]". He felt utterly lost and, having left Darwin's heat, was plunged into a cold Sydney day in May. Arriving with other Germans, the group was photographed by a Sydney Morning Herald photographer, appearing in print the next morning under the headline 'German Scientists Arrive'. Henry commented that it was a rather "*bombastic title*". The photograph caption also misidentified Henry as a Mr Wassermann. Some thought that it was done deliberately to prevent victimisation and aggressiveness by those who opposed Germans arriving and working in NSW. Henry thought this was a feeble excuse and that it was most likely a journalistic error. Mr (Wally) Wassermann was in fact a surveyor and did travel with Henry on their way to Cooma and then on to the Adaminaby staging camp.

2.1 Henry, the Surveyor

Men and women from Europe outnumbered Australians on the Snowy Scheme. McHugh (1995) noted that the atmosphere in the camps was not always harmonious. The Germans often held senior positions in survey and, unless they were particularly diplomatic, their methods could easily rankle with some of the other Europeans. A Czech chainman took umbrage at Wally Wassermann's curt manner of addressing him and said "*Hold on, this isn't Germany now, this is free Australia!*" Wally got the message, and the two eventually became good friends.

There were also some clashes with Australian surveyors over the use of the term 'surveyor'. Henry was not registered or licensed and regarded any restriction on the use of the term as a "*professional humiliation*". The objection was largely at the local level as the Snowy Mountains Hydro-Electric Authority highly valued European experience and to it, Henry acknowledged, he was a 'surveyor'.

At many camps, surveyors were German and chainmen were Polish. Wartime animosity sometimes came through. Henry explains in the interview with Unger (1974) that on his first day of surveying, while providing instructions to his Polish chainman for some work in difficult terrain, Henry tried to explain the theory of compensating errors and hence better ways of carrying out the measurements. A few days later, Henry said, he had a revolt on his hands and was "*likened to some Gestapo bloke trying to re-establish a concentration camp*". Henry said he quickly realised the value of boiling the billy and, using his sense of humour, established a reasonable working relationship over time. In Figure 5, Henry is seen surveying at Island Bend near Guthega in the Snowy Mountains.

Figure 5: Henry Werner at Island Bend in the Snowy Mountains, 1951 (McHugh, 1995).

Henry was mainly engaged in engineering surveys, varying from road location to dam construction surveys and supervision of contracts. He was involved in the early levelling, traversing and control work at Eucumbene Dam. Henry tells Unger (1974) that once, while carrying out early investigations into a road to the Eucumbene Portal using magnetic compass and simple distance techniques, he became lost in a blizzard not far from the camp. He was unaware that the basalt in the region was deflecting the compass needle and after 2½ hours of surveys with snow all around, blazing trees and painting them red as they went, his team finished up unexpectedly back at the camp, conveniently beside the fire, as he had unknowingly surveyed in a circle.

Some of the unique challenges confronted and managed by Henry and the teams of surveyors working on the Snowy Scheme stemmed from the reality that most were not trained mining surveyors and had to learn mining terminology from scratch and how to deal with miners more familiar with mining iron ore or coal than they were with driving tunnels. Henry mentioned to Unger (1974) that some of the problems encountered were unique to the surveyors but not unique to construction. He said that with a good university background, the surveyors could adapt and they did. With one or two exceptions, most people involved with surveying for the tunnels were graduates of European universities, particularly German ones.

Henry was extremely proud of his survey work carried out for the Snowy Scheme and identified two personal construction highlights to Unger (1974). The first being the completion of the concrete-arch Tumut Pond Dam, which provided challenges requiring survey techniques to be adapted from European university texts, refined for the local conditions. The monitoring methods needed to be easily replicated as the pace of construction was "*hectic*". To achieve the precision required and be confident as the concrete arch was being constructed, four or five epochs were needed to be surveyed and calculated each day. The second highlight was seeing the nearby Tantangara Tunnel meet in the middle!

Unger (1974) asked Henry about the meritorious aspects of the Snowy Scheme. He responds that in pure surveying terms it was, for the first time in Australia, the use of one point of origin for all surveys – what would shortly after become known as integrated surveys. In more esoteric terms, Henry believes it was the successful integration of peoples from all over the world and being a part of the major training place for future generations of construction and surveying leaders in Australia. On personal terms, Henry well understood that "*the experience and reputation that went with* [working on the Snowy Scheme] *got me a good interview with the University* [of New South Wales]."

2.2 Henry, the Academic

In 1960, Henry Werner joined the fledgling Department of Surveying in the School of Civil Engineering at UNSW as a lecturer. Henry made an early impression on students as he was a year 1 surveying lecturer (Figure 6). Not only was his accent strange to most students but also his sense of humour. Loeffel (2007) includes several anecdotes. Students learnt to correctly pronounce 'kilometre' in a distinctly German accent. Henry's 'History of Surveying' lectures were always informative and amusing with references to his time on the Snowy Scheme and on Egyptian survey history. Henry related to young students on a practical level. He updated each year's notes with handwritten additions. He once handed out mine surveying notes in German. Henry's marking notes were legendary... from 'mm' (millimetre madness) to Bible quotes for bad handwriting (e.g. "*see Daniel 5:8*"). At survey camps, to make exercises more interesting, Henry would provide a prize buried under a coordinated point (often in the form of beer).

Figure 6: Henry delivering a lecture at UNSW, 1976 (courtesy of UNSW).

Henry's celebrated research work was his more than 6-year project, commencing in 1964, on the precision levelling and assessment of the degree of settlement for the Sydney Opera House foundations, particularly those resulting from tidal movements. The results demonstrated that the Opera House rose and fell "*a couple of centimetres*" with the tides due to the movement of water into and out of the sandstone.

Henry Werner retired from UNSW in 1978 after 18 years of service. Photos from his farewell dinner show elements of Henry's quirky personality (Figure 7). During Henry's time at UNSW, some 700 students were exposed to his ideas in the pursuit of knowledge. His methods were innovative, original and at times unorthodox. Teaching, for Henry, was an adventure in participation in which the student had to extend him or herself at least as much as the lecturer.

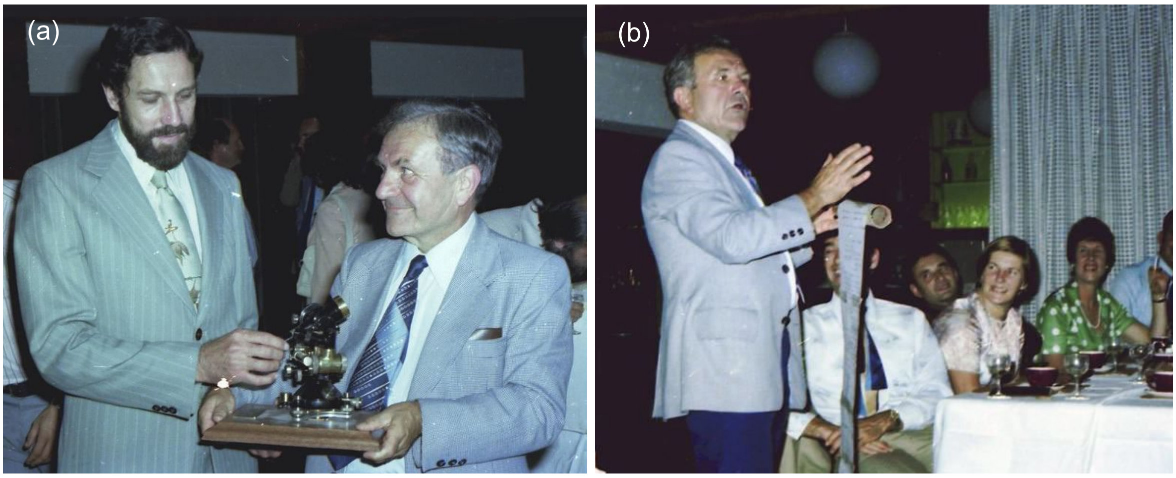


Figure 7: (a) Prof. Peter Angas-Leppan and Henry with typical 'mischievous' look, and (b) Henry reading his farewell speech... from an 'Egyptian' scroll, both 1978 (courtesy of UNSW).

2.3 Henry, the Writer

Henry joined the Institution of Surveyors in 1959 and he was elected a Fellow in 1970. He was an active participant in Institution affairs and contributed many papers to *The Australian Surveyor* and enlivened the correspondence pages of the *NSW Surveyors' Monthly Bulletin*, and later *Azimuth*, with letters presenting provocative challenges in an often-humorous style (N.N., 1984).

As commented in N.N. (1980), Henry's "*attitude to research was that of a labour of love, directed not towards self-advancement but instead towards the advancement of scientific knowledge for its own sake.*" Henry's major contribution was devoted to an historic compilation of surveying events through time, embracing all its branches. Published in 1966 as 'A calendar of the development of surveying' (on one occasion using the spelling 'calender' and on another replacing the word 'development' with 'history'), it comprised papers in eight consecutive issues of *The Australian Surveyor* commencing with Werner (1966) and concluding with Werner (1968). The late Professor Harry Biesheuvel of the University of Natal, where Henry spent a sabbatical year in 1968, wrote that "*Henry's 'Calendar' was a monumental piece of research which will be of inestimable value to all those who in their teaching get beyond technicalities of the subject and relate it to its impact on man and human society.*"

3 HENRY AND ME

I had the privilege of first meeting Henry Werner as a surveying lecturer and 'prac' supervisor during my time at UNSW (1974-1977). Henry was in the final years of his career. My main recollection of the time was being in a lecture hall with Henry passionately delivering lectures on the history of surveying. Whilst history is part of what we do as surveyors, Henry was going back way beyond my then knowledge and was talking about times that I had only loosely known from social studies in primary school and Charlton Heston movies. To that history he was adding themes of mathematics, measurement, astronomy, cartography and geodesy mixed with a dose of philosophy. Henry was legendary and memorable to anyone within his orbit and to many outside of it.

After university, I was working at the NSW Department of Public Works and came across Henry again during the Department's Sydney Opera House monitoring surveys in 1981. Due to Henry's previous knowledge and extensive survey work at the Opera House in the 1960s, he was enlisted by the Department to assist, observe and book observations during the 1981 monitoring surveys (Figure 8). A year or so later, I was appointed an organiser for the Department's 'Survey and Property Branch Conference 1982'. Henry was invited to deliver an address to the conference that he titled 'The philosophy of progress: Any lesson [sic] from the history of surveying?'. That address formed the basis of Henry's 1984 paper which was to come later. In Werner (1984), Henry comments that his address to the conference mainly "*described the dimensions of the Great Pyramid of Giza, near Memphis on the Nile River in Egypt*" and that "*the address was short on philosophising and long in an informal talking manner... utterly unsuitable for printing.*"

Figure 8: Henry Werner reading directions on P7, S.E. Pylon SHB, 1981 (courtesy of NSW Public Works).

A year or so after the Public Works conference, Henry contacted me to seek help to review and edit a paper he was preparing for publication in *The Australian Surveyor*, the national surveying journal of its time. Henry had shortly before been diagnosed with an incurable cancer. The diagnosis appeared to trigger Henry into action. He had had a paper in his mind for some time now and the address to the Public Works conference a year earlier did not go far enough. Now was the time. It would be his legacy paper.

I recall Henry saying that as his cancer developed his thought capacity would be diminished. The 28-year-old me, who struggled with level 2 English at the HSC, would need to be his editor, grammar and spell checker, fact checker and 'project manager'. At the time, Henry and his wife, Ruth, lived in a beautiful federation home in the Sydney suburb of Beecroft. I lived only a 15-minute drive away. The decision to help him was an easy one.

Each week on a Tuesday night, as I recall, I would attend Henry's house. We would sit in the traditional lounge room either side of a small table. Henry would go through his handwritten drafts of the various sections of his paper. We would chat, he would show and explain the reference texts, ask me what I thought about various parts of his draft and make amendments... if he agreed. I would take that section away, review and check against his references again and arrange for it to be typed. The next week, I would return the typed section for Henry's final review and any discussion. The whole process would then recommence on Henry's next handwritten section.

As time went by, Henry's ability to concentrate for long periods of time noticeably diminished. Our meetings became shorter and although he generally managed to have his draft sections ready on time, he began to rely on me more and more. If I thought there was a better way to write something, he would listen and mostly simply agree. It took Henry and I four to five months to complete the paper and prepare all the accompanying diagrams. The final paper by A.P.H. Werner, titled 'The philosophy of progress: Any lessons from the history of surveying?' was submitted to *The Australian Surveyor* on 10 May 1984 and published in the September 1984 edition (Werner, 1984).

4 THE 1984 PAPER

Henry commences his paper with a short abstract (Werner, 1984). He explains how his paper is presented in two parts. "*The first, with the help of history, shows the need for an appreciation, and adoption, of spiritual aims in progress to match the leaps and bounds of material progress...*" The second part relates to spiritual and material progress as evidenced by the Great Pyramid of Giza in Egypt, particularly the significance of the measurements extracted there from. This paper concentrates predominantly on the first part of Werner (1984).

In his introduction, Henry apologises to readers familiar with his quality of publishing, suggesting they may detect shortcomings but hoped they would be small. It was an acknowledgement of his failing health. Henry notes that "*Science, or just surveying, has progressed at such a fantastic rate since World War II that few surveyors have had the time, and have not interpreted this development, except by uttering generalities. Indeed the 'great' of international geodesy are known by formulae, not any philosophy connected thereto.*"

Interestingly, the Editorial to the September 1984 edition of *The Australian Surveyor*, in which Henry's paper was published, focused on the new "*Global Positioning System (GPS) being heralded as a technique that will revolutionise surveying in much the same way as EDM did in the 1960s.*" Surveyors were encouraged to "*act now and prepare for GPS.*" Although education was also encouraged, there was no mention of any philosophical considerations about the use by surveyors of what was originally an application limited to use by the United States military. In wrapping up his introduction, Henry observes that "*The surveyors' present lack of interest in any philosophy supporting their deeds is a sad abdication of ethical responsibility which is, in terms of international law (Nürnberg, 1945), a despicable lack of attitude.*"

4.1 Philosophy

The word philosophy comes from the Greek 'philo' (love) and 'sophia' (wisdom) and so is literally defined as 'the love of wisdom'. Henry notes that the Oxford dictionary (4th edition) describes philosophy as "*a love of wisdom or knowledge, especially that which deals with ultimate reality or with most general causes and principles of things.*" The Cambridge online dictionary describes philosophy as "*the use of reason in understanding such things as the nature of the real world and existence, the use and limits of knowledge, and the principles of moral judgement.*"

Philosophy can be a difficult concept to understand when continually surrounded by daily engineering and real-world surveying problems and deadlines. There are hundreds of definitions of philosophy on the internet. However, the online World History Encyclopedia [sic] attempts to break it down to first principles. It describes philosophy as "*the study of the most basic and profound matters of human existence.*" It wonders exactly when and where philosophy first began to develop. "*Uncertain*" it says, but finds the simplest answer is that "*it would have begun – at any place in the distant past – the first time someone asked why they were born, what their purpose was, and how they were supposed to understand their lives.*"

4.2 The Philosophy of Progress

In Werner (1984), Henry poses "*Is it necessary to analyse progress by means of a philosophy?*" He notes that a French philosopher said that "*true scientific progress leads from error*" and that "*there are also natural and moral philosophies. General causes* [of progress] *in the history of surveying are wars, Halley's Comet, man's vanity... and, if circumstances are favourable, lead to discovery and progress*."

Henry postulates that "*a proper philosophy of progress demands that the researcher and scientist asks oneself: does my research serve the progress of mankind?*" Henry quotes an example of the doubling of computer capacity from 4 K to 8 K as numerical progress. (That may not seem much, but it was the early 1980s and it is the concept!) "*Progress could be expressed in savings of time and remuneration. A philosophy of dollars!*" So, "*The more rapid the numerical (or material) progress, the faster grow moral responsibilities.*"

Henry mentions a surveying example whereby the advances in geodesy led to baseline measurement by the 18th century. "*Progress was made because of the need for maps, for political or military reasons, ultimately to make better wars. Not much of a progress for people.*" The latter half of the 20th century saw the emergence of better positioning by satellite or the Global Positioning System (GPS). Henry had concerns: "*We have better updating of coordinates and are guaranteed a better wipe-out next war.*" Henry does not leave it there though and poses that "*moral obligation seem foreign words to a geodesist.*" However, "*The difficulty is that we do not know about the long term effects of any progress.*" But, "*There is no excuse for supplying solutions under contract for missile projectories* [sic]."

4.3 Progress

Henry states that "*Material progress is when a method or instrument improves our knowledge.*" He muses "*Was the appearance of boundary stones in Egypt and Mesopotamia material progress? Yes, it secured rights and orderly agricultural production and engaged their Gods in the process. The midday sun shadow falling over the north face of the pyramid at Giza gave surveyors a line for orientation on the muddy flats when setting out the plots after the flood had subsided.*"

Henry continues that "*Material progress was balanced by spiritual attitudes. Did a faster 'religious' survey give, beside material progress, a greater spiritual one? Of course, a quicker survey gave a better production which was ultimately considered to show the Gods being favourably inclined.*" He comments "*If progress was under threat anywhere, one observes a prompt acceleration of progress. Amazing what fear does to rulers.*" So, in those circumstances, "*All scientific progress was without responsibility: an easy time for everyone on the winning side.*" Henry goes further: "*After the war, the German technical progress was no longer a threat, but the Russian Bear gave rise to incredible progress. The rate of it was so breathtaking that anyone worrying about ethics or God seemed to be an odd fellow.*"

Henry had concerns that "*magnificent progress has now lost speed and concern for absence of spiritual responsibility is popping up everywhere.*" So, "*What happens if scientists do not attempt to balance the two parts of progress? They become obsessed with their work and forget their people. Einstein saw this too late and felt deeply upset.*" Henry sums up his thoughts with this: "*Any human endeavour which tries to balance the physical gains achieved by scientists and technologists* [including surveyors] *with an increased awareness of the consequences of such progress on the community is real progress.*"

Students and tertiary education were not left out of Henry's thoughts on progress. "*The influx into tertiary education began in the late 50s on a grand scale... Only since 1980 is there evidence of a better educated young person giving hope that our community is progressing.*" "*If our students had to study the history of surveying properly, the universities could invite Rabbis and Imams to lecture on their views on the need for acknowledging God in the sciences; it would enrich the presently pitifully poor attitudes to professional ethics. For instance, geometry and numbers had a divine significance.*"

In concluding his thoughts on philosophy and progress, Henry summarises: "*A philosophy of the history of surveying should measure material and spiritual progress. This act requires a love of wisdom and knowledge. Usually, wisdom reigns at a higher level. Knowledge comes from data and wisdom from their proper use.*"

5 MOTIVATIONS TO WRITE THE 1984 PAPER

It is hard to recall, 40 years on, if Henry ever said to me why he wanted to give that particular address to the Public Works conference in 1982, an address based on philosophy and lessons from surveying history. It is easy to see why he consequently wanted to write the 1984 paper. It was simply a natural progression for an academic and fervent contributor to academic journals. He had delivered his address to the Public Works conference before his terminal diagnosis, so submitting a subsequent paper to *The Australian Surveyor* was almost certainly on his mind. But was there more to his motivation? Henry retired from full-time work in 1978, 4 years before his address to the Public Works conference in 1982. So in conjunction with his terminal diagnosis, was Henry's motivation simply to write one last paper of a cautionary nature for future generations of surveyors? Maybe his motivation was more deeply seated than that and there may be clues from his experiences and general philosophical approach to life and work. The following sections provide some additional possible influences.

5.1 Germany Before World War II

The following three paragraphs (sourced from Wikipedia) are included for background only. They provide a snapshot of the political and social times in Germany through Henry Werner's formative years. One can only imagine that they had an impact on him and left him with lasting memories.

The Great Depression of the 1930s severely impacted Germany's progress. There was high unemployment and subsequent social and political unrest. On 30 January 1933, Adolf Hitler was appointed as Chancellor to head a coalition government including his far-right Nazi Party. Hitler promptly used his powers to thwart constitutional governance and suspend civil liberties, which brought about the swift collapse of democracy and the creation of a one-party dictatorship under his leadership.

In the midst of the Great Depression, the Nazis restored economic stability and ended mass unemployment using heavy military spending. Financed by deficit spending, the regime undertook extensive public works projects including the Autobahnen (motorways) and a massive secret rearmament program, forming the Wehrmacht (armed forces). Racism, Nazi eugenics, anti-Slavism and especially anti-Semitism were central ideological features of the regime. Christian churches and citizens that opposed Hitler's rule were oppressed and leaders imprisoned. Education focused on racial biology, population policy, and fitness for military service.

From the latter half of the 1930s, Nazi Germany made increasingly aggressive territorial demands, threatening war if these were not met. Germany invaded Poland on 1 September 1939, launching World War II in Europe.

5.2 World War II and Nuclear Weapons

Henry turned 15 the year that Adolf Hitler came to power. He turned 21 at the outbreak of World War II and spent the entire war assigned to a German anti-aircraft unit. He turned 27 the year World War II ended. This tumultuous time in German, European and world affairs must have left an indelible mark on the young Henry Werner. He was educated, a scientist/surveyor and a thinker. Throughout his 1984 paper, there are multiple references to World War II, wars in general, ethics, international law, Nürnberg, bombs and nuclear armament.

He asserts that "*The issue is now* [in 1984] *to question the international reputation of mainly computer manufacturers who earn millions from the nuclear armament industries. We should refuse dealing with them on that ground.*" Many who saw last year's 'blockbuster' film, 'Oppenheimer', will know that Albert Einstein was an associate of Robert Oppenheimer, the lead scientist on the Manhattan Project to design and build the first atom bomb. In the film, Oppenheimer says to Einstein: "*When I came to you with those calculations, we thought we might start a chain reaction that might destroy the entire world.*" Einstein responds, "*What of it?*" to which Oppenheimer replies "*I believe we did.*"

Previously we have learnt from Henry that scientists focused on their work can forget the human side of progress. Henry's example was Einstein who, he noted, "*came to that realisation too late and felt deeply upset.*" In Bird and Sherwin (2005), the Danish physicist Niels Bohr, a great friend and mentor of Robert Oppenheimer, wrote that "*Knowledge is itself the basis of civilisation, but any widening of the borders of our knowledge imposes an increased responsibility on individuals and nations through the possibilities it gives for shaping the conditions of human life.*" That sounds very much like our own Henry Werner.

Los Alamos in New Mexico was established in 1943 as Project Y, a top-secret site for designing nuclear weapons under the Manhattan Project during World War II. Many of the world's most famous scientists, including Nobel Prize winners, were brought together at Los Alamos. Initially they were focused on unravelling the secrets of nuclear fission and producing an atom bomb. Bird and Sherwin (2005) provide great insight into the feelings of the scientists over time. "*By late 1944, a number of scientists at Los Alamos began to voice their growing ethical qualms about the continued development of the 'gadget'.*" Meetings were called to discuss "*the impact of the 'gadget' on civilisation.*" They held meetings and pondered questions such as "*What will this terrible weapon do to the world? Are we doing something good, something bad? Should we not worry about how it would be applied?*"

"*On July 12 1945, an Army poll of 150 scientists in the project, seventy-two percent favored a demonstration of the bomb's power as against its military use without prior warning.*" The first nuclear test occurred near Alamogordo, New Mexico, codenamed 'Trinity', on 16 July 1945. It was an 'unearthly' success. Two other atomic weapons were soon produced and used in the attacks on Hiroshima and Nagasaki... without warning. As Henry would say, the scientists forgot the human side of progress until it was too late.

5.3 A Calendar of the Development of Surveying

Henry's 'A calendar of the development of surveying' was first published in *The Australian Surveyor* in September 1966 (Werner, 1966) and continued in the next seven issues of the journal over a 2-year period. In his opening remarks he notes that "*The transmission of knowledge is effected by direct contact between people and the study of old instruments and documents.*"

Further, Henry includes his reasons for writing this epic surveying calendar:

- Few surveyors have ever attempted to write a comprehensive history of surveying in all its forms.
- To encourage interest and to open avenues of communication between surveyors of all countries for better understanding and efficiency.
- To give students required clues for serious study.
- So specialist surveyors may experience moments of serendipitous relaxation while searching for information of special value to them. Henry quips further: "*Even a fanatic specialist may have preserved enough sense of humour to enjoy reading that a musician designed telescopes or a brewer spent his nights looking through them, geodesists read Omar Khayyam's non-astronomical verses, poets discussed global mapping and emperors declared the new moon to have risen.*"

In his calendar, Henry is linking technical knowledge and endeavour to humanity in a fundamental way. He also has his eye on the future, one being enhanced by a clear mind, broad and open communication, continued learning and moments of respite. Perhaps we see here Henry's philosophical approach to progress and a future influenced by clear thinking and learning from the past.

6 FORTY YEARS ON – ANY RELEVANCE IN 2024?

6.1 Artificial Intelligence

According to Smith et al. (2006), "*The term 'artificial intelligence' was first coined by John McCarthy in 1956 when he held the first academic conference on the subject. But the journey to understand if machines can truly think began much before that. In 1945, Vannevar Bush's seminal work 'As we may think' proposed a system which amplifies people's own knowledge and understanding. Five years later, Alan Turing wrote a paper on the notion of machines being able to simulate human beings and the ability to do intelligent things, such as play chess.*"

AI robots have been around for much longer in film. Press (2016) notes that the 1927 science-fiction film 'Metropolis' features a robot double of a peasant girl, Maria, which unleashes chaos in Berlin of 2026 – it was the first robot depicted on film. Another good example is C-3PO in 'Star Wars'. C-3PO appears to be an outlier in that it is generally a good robot in terms of relations with humans.

Often though, in film, 'intelligent' robots go off the rails and cause havoc and generally threaten the Earth or the human race with destruction. A recent example was the 2023 film 'The Creator'. Set in the year 2065, the film depicts a world in which humans and AI robots coexist. However, after an AI-related nuclear event in Los Angeles, the West stops development of AI and finds itself in conflict with New Asia (an amalgamation of East Asian countries). War erupts between the human race and the forces of AI. Humans must hunt down and kill the Creator, the elusive architect of advanced AI who has developed a mysterious weapon with the power to end the war… and mankind itself.

Back to the present and with the recent appearance of programs such as ChatGPT, generative AI and machine learning are very much in the public spotlight. Generative AI builds on the foundation of machine learning and turns machine learning inputs into content. Generative AI can both learn to generate data and then turn around to critique and refine its outputs (Robb, 2023).

So, with a little browsing through news media over the past few months, it is not hard to find articles both positive and negative towards generative AI. Dr Andrew Leigh, Assistant Minister for Competition, gave a speech in September 2023 about AI's rapidly growing role in the economy. He says the rise of AI engines has been remarkable and offers the potential for "*immense economic and social benefits*" and "*has the potential to turbocharge productivity*".

I suspect that Henry may have said he had heard those arguments before and would like to see a little more work on understanding the human consequences of such progress. He may have felt vindicated or perhaps depressed if he could have read the following media reports from 2023:

- Sydney Morning Herald (SMH), 31 May 2023 (Gregg et al., 2023): "*Mitigating the risk of extinction from AI should be a global priority alongside other societal-scale risks such as pandemics and nuclear war*," according to the statement released by the non-profit Centre for AI Safety. The open letter was signed by more than 350 researchers and executives, including chatbot ChatGPT creator, OpenAI's CEO, Sam Altman, as well as 38 members of Google's DeepMind artificial intelligence unit.
- SMH, 22 September 2023 (Gittins, 2023): "*Scientists have been talking about AI since the 1950s... It took the telephone 75 years to reach 100 million users, the mobile phone took 16 years, the web took 7 years*" whereas ChatGPT "*took just 2 months*". "*We should beware of established businesses asserting their right to train AI models on their own data (which is how the models learn), while denying access to that data to competitors or new businesses seeking to enter the industry... The latest ChatGPT version uses data up to only 2021* [at the time of writing]" so may not be using current data. "*The big question is how amenable to competition the development of AI is?*"
- Reuters, 26 October 2023 (Sandle, 2023): "*British Prime Minister Rishi Sunak said only governments could tackle the risks posed by AI, a technology he said could make it easier to build chemical or biological weapons, spread fear and, in a worse-case scenario, escape human control. Speaking ahead of a global gathering he has convened next week*

to examine the risks of the technology, Sunak said he hoped the participants could agree on the nature of the risks and establish a global panel to assess them."

- GRC World Forums, 31 October 2023 (GRC World Forums, 2023): "*The British Prime Minister, Rishi Sunak, has disclosed plans for the UK to house the world's first Artificial Intelligence (AI) Safety Institute. In a speech in London yesterday, Sunak detailed the institute's pivotal role in advancing global understanding of AI security. He underscored its core mission of thoroughly assessing and understanding risk factors associated with emerging AI models, ranging from social biases to more extreme threats. The PM also highlighted the institute's commitment to transparency; plans are in place to share certain data publicly while retaining national security information for circulation with like-minded governments. One key aim is to guarantee the safety of AI models before their public release, Sunak asserted.*"
- SMH, 3 November 2023 (Swan, 2023): "*Cybersecurity researchers are sounding an alarm about the hacking community's answer to ChatGPT, a new generative AI tool dubbed WormGPT, which is being used to create sophisticated attacks on Australian businesses. WormGPT is being described as similar to ChatGPT, but with no ethical boundaries or limitations, and researchers say hundreds of customers have already paid for access to the tool on the dark web.*"

Henry Werner may have seen the film 'Metropolis'. He may have even read Frank Herbert's 1964 novel 'Dune', set well after the 'age of computers' had come and gone to a calamitous end. Regardless, I suspect Henry was well aware of the term 'artificial intelligence'. Whether he could have envisaged generative AI coming along is debatable, but even so the lessons in his 1984 paper still apply and are still relevant today. He certainly had concerns over the global tech giants earning billions from nuclear armaments and other defence industry contracts. So why would he not have concerns over a small number of global tech giants holding the keys to generative AI?

In Werner (1984), Henry shows us a way forward and makes the following statement which I repeat here due to its continuing relevance today to generative AI and other breakthrough technologies: "*Any human endeavour which tries to balance the physical gains achieved by scientists and technologists with an increased awareness of the consequences of such progress on the community is real progress.*" It is evident from the above media clippings that we still have a long way to go but if we bear Henry's words in mind, there is a way.

6.2 AI and Surveying

Hess (2023) tells us "*The integration of AI and machine learning (ML) is helping land surveyors to automate data processing and analysis, and to identify patterns and trends that may not be easily discernible through traditional methods.*" What does seem to be clear is that large datasets, such as those created by Light Detection and Ranging (LiDAR) or laser scanning, are particularly suited to analysis by AI. Mehta (2021) defines AI in simple terms as "*the capacity of a computer to act intelligently as opposed to natural intelligence in humans. This 'intelligence' is implemented in the form of algorithms to perform specific tasks, learn, and adapt to provide solutions.*"

Clifford (2023) suggests that "*some areas of surveying do not lend themselves to AI. For example, boundary surveying, or determining lines of ownership, is often referred to as 'the art and science of surveying', as it isn't as simple as measuring between physical monuments and certifying the results. In this regard, it seems unlikely that an honest professional would* *cede their judgements to a machine. However, there are plenty of areas that could offer opportunities for AI to enhance the industry.*"

A review of several websites discloses that some areas of potential application for AI in surveying may be (amongst others): title reports, accelerating data extraction for ground penetrating radar, construction control and layout, deformation monitoring, LiDAR and drone or Unmanned Aerial Vehicle (UAV) data analysis, scanning railway lines to quickly get a better overall view of their condition, reduced overheads and reduction of post-processing time. In addition, machine learning algorithms can be used to automatically detect and map changes in land use over time, allowing for land surveyors to easily recognise areas that may be of interest or concern.

Encouragingly, Hinds (2023) "*does not expect AI to replace the role of a surveyor. Instead, AI-powered software and tools will continue to help surveyors collect, process, and analyse large amounts of data, making it easier to map out land features, identify potential hazards, and assess the impact of development projects.*" This seems to be the general view at the moment.

A few years ago, on Reddit (2019), there was some interesting chat about AI and land surveying. The view of 'majorkev' was that "*AI... will make more work faster to do. Does that mean you'll be able to roll into the office at 8 and go home by noon? Absolutely not... AI will bring about a calamity of sorts where you will have fewer people doing actual work, but there will be more work for them to do. People won't be stress free, or working shorter hours since paradigms will shift, and we'll all go along for the ride.*"

Although progress using generative AI seems to be widely embraced and encouraged across the surveying landscape, Henry would be disappointed that there seems to be little thought to ethical concerns and impacts on the community. However, there was one group, Land Surveyors United (2023), who made these comments via its 'AI for Land Surveyors Hub': "*AI also holds the potential to enhance the capabilities of land surveyors, improve efficiency, and provide new opportunities for innovation. The integration of AI into the field of land surveying requires careful consideration, ethical discussions, and ongoing collaboration between technology developers and surveying professionals.*" And "*As with any emerging technology, ethical considerations are important when implementing AI in land surveying. Privacy concerns, data security, and the responsible use of AI algorithms are some of the aspects that surveyors need to address to ensure ethical practices*."

Land Surveyors United also wanted to know "*what the surveyors of the world think.*" In August 2023, they arranged a 4-day 'SurvAI Forum'. It concluded that professional land surveyors appear to have various concerns and fears regarding the adoption of AI. It provided a list of reasons why professional land surveyors seem to be fearful of AI, including job displacement, accuracy and reliability, liability and responsibility, data privacy and security, loss of professional judgement, dependency on technology, initial investment and training, unpredictable technological advances, loss of human interaction, and ethical and cultural considerations.

It is difficult to find Australian based discourse on the future benefits and consequences of AI, machine learning or deep learning in connection with surveying. However, at the time of writing in late 2023, the Geospatial Council of Australia is advertising a webinar to be held in February 2024, titled 'An introduction to AI in smart infrastructure and the geospatial world'.

It aims to discuss tools like GeoChatGPT, GeoAI and emerging advanced cartography techniques.

If Henry were here now, I suspect he would be pleased with the approach taken by Land Surveyors United for promoting knowledge around AI and raising questions of ethics and consequences for consideration by land surveyors and others. He would also be encouraging the Geospatial Council of Australia and others to keep their scope wide and include topics of ethics, moral responsibilities and consequences as generative AI evolves our techniques, technology, work and lives.

So, how relevant is Henry's message in his 1984 paper now in 2024 and beyond? Henry said "*Are surveys progressing rightly then? I hope so. It is clear that both parts of progress should not be separated from each other.*" Technological progress progressing hand-in-hand with the understanding of ethical and moral consequences is a message just as relevant to AI today as it was to GPS in 1984 or Egyptian measurements in 3,000 B.C.

7 CONCLUDING REMARKS

A.P.H. "Henry" Werner passed away in September 1984, the same month that his 1984 paper was published in *The Australian Surveyor*. Henry's formative years spanned from World War I through and beyond World War II. Given his life experiences, his devotion to the history of surveying and his spiritual appreciation of progress, it is not surprising that in the final months of his life he was motivated to the extent that he would produce a paper to caution future generations of surveyors and spatial scientists to tread carefully when adopting new technology. By all means 'push the boundaries' but do it in a way that includes ethical awareness and amelioration of detrimental consequences.

On the 40th anniversary of his passing and the publication of his 1984 paper, it has been my honour to bring the life and words of Henry Werner to APAS2024. Henry would expect that you will hear and act on his words and even further develop his message going forward. He has good reason for that expectation because, in his words, there is "*the need for an appreciation, and adoption, of spiritual aims in progress to match the leaps and bounds of material progress... to promote a greater awareness of the far-reaching consequences of progress in relation to the future of mankind.*"

ACKNOWLEGEMENTS

My thanks go to Rachael Greenwood and her staff at the Institution of Surveyors NSW for access and scanning of historic copies of *The Australian Surveyor* and *Azimuth*. I also thank Dr Craig Roberts at UNSW for encouragement and access to photographs of Henry Werner. The National Library of Australia deserves my thanks for arranging access to the Margaret Unger Oral History Collection and in particular Ping Yang, Coordinator Digitisation on Demand, for the digitisation from the original cassette tape of the 1974 interview with Henry Werner.

Late in the development of this paper, I was able to make contact with Sibylle Werner, Henry and Ruth's daughter, who calls Berlin her home but is currently living in Queensland. Sibylle has enthusiastically supported my endeavour to bring her Papa's wise words and philosophical thoughts from 1984 to us all here in 2024. Sibylle has provided many photographs and documents from her family collection to enhance this paper and the presentation. My sincere thanks go out to her.

Lastly, I would like to thank a legend, the Late Mr Henry Werner, for pushing the boundaries way beyond my own personal comfort zone all those years ago and consequently for giving me the opportunity to write this paper in his honour for the APAS2024 conference.

REFERENCES

Bird K. and Sherwin M.J. (2005) *American Prometheus: The triumph and tragedy of J. Robert Oppenheimer,* Atlantic Books, London, 736pp.

Clifford M. (2023) Can AI and land surveyors play nicely? *LiDAR News*, https://lidarnews.com/articles/can-ai-and-land-surveyors-play-nicely/ (accessed Mar 2024).

Gittins R. (2023) AI will make or break us – probably a bit of both, *The Sydney Morning Herald,* 22 September 2023, https://www.smh.com.au/business/the-economy/ai-will-make-or-break-us-probably-a-bit-of-both-20230921-p5e6nr.html (accessed Mar 2024).

GRC World Forums (2023) UK unveils world's first AI safety institute, https://www.grcworldforums.com/knowledge/uk-unveils-worlds-first-ai-safety-institute/9127.article (accessed Mar 2024).

Gregg A., Lima C. and De Vynck G. (2023) AI poses 'risk of extinction' on par with nukes, tech leaders say, *The Sydney Morning Herald*, 31 May 2023, https://www.smh.com.au/technology/ai-poses-risk-of-extinction-on-par-with-nukes-tech-leaders-say-20230531-p5dct6.html (accessed Mar 2024).

Hess K. (2023) What new developments are there in the world of land surveying? Surveying Task Force, https://www.alifewithoutlimits.com.au/blog/what-new-developments-are-there-in-the-world-of-land-surveying/ (accessed Mar 2024).

Hinds E. (2023) AI & surveying, Landform Surveys (UK), https://www.landform-surveys.co.uk/news/thoughts/ai-surveying/ (accessed Mar 2024).

Land Surveyors United (2023) Embracing the future: Understanding AI's role in our lives, https://landsurveyorsunited.com/hubs/ai/forum/topics/day-4-of-ai-for-land-surveyors-are-you-afraid-of-ai (accessed Mar 2024).

Loeffel R. (2007) *The History of the UNSW School of Surveying and Spatial Information Systems: 1949-2007*, The University of New South Wales, Sydney, 192pp.

McHugh S. (1995) *The Snowy: The people behind the power*, Angus & Robertson, Sydney, 272pp.

Mehta R. (2021) Artificial Intelligence translating geospatial data into knowledge, Spatial Source, https://www.spatialsource.com.au/artificial-intelligence-translating-geospatial-data-into-knowledge/ (accessed Mar 2024).

N.N. (1980) Personalities of the profession: Arthur Paul Heinz Werner, *The Australian Surveyor*, 30(3), 197-198.

N.N. (1984) Obituary: Arthur Paul Heinz Werner, *Azimuth*, November 1984, 14.

Press G. (2016) A very short history of Artificial Intelligence (AI), Forbes, https://www.forbes.com/sites/gilpress/2016/12/30/a-very-short-history-of-artificial-intelligence-ai/?sh=394e58a96fba (accessed Mar 2024).

Reddit (2019) How will AI affect surveying? https://www.reddit.com/r/Surveying/comments/eypoz8/how_will_ai_affect_surveying/ (accessed Mar 2024).

Robb D. (2023) Generative AI vs. machine learning, eWeek, https://www.eweek.com/artificial-intelligence/generative-ai-vs-machine-learning/ (accessed Mar 2024).

Sandle P. (2023) UK's Sunak says only governments can tackle AI risks, Reuters, https://www.reuters.com/technology/uks-sunak-says-ai-risks-must-be-addressed-ahead-key-safety-summit-2023-10-25/ (accessed Mar 2024).

Smith C., McGuire B., Huang T. and Yang G. (2006) The history of Artificial Intelligence, University of Washington, https://courses.cs.washington.edu/courses/csep590/06au/projects/history-ai.pdf (accessed Mar 2024).

Swan D. (2023) Meet hackers' favourite new tool: WormGPT, *The Sydney Morning Herald,* 3 November 2023, https://www.smh.com.au/technology/meet-hackers-favourite-new-tool-wormgpt-20231102-p5eh5l.html (accessed Mar 2024).

Unger M. (1974) A.P.H. Werner interviewed by Margaret Unger in the Margaret Unger oral history collection, National Library of Australia, https://trove.nla.gov.au/work/243135608?keyword=henry%20werner%20unger&title=a.%20p.%20h.%20werner (accessed Mar 2024).

Werner A.P.H. (1966) A calendar of the development of surveying, *The Australian Surveyor*, 21(3), 847-874.

Werner A.P.H. (1968) A calendar of the development of surveying, *The Australian Surveyor*, 22(2), 131-140.

Werner A.P.H. (1984) The philosophy of progress: Any lessons from the history of surveying? *The Australian Surveyor*, 32(3), 167-192.

Art by Surveyors and Surveyors in Art

John F. Brock
Brock Surveys
brocksurveys@bigpond.com

ABSTRACT

If someone was asked which painting is the most famous in the world, it can be expected that most would say the Mona Lisa. Most people would also be familiar with the painting popularly known as Whistler's Mother. However, there would be few who are aware that the first artist, Leonardo Da Vinci, was also a prominent land surveyor and town planner, while the second artist James Abbott McNeill Whistler's father, George Washington Whistler, was an eminent railway surveyor for Tsar Nicholas I of Russia. Throughout world history, surveyors have long been recognised as excellent judges of measurement and scale. During times of war they were often engaged as frontline reconnaissance scouts whose duty it was to accurately sketch enemy positions with calculations of distance determined to elevate and aim weaponry like cannons and mortars at the right trajectory for maximum impact. Such surveyor artists from the arena of war include Sir Thomas Mitchell, longest serving NSW Surveyor-General and Colonel William Light, South Australia's first Surveyor-General and founder of Adelaide, active during the Peninsula Wars against Spain. This paper introduces the reader to a vast kaleidoscope of colourful characters with an impressive collection of artworks either made by surveyors or featuring surveyors. Some works featuring surveyors have even been made by the hand of the surveyor himself, contributing to a gallery of great masterpieces for your visual delight.

KEYWORDS: *Mona Lisa, Leonardo Da Vinci, Whistler's Mother, James Whistler, surveyors, artwork.*

1 INTRODUCTION

Art is one form of passive recreation that has captured the curiosity of millions of viewers throughout the history of mankind. The great masters of the Renaissance and other eras of artistic creativity have given the onlookers much pleasure while at the same time their brushwork has provided a colourful representation of the contemporary periods in which they lived. Before photography came into vogue in the mid-1800s, the only visual depiction of historical events and surroundings was through paintings and sketches. The certain fact that many of these penmen of renown were either surveyors or related to a surveyor was not coincidental to the high quality and preciseness of their brilliant artworks. Some of the works shown in this paper are masterpieces made by a surveyor or a relative of a surveyor while some pieces depict surveyors at work. My personal favourites are the paintings which feature surveyors at work, actually done by the surveyor himself. You will be surprised by some of the great works done, and your eyes will feast upon this corpus of artworks included in this potpourri of colour and history.

There are few who would not say that the most famous painting in the world is the Mona Lisa. Most people would also be familiar with the painting popularly known as Whistler's Mother (Figure 1), but the professions of their respective creators are far less well-known (Figure 2).

Figure 1: The Mona Lisa by Leonardo Da Vinci (left), and A Study in Grey aka Whistler's Mother by James Abbott McNeill Whistler.

Figure 2: Portraits of Leonardo Da Vinci (left), George Washington Whistler (centre) and James Whistler (right).

2 MASTERPIECES BY SURVEYORS

Leonardo Da Vinci (1452-1519) was not just a prolific artist, he was also a qualified hydraulic engineer, town planner, land surveyor and inventor of genius. He was so clever that he even made his own surveying instruments with which he would carry out his survey work (Figure 3)! He made town plans for these new towns based on his own surveys plus he would then set out these new suburban areas. His 1502 Town Plan of Imola (when he was aged 50) is believed to be the earliest Renaissance geometric town view to have been made (Figure 4). Although some dispute prevails, the consensus is that he surveyed this plan himself, perhaps using an older 1473 map to check his measurements (Blevins, 2010). One author says: "*The development of the measuring and surveying techniques promoted by the Renaissance 'engineers' and the fortunes of the work by Piero del Massaio were at the basis of the cartographic experiments of Leonardo da Vinci and Girolamo Bellarmato. Already in his paintings and drawings, Leonardo depicted the landscape with a surprising scientific spirit. The meticulous cartographical sketches represented the prelude of the veritable maps, where art and science, drawing and measurements came together to attain extraordinary results*." (Institute and Museum of the History of Science, 2024).

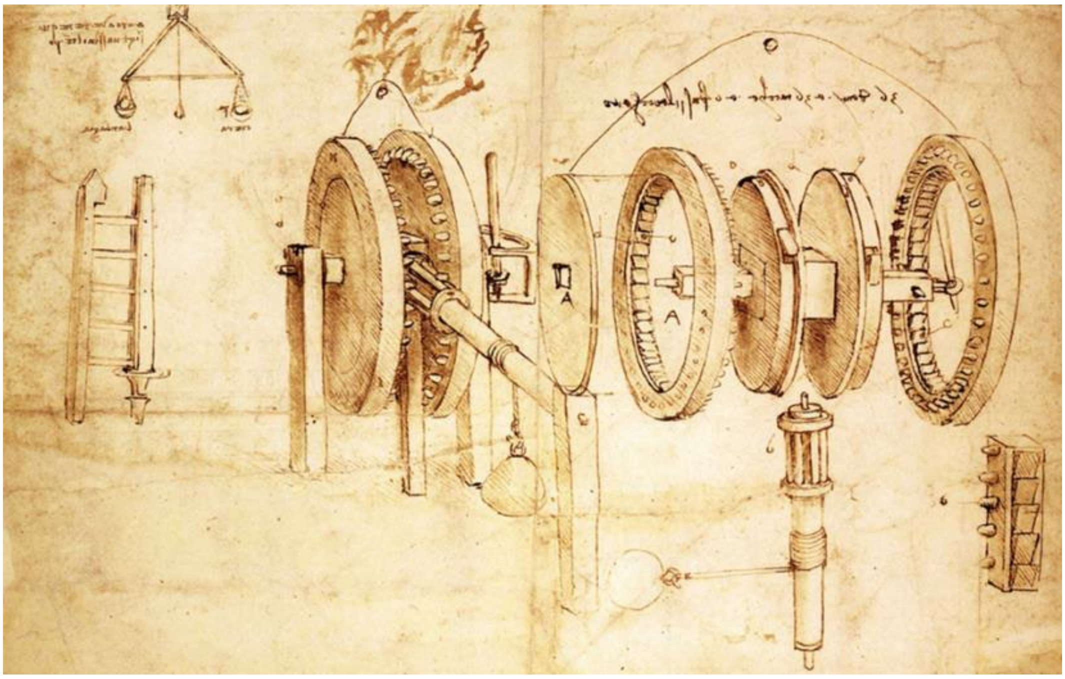


Figure 3: Measuring instrument called a pedometer made by Da Vinci.

Figure 4: Da Vinci's 1502 town plan of the Italian location of Imola, which was also surveyed by him with surveying instruments made by himself.

George Washington Whistler (1800-1849) (see Figure 2), appropriately named because US first President George Washington was also a surveyor, was a renowned railway surveyor who was invited by Russian engineer Pawel Melnikov on the order of Tsar Nicholas I to survey the 420-mile St. Petersburg to Moscow railway line in 1842 (Figure 5). Whistler was born in Indiana in 1800, graduating from the US Military Academy at West Point, New York in 1819. He surveyed boundaries and designed several railroads and canals, serving as a topographer in the US Corps of Artillery from 1819 to 1821. After a distinguished record of surveying numerous US railroads, he went to Russia at the behest of the Tsar. Dying there in 1849, he missed the opening of the line in 1850, but he was awarded the order of St. Anne by the Russian Emperor (ASCE, 2024). His son James (1834-1903) attended West Point like his father where he studied drawing but was dismissed from the academy when he failed chemistry. He then worked in the drawings division of the US Coast and Geodetic Survey, mapping the entire US coast for military and maritime purposes before leaving to venture to Paris to study his love of art (Weinberg, 2010).

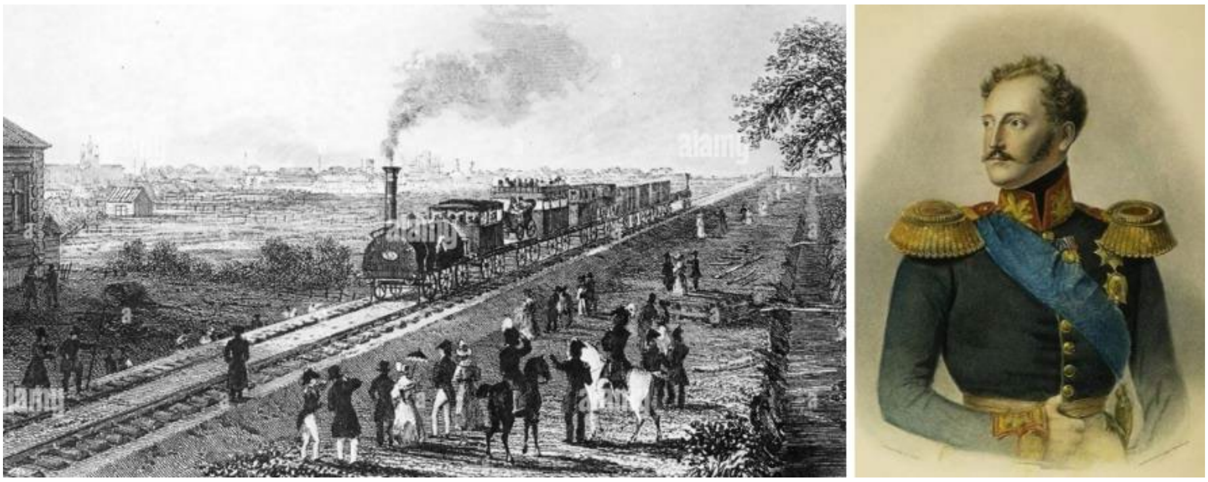


Figure 5: Etching of the Moscow to St. Petersburg railroad (left), with Tsar Nicholas I looking on (right).

Another US artist with an Australian association and father, also a surveyor, was (Paul) Jackson Pollock (1912-1956) whose artwork Blue Poles hangs in the Australian National Art Gallery in Canberra after a controversial purchase of it by the acting Director of the National Gallery of Australia, James Mollison, on behalf of Prime Minister Gough Whitlam's government for $1.3 million in August 1972 (NMA, 2024) (Figure 6). At the time, this was the most ever paid for an American painting anywhere in the World! As a consequence, the Prime Minister was widely criticised at the time, but now, with this piece of art valued at $350 million, the critics of the period have been well muted!

Figure 6: Australian Prime Minister Gough Whitlam poses in front of his government's purchase, Blue Poles.

Jackson's father LeRoy McCoy Pollock (1876-1933) was a US government surveyor in Arizona and California in the 1920s and 1930s (Figure 7). The family's travels in the American West left a lasting impression on his young son with Native American sand painting bearing the most profound influence on his painting techniques (Smith, 2010).

Figure 7: Surveyor LeRoy Pollock (left), and self portrait of Jackson Pollock with art backdrop (right).

3 ART BY SURVEYORS

During the early years of the Colony of New South Wales (now Australia), there were many surveyors who were gifted artists with particular note of three Surveyors-General of NSW, South Australia and Victoria contributing most substantially to the record of that formative era. Sir Thomas Mitchell (NSW, 1792-1855) and William Light (1786-1839, first Surveyor-General of South Australia 1836-1838) had both served under the Duke of Wellington in the Peninsula Wars on the Iberian Peninsula as forward scouts whose depiction of enemy posts were critical to the conduct of the battle. Robert Hoddle (1794-1881) was the first Surveyor-General of Victoria from 1851-1853, before this being engaged in the NSW Surveyor-General's Department under the leadership of Thomas Mitchell, the fourth Surveyor-General of NSW from 1828 to 1855 (Figure 8).

Figure 8: Self portrait of SA Surveyor-General William Light (left), and Victorian Surveyor-General Robert Hoddle (right).

Some selected samples of their works can be viewed in Appendix A. Mitchell painted one of the first images of the Pink Cockatoo or Leadbeater's Cockatoo (*Cacatua Leadbeater*) whose more common name is now Major Mitchell's Cockatoo (Figure 9). David Elder (1987) provides an extensive collation of much of Light's artwork, showing full colour reproductions of some of the great Surveyor-General's works representative of his vast world travels. Many more pieces of his brilliant collection were lost when his house burnt down in January 1839. Light was SA Surveyor-General from 1836-1838, then was a partner in the private survey consultancy Light Finniss & Co. in 1838-1839 with Boyle Travers Finniss, later to become South Australia's first Premier in 1856.

Figure 9: Painting of the Pink Cockatoo by Thomas Mitchell (left), and portrait of Thomas Mitchell (right).

One early NSW surveyor, George William Evans (1780-1852), was leader of the expedition to open up new country in the Blue Mountains out to Bathurst in western NSW, as well as assisting (it may be closer to the facts to say 'saving') NSW Surveyor-General John Oxley on his sojourns to the north and south of NSW. His portrait was painted by noted colonial artist, Augustus Earle (1793-1838) in circa 1825, displaying his circumferentor and survey plan (Figure 10).

Following after the three explorers Gregory Blaxland, William Lawson and William Wentworth, who found a crossing over the Blue Mountains (the mountain barrier west of Sydney) in 1813, he started his survey traverse in December 1813 and continued into 1814, thus extending the limits of settlement as far as Bathurst, which would in 1815 become the first inland European town in Australia and named after the Earl Bathurst by Governor Lachlan Macquarie. The first western road over the Blue Mountains was completed in a mere 6½ months by road builder William Cox and his team of marines and convicts with the Governor taking a tour along the new road in 1815 with Evans and Oxley in company for at least part of the journey. A selection of Evans' art recorded during the early settlements in Sydney, Parramatta, Windsor and Tasmania in the early years of the 1800s is shown in Appendix A.

Figure 10: The Grave of a Native of Australia (1820) by George Evans (left), and portrait of George Evans (c. 1825) by Augustus Earle (right).

4 SURVEYORS IN ART

Some of the earliest surviving examples of surveyors in art can be found in the ancient Egyptian Necropolis of Sheikh Abd el-Qurna in the Valley of the Nobles, which is in close proximity to the Valley of the Kings and the Valley of the Queens in Luxor, southern Egypt. Being New Kingdom (1552 BC-1069 BC) rock cut tombs, they are not far from where the legendary intact burial tomb of Tutankhamun was unearthed by Howard Carter in 1922. Four tombs with surveyor scenes are extant from about 1400 BC: Khaemhet (a relief sculpture work, Theban Tomb [TT] 57), Amenhotep-si se (TT 75, a sketch of this scene is available), Djeserkareseneb (TT 39, Figure 11) and Menna (TT 69, Figure 12), which has the only known representation of the sacred measuring cord pulled tightly displaying the knotted graduations at intervals of 3 Royal cubits each. A Royal cubit is about 0.525 metres in length so that each knot was to be found roughly 1½ metres apart. Royal measuring rods have been discovered that would appear to be indicative of a standard of measurement not strictly determined by the distance of the elbow to the fingertips of the incumbent Pharaoh, which of course would not be identical between dynasties.

Figure 11: Tomb painting (c. 1400 BC) from the burial of Scribe Surveyor Djerserkareseneb and his survey party with the sacred measuring rope hanging loosely.

Figure 12: Famous New Kingdom tomb painting (c. 1400 BC) of Scribe Surveyor Menna and his survey party with the only scene of the sacred measuring rope pulled taut showing the knots at 3-cubit intervals.

There are a large number of paintings of first US President surveyor, George Washington (1732-1799), who was District Surveyor of the County of Culpeper at the age of 17. He was portrayed by many different artists shown carrying out survey work in the rural areas of the USA. There is even a life-sized panorama in the museum which can be found at his country estate Mount Vernon along the Potomac River in Richmond, Virginia, using what American surveyors call a surveyor's compass (aka what Australian surveyors call a circumferentor) in an authentic recreation of George Washington making observations in the woods (Figure 13). On a megalithic scale, the Gortzon Borglum sculpture of Mount Rushmore depicts the three US President surveyors in giant detail as gazing down upon the thousands who visit this site every year: George Washington, Thomas Jefferson (1743-1826) and Abraham Lincoln (1809-1865). There is a bronze life-sized statue of Thomas Jefferson in the Flagler Court Garden at the University of Virginia with his transit in a pose replicating his 1817 survey of this project. Jefferson even had a transit (theodolite) built to his specific design when this surveying instrument was in its embryonic stages. This original instrument can be seen in Jefferson's house 'Monticello' in Charlottesville, Virginia.

Figure 13: Two scenes of George Washington at work surveying.

Another well-known US surveyor is Benjamin Banneker (1731-1806) who is referred to as "the first African American man of science" and was an appointee of George Washington to assist Andrew Ellicott in the survey of the capital territory of Washington DC commencing in 1791 (Figure 14). As he was a self-taught and well-skilled astronomer, there are numerous paintings of Benjamin Banneker alongside large astronomical telescopes as well as surveying instruments of the day and survey plans. He even made a working clock entirely of timber and compiled an Astronomical Almanack and Ephemeris in 1793, of which he sent a copy to Thomas Jefferson, who also held Benjamin Banneker in the highest esteem. To commemorate the joint survey of the new Federal Territory and the Capital of Washington DC by the two surveyors appointed by George Washington to carry out the work, the installation of a mural titled 'Andrew Ellicott and Benjamin Banneker surveying the boundaries of Washington DC' by William Smith (1968) was unveiled at the Banneker-Douglas Museum at Annapolis, Maryland, on 5 February 2022 (Figure 15).

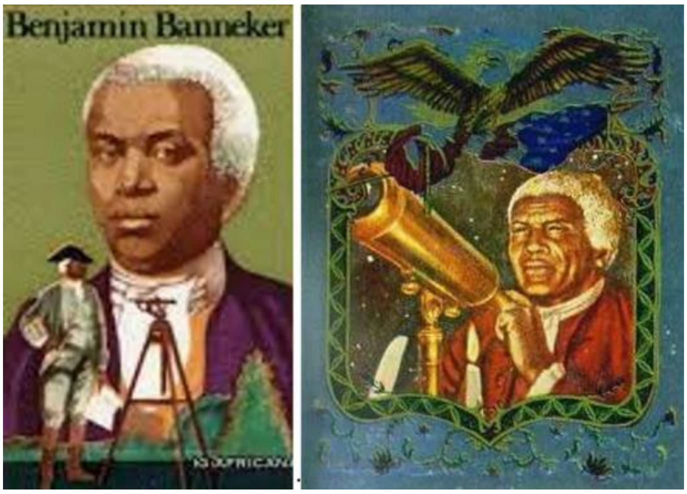


Figure 14: Two images of Benjamin Banneker surveying (left) and star gazing (right).

Figure 15: Mural of 'Andrew Ellicott and Benjamin Banneker surveying the boundaries of Washington DC' by William Smith (1968), unveiled in 2022 at the Banneker-Douglas Museum in Annapolis, USA.

A prolific group of like-minded artists developed in Australia in the late 1800s, named 'The Heidelberg School' (c. 1886-1900) as they originated in this rural area east of Melbourne. This artistic movement was referred to as Australian Impressionism, featuring famous homegrown names such as Tom Roberts, Fred McCubbin and Arthur Streeton (1867-1943) who penned such loved works as 'Shearing the Rams' (TR 1890), 'The Golden Fleece' (TR 1894), 'Bailed Up' (TR 1895), 'Down on his Luck' (FM 1889), 'Bush Idyll' (FM 1893) and 'Fire's On' (AS

1891), all of which proudly hang in the Art Gallery of New South Wales in Sydney. It just so happens that Arthur Streeton must have travelled with or visited a surveyor's camp in the bush, which was the subject of his work 'Surveyor's Camp' (1896) (Figure 16).

Figure 16: Surveyor's Camp by Arthur Streeton (1896).

One of the lesser-known members of this elite fraternity was Charles Conder. Due to the wild lifestyle he led back in England, his family shipped him off to NSW to take up employment with his uncle, William Jacomb Conder, who was a surveyor employed by the Surveyor-General to carry out the Triangulation Survey of NSW. The harsh environment of the Australian bush and lack of wider human contact were not enjoyed by Charles who preferred the more Bohemian activities available amongst his chosen sect of artists. Most of his works were landscapes and holiday scenes at Australian beaches (Figure 17) but there was one painting he titled 'Landscape with Theodolite' (c. 1887) (Figure 18).

Figure 17: A Holiday at Mentone by Charles Conder (1888).

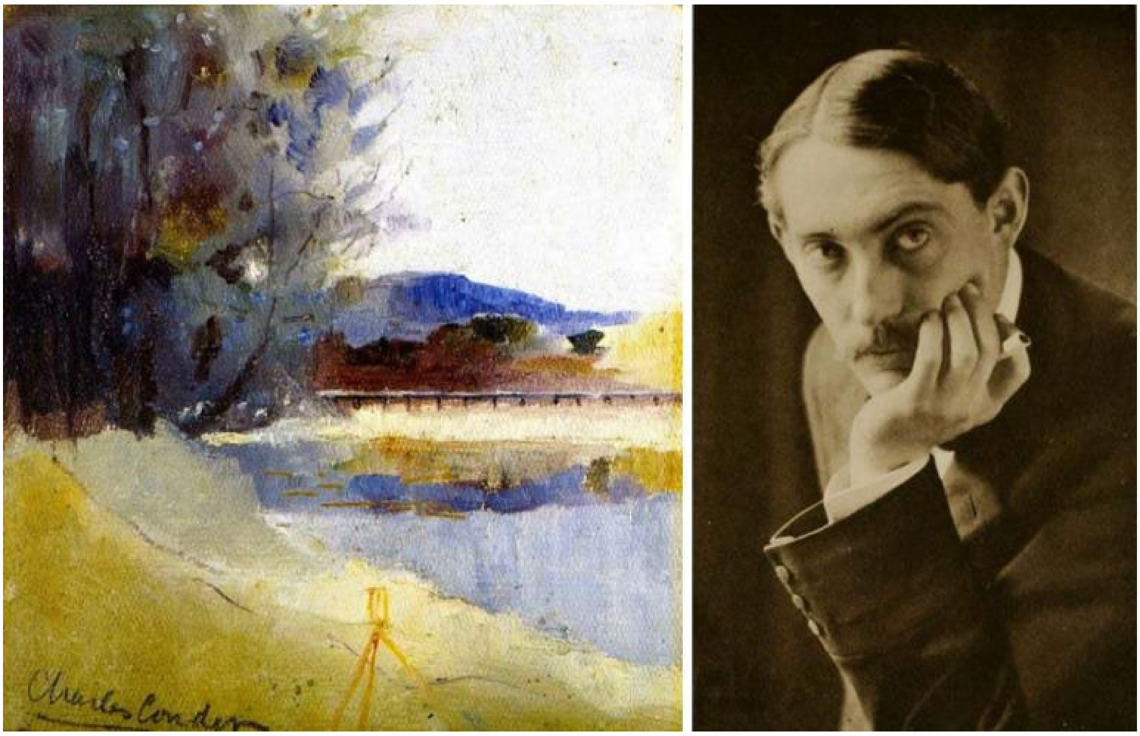


Figure 18: Landscape with Theodolite by Charles Conder (left), and Charles Conder (right).

One noted Australian painter of the Goldrush era was Samuel Thomas (S.T.) Gill (1818-1880) who published a book of sketches depicting life on the goldfields and in the Australian outback (Gill, 1865) (Figure 19). Two of his works contain surveyors at work in the 1860s using the surveying tools of the time, which were the circumferentor and the Gunter's chain (Figures 20 & 21). In his sketchbook can be found lively depictions of daily life on the goldfields and in outback Australia, with some illustrations of the native fauna perhaps more resembling the megafauna of the prehistoric eras than the actual wildlife of the outback areas.

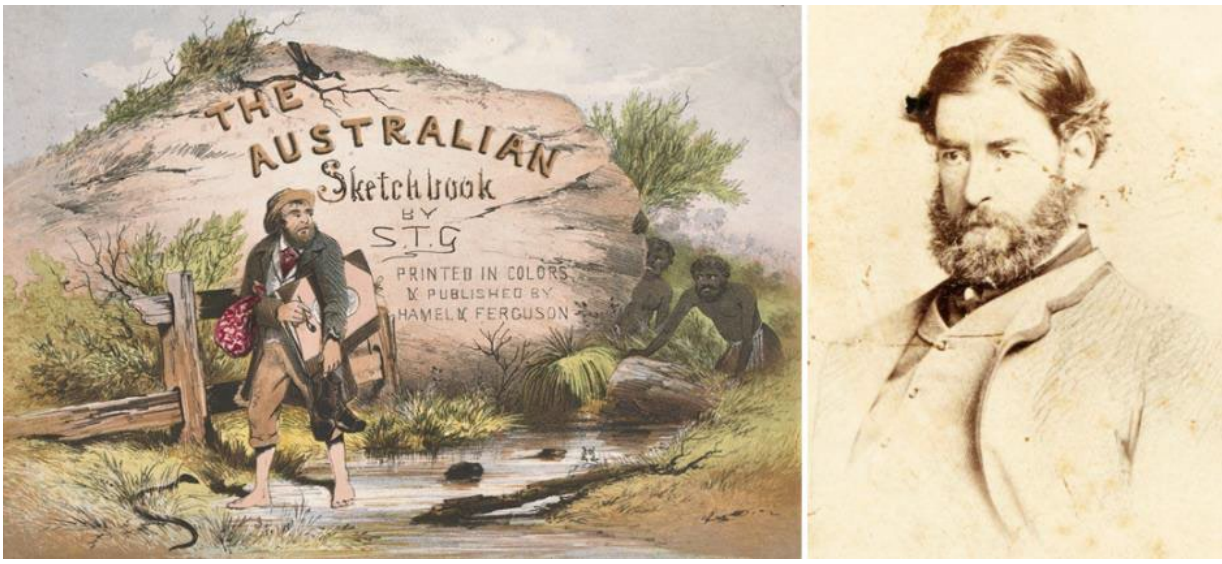


Figure 19: The cover of the S.T. Gill publication 'The Australian Sketchbook' (left) and S.T. Gill (right).

Figure 20: The Surveyors by S.T. Gill (c.1866).

Figure 21: Another painting by S.T. Gill, showing a survey party in the desert.

A surveyor in the employment of NSW Surveyor-General Thomas Mitchell, who later became the first Surveyor-General of New Zealand in 1839, was Felton Mathew (1801-1847). His surveys of the outer sparsely occupied areas west and north of Sydney have left some amazing survey marks cut into the sandstone and carved into the surviving trees from the 1830s (Figure 22). He died in 1847 and is buried in Lima, Peru, where he took ill aboard the ship returning to England and passed away after being taken ashore (Duder, 2015).

Figure 22: 1843 work by Major Thomas Bunbury of Mathew (in blue coat) observing bearings from the top of Rangitoto, looking southerly (left), and daguerreotype of Mathew probably taken in London 1845-46 (right).

San Francisco's Coit Tower hosts a series of murals painted inside, featuring some surveyor images (San Francisco Recreation & Parks, 2024). The building was erected in 1932-33, its design being said to represent a fire hose nozzle, as the major benefactor of its erection, Lillie Hitchcock Coit, loved the fire brigade, often seen riding along on various fire trucks dressed as a fireman despite the disdain of the male fraternity! The large 'Surveyor' mural (1934) by Clifford Wight is striking at 3 metres in height (Figure 23). There is another scene of work including a surveyor by Tara Bradford, entitled 'Surveying the Land' (1934) (Figure 24).

Figure 23: 3-metre-high giant surveyor mural in Coit Tower by Clifford Wight.

Figure 24: Coit Tower in San Francisco (left), and Surveying the Land mural by Tara Bradford (1934) (right).

One of Australia's prominent artists from the modern era is "Pro" Hart (Kevin Charles Hart, 1928-2006) whose style was quite controversial due to its abstract technique of portraying rather small figures in scenes of rustic colour of the Australian bush and outback. He was commissioned to do a painting for the Institution of Surveyors Australia National Congress held in Sydney in 1988 (Figure 25) from which a limited edition of 500 personally signed prints were available for purchase, one of which can be viewed in the Institution of Surveyors NSW (ISNSW) office in Sydney. He also created two other works featuring surveyors both titled 'The First Surveyor' (Figures 26-27), one in 1971 and one in 1974 which accompanied the "Banjo" Paterson poem of the same name in the book 'Poems of Banjo Paterson – Illustrated by Pro Hart' (Paterson, 1974).

Figure 25: Pro Hart work commissioned for the 1988 ISA Congress in Sydney.

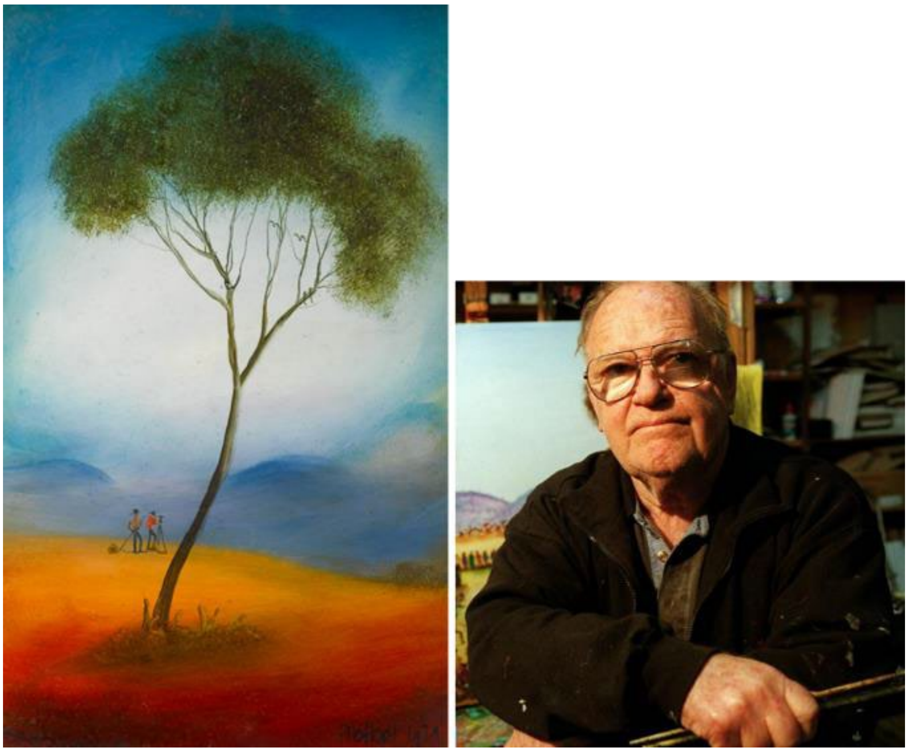


Figure 26: The First Surveyor by Pro Hart (1971) (left), and Pro Hart (right).

Figure 27: The First Surveyor by Pro Hart (1974).

5 SURVEYORS IN ART BY SURVEYORS

Now we come to my absolute favourite group of surveyor art, when the actual surveyor illustrates himself or other surveyors carrying out their work with the equipment of the period in surroundings which probably have changed markedly since the origin of the images.

John Joseph William Molesworth Oxley (1784-1828) was the third Surveyor-General of NSW from 1812-1828 when he died suddenly after a survey field trip, to be succeeded by Thomas Mitchell, his then deputy. Oxley made several exploratory journeys with George Evans to guide him. He would supplement his journals with sketches and paintings, with at least one containing a scene with surveyors overlooking new territory of the Liverpool Plains (Figure 28).

Figure 28: Oxley painting looking at the Liverpool Plains (left), and side portrait of Oxley (right).

Contemporaneous with Oxley was great Norfolk Island born mariner Phillip Parker King (1791-1856) who made explorations in the north-western part of Australia between 1819 and 1822. The maps he drew were the first such drawings to bear the name ‘Australia’, having the official endorsement of the British Admiralty who had hitherto expressly forbidden such an appellation. On his voyages he was joined by John Septimus Roe (1797-1878), later to become first Surveyor-General of Western Australia from 1828 to 1870, and Indigenous man Bungaree (c. 1775-1830), who had also been with epic navigator Matthew Flinders on his circumnavigations of Van Dieman’s Land on the Norfolk (1798) and mainland Australia on the Investigator (1801-1803) (Figures 29 & 30). He produced an impressive collection of images of his journeys. Phillip Parker King became the first Australian born Admiral in the British Navy in 1855, the year before he died.

Figure 29: Portraits of John Septimus Roe (left), Bungaree by Phillip Parker King (centre), and Phillip Parker King (right).

Figure 30: Painting by Phillip Parker King, showing himself and Roe carrying out coastal survey observations.

Another notable surveyor artist in the service of the Surveyor-General's Department was William Romaine Govett (1807-1848). His survey tasks saw him carry out measurements in some of the more mountainous terrain in the Blue Mountains and the Colo Valley. He had a collection of sketches and paintings published in the local newspaper with much Indigenous content and the local fauna gaining prominence (Figure 31). He also composed two images demonstrating some of the survey work with which he was involved. One shows a surveyor's assistant hanging precariously on a rope ladder while descending to the lower ground level in the Colo Valley (Figure 32), while another could well be the first accident scene investigation (ASI) ever depicted, showing him alongside his circumferentor ready to monitor the scene of a bullock wagon which had crashed over the edge of the roadway at Mount Victoria in the Blue Mountains, west of Sydney in the 1820s (Figure 33).

Figure 31: Portrait of William Romaine Govett (left), and work of "corrobary" (i.e. corroboree) peculiar dance of the natives (right).

Figure 32: Painting by William Romaine Govett of surveying in the precipitous country of the Colo Valley.

Figure 33: Accident at Mt. Victoria by William Romaine Govett.

At the Surveyors Historical Society Rendezvous in San Felipe de Austin in Texas in September 2023, I gave a presentation on the Four Surveyors of the Alamo and the surveyor/artist of San Antonio (Brock, 2023). This research revealed a property developer named Henri Castro who had brought surveyors from all over the world and the United States to survey his new townships, one named Castroville, in the new Republic of Texas in the 1830s and 1840s.

One of these was a gifted artist, Jean Louis Theodore Gentilz from France, who put his pen to the canvas to record the lives and activities of the new settlers and indigenous occupants of San Antonio after the renowned siege of The Alamo in February 1836 (Figure 34). He made one notable work depicting a survey party at work with a Gunter's chain and surveyor's compass about 1845, called 'Stick and Stock' (Figure 35). The surveyor at the compass is believed to be Gentilz himself with the man on the horse being John James apparently directing the survey party. This work is the only one known depicting his colleagues from the Castroville era. It has an alternative title of 'Surveying in Texas before Annexation to the U.S.' (Kendall, 1974).

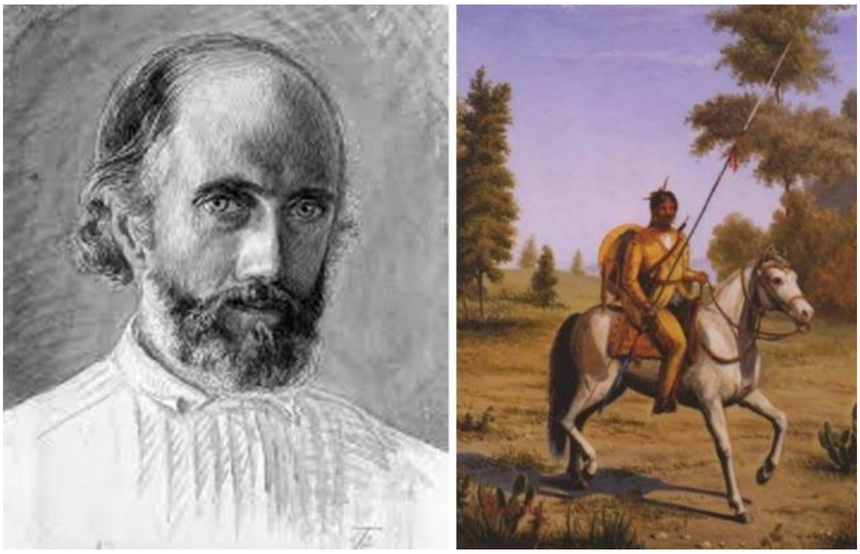


Figure 34: Sketch of Theodore Gentilz (left), and Comanche Chief by Theodore Gentilz (c. 1845) (right).

Figure 35: Stick and Stock by Theodore Gentilz (c. 1845), showing surveyors in an undeveloped area of San Antonio.

When visiting the ISNSW office in Goulburn Street, Sydney, I always look at the great paintings and photographs of our ancestors who made such a notable contribution to the profession of surveying, leaving us with some tangible images and artefacts from their eras of work. The collage of photo portraits of past presidents is one of my favourites in this collection along with a painting done by past President Louis Albert Curtis (grandfather of ISNSW member Bob Curtis, who passed away in 2022), who had painted the excellent piece hanging in the hallway titled ‘Water Conservation Survey Camp, Gwydir River, Moree 1892’ with some Indigenous visitors resting peacefully in front of the row of tents amongst the trees in this outback area of NSW. Louis’s picture notes that he was ISNSW President from 1911-1913 (Figure 36).

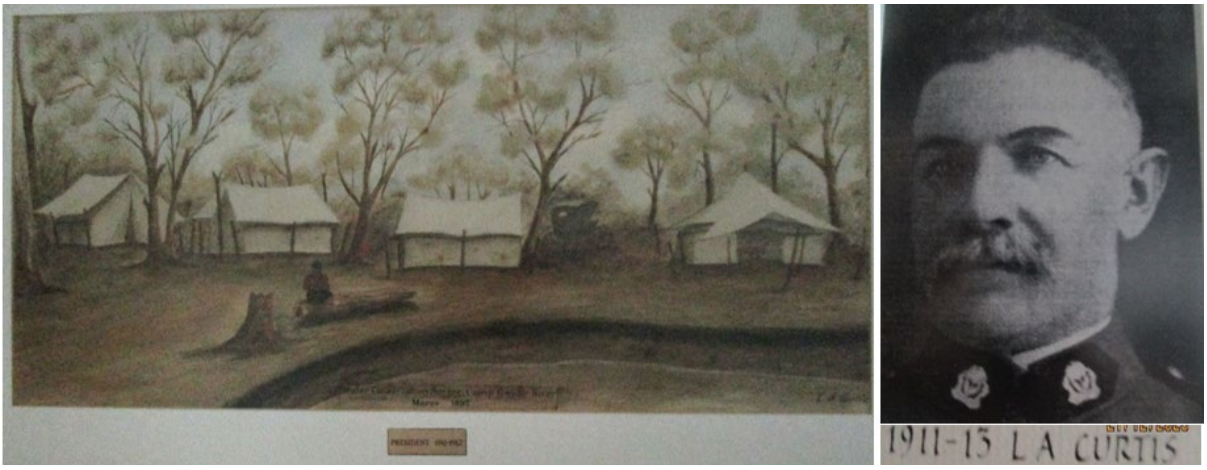


Figure 36: Surveyors Camp at Moree by ISNSW President Louis A. Curtis (left), and Louis A. Curtis (right).

During attendance at the 2011 International Conference on the History of Cartography (ICHC) held in Moscow, ISNSW member and former President, David Lorschy, mentioned that he had seen a mural with a lady surveyor on the walls of the Moscow underground railway, so we set off in pursuit of this work with great excitement. Unfortunately, it was with great dismay after a rather lengthy search that I sat down for a rest. When my partner Kerima-Gae saw me and looked up, the subject of the hunt was right there on the wall directly above me (Figure 37)!

Figure 37: The author sitting unbeknown under the Russian underground railway mural of a woman surveying in the Moscow underground railway system, with a close-up of the mural on the right.

6 CONCLUDING REMARKS

There are many works of art in painting and sculpture which cover a wide representation of styles, artists and famous historical figures as an indication of just how noteworthy the works of surveyors are. This paper has introduced the reader to a vast kaleidoscope of colourful characters with an impressive collection of artworks either made by surveyors or featuring surveyors. In addition to the works presented in the body of this paper, the Appendices provide a relatively brief sample of more art which has been created by and about surveyors. When it comes to interesting subjects to depict in art and sculpture, there is no doubt that surveyors do rate highly in this genre.

REFERENCES

ASCE (2024) George Washington Whistler, https://www.asce.org/about-civil-engineering/history-and-heritage/notable-civil-engineers/george-washington-whistler (accessed Mar 2024).

Blevins B.S. (2010) Leonardo Da Vinci: Land surveyor and cartographer, *Proceedings of FIG Congress 2010 – History Workshop*, Sydney, Australia, 10-11 April, 17pp.

Brock J.F. (2023) Four surveyors of the Alamo and the surveyor/artist of San Antonio, Presented at 2023 Surveyors Rendezvous, San Felipe de Austin, Texas, USA, September 2023 (abstract and other information available from the author).

Duder T. (2015) *Sarah Mathew: Explorer, journalist and Auckland's 'First Lady'*, David Ling Publishing, Auckland, 208pp.

Elder D. (1987) *Art of William Light*, Wakefield Press, Adelaide, 148pp.

Gill S.T. (1865) *The Australian sketchbook*, Hamel & Ferguson, Melbourne, 24 plates.

Honolulu Museum of Art (2024) Surveying a region, https://ukiyo-e.org/image/honolulu/6040 (accessed Mar 2024).

Institute and Museum of the History of Science (2024) Cartography in Tuscany, https://brunelleschi.imss.fi.it//itineraries/itinerary/CartographyTuscany.html (accessed Mar 2024).

Kendall D.S. (1974) *Gentilz: Artist of the Old Southwest*, University of Texas Press, Austin, 127pp.

NMA (2024) Defining moments: Blue Poles, https://www.nma.gov.au/defining-moments/resources/blue-poles (accessed Mar 2024).

Paterson A.B. (1974) *Poems of Banjo Paterson – Illustrated by Pro Hart*, Lansdowne Press, Sydney, 136pp.

San Francisco Recreation & Parks (2024) Coit Tower, https://sfrecpark.org/facilities/facility/details/Coit-Tower-290 (accessed Mar 2024).

Smith M.E. (2010) How Jackson Pollock worked, https://entertainment.howstuffworks.com/arts/artwork/jackson-pollock.htm (accessed Mar 2024).

Weinberg H.B. (2010) James McNeill Whistler (1834-1903), https://www.metmuseum.org/toah/hd/whis/hd_whis.htm (accessed Mar 2024).

APPENDIX A: SELECTED ARTWORK BY SURVEYORS

William Light

Figure A1: First campsite near Adelaide in South Australia, January 1837.

Figure A2: The brig Rapid in the rough seas of Rapid Bay, South Australia, 1836.

Figure A3: Beni Hassan in Egypt, 1820s.

Robert Hoddle

Figure A4: Waterfall, possibly in NSW (1845) (left), and Coliban Falls, Coliban River, Victoria (right).

Thomas Mitchell

Figure A5: Victoria Pass, c. 1830s.

Figure A6: The Passage of the Blacks, c. 1830s.

Figure A7: Drawing of the recently shot bushranger “Bold” Jack Donohoe (1833) (left), and Thomas Mitchell (right).

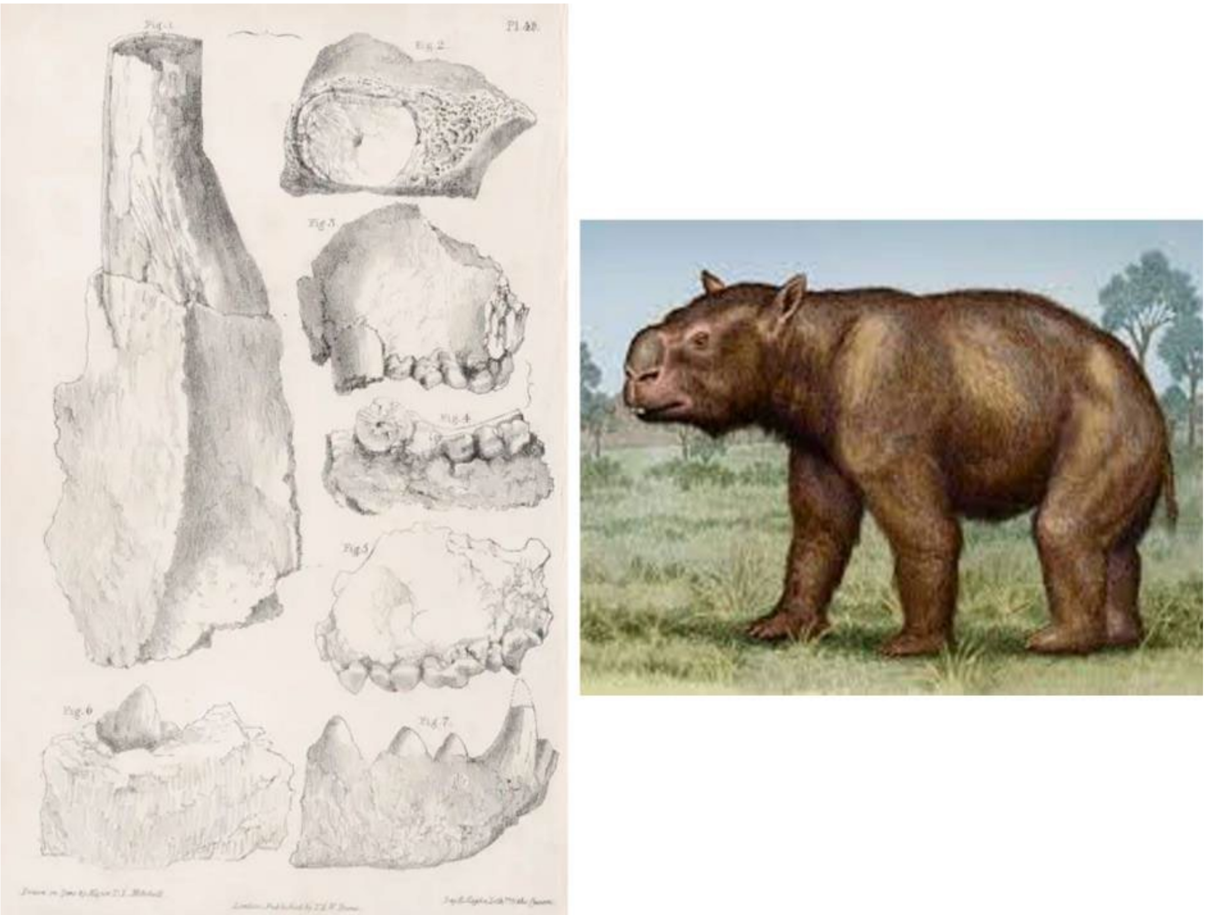


Figure A8: Detail drawing of the fossils found at Wellington Caves, NSW, in 1838 (left), later identified by British dinosaur doyen, Sir Richard Owen, as the first specimens of Australian megafauna from prehistoric times. It was a Diprotodon, which was the ancestor of the modern-day wombat but weighing 1-2 tonnes as shown in the artist’s recreation (right).

George Evans

Figure A9: Sydney from the western side of the Cove, c. 1803 (attributed to G.W. Evans).

Figure A10: The Settlement on the Green Hills, Hawksburgh (i.e. Hawkesbury) River.

Figure A11: Government House, Parramatta.

Figure A12: View of Sullivan Cove, Van Dieman’s Land, 1804 (watercolour possibly by G.W. Evans).

Figure A13: The grass tree, and blacks kindling fire.

Figure A14: Cutter's Inn, Mittagong, Argyle Road, as it appeared in 1828.

Figure A15: Three black women weeping over a grave.

Japanese surveyors

Figure A16: A Japanese painting of surveyors at work during the Edo Period (1600-1868) with the title 'Surveying a Region' by Katsushita Hokusai (1848) (Honolulu Museum of Art, 2024).

Figure A17: Japan's most famous surveyor, Ino Tadataka (1745-1818).

Figure A18: Detail of artwork showing one of Ino Tadataka's survey teams at work surveying the Port of the Mitarai District in 1806 in present day Kure, Hiroshima.

APPENDIX B (and that's B for Brock!)

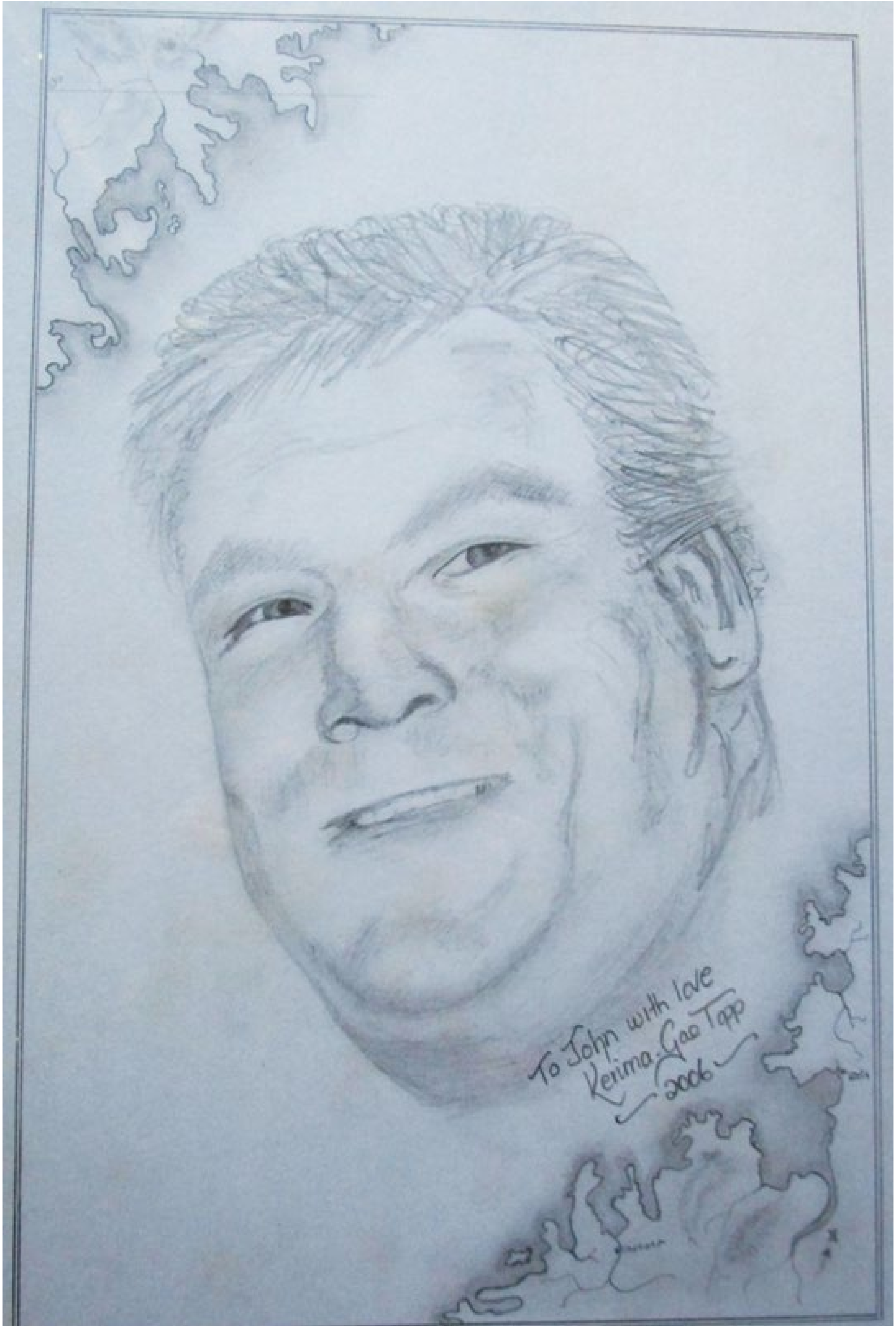


Figure B1: Portrait sketch of the surveyor/author done secretively by Kerima-Gae Topp (2006).

Back in Blacktown: Aboriginal Claims Deserve Consideration

Fred de Belin
City of Ryde
fdebelin@ryde.nsw.gov.au

ABSTRACT

In 1814, Governor Macquarie agreed with advocates that steps should be taken to accommodate and assimilate the native population that was living in and around the limits of the colony. The displacement policy adopted by the government was just not working and random clashes by some of the Aboriginal population were becoming more frequent, better organised and more hostile. Governor Macquarie fully supported an idea to establish a school for Aboriginal children, which would teach them the ways and culture of the British along with the Christian values. Land at Parramatta, behind St. John's Church, was set aside to build a 'Native Institute' (later nominated for Aboriginal orphans). This was all very paternal and doomed to eventual failure but nevertheless undertaken in hopeful spirit. In addition, the government promised to grant land to Aboriginal elders so that they could learn and demonstrate the social and cultural advantage of tilling the soil and raising crops. From a cadastral point of view, this paper looks at a period in early settlement when Aboriginals were still very much a part of the landscape and, rather than being forced underground and away, there occurred the very first attempts at assimilation of some of the Aboriginal population by way of land grants. It showcases some very interesting concepts, which are only now, 200 years later, being recognised by the Australian people.

KEYWORDS: *Cadastral surveying, Aboriginal land grants, Governor Macquarie, Colebee, Maria Lock.*

1 INTRODUCTION

This paper begins at a time 25 years after the arrival of the First Fleet, at a time when grants of Crown land were readily being dispensed to notable citizens… and to ex-convicts who had served their sentence… and at a time when the Aboriginal clans of the Cumberland Plain were desperately trying to cling to their traditional lands. From a cadastral point of view, this paper discusses a period in early settlement when Aboriginals were still very much a part of the landscape and, rather than being forced underground and away, the very first attempts occurred at assimilation of some of the Aboriginal population by way of land grants. The paper showcases some very interesting concepts, which are only now, 200 years later, being recognised by the Australian people.

1.1 An Introduction to the Times of Governor Macquarie

Governor Lachlan Macquarie, an army man, took up office on 1 January 1810 as the fifth Governor of the colony, following Governor William Bligh and a precession of navy men. Macquarie was the Governor for 11 years and oversaw the building of new roads, the erection of fine buildings and the first organised attempts at assimilating some of the Aboriginal population into the ways of the Europeans.

Three events occurred which set this narrative in motion. Surveyor George William Evans, in November 1813, continued the route of Blaxland, Wentworth and Lawson in traversing the Blue Mountains and opening the way into the Central West. Accompanying Evans as a guide was an Aboriginal from the Richmond area named Colebee.

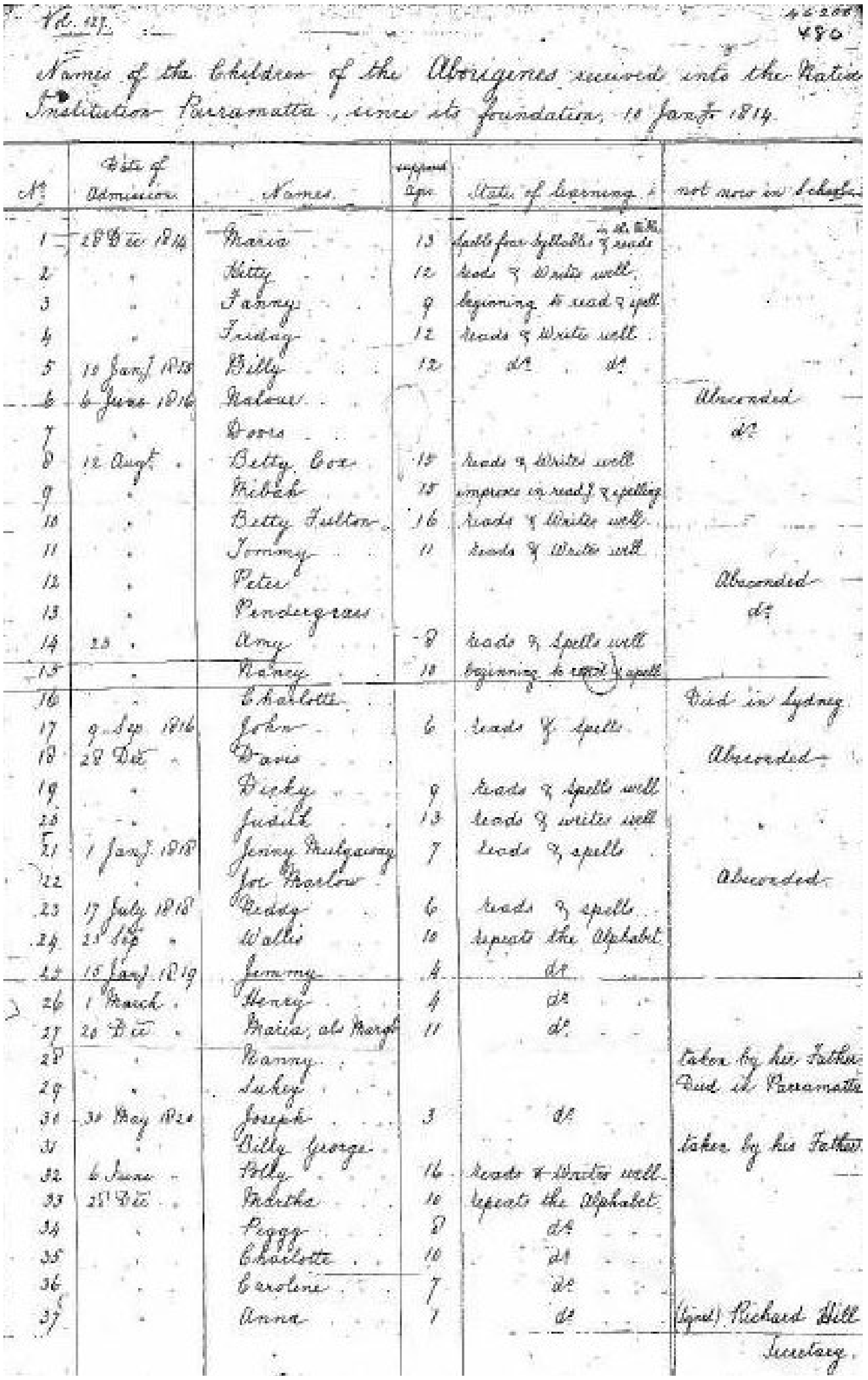
It was immediately after this event, which paved the way for rapid inland expansion, that Governor Macquarie agreed with advocates that steps should be taken to accommodate and assimilate the native population that was living in and around the limits of the colony. Emulating the trend in Britain at that time, of establishing boarding schools and institutions of learning, Macquarie established a “School for the Education of the Native Children” under the management and care of William Shelly and his wife.

Then an incident of mass Aboriginal deaths occurred in April 1816. What was intended to be a straight-forward round-up of several militant Aboriginals, who were known to be responsible for the killing of several farmworkers in the Camden district, resulted in the unintended deaths of 14 Aboriginal women and children at Appin.

1.2 The Parramatta Native Institution

The “Parramatta Native Institution” was set up in 1814 on land behind the grounds of St. John’s Church of England in Parramatta (see Appendix A). Governor and Mrs Macquarie were the school’s patrons and there was a 7-member committee including such notables as John Thomas Campbell, D’Arcy Wentworth, William Redfern, Hannibal McArthur, the Reverend William Cowper, the Reverend Henry Fulton and Rowland Hassall.

A student list (Figure 1 and Appendix B) shows the 37 children who were taught at the Parramatta Native Institution between 1814 and 1821. Colebee’s sister Maria is listed as number 1. Her date of admission was 28 December 1814, her supposed age was seven and her state of learning was noted as spells four syllables in the Bible and reads. Her age is written as 13 in 1821. Two other notable students are Betty Fulton (no. 10) and Polly (no. 32), both aged 16.



Vol. 127 46200 480

Names of the Children of the Aborigines received into the Native Institution Parramatta, since its foundation, 10 Jany 1814.

No	Date of Admission	Names	supposed Age	State of learning	not now in School
1	28 Dec 1814	Maria	13	Spells four syllables & reads in the Bible	
2	"	Kitty	12	Reads & Writes well	
3	"	Fanny	9	beginning to read & spell	
4	"	Friday	12	Reads & Writes well	
5	10 Jany 1815	Billy	12	do do	
6	6 June 1816	Nalour			Absconded
7	"	Doora			do
8	12 Augt "	Betty Cox	15	Reads & Writes well	
9	"	Kibbah	15	improves in read & spelling	
10	"	Betty Fulton	16	Reads & Writes well	
11	"	Tommy	11	Reads & Writes well	
12	"	Peter			Absconded
13	"	Pendergrass			do
14	25 "	Amy	8	Reads & Spells well	
15	"	Nancy	10	beginning to read & spell	
16	"	Charlotte			Died in Sydney
17	9 Sep 1816	John	6	Reads & spells	
18	28 Dec "	Davis			Absconded
19	"	Dicky	9	Reads & spells well	
20	"	Judith	13	Reads & writes well	
21	1 Jany 1818	Jenny Mulgaway	7	Reads & spells	
22		Joe Marlow			Absconded
23	17 July 1818	Reddy	6	reads & spells	
24	25 Sep "	Wallis	10	Repeats the Alphabet	
25	15 Jany 1819	Jemmy	4	do	
26	1 March "	Henry	4	do	
27	20 Dec "	Maria, als Margt	11	do	
28	"	Nanny			taken by her Father
29	"	Sukey			Died at Parramatta
30	30 May 1820	Joseph	3	do	
31	"	Billy George			taken by his Father
32	6 June "	Polly	14	Reads & Writes well	
33	25 Dec "	Martha	10	Repeats the Alphabet	
34	"	Peggy	8	do	
35	"	Charlotte	10	do	
36	"	Caroline	7	do	
37	"	Anna	7	do	(Sgd) Richard Hill Secretary

Figure 1: List showing the 37 children who were taught at the Parramatta Native Institution (1821).

An undated sketch (Figure 2) shows a "Public Conference with those tribes of the Natives residing in the Cumberland Plain" at the marketplace in Parramatta. With a feast of roast beef, bread and jugs of ale, it was intended to recruit students by communicating the aims and purpose of the Native Institution, along with plans to offer land grants. St. John's Church of England can be seen in the background (Figure 3).

Figure 2: Sketch showing picnic day at Parramatta, with St. John's Church of England in the background (undated).

Figure 3: Excerpt of the sketch and St. John's church today (2021).

Notice that on an 1832 map (Figure 4), the sketch shows "Native Orphan Institution", the Church of St. John and land of William and Elizabeth Shelly.

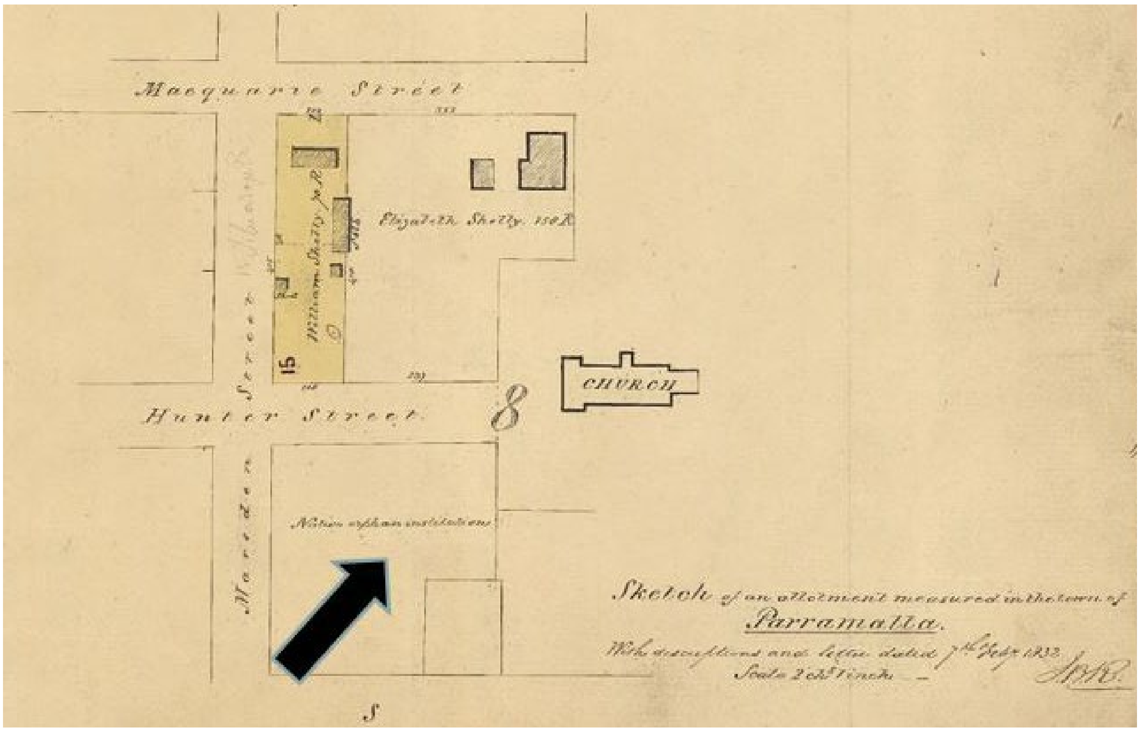


Figure 4: Sketch of the allotment of William Shelly (1832).

Figure 5 shows an aerial image today of the land depicted in the sketch. Notice the shadows cast by the spires and the additions to the church.

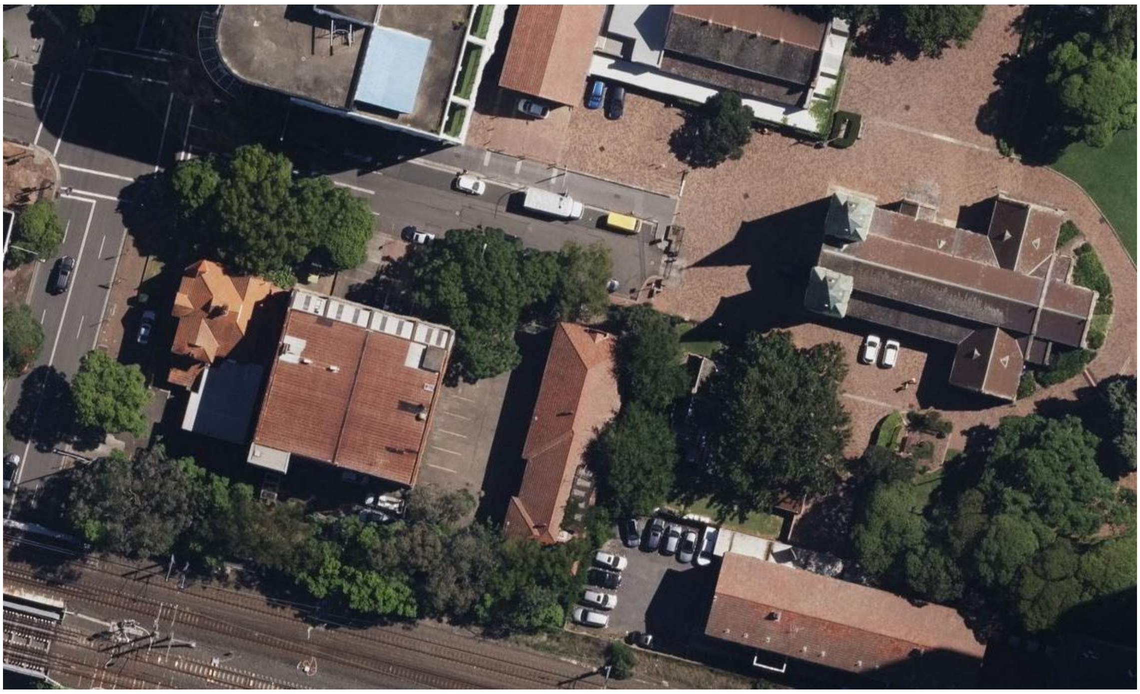


Figure 5: The same site today (2024).

The institution site today still houses an institute (Figure 6), just not the native one.

Figure 6: 'Trinity Institute' (2022).

It is clear from the general orders for the institution (see Appendix A) that the intention was for the Aboriginal children to lose their language, their culture, their heritage and their Aboriginal way of life. The children were taught to read and write, learn Bible scriptures and arithmetic. The girls focused on domestic duties and needlework, while the boys learned about farming and machinery (so much for gender equality). By 1821, it was decided to relocate the Native Institution from Parramatta to an area which became known as Blacks Town (Figure 7).

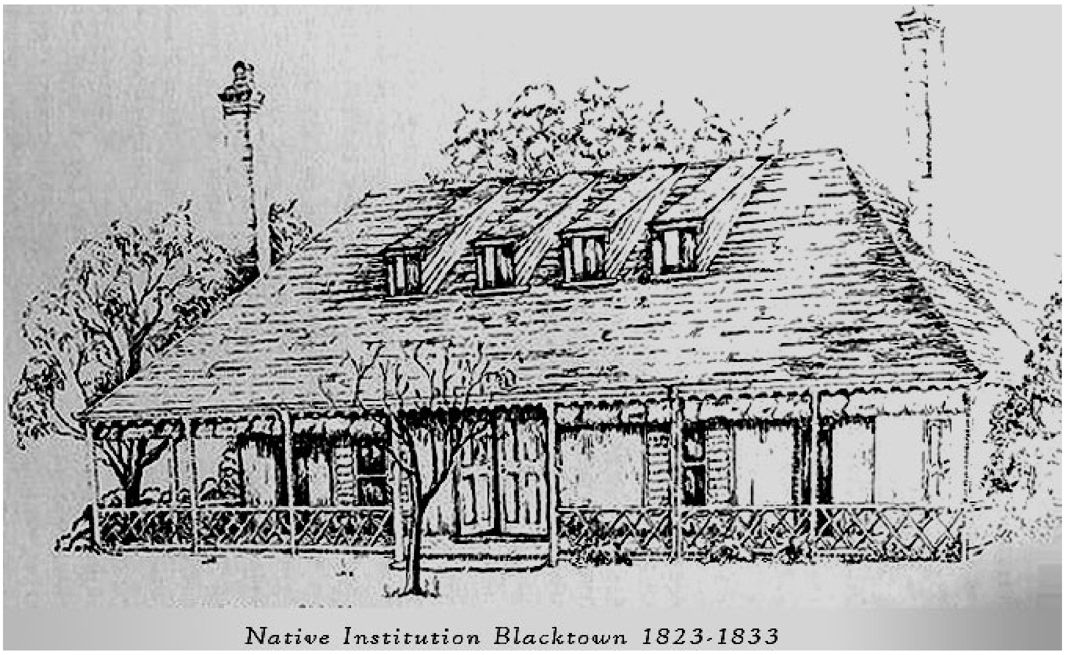


Figure 7: The Native Institution re-sited to Blacks Town.

1.3 The Round-Up at Appin in April 1816

On 9 April 1816, Governor Macquarie ordered a detachment of the 46th Regiment to march from Liverpool to the Cow Pastures and proceed to round up several militant Aboriginals in the Camden District. The instructions from the Governor (see Appendix C) were militaristic and brutal but did include "spare all women and children and not kill any of them."

On 7 May 1816, at the end of this disastrous and unsuccessful campaign, Governor Macquarie paid sums of money or granted orders on the King's stores to those who accompanied the soldiers as guides, carters etc. (see Appendix D).

"*Remunerations to Native Guides:*
To Bidjee Bidjee
To Harry
To Bundell
To Tindall
To Colebee
To Creek-Jemmy – or Nurragingy
Each a Complete Suit of Slops including Blanket – 4 Days Provisions, Half Pint of Spirits – and Half Pound of Tobacco."

Each Aboriginal on this list of native guides was offered and promised a grant of land by Governor Macquarie.

2 FIRST LAND GRANT IN THE COLONY TO AN ABORIGINAL

This significant event, which inevitably led to the name Blacktown, is one of momentous importance in the history of Australia: the first land grant given to an Aboriginal. At the heart of the Blacktown story stand Colebee and Nurragingy, two Aboriginals highly regarded by both the Aboriginal and European communities. The motives were clearly to bring a just and peaceful resolution to the years of conflict that marred the progress of European settlement along the Hawkesbury, Nepean, Colo and the South Creek.

It was in recognition of such service that Governor Macquarie wrote in his diary on 25 May 1816: "*On this occasion I invested Nurragingy, alias Creek Jemmy with my Order of Merit by presenting him with a handsome Brass Gorget or Breast Plate, having his name inscribed thereon in full – as chief of the South Creek Tribe – I also promised him and his friend Colebee a Grant of 30 acres of land on the South Creek between them as an additional Reward for their fidelity to Government and their recent good conduct.*"

A land grant was a *big* deal. A land grant was a grant of citizenship. An owner of land in the British dominions could vote in the British elections for parliament. This led to much angst in Britain because so many ex-convicts had become landowners through government grant, and now land was being granted to an Aboriginal.

The first land grant was made official in 1819, with a grant of 30 acres to Colebee (Figure 8), along the Richmond Road, as promised by Governor Macquarie in 1816.

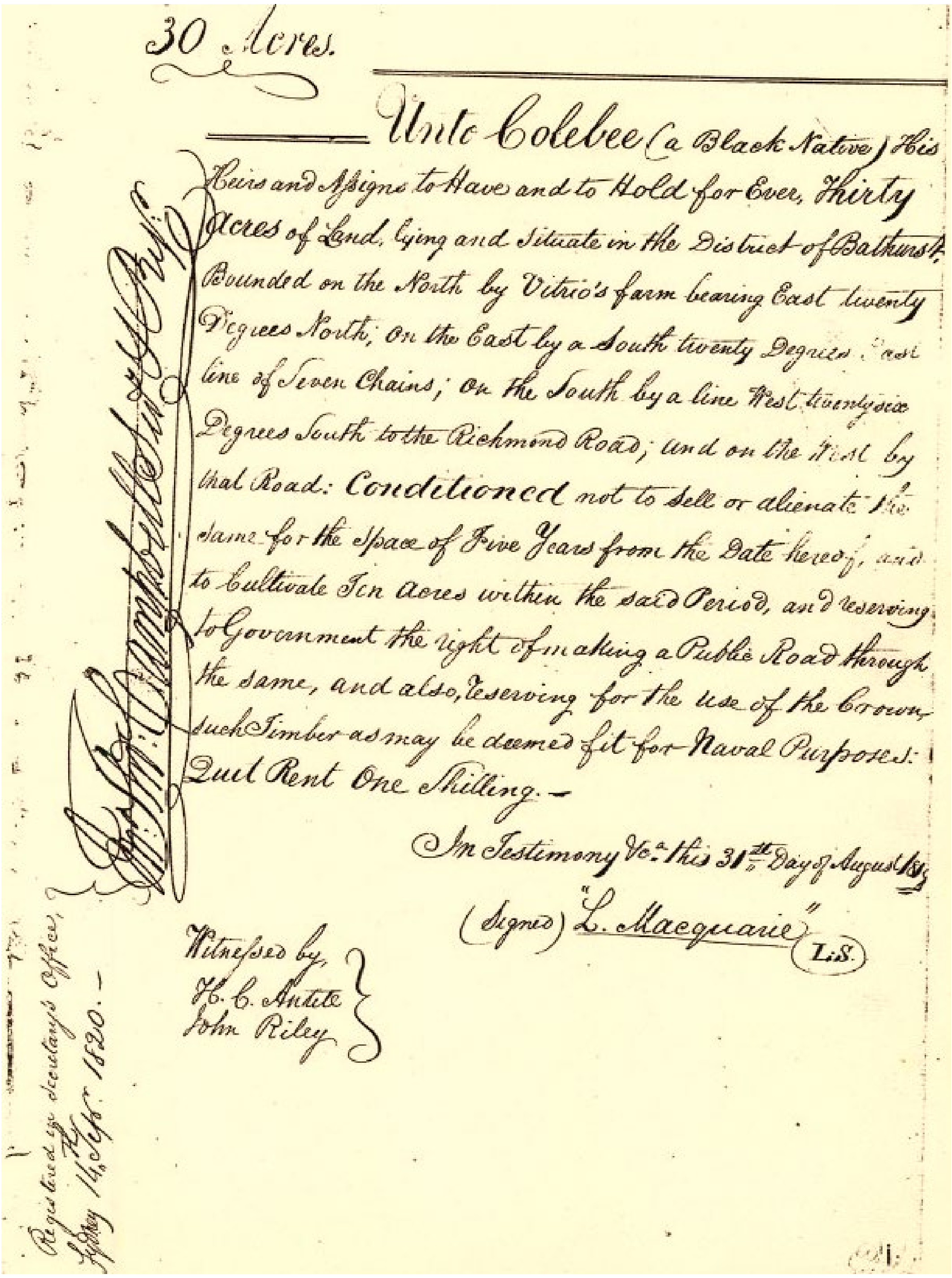


Figure 8: The official grant to Colebee (1819).

A transcript of the land grant to Colebee follows:

"*30 Acres*
Unto Colebee (a Black Native) his Heirs and Assigns to Have and to Hold for ever, Thirty Acres of Land, lying and Situate in the District of Bathurst, Bounded on the North by Vitrio's farm bearing East twenty Degrees North, On the East by a South twenty Degrees East line of Seven Chains; on the South by a line West twenty six Degrees to the Richmond Road; And on the West by that Road: Conditioned not to Sell or Alienate the same for the Space of Five Years from the date hereof, and to Cultivate Ten Acres within the Said Period, and Reserving

to Government the right of making a Public Road through the same, and also, Reserving for the Use of the Crown, such Timber as may be deemed fit for Naval Purposes: Quit Rent One Shilling. –

In Testimony this 31st Day of August, 1819
(signed L. Macquarie)

Registered in Secretary's Office,
Sydney 14th Sept, 1820."

Note that the land district at that time was known as "Bathurst" (Figure 9), later to become the Parishes of Gidley and Rooty Hill and several others.

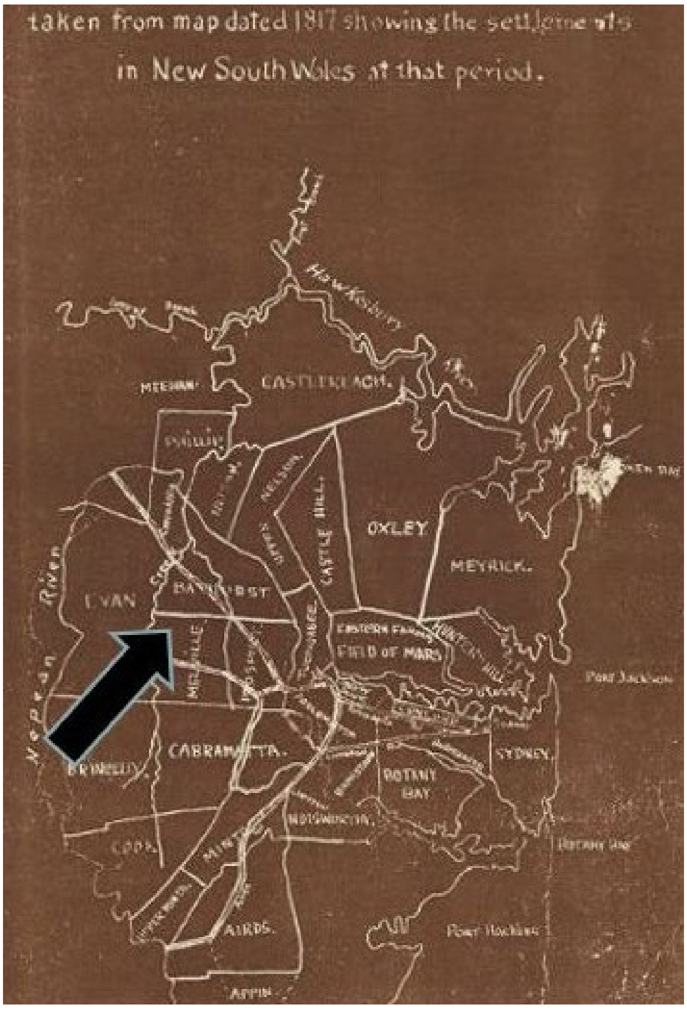


Figure 9: From a map showing the land districts at that time (1817).

An early Parish map (Figure 10) shows the location of Colebee's grant along the Richmond Road. Notice how the Parish map nominates Colebee and Jemmy as grantees on the same parcel. Notice also, the lack of any surrounding Aboriginal Grants! An even earlier map (Figure 11) shows that the grant site as vacant.

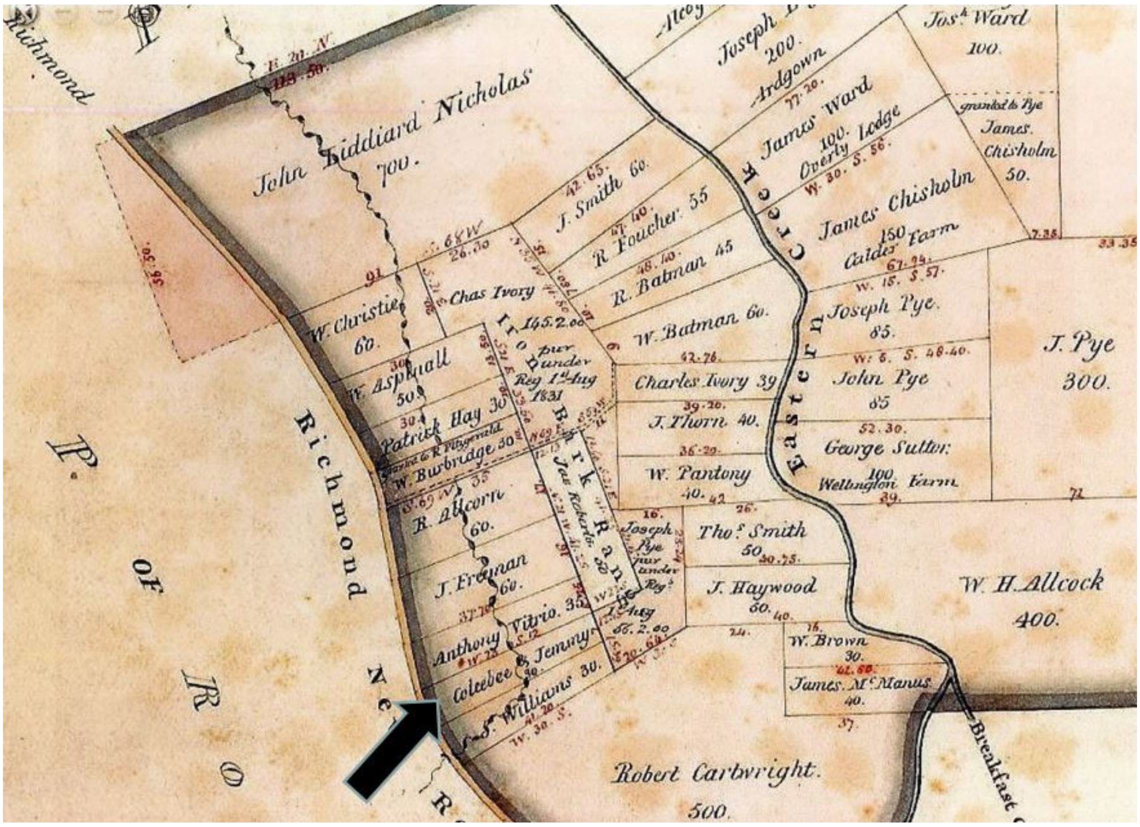


Figure 10: Early Parish map showing the 30-acre grant to Colebee (1835).

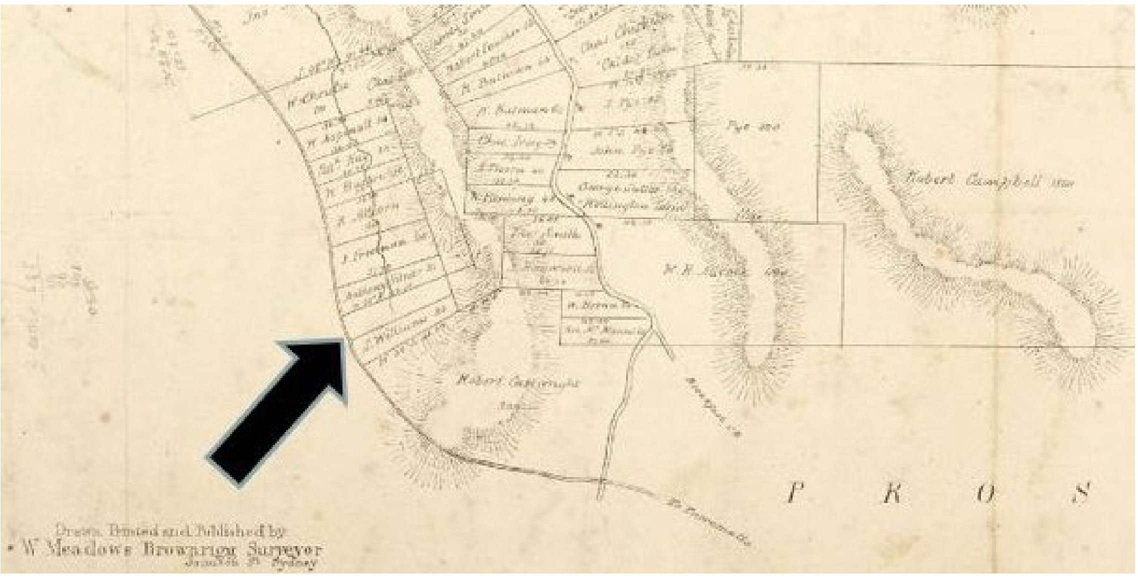


Figure 11: An earlier map showing the land parcel as vacant.

3 SUBSEQUENT GRANTS

A newspaper clipping (Figure 12), concerns the marriage on 15 March 1821 of Michael, a native constable at Richmond, and Robert, son of Creek Jemmy, to Betty Fulton and Polly, two girls from the Parramatta Native Institution. Both girls were 16 at the time. It says: "*Shortly after the marriage the two couple [sic]set off with the Deputy Surveyor General to* *have their respective farms measured*." James Meehan was Deputy Surveyor General, under Oxley.

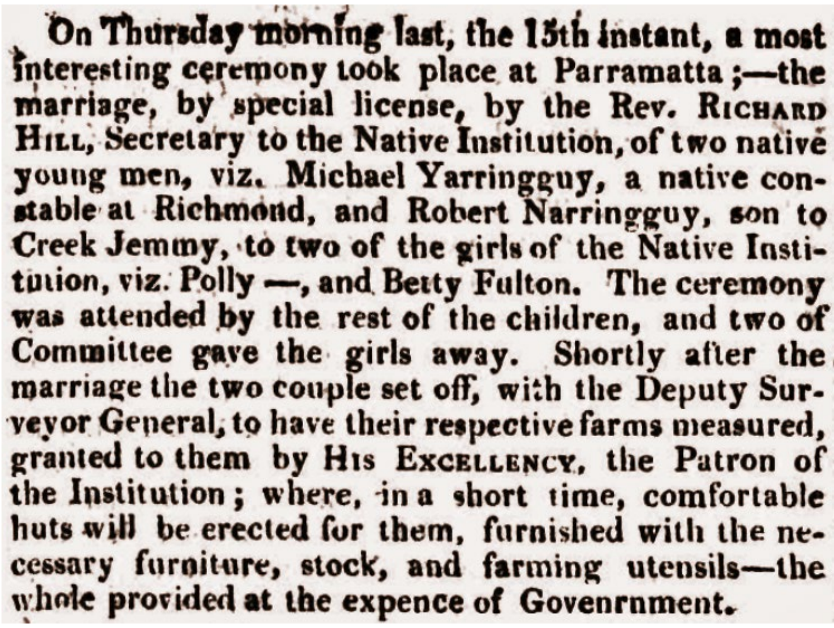
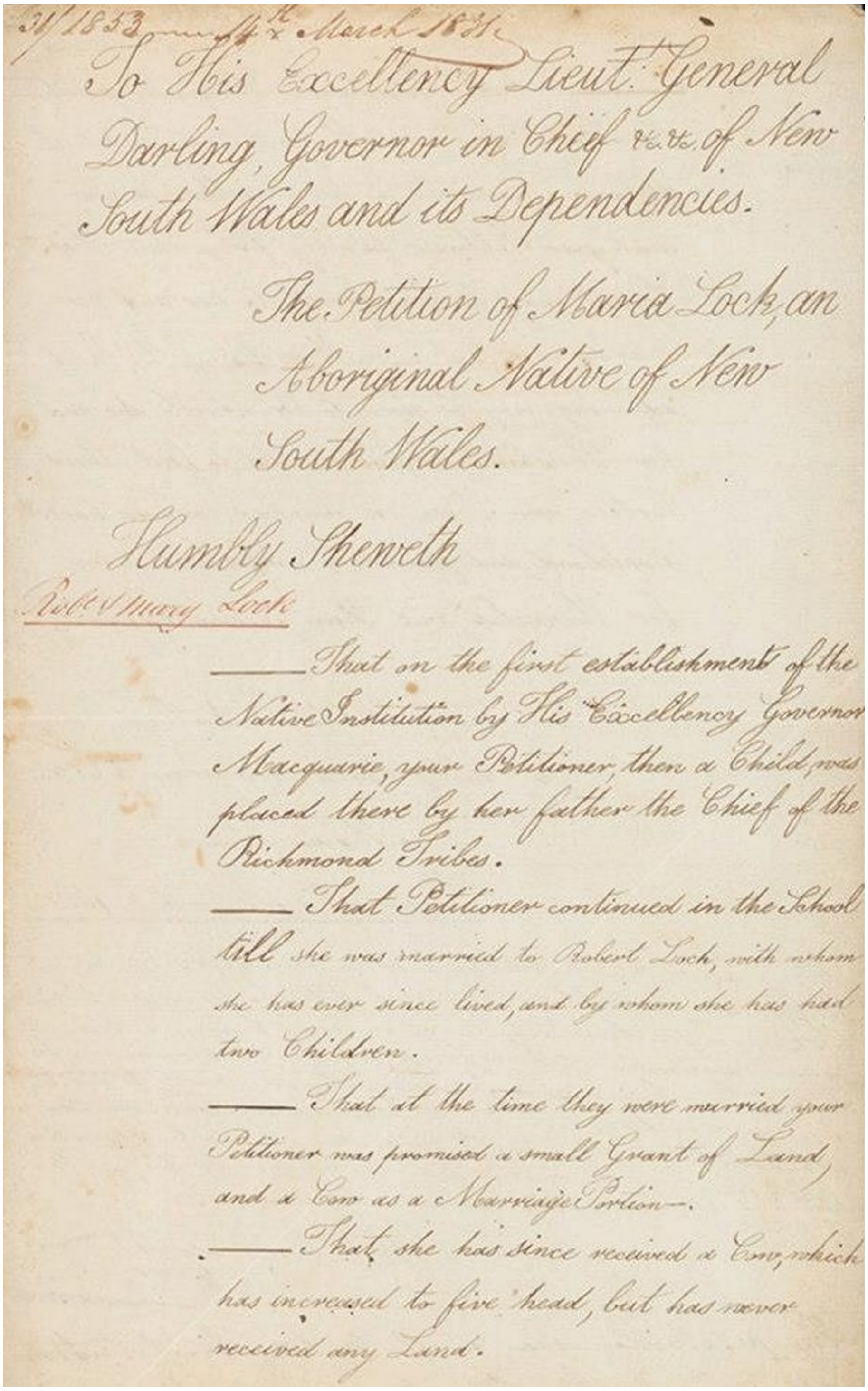

On Thursday morning last, the 15th instant, a most interesting ceremony took place at Parramatta;—the marriage, by special license, by the Rev. RICHARD HILL, Secretary to the Native Institution, of two native young men, viz. Michael Yarringguy, a native constable at Richmond, and Robert Narringguy, son to Creek Jemmy, to two of the girls of the Native Institution, viz. Polly —, and Betty Fulton. The ceremony was attended by the rest of the children, and two of Committee gave the girls away. Shortly after the marriage the two couple set off, with the Deputy Surveyor General, to have their respective farms measured, granted to them by HIS EXCELLENCY, the Patron of the Institution; where, in a short time, comfortable huts will be erected for them, furnished with the necessary furniture, stock, and farming utensils—the whole provided at the expence of Govenrnment.

Figure 12: Newspaper clipping announcing to the colony the marriages of Betty Fulton and Polly (1821).

On 26 January 1824, Maria married Robert Lock, a carpenter who worked on the construction of the new Native Institution at Black Town. This appears to be the first government/church sanctioned Aboriginal-British union within the colony. Is there added significance in the date of their marriage? Maria and Robert settled in Black Town in a timber hut on four acres adjoining the Native Institution, but a year later moved to the Reverend Robert Cartwright's farm at Liverpool. Over the following years, Maria continued to pursue the land grant she had been promised, but not received, at the time of her marriage. She petitioned Governor Darling in1831 (Figures 13 & 14):

"*To his Excellency Lieut. General Darling, Governor in Chief of New South Wales ... The Petition of Maria Lock, an Aboriginal Native of New South Wales. Humbly Sheweth that on the first establishment of the Native Institution … your Petitioner, then a Child, was placed there by her father, the Chief of the Richmond Tribes. That Petitioner continued in the School till she was married to Robert Lock, with whom she has ever since lived, and by whom she has had two children. That at the time they were married your Petitioner was promised a small Grant of Land, and a cow. as a Marriage Portion. That she has since received a cow, which has increased to five head, but has never received any land.*"

"*That Governor Macquarie gave her brother Coley (Colebee) a small Grant of Land at Black Town and as her brother is now dead your Petitioner humbly prays that this Grant may be transferred to her, and her Children, or that a small portion of the land adjoining may be given to her, whereby she and her Husband may be enabled to feed their Cattle, now seven in Number, earn an honest livelihood, and provide a comfortable home for themselves and their increasing family.* *Maria Lock* *Liverpool March 3rd 1831*."



31/1853 4th March 1831

To His Excellency Lieut. General Darling, Governor in Chief &c.&c. of New South Wales and its Dependencies.

The Petition of Maria Lock, an Aboriginal Native of New South Wales.

Humbly Sheweth

Robt & Mary Lock

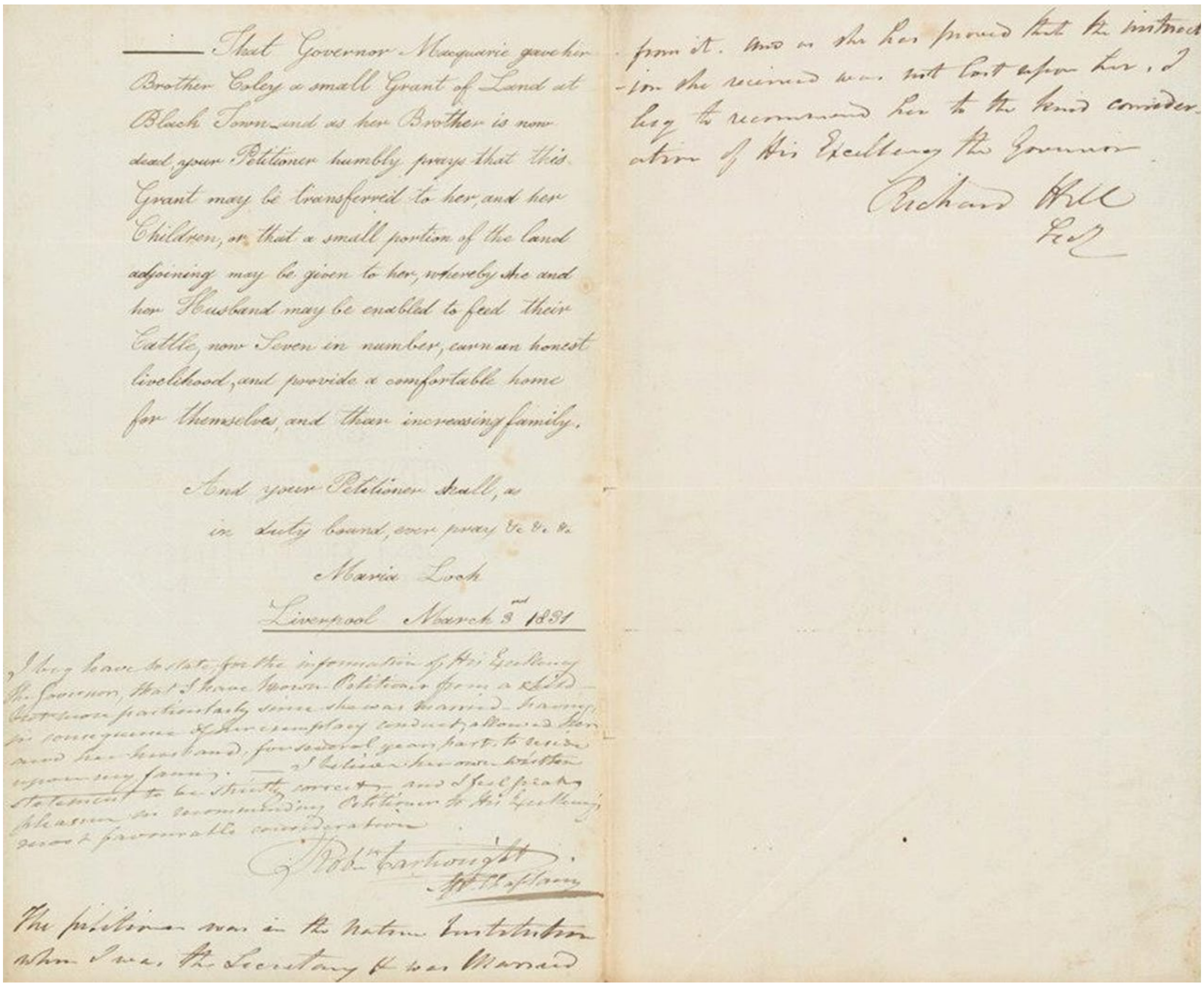
—— That on the first establishment of the Native Institution by His Excellency Governor Macquarie, your Petitioner, then a Child, was placed there by her father the Chief of the Richmond Tribes.

—— That Petitioner continued in the School till she was married to Robert Lock, with whom she has ever since lived, and by whom she has had two Children.

—— That at the time they were married your Petitioner was promised a small Grant of Land, and a Cow as a Marriage Portion.

—— That she has since received a Cow, which has increased to five head, but has never received any Land.

Figure 13: The petition of Maria Lock to Governor Darling (1831).


—— That Governor Macquarie gave her Brother Coley a small Grant of Land at Black Town and as her Brother is now dead, your Petitioner humbly prays that this Grant may be transferred to her, and her Children, or that a small portion of the land adjoining may be given to her, whereby she and her Husband may be enabled to feed their Cattle, now Seven in number, earn an honest livelihood, and provide a comfortable home for themselves and their increasing family.

And your Petitioner shall, as in duty bound, ever pray &c. &c. &c.

Maria Lock

Liverpool March 3rd 1831

I beg leave to state, for the information of His Excellency the Governor, that I have known Petitioner from a child but more particularly since she was married, having in consequence of her exemplary conduct allowed her and her husband, for several years, [illegible] I believe her own written statement to be strictly correct, and I feel great pleasure in recommending Petitioner to His Excellency's most favourable consideration.

Robt. Cartwright
Chaplain

The petitioner was in the Native Institution when I was the Secretary & was married from it. And as she has proved that the instruction she received was not lost upon her, I beg to recommend her to the kind consideration of His Excellency the Governor.

Richard Hill

Figure 14: Part of the petition of Maria Lock to Governor Darling (1831).

It came with an added endorsement "*recommending Maria to his Excellency's most favourable consideration. Robert Cartwright. Chaplain.*" This was the same Robert Cartwright who also owned the 500 acres adjoining on the Richmond Road. With the deaths of Colebee and Nurragingy, Nurragingy's two sons and Colebee's sister, Maria now Lock, petitioned the Governor for transfer of the 1819 grant. Nurragingy had lived continuously on the land, however, because the land grant was registered in Colebee's name, the title should pass to Maria! But this is not the last we hear of Nurragingy.

A side note (Figure 15) shows a request to the Surveyor General, no less, that he set aside some land: "*Request that the Surveyor General will set apart a few acres, 30 or 40 for this woman's husband as near her present residence as suitable land can be found.*"

In 1833, Maria received the first land grant to an Aboriginal woman, 40 acres at Liverpool, "*in trust for the said Maria Lock during her life for the sole and separate use without the control of her present or future husband she may have and remain in trust for the heirs of the said Maria Lock by you her present husband the said Robert Lock begotten.*"

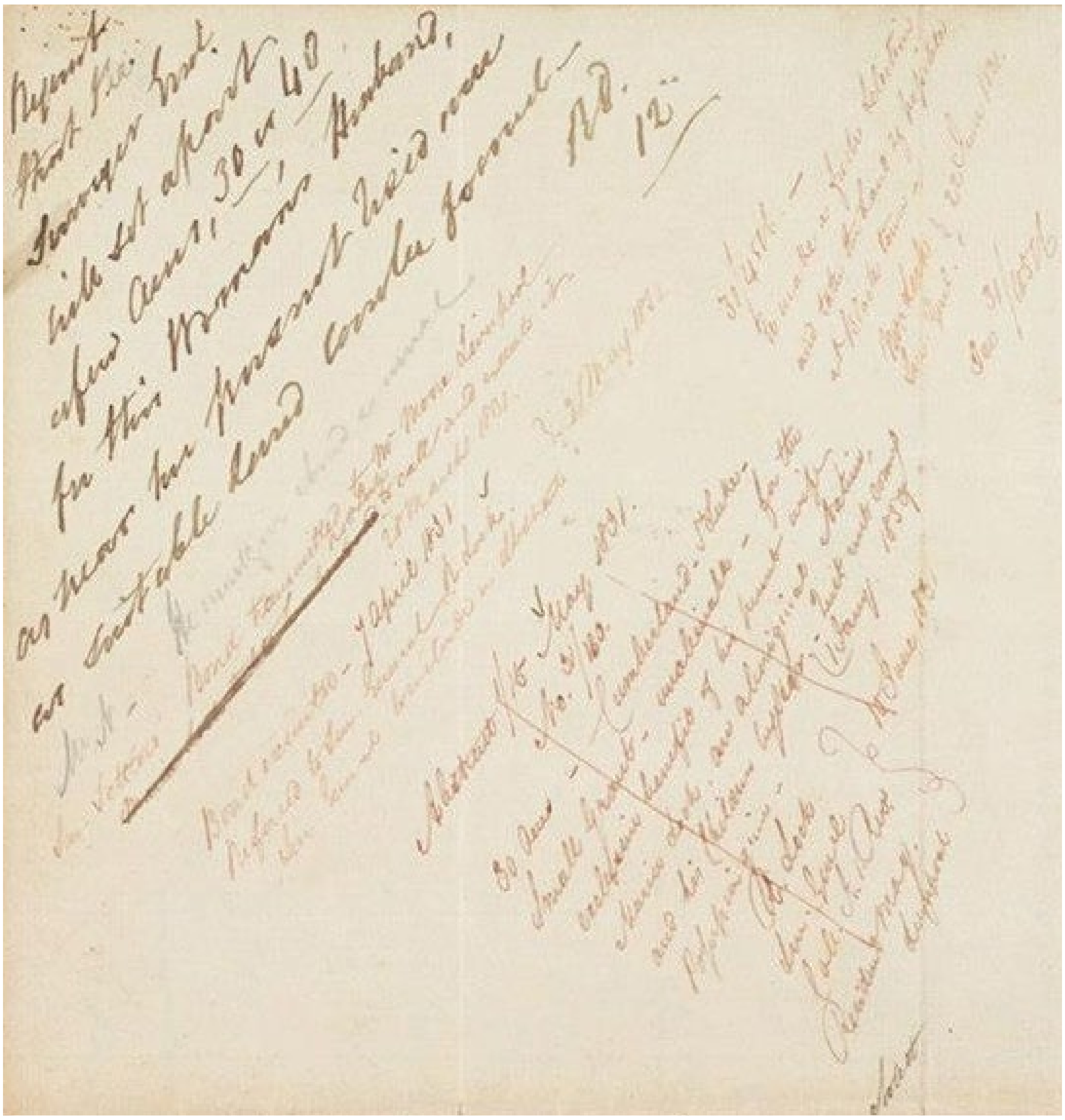
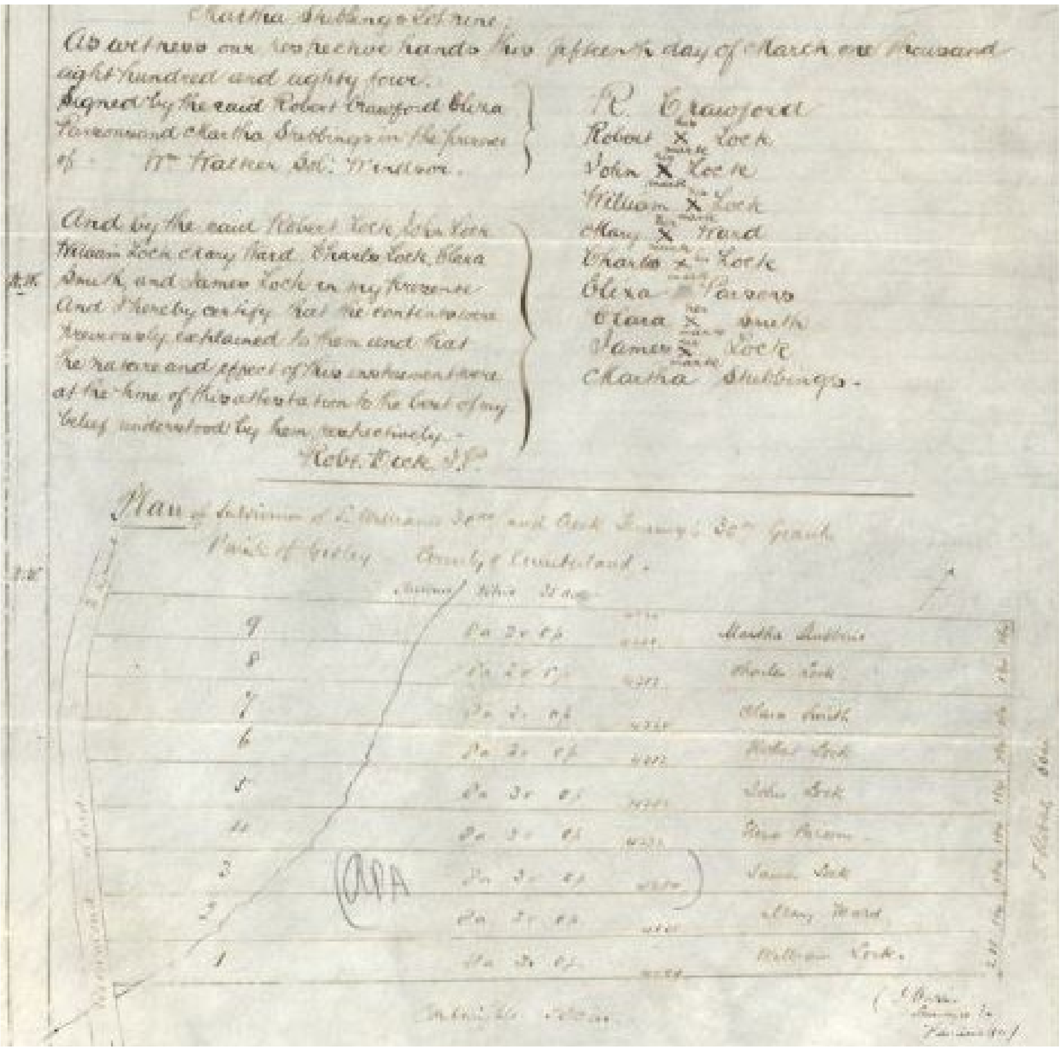


Figure 15: A side note showing a request to the Surveyor General.

Later, in 1843, Maria finally received her brother Colebee's 30-acre grant and returned to Black Town. Maria, with her husband, then went on to acquire 30 acres adjacent to the Colebee grant. Thus Maria then had title to 60 acres at Blacktown plus 40 acres of land at Liverpool. Upon her death, the whole estate was divided equally between her surviving children (Figures 16-18).



Martha Stubbings
As witness our respective hands this fifteenth day of March one thousand eight hundred and eighty four.
Signed by the said Robert Crawford Eliza Parsons and Martha Stubbings in the presence of

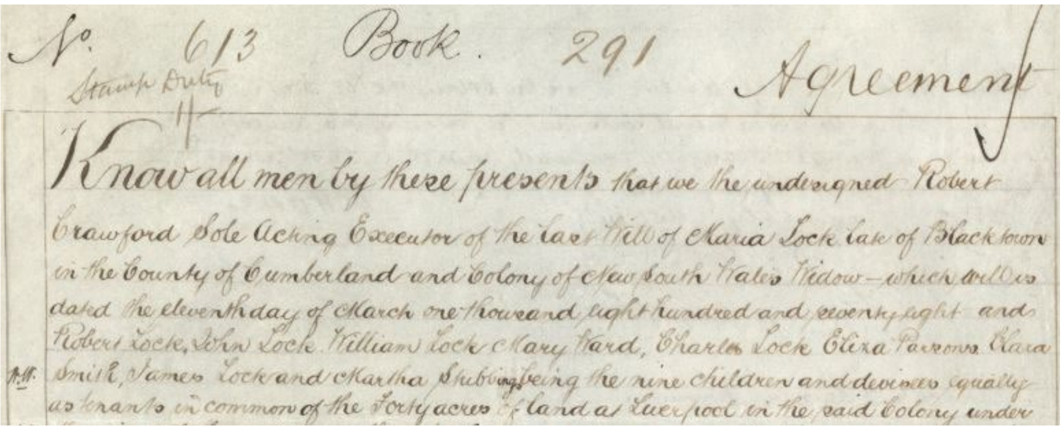
And by the said Robert Lock John Lock William Lock Mary Ward Charles Lock Clara Smith and James Lock in my presence And I hereby certify that the contents were previously explained to them and that the nature and effect of this instrument were at the time of this attestation to the best of my belief understood by them respectively. -
Robt. Lock J.P.

R. Crawford
Robert X Lock
John X Lock
William X Lock
Mary X Ward
Charles X Lock
Eliza Parsons
Clara X Smith
James X Lock
Martha Stubbings.

Plan of subdivision

9	Martha Stubbings	
8	Charles Lock	
7	Clara Smith	
6	Robert Lock	
5	John Lock	
4	Eliza Parsons	
3	James Lock	
2	Mary Ward	
1	William Lock	

Figure 16: The document showing the devise of Maria's 60 acres estate in Blacktown (1878).

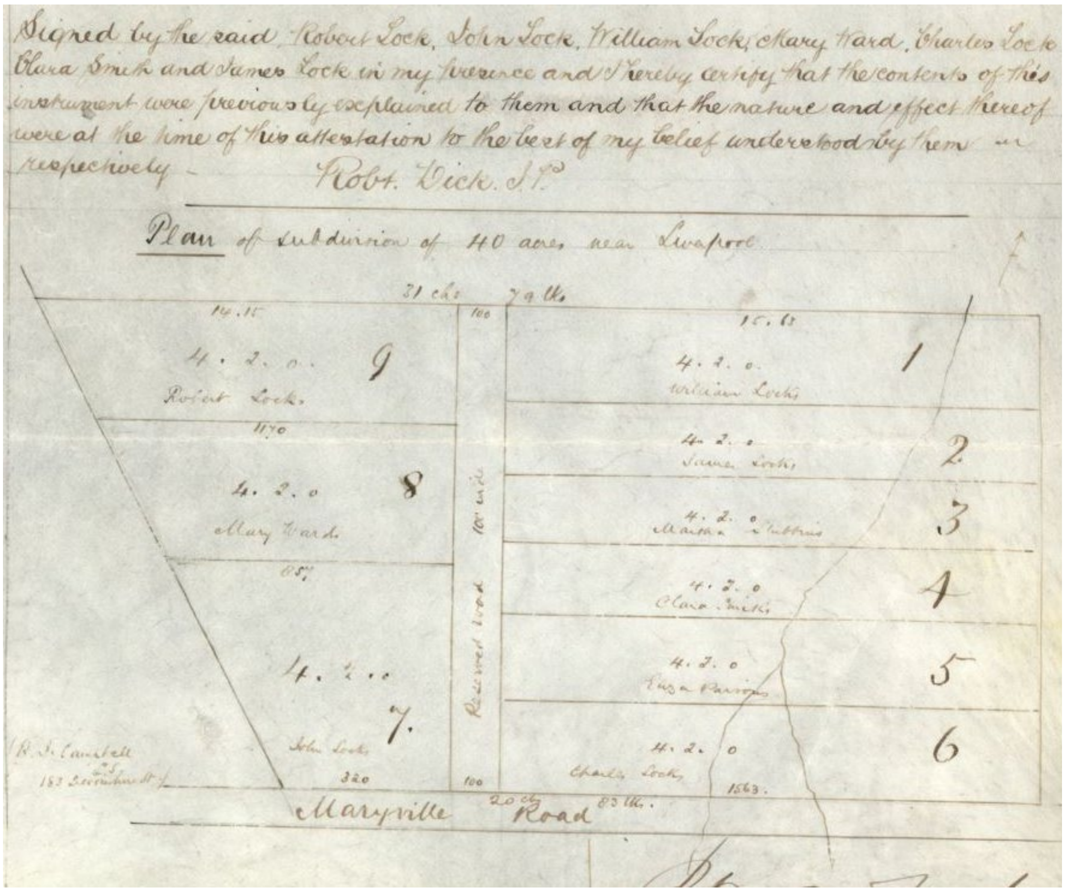


No. 613 Book. 291 Agreement
Stamp Duty

Know all men by these presents that we the undersigned Robert Crawford Sole Acting Executor of the last Will of Maria Lock late of Blacktown in the County of Cumberland and Colony of New South Wales Widow – which Will is dated the eleventh day of March one thousand eight hundred and seventy eight and Robert Lock, John Lock William Lock Mary Ward, Charles Lock Eliza Parsons Clara Smith, James Lock and Martha Stubbings being the nine children and devisees equally as tenants in common of the Forty acres of land at Liverpool in the said Colony under

Figure 17: The agreement setting the devise of Maria Lock's estate (1878).

An excerpt of the transcript of the agreement setting the devise of Maria Lock's estate (1878), shown in Figure 17, follows: "*Know all men by these presents … last will of Marie Lock late of Blacktown … widow … which will is dated the eleventh day of March 1878 … a list of her nine children … devised equally …*"



Signed by the said Robert Lock, John Lock, William Lock, Mary Ward, Charles Lock Clara Smith and James Lock in my presence and I hereby certify that the contents of this instrument were previously explained to them and that the nature and effect thereof were at the time of this attestation to the best of my belief understood by them respectively – Robt. Dick J.P.

Plan of subdivision of 40 acres near Liverpool

Figure 18: The document showing the devise of Maria's 40-acre estate in Liverpool (1878).

4 STATUS OF THE LAND IN BLACKTOWN TODAY

Lots 9 and 8 of the subdivision of Maria Lock's land (see Figure 16) were eventually subdivided into a housing estate in 2014 (Figure 19).

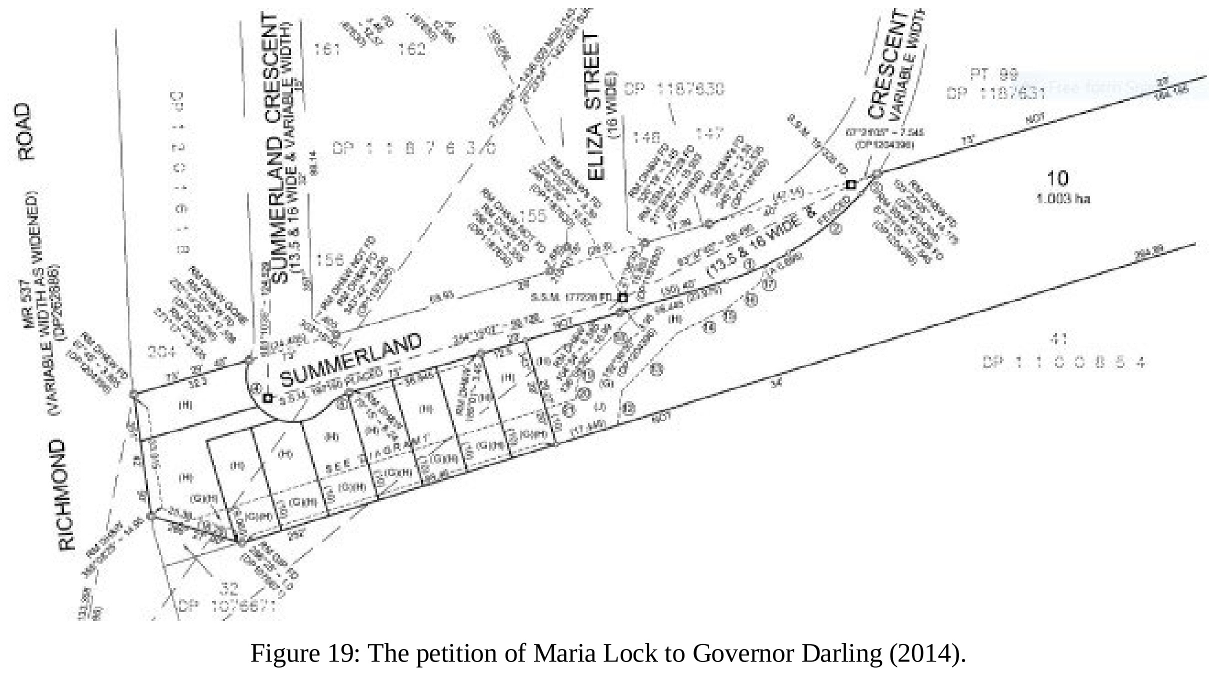


Figure 19: The petition of Maria Lock to Governor Darling (2014).

The remainder of her land in Blacktown, about 800 m by 250 m, is vacant and undeveloped and now owned by the state government in the form of Transport for NSW (Figures 20 & 21). The arrow in Figure 21 points to the location of Colebee's land grant in 1819.

Figure 20: Aerial image of the remainder of Maria Lock's land in Blacktown.

Figure 21: Current street view image of the remainder of Colebee's and Maria's land.

In conclusion, Lachlan Macquarie has left his name for posterity on numerous places. Colebee and Nurragingy have likewise left a legacy (Figure 22): Colebee Crescent in Oakhurst (middle arrow), Nurragingy Reserve at Doonside (bottom arrow), the suburb of Colebee (top arrow) and the City of Blacktown.

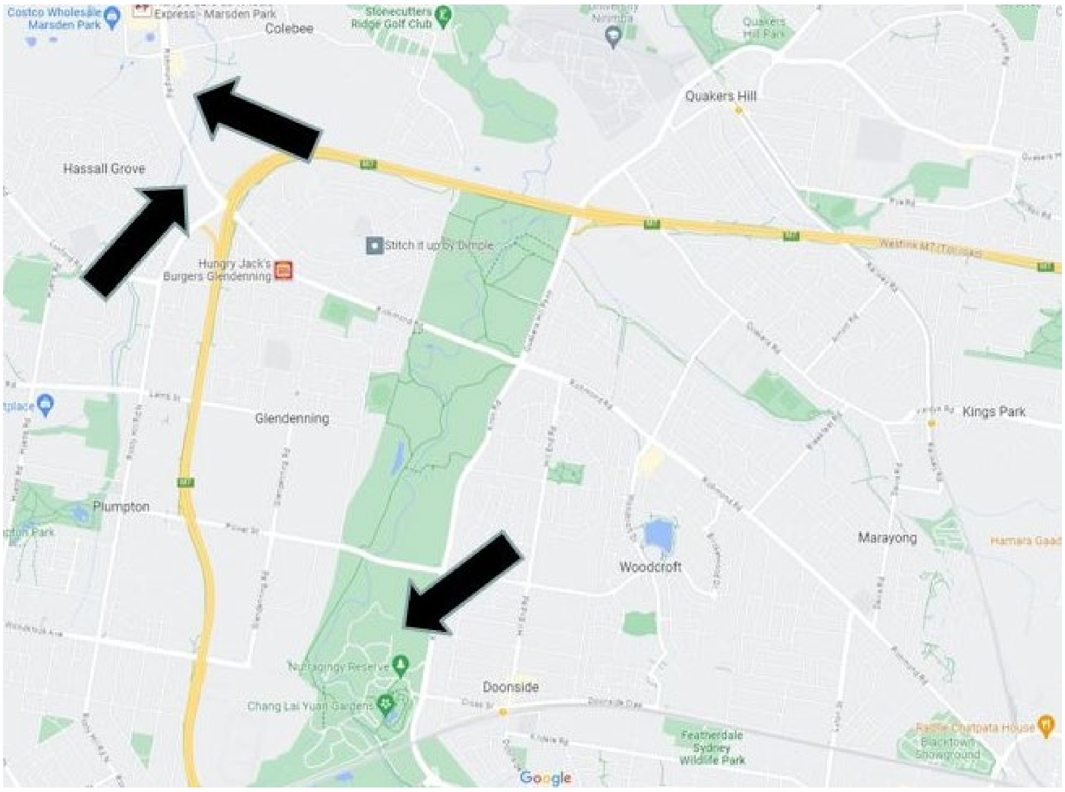


Figure 22: Map showing the locations of the Colebee and Nurragingy legacy.

REFERENCES

de Belin F. (2013) Alienation of an alien nation, *Proceedings of Association of Public Authority Surveyors Conference (APAS2023)*, Coffs Harbour, Australia, 20-22 March, 56-77.

APPENDIX A: ESTABLISHMENT OF THE NATIVE INSTITUTION, 1814

With a view to improving conditions for the Aboriginal people, Macquarie established a "school for the education of the native children" under the management and care of William Shelly. NR Government and General Order Government House Sydney, Saturday 10 December 1814 Civil Department:

His Excellency the Governor having long viewed with sentiments of commiseration the very wretched state of the Aborigines of this country; and having resolved in his mind the most probable and promising means of ameliorating their condition, has now taken the resolution to adopt such measures as appear to him best calculated to effect that object, and improve the energies of this innocent, destitute and unoffending race. With this anxiety to make one experiment so interesting to the feelings of humanity, and to endeavour to ascertain how far the condition of the natives may be improved by the application of such means as are within his power, His Excellency feels that he is making an acknowledgement to which they are in some degree entitled, when it is considered that the British settlement in this country, though necessarily excluding the natives from many of the natural advantages they had previously derived from the animal and other productions of this part of the territory, has never met with any serious or determined hostility from them, but rather a disposition to submit peaceably to such establishments as were necessarily made on the part of the British government on the formation of this settlement. With a view, therefore, to effect the civilization of the Aborigines of New South Wales, and to render their habits more domesticated and industrious His Excellency the Governor, as well from motives of humanity as of that policy which affords a reasonable hope of producing such an improvement in their condition as may eventually contribute to render them not only more happy in themselves, but also in some degree useful to the community, has determined to institute a school for the education of the native children of both sexes and to assign a portion of land for the occupancy and cultivation of adult natives, under such rules and regulations as appear to him likely to answer the desired objects, and which are now published for general information.

First, that there shall be a school for the Aborigines of New South Wales, established in the Town of Parramatta, of which His Excellency the Governor is to be patron and Mrs Macquarie patroness.

Secondly, that there shall be a committee, consisting of seven gentlemen, for conducting and directing the institution; one of the committee to act as treasurer and secretary.

Thirdly, that the institution shall be placed under the immediate management and care of Mr William Shelly as Superintendent and Principal Instructor.

Fourthly, that the main object of the institution shall be civilization of the Aborigines of both sexes.

Fifthly, that the expenses of the institution shall be defrayed for the first two years by government, in such manner as the Governor may deem expedient; but with a view to extend the benefits of it after that period, that subscriptions shall be solicited and received from public societies and private individuals.

Sixthly, that this institution shall be an asylum for the native children of both sexes, but no child shall be admitted under four, or exceeding seven years of age.

Seventhly, that the number of children to be admitted in the first instance, shall not exceed six boys and six girls, which numbers shall be afterwards increased according to circumstances.

Eighthly, that the children of both sexes shall be instructed in common, reading, writing and arithmetic; that the boys shall also be instructed in agriculture, mechanical arts, and such common manufactures as may best suit their ages, and respective dispositions; that the girls shall also be taught needlework. For all which purposes, instructors, properly qualified, will be employed.

Ninthly, that the Manager or Superintendent shall have the immediate care of the children, the purchase of provisions, and of the materials for employing them, together with the disposal of the articles manufactured by the children.

Tenthly, that a portion of land shall be located for the use of adult natives, which shall be invited and encouraged to cultivate it and that such assistance shall be rendered them for that purpose by government, as may be deemed expedient: That the management and superintendence thereof shall be also vested in Mr Shelly; and under his immediate inspection, subject to such directions as he shall receive from the committee.

Eleventhly, that the committee shall meet quarterly at the town of Parramatta, on the first Wednesday in each succeeding quarter, for the purpose of inspecting and auditing the quarterly accounts of the Manager; and also of examining the pupils as to their progress in civilization, education, and morals; and how far the necessary attention has been paid to their diet, health, and cleanliness. That the committee (which shall at no time consist of less than five members) shall have power to take cognizance of and correct any existing abuses, and frame such additional regulations as may appear necessary for the improvement and benefit of the institution.

Twelfthly, that the committee shall make a written report of the result of their observations and enquiries, at their quarterly meeting, to His Excellency the Governor, as a patron of the institution; and also of such rules and regulations as they may deem necessary to frame for the benefit of the institution; which must receive the sanction of the Governor, previous to their being carried into effect.

Thirteenthly, that the proposed institution shall be opened for the reception of the prescribed number of children, on Wednesday the 18th day of January next, being the auspicious anniversary of the birth of our Most Gracious Queen.

Fourteenthly, that no child, after having been admitted into the institution, shall be permitted to leave it, or be taken away by any person whatever (whether parents or other relatives) until such time as the boys shall have attained the age of sixteen years, and the girls fourteen years; at which ages they shall be respectively discharged.

Fifteenthly, the undermentioned gentlemen having expressed their willingness to forward and promote the objects of the proposed institution. His Excellency is pleased to constitute and appoint them (with their own concurrence) to be the committee for conducting and directing all the affairs connected therewith committee:
1. John Thomas Campbell, Esquire
2. D’Arcy Wentworth, Esquire
3. William Redfern, Esquire

4. Hannibal McArthur, Esquire
5. The Reverend William Cowper
6. The Reverend Henry Fulton
7. Mr Rowland Hassall

His Excellency is further pleased to appoint John Thomas Campbell, Esquire to be secretary and treasurer of the institution. By Command of His Excellency The Governor, (Signed) J T Campbell, Secretary.

APPENDIX B: PARRAMATTA NATIVE INSTITUTION ADMISSIONS LIST

No.	Date of admission	Names	Supposed age (in 1821)	Tribe
1	28 Dec 1814	Maria	13	Richmond
2	28 Dec 1814	Kitty	12	Prospect
3	28 Dec 1814	Fanny	9	Cattai Creek
4	28 Dec 1814	Friday	12	Portland Head
5	10 Jan 1815	Billy	12	South Creek
6	6 Jun 1816	Nalour	—	—
7	6 Jun 1816	Doors	—	—
8	12 Aug 1816	Betty Cox	15	Hawkesbury
9	12 Aug 1816	Milbah	15	Cowpastures
10	12 Aug 1816	Betty Fulton	16	Cowpastures
11	12 Aug 1816	Tommy	11	Hawkesbury
12	12 Aug 1816	Peter	—	—
13	12 Aug 1816	Pendergrass	—	—
14	23 Aug 1816	Amy	8	Botany Bay
15	23 Aug 1816	Nancy	10	Botany Bay
16	23 Aug 1816	Charlotte	—	—
17	9 Sep 1816	John	6	Cattai Creek
18	28 Dec 1816	Davis	—	—
19	28 Dec 1816	Dicky	9	—
20	28 Dec 1816	Judith	13	Mulgoa
21	1 Jan 1818	Jenny Mulgaway	7	Mulgoa
22	1 Jan 1818	Joe Marlow	—	Prospect
23	17 Jul 1818	Neddy	6	Prospect
24	25 Sep 1818	Wallis	10	Newcastle
25	15 Jan 1819	Jemmy	4	Newcastle
26	1 Mar 1819	Henry	4	Kissing Point
27	20 Dec 1819	Maria (Margaret)	11	—
28	20 Dec 1819	Nanny	—	—
29	20 Dec 1819	Sukey	—	—
30	30 May 1820	Joseph	3	—
31	30 May 1820	Billy George	—	—
32	6 Jun 1820	Polly	16	—
33	28 Dec 1820	Martha	10	—
34	28 Dec 1820	Peggy	8	—
35	28 Dec 1820	Charlotte	10	—
36	28 Dec 1820	Caroline	7	—
37	28 Dec 1820	Anna	1	—

APPENDIX C: GOVERNOR'S INSTRUCTION TO ROUND UP MILITANT ABORIGINALS IN THE CAMDEN DISTRICT

Gov House, Sydney
9th April 1816
Sir,

1. *Having nominated you to command the detachment of the 46th Regiment proceeding tomorrow to the Cow Pastures, you will be governed by the following instructions in the execution of the duty you are thus ordered upon.*
2. *You will march tomorrow morning at 7 o'clock from Sydney for Liverpool with your detachment, along with that of Captain Wallis, and on your arrival there you will communicate with Mr. Moore the Magistrate, and obtain all the information you can from him relative to the Hostile Natives – and the parts of the Country they are most likely to be fallen in with. Having obtained this intelligence, and rested your detachment at Liverpool tomorrow night, you will set out on your march early the following morning for the Cow Pastures, crossing the River Nepean near the old Government hut, and proceeding direct to Mr. McArthur's Farm, where you will find and take under your command the ( ) Party of the 46th Regiment at present stationed there.*
3. *On your march from Liverpool to the Cow Pastures, you are to apprehend all the Natives you fall in with and make Prisoners of them. If they refuse to surrender, or make any show of resistance, or attempt to run away, you are to fire upon them, until compelled to surrender. Such Prisoners as you take are to be sent back to Liverpool to be confined there; and such adult male Natives as may be killed you are to cause to be hanged on trees in conspicuous Parts of the Country they fall in. You are to spare all Women and Children and not to kill any of them if you can possibly avoid it. If however any should be killed, they are to be interred where they may happen to fall.*

   You are to remain stationary at Mr. McArthur's Farm at the Cow Pastures until you hear from Captain Schaw after he has crossed with his Party to that side of the River; and then act in cooperation with him according to circumstances, but in case you should learn that any number of Natives are lurking within a few miles of your station, or are likely to be cut off by your making a movement, you are immediately march with your whole detachment against them – and take them Prisoners as is herein already directed. It is very probable that the Natives who may be driven from their lurking places by Captain Schaw may attempt to escape by some of the passes near your Station, and it may be in your power to intercept them by making a timely and judicious movement towards such Passes, which your Guides will lead you to. I have inserted in the margin the names of the Guides (Mr. Jackson and Tindal) who are to attend you to the Cow Pastures and to remain with you there. I also enclose herewith a list of the names of such Natives as are known to be hostile, and whom you will do everything in your power to apprehend and bring Prisoners to Sydney.
4. *After Captain Schaw has completed the service he is now sent on, he will ( ) you thereof and you will then join him and return with him to Sydney, by the way of Parramatta, reporting to me in writing on your arrival at Sydney the result of your particular operations during you absence.*

   I have the honour to be
   Sir, your most obedient Servant

L.M.
Governor in Chief of
New South Wales

APPENDIX D: REMUNERATION FOR THOSE ACCOMPANYING THE MILITARY DETACHMENTS EMPLOYED AGAINST THE NATIVES

Tuesday 7th May 1816 (!)

"*I this day paid the following Sums of money – or granted Orders on the King's Stores for Liquor, Provisions, and Slops, to the undermentioned European and Native Guides, Constables, Carters &c. who accompanied the Military Detachments recently employed against the Natives: —*

Remunerations in Cash —
To John Warbey – Guide £12. –. – Currency.
To John Jackson – Guide £12. –. – do.
To John Pawson – Guide £12. –. – do.
To Thomas Simpson – Guide £12. –. – do.
To Joseph Mc.Loughlin – Guide £12. –. – do.
To Christopher Anderson – Carter £5. –. – do.
To Henry Mc.Kudding – Cart Hire &c. £9. 5. – do.
To Thomas Nobles – Guide £3. –. – do.
To Corporal Partridge 46th. Repairing Carts £3. –. – do.
To Private Lidstone 46th. Repairing Carts £3. –. – do.

Total Cash Remunerations £80. 5. – Currency.
The 5 first mentioned Guides received also from the Store each a Complete Suit of Slops including Shoes and Blankets – and also four Days Provisions. —

To each Non-commissioned Officer & Soldier employed on the late Service, there were issued from the King's Store one Pair of Shoes and Half a Pint of Spirits.

Remunerations to Native Guides: —
To Bidjee Bidjee
To Harry
To Bundell
To Tindall
To Colebee
To Creek-Jemmy – or Nurragingy

Each a Complete Suit of Slops including Blanket – 4 Days Provisions, Half Pint of Spirits – and Half Pound of Tobacco.

I also gave Orders on the Store to the undermentioned Commissioned Officers employed on the late Service against the Natives for the quantities of Spirits specified against their respective Names – as Donations from Government to defray in part their Extra Expenses whilst Employed on the said Service:

To Captain Schaw 15 Gallons
To Captain Wallis 15 Gallons
To Lieut. Dawe 10 Gallons
To Lieut. Grant 10 Gallons
To Lieut. Parker 10 Gallons

To Asst. Surgeon Bush 10 Gallons

N.B. *To each of the Non-commissioned Officers & Soldiers of the 46th. Regiment left out on Duty in the Bush, the same indulgences are intended to be given on their return to Head Quarters as have been granted to their Brother Soldiers already come in. —*

L. M.*”*