Building a Base for Better Boundaries

Rick Carruthers
Transport for NSW
Rick.Carruthers@transport.nsw.gov.au
Fred de Belin
City of Ryde
fdebelin@ryde.nsw.gov.au

ABSTRACT

In recent decades there have been several significant changes in positioning technology, most notably the advent of Global Navigation Satellite Systems (GNSS). As precise, sub-decimetre positioning becomes accessible to an increased number of users, issues with the current cadastral system become more apparent. In New South Wales, most digital cadastral information was created in the 1980s and 1990s by duplicating and tracing information from charting maps and other historic plans, leaving much to be desired in terms of accuracy, validation and completeness of the data. Most of the previous research on improving the cadastre in NSW has concentrated on the viability and realisation of a legal coordinated cadastre. This generally involves a systematic back-capture and adjustment of survey measurements, which comes hand in hand with challenges in regards to legal boundary definition. However, there exist a number of proposals with the intention to upgrade the spatial accuracy of the cadastre so that it can meet the expectations of all users, while remaining within the current legal framework for land tenure and survey regulations. This paper examines and implements these proposals in a large-area case-study analysis. The case study involves an extensive land subdivision, which occurred in the City of Ryde in 1882-1885. The subdivision was connected to and directly related to a major trigonometrical (trig) station network. Many of these early trig stations and certainly many of the original corner marks still exist. Tying this original survey to the modern survey control network as delivered through the Survey Control Information Management System (SCIMS) provides a direct comparison between the current Digital Cadastral Database (DCDB) and the original Ryde cadastre as evidenced by marks found from the 1882-1885 survey. Does the modern cadastre differ from the first cadastre?

KEYWORDS: *Cadastre, DCDB, original boundary, comparison.*

1 INTRODUCTION

In 1841, astronomers, mathematicians and geodesists understood that the accuracy of measurement required to produce a sound triangulation network over a large area was effectively 50 mm in 7 km for an accurate baseline and 50 mm over 7 km for accurate angle work. This was not achievable in 1841, at a time when Mitchell was surveying the 19 counties by way of a triangulation network. When Charles Robert Scrivener carried out cadastral survey work in 1882-1885, within the Field of Mars Common, at Ryde, his reliance on triangulation was fully justified because things had improved, and modern-day field survey accuracy was achievable.

As precise, sub-decimetre positioning becomes accessible to an increasing number of users through Global Navigation Satellite System (GNSS) technology, issues with the current cadastral system start to become more apparent. In New South Wales, most digital cadastral information was created in the 1980s and 1990s by tracing charting maps and other historic plans, which compromised the accuracy and completeness of the data. As such, the Digital Cadastral Database (DCDB) in its current state is not fit-for-purpose for the broader public. The objective of this paper is to identify methods that can be used to upgrade the spatial accuracy of the cadastre so that it can meet the expectations of users, while remaining within the current legal framework for land tenure and survey regulation.

Most of the previous literature on improving the DCDB in NSW has concentrated on the viability and realisation of a legal coordinated cadastre, which generally requires a systematic back-capture and adjustment of survey measurements, presenting challenges with regards to legal boundary definition. However, an optimal positional uncertainty can theoretically be achieved without significant resurvey or back-capture. Rather, the DCDB can be aligned with other datasets, including satellite imagery, control surveys and road alignments, and then non-rigorously adjusting boundaries in the pursuit of spatial improvement. This paper examines and implements one such proposal in a case-study analysis. Historical survey data from 1882-1885 is combined with modern survey observations, then passed through a least squares adjustment. The results are compared against the current DCDB, highlighting the potential application of this approach to other areas of NSW.

2 THE STATE OF THE STATE CADASTRE

Inaccuracies in cadastral data are apparent when overlaid with other geographic data and aerial photography. Factors which account for inaccuracies in digital cadastres are well documented. After the creation of the initial digital databases, subsequent plans of survey have often not been well integrated into the digital cadastre. To meet most needs, organisations employ a fit-to-fabric method to upgrade their cadastre. This involves fitting new features within the existing cadastral framework. In many cases, this leads to new surveys being adjusted to fit to boundaries which may be derived from hardcopy maps that are spatially inaccurate. This has the effect of degrading the spatially accurate data and causing misalignments between digital boundaries and their true ground position (Figure 1).

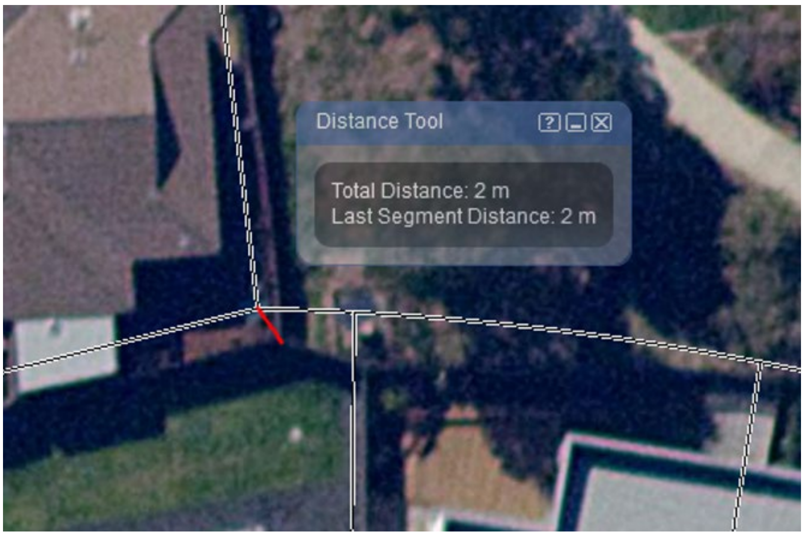


Figure 1: Variation between the DCDB and aerial imagery in SIX Maps (DCS Spatial Services, 2021).

In NSW, the following attribute in Williamson's (1996) vision has not yet been achieved: "The coordinated cadastre and associated procedures would result in every point being able to be represented by a single set of coordinates having an accuracy of approximately ±0.03 m in urban areas, ±0.2-0.3 m in rural areas and ±0.5-2.0 m in large properties or mountainous terrain."

2.1 Problems Arising from an Inaccurate Digital Cadastre

In a Cadastre NSW stakeholder analysis report (LPI, 2016), three priority problems and opportunities relating to the digital cadastre were identified. One key problem pertained to the fact that users of the digital cadastre have limited capacity to gauge its accuracy. This creates large cost increases in infrastructure and property development, as the digital cadastre cannot be relied on for site assessments during early project planning. Additionally, preliminary designs, plans and estimates based on inaccurate digital cadastres can result in costly re-works needing to be undertaken. Surveyors have reported cases where large infrastructure projects have exhausted significant resources to capture survey data that was already available in other areas of government, simply due to uncertainties over the data accuracy.

Uncertainties also exist where stakeholders rely on the DCDB to overlay their assets. For example, despite having the correct coordinates for a given structure, it may appear to be fully or partially located within a neighbouring land parcel due to a poor cadastre and the inaccurate positioning of underground assets in relation to boundaries. Additional work is often needed for both surveyors and developers to assess the locations of underground infrastructure in relation to boundaries. Having an inaccurate digital cadastre also hinders the ability of many authorities to enforce regulations.

2.2 Problems Arising from Management of Digital Cadastral Data

A second key problem relates to NSW not having a single digital cadastre that is used across government and industry. Instead, organisations currently use and maintain over 100 digital cadastres across the State, differing in their extent, spatial accuracy and information stored. Many councils and utility providers create and maintain their own spatial datasets and are thus driven to maintain their own version of the digital cadastre to align with their own datasets and needs. The problem here is that updates to these custom versions of the DCDB are not uniformly coordinated. In many cases users base their own cadastres around the NSW DCDB, however incidents have arisen where land boundaries are updated by DCS Spatial Services without notification to the relevant users. The lack of any comprehensive notification process causes an even further divide between different cadastres. This is representative of a poor framework for sharing cadastral data, with many users being unaware of when boundaries in the NSW cadastre are spatially updated.

For many organisations, maintaining their own digital cadastre means overcoming duplication and misalignment of data, which adds significant time and cost to their operations. The lack of a 'single source of truth' results in delays in assessing, approving and registering subdivision plans due to the need for checking and verification within different cadastres. Barriers to increased delivery of other digital services have also arisen from the lack of a coordinated digital cadastre. Utility providers are generally unwilling to release their digital datasets because of known misalignments with other datasets, meaning that users of Dial Before You Dig (DBYD) searches are required to digitise data from PDF maps. In a similar vein, the NSW ePlanning viewer contains a 'buffer' of 2-3 metres around parcel selections to cater for misalignment between councils' Local Environment Plans (LEPs) and the digital cadastre.

3 IMPROVING THE DCDB IN PRACTICE

In Australia, the doctrine of 'monuments over measurements' stipulates that surveyors must adopt boundaries as the original survey intended, taking into account monuments, survey marks and other natural or constructed features. The placing of alignment posts and other reference marks has, over many years, attempted to lock down the cadastre so that corner re-instatement is straightforward and repeatable. In more recent decades, the system of coordinated survey marks in the Survey Control Information Management System (SCIMS) has been used to position the cadastre with respect to the Geocentric Datum of Australia (GDA) and the Map Grid of Australia (MGA). However, the practice in modern surveying tends toward performing work on individual lots in a very localised area. This means that differences and ambiguities in measurements between lots are left unaccounted for, causing small sections of the cadastre to fit together very well, but not so when looking at the whole, bigger picture.

In order to create an accurate digital cadastre on a larger scale, an approach needs to be taken where first a stable framework is fixed in place, before filling in the finer details. This is reflective of a 'whole to the part' approach. The most common suggestion is the reconstruction and fixing of road patterns, upon which a rigid cadastre can be positioned.

Land within the City of Ryde Local Government Area (LGA) is an ideal candidate to trial and evaluate this approach (Carruthers, 2020). This case study investigates the history of the land in City of Ryde and how its cadastre developed over time. Then, by using the approach of connecting historical survey control data to the survey control network through SCIMS, it is possible to see how this data fits in relation to the current DCDB, when comparing remaining survey marks, corners, street intersections and other common points. Through this, any differences or shifts in the DCDB can be found. Ultimately, this case study can be used to help answer the question of how applicable this approach may be to other areas of NSW or indeed Australia.

4 THE FIELD OF MARS CASE STUDY

The first land grants in the Ryde area occurred in 1792-1809. These first grants formed what is essentially the first cadastre in Ryde. However, they contained no survey information, only being depicted on maps as rectangles with areas (e.g. 30 acres). In 1804, the then Governor, Phillip Gidley King, set aside a large tract of Crown land called the Field of Mars Common, which abutted those first grants. Expansion pressures caused the Government to subdivide and release parts of the Common commencing in 1882.

The boundaries in this second wave of Crown Grants were survey accurate and carried out by Charles Robert Scrivener. One of his surveys, Crown Plan 15.440 (Figure 2), was dated 1883 and titled "Plan of a Survey of Field of Mars Common and Grants adjacent thereto". This plan covers an area in excess of 25 km^2, from Pennant Hills to Hunters Hill (Figure 3). An overlay onto satellite imagery (Figure 4) shows the full extent of Scrivener's survey.

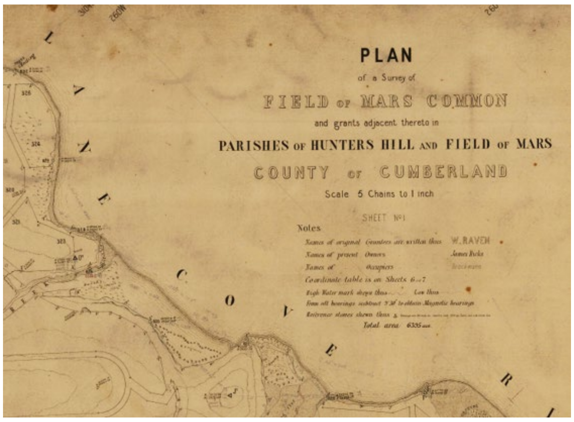


Figure 2: Detail from Crown Plan 15.440 – 1883.

Figure 3: Extent of Crown Plan 15.440 – 1883.

Figure 4: Crown Plan 15.440 overlaid on Google Earth satellite imagery – 2020.

Due to the clarity and the perfect preservation of Crown Plan 15.440 itself, it is possible to completely rebuild the original survey from the plan document. As part of his work, Scrivener utilised a coordinate system, giving an X and Y value for each point. The datum that is used has horizontal coordinate values increasing from east to west, thus requiring a negative sign to flip the coordinate system to match modern convention of Easting and Northing values. Provided on sheets 6 and 7 of the 1883 plan are several tables of coordinates, amounting to 622 lines of survey data (Figures 5 & 6).

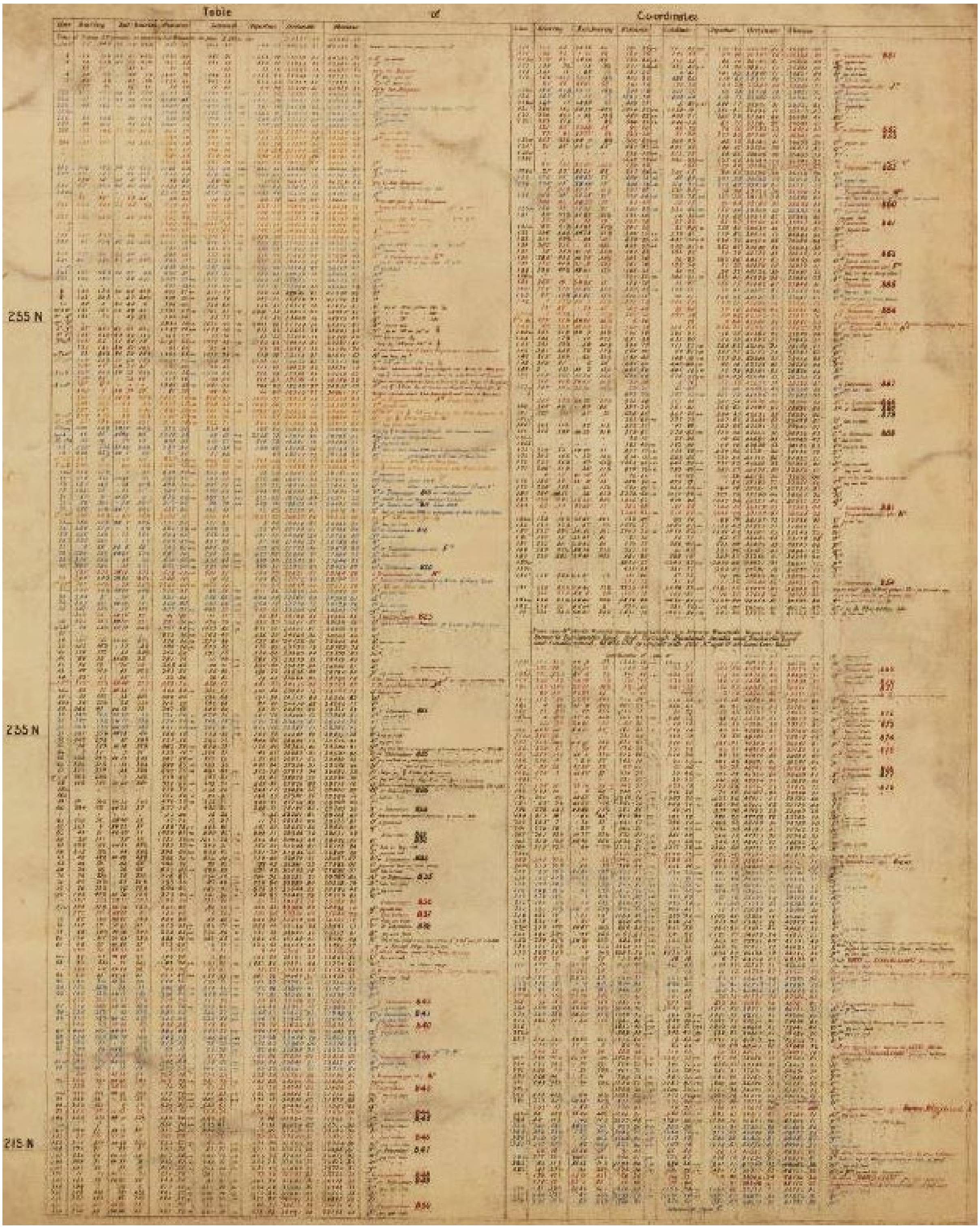


Figure 5: Detail from sheet 7 of Crown Plan 15.440, showing table of coordinates – 1883.

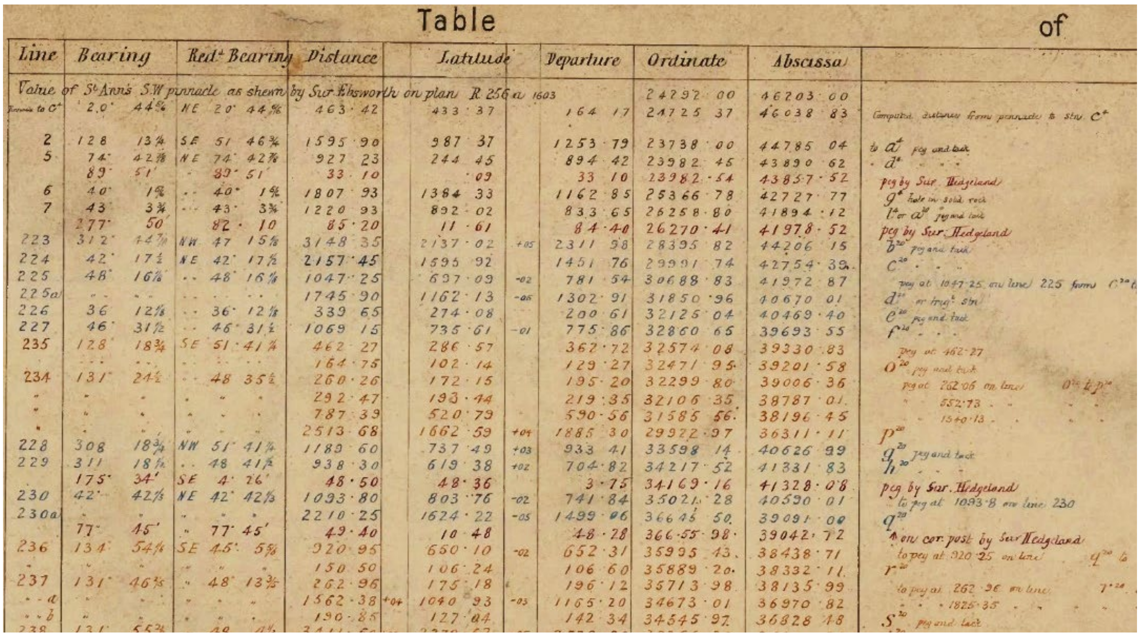
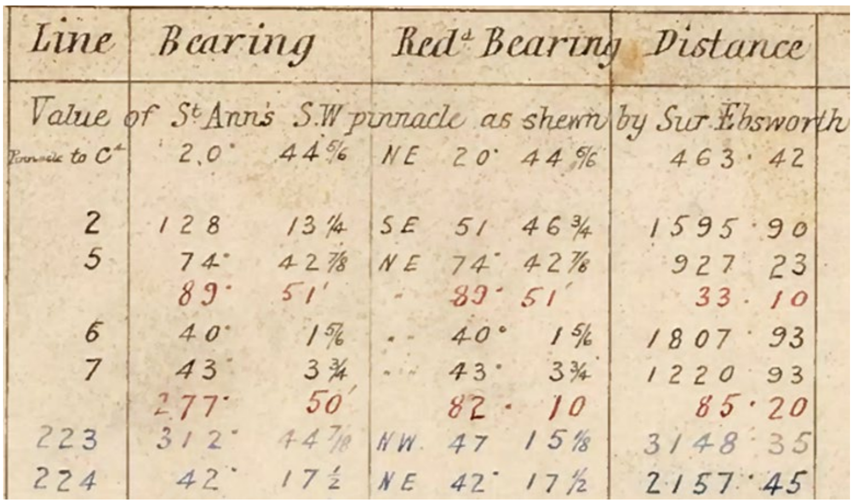


Figure 6: Detail of Crown Plan 15.440, showing line, bearing, distance, coordinates and point notes – 1883.

Of particular interest is that Scrivener's survey shows connections to a network of trigonometric marks within the area. These trigonometrical (trig) stations are generally located on the bank along the Lane Cove River, as well as high points on hills in the region.

Contained within the table (Figure 7) is information for any given traverse line:

- *Bearing*: horizontal angle between the line direction and north, values given to nearest 5 seconds of arc.
- *Reduced Bearing*: horizontal angle made by the line with the north/south line (whichever is closer) in the east or west direction.
- *Distance*: given in links to two decimal places (approx. 2 mm).
- *Latitude*: the change in Northing (ΔY) along the line.
- *Departure*: the change in Easting (ΔX) along the line.
- *Ordinate*: the Y coordinate of the next point.
- *Abscissa*: the X coordinate of the next point.
- *Remarks*: information regarding the type of mark that was placed.



Line	Bearing	Red^d Bearing	Distance
Value of St Anns S.W pinnacle as shewn by Sur Ebsworth			
Pinnacle to C^d	2.0° 44⅝	NE 20° 44⅝	463·42
2	128 13¼	SE 51 46¾	1595·90
5	74° 42⅞	NE 74° 42⅞	927 23
	89° 51′	89° 51′	33·10
6	40° 1⅝	40° 1⅝	1807·93
7	43° 3¾	43° 3¾	1220 93
	277° 50′	82·10	85·20
223	312° 44⅞	NW 47 15⅛	3148·35
224	42° 17½	NE 42° 17½	2157·45

Figure 7: Detail of Crown Plan 15.440, displaying its clarity – 1883.

In addition to these, Scrivener has provided, in separate columns, small corrections (less than 1 link) to both the distances and latitudes (Δy). This has the effect of stretching the survey along the north-south direction. It can be deduced that these small adjustments have been made to fit the survey onto the trigonometric network. From these corrections it is also evident that the bearing observations were considered more accurate, as they have been preserved; in favour of altering distance observations when adjusting the survey.

The data supplied in the plan allows some options when rebuilding Scrivener's survey digitally:

- Input of raw bearings and distances.
- Input of changes in X and Y.
- Input of the calculated final coordinates.

Checking these methods against one another confirms that there are minimal or no errors in Scrivener's coordinate calculations (Table 1).

Table 1: Checking Scrivener's calculations for errors.

Check	Mean Difference (m)	Standard Deviation σ (m)	Max Difference (m)
Given (uncorrected) ΔY, calculated Distance * cos(Bearing)	0.002	0.004	0.020
Given (corrected) ΔY, calculated Distance * cos(Bearing)	0.004	0.005	0.020
Given ΔX, calculated Distance * sin(Bearing)	0.001	0.001	0.007

Using a sample set of more than 60 traverse lines transcribed from Scrivener's table, it is possible to see that the differences between the raw survey observations and calculated coordinates are negligible. The ΔY values with the corrections applied have a few millimetres of discrepancy, as expected, while the ΔX are effectively identical.

From this it can be concluded that Scrivener's adjusted and final coordinates are suitable to use in rebuilding the survey. The table of coordinates has subsequently been transcribed in Excel and imported to Computer-Aided Design (CAD) software to reproduce the plan in digital form.

5 FIELD WORK FOR THE FIELD OF MARS CASE STUDY

The field work was conducted with a Trimble SPS585 GNSS Smart Antenna Reveiver (Figure 8). GNSS Network Real-Time Kinematic (NRTK) was suitable for this project due to the large area being covered. To improve accuracy, the indicated marks were surveyed multiple times to eliminate any biases in the satellite constellation. A Trimble S7 total station was also used to gather additional data where satellite visibility was poor.

In order to obtain an MGA2020 fix of the cadastre, first and foremost, suitable connections need be made between the historical plan and existing features. As a starting point, the coordinates provided by Scrivener were imported to AutoCAD, then scaled by 0.201168 (links-to-metres conversion factor) and rotated to roughly align with aerial imagery.

Figure 8: GNSS NRTK field work.

Fortunately, it is immediately evident that many original marks have survived. The sites of some trig stations also remain to this day (Figure 9a) or have been replaced exactly by State Survey Marks (SSMs) which have known coordinates. The survey depicts many rock marks, which are predominantly located along the sides of the Lane Cove River, Porter's Creek and Devlin's Creek. Through previous field investigations, original rock marks from Scrivener have been found in the Ryde area (de Belin, 2017, 2018). Generally, the rock marks (Figure 9b) have been well preserved, with deep drilled holes, chiselled Portion numbers and direction lines cut into the rock.

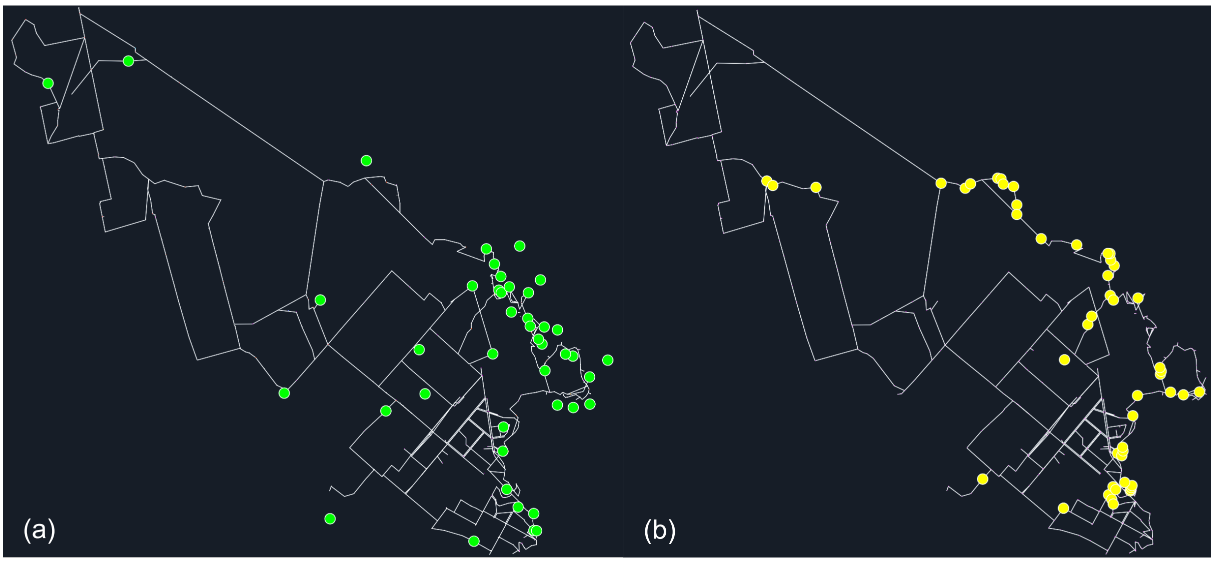


Figure 9: Crown Plan 15.440 with location of (a) trig stations and (b) rock marks highlighted.

The trig station J13 (Figure 10), just north of current-day Delhi Road, was replaced by SS71410 in 1991 (Figure 11) to form part of a control plan for the Department of Main Roads (now Transport for NSW). This is a Class B survey mark (Figure 12), with horizontal coordinates sourced from AGD66, transformed to GDA94, then transformed to GDA2020.

Survey marks "835", "832", "828", "822", "820" and "815", all located on rock shelfs along the western shore of the Lane Cove River, were used as the sites for SSMs in 1979 and 1980 by the Maritime Services Board of NSW, in connection with hydrographic surveys of the river. Details of these marks can be found in Appendix A – these are Class B survey marks, with horizontal coordinates sourced from GDA94, then transformed to GDA2020.

Figure 10: Detail from Crown Plan 15.440, showing trig J13 – 1882.

Figure 11: Original trig J13 with SS71410 implanted and broad arrow cut – 2020 image.

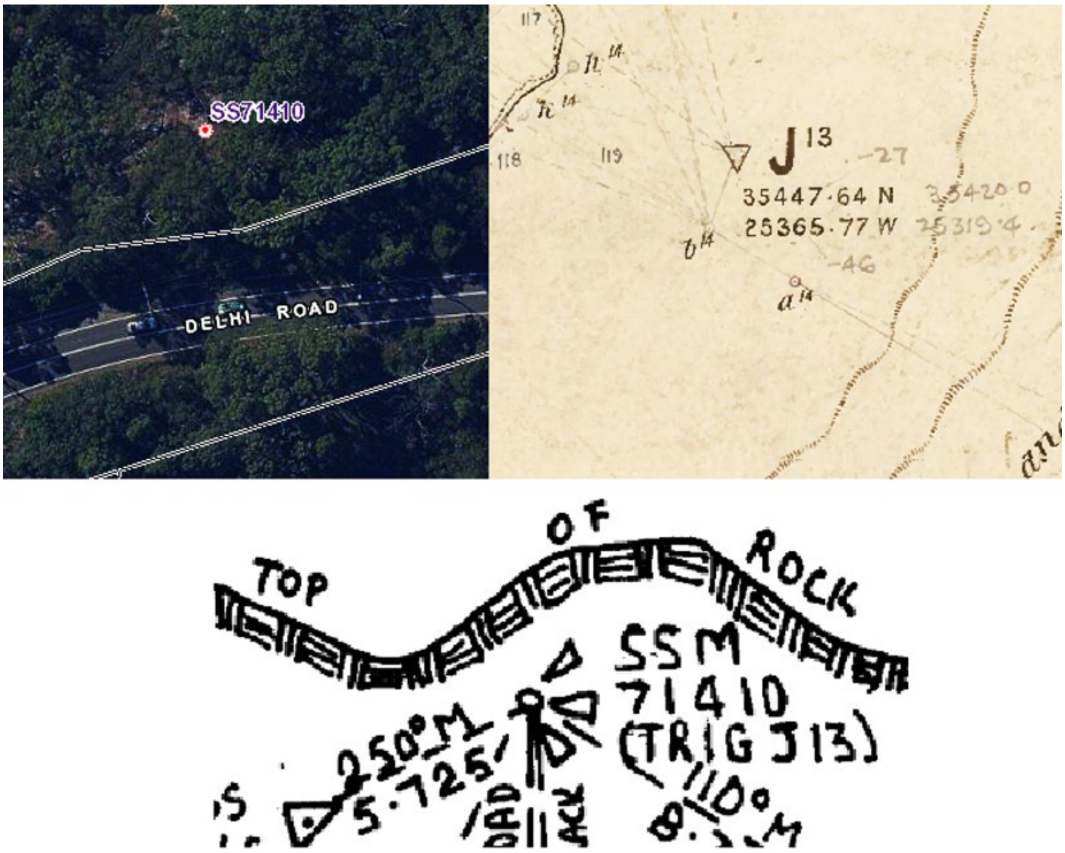


Figure 12: Detail from SS71410 locality sketch and SIX Maps/DCDB image.

On the corner of Higginbotham Road and Monash Road, Gladesville, the City of Ryde survey team has found, and subsequently placed a cover box over, the rock mark R5 indicating the south-east corner of portion 298 (Figure 13).

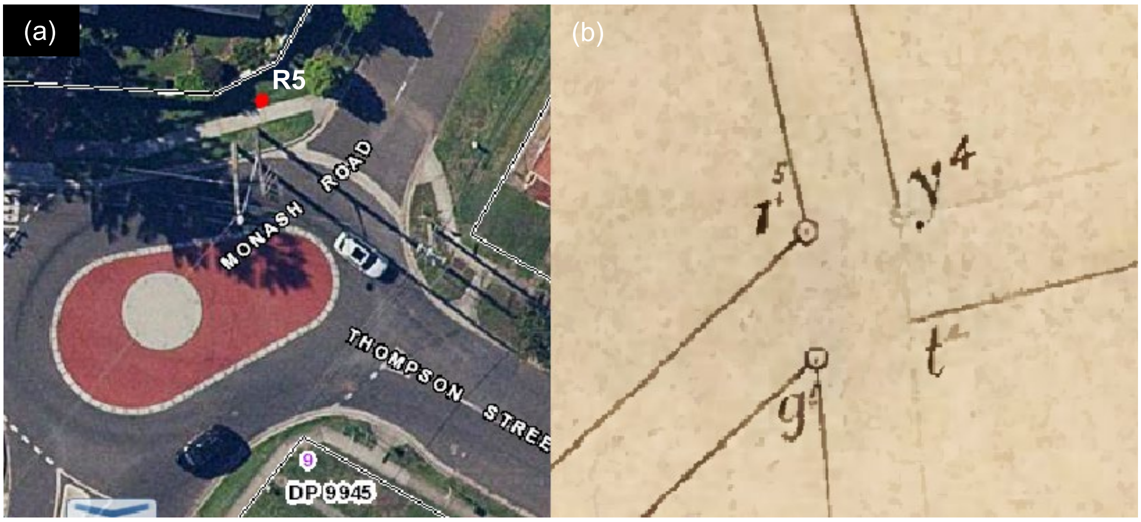


Figure 13: Rock mark R5 location (a) highlighted red in SIX Maps, and (b) in Crown Plan 15.440.

At the intersection of Beecroft Road and Pennant Hills Road, Epping, is the location of the former trig station Red Hill (Figure 14). An investigation of its SCIMS report reveals that the land on which the survey mark was located was resumed for purposes of the Main Roads Act. The concrete trig monument was destroyed in 1976 by a car collision. Fortunately, connections were made to witness marks and other nearby marks such that its coordinates can be determined. SCIMS shows this mark, although now destroyed, as being Class 2A, with a Positional Uncertainty of 0.04 m and Local Uncertainty of 0.04 m.

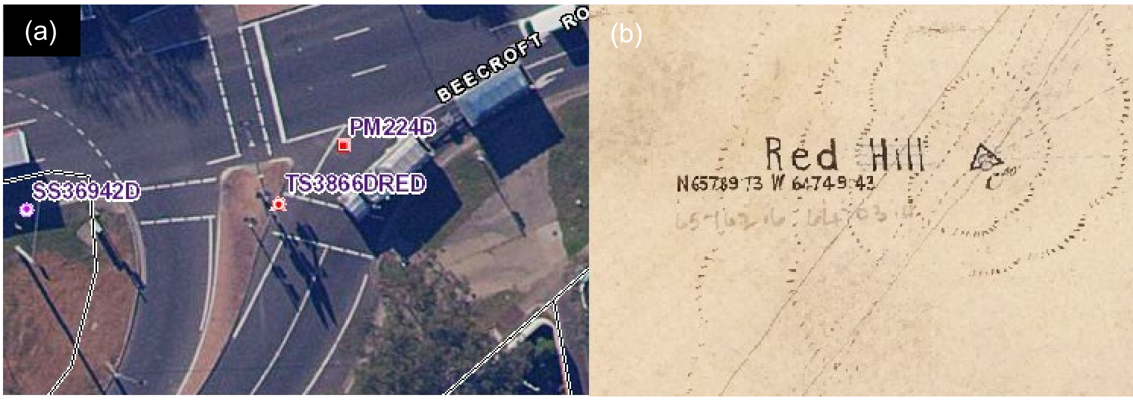


Figure 14: (a) TS3866 RED (destroyed) in SIX Maps, and (b) TS Red Hill in Crown Plan 15.440.

Trig station Pennant is located on Castle Hill Road (Figure 15). The current status of the mark is “not found”, however there are connections to nearby marks. The trig is recognised as Class C.

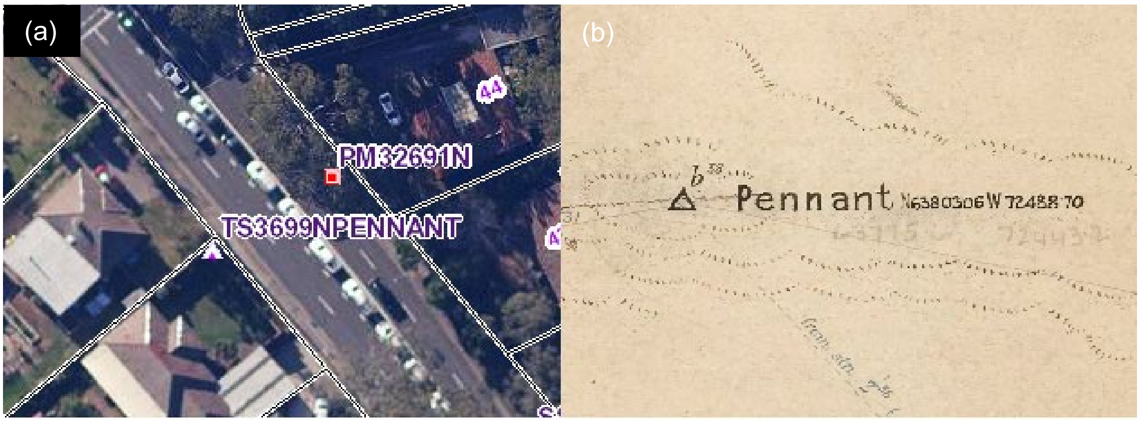


Figure 15: (a) TS3699 PENNANT (not found) in SIX Maps, and (b) TS Pennant in Crown Plan 15.440.

Although there are coordinates for the Red Hill and Pennant trig stations, it is preferable to find some physical marks at the northern end of the survey to improve the geometry of the common control points used in the adjustment of the survey.

As shown on sheet 4 of Crown Plan 15.440, Scrivener’s traverse follows Devlin’s Creek north from Epping town centre. One of his traverse stations (shown on the plan as “hole in rock”), is located within Lyne Road Reserve in Cheltenham. Being sited within a public park significantly improves the chances of that mark’s survival.

Using handheld GPS, the approximate location of the mark indicated a rocky embankment overlooking the creek. The clearing of soil and leaf litter revealed a drill hole and wing (DH&W) in the rock (Figure 16). An investigation of DP 879542, in addition to all other previous surrounding survey plans, including the relevant portion plan, showed no evidence of this rock mark ever being found nor connected to.

Figure 16: Scrivener's traverse station DH&W in rock – 1883.

Due to the dense vegetation, surveying the rock mark with GNSS NRTK was not viable. A short GNSS baseline was set up in a nearby open field (Figure 17) and surveyed. The robotic total station was then used to connect by traverse and obtain a more accurate position for the found rock mark. In summary, a total of 11 marks in Scrivener's plan have thus far been assigned coordinate values, via SCIMS and survey (Figure 18).

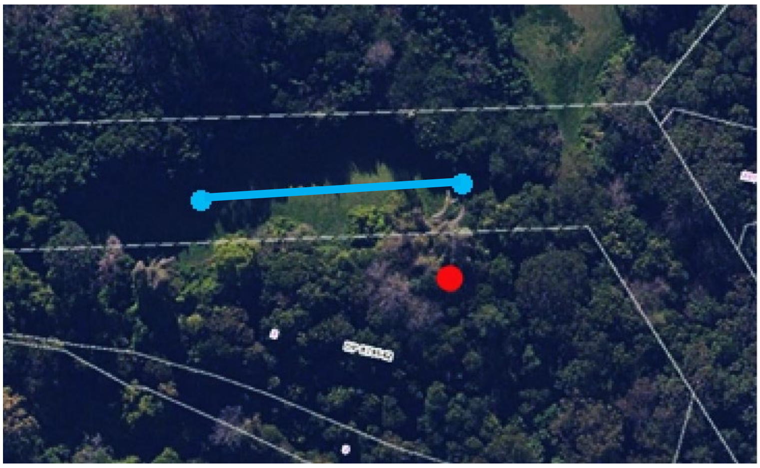


Figure 17: GNSS baseline (shown blue) near Scrivener's traverse station (shown red).

Figure 18: Crown Plan 15.440 with known and located marks highlighted.

In all cases, marks were occupied by GNSS for 2 minutes, with 120 epochs being recorded. Precision values were determined from the Dilution of Precision (DOP) and the Root Mean Square (RMS):

- Horizontal precision = HDOP x RMS x 3.0.
- Vertical precision = VDOP x RMS x 3.0.

6 RESULTS

Horizontal precision was generally found to be 20 mm, with some measurements having a precision of 10 mm, dependent on the sky view. Comparisons with SCIMS coordinates, where they were available, saw a general level of agreement with the survey data. Thus, SCIMS coordinates have been adopted in some of the cases where nearby trees and obstructions may have accounted for poorer residuals. In the case of the rock mark in Lynne Road Reserve, the combined errors from surveying the peg and the ensuing resection has resulted in a horizontal precision of 50 mm.

An initial comparison (Table 2) can be made by anchoring the plan on trig J13 and adopting the azimuth towards TS Red Hill, i.e. the two marks which are the furthest apart.

Table 2: Initial comparison of marks.

Mark	Coordinates from Initial Swing (m)	Coordinates from SCIMS & GNSS Survey (m)	Difference (m)
J13	E: 328697.663 N: 6258995.800	E: 328697.663 N: 6258995.800	0.000
N12	E: 328379.409 N: 6258554.800	E: 328379.491 N: 6258554.758	0.092
E12	E: 328178.961 N: 6258084.563	E: 328179.132 N: 6258084.558	0.171
S11	E: 327950.801 N: 6257521.891	E: 327951.046 N: 6257521.914	0.246
TS Pennant	E: 319120.125 N: 6264534.070	E: 319120.218 N: 6264533.905	0.189
TS Red Hill	E: 320669.823 N: 6264960.774	E: 320669.980 N: 6264960.657	0.196
A9	E: 328204.915 N: 6256467.246	E: 328205.221 N: 6256467.348	0.323
S8	E: 328535.257 N: 6255644.182	E: 328535.644 N: 6255644.400	0.444
R5	E: 326788.228 N: 6256353.300	E: 326788.655 N: 6256353.266	0.428
E36	E: 322013.306 N: 6262560.914	E: 322013.670 N: 6262560.708	0.418
TS Gordon	E: 328211.945 N: 6261395.844	E: 328211.957 N: 6261395.643	0.201

From this comparison we can begin to infer the quality of Scrivener's observations, such as 200 mm in 7 km. To try and achieve the optimal positional uncertainty as envisaged in section 3, it is necessary to carry out a least squares adjustment of Scrivener's work to achieve a more realistic comparison with the SCIMS network. The software package FIXIT4, developed by Dr Bruce Harvey at the University of New South Wales, has been used to rotate, shift and scale Crown Plan 15.440 onto the field survey data. In simple terms, the output of the least squares model minimises the sum of the squares of the residuals of the observations.

The final coordinates from Scrivener's survey marks were chosen and transcribed, as opposed to the raw observations, in order to retain the adjustments that were originally applied. However, this leads to a problem when compiling the dataset for FIXIT4, as FIXIT4 requires the bearing and distance data to create the adjustment. It was impractical to transcribe all the observations in addition to the coordinates. Thus, this information was calculated in a reverse manner. Most of the survey marks are listed sequentially, in the same order as the traverse occurred, allowing the calculation of bearings and distances to be automated between each point and the next via Excel (Figure 19).

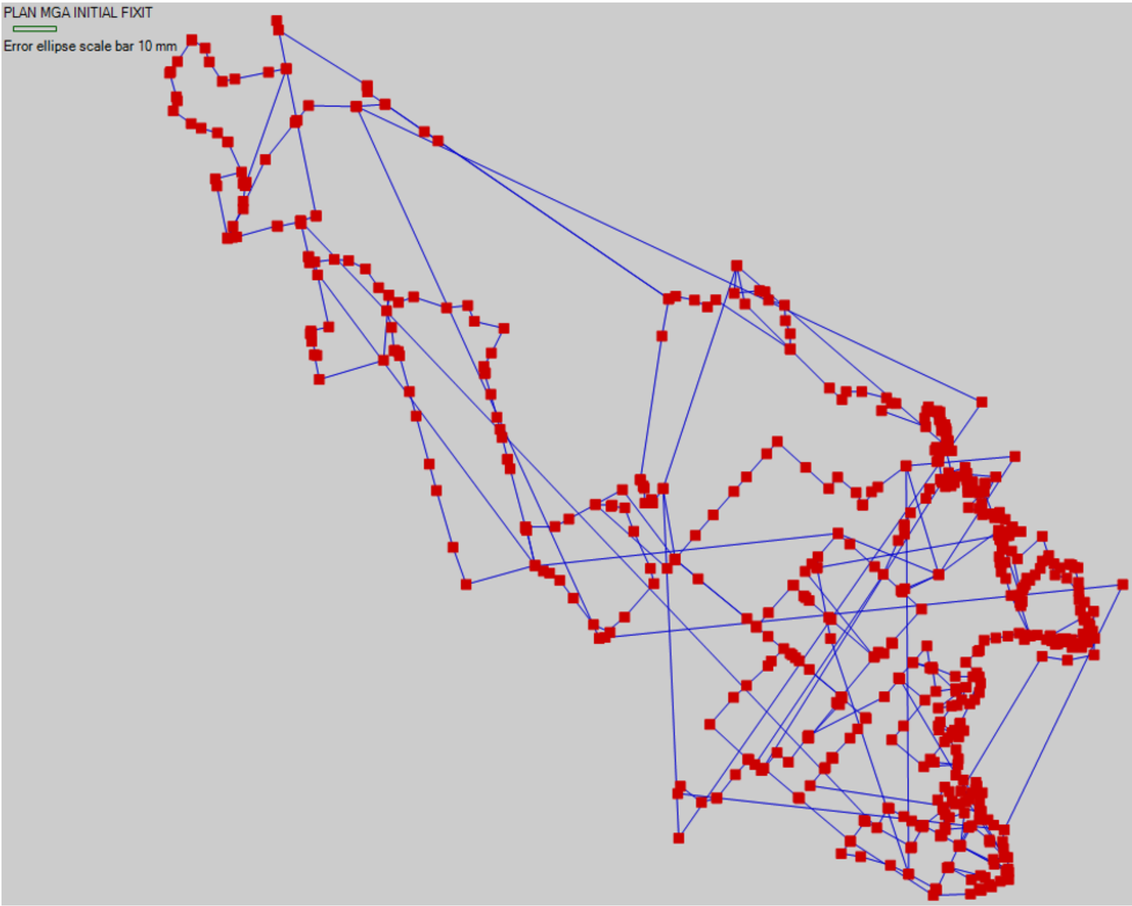


Figure 19: Initial FIXIT4 input file.

The next step is to remove lines that form connections where there were no connections and reattach broken lines. This occurs every time the traverse table jumps to a new starting point. Some instances of this have required finding the relevant survey data in Scrivener's other Crown Plan 386.2030, due to the required dimensions missing from the subject plan. At this time, duplicate points are also deleted, and references to them are redefined to the first instance of the point. This enables closure of all the internal loops of the survey.

Another revision involves the inclusion of selected bearings for trig stations. The overwhelming majority of the trig stations in Crown Plan 15.440 show bearing connections to traverse points but not distances. As such, they have been initially removed from the model. However, for the few trig stations that have been recorded and act as fixed points in the survey adjustment, bearing lines have been re-added. These particularly long lines have been given a higher weighting (½ standard deviation of the other bearing observations) to lock in the geometry of the plan (Figure 20).

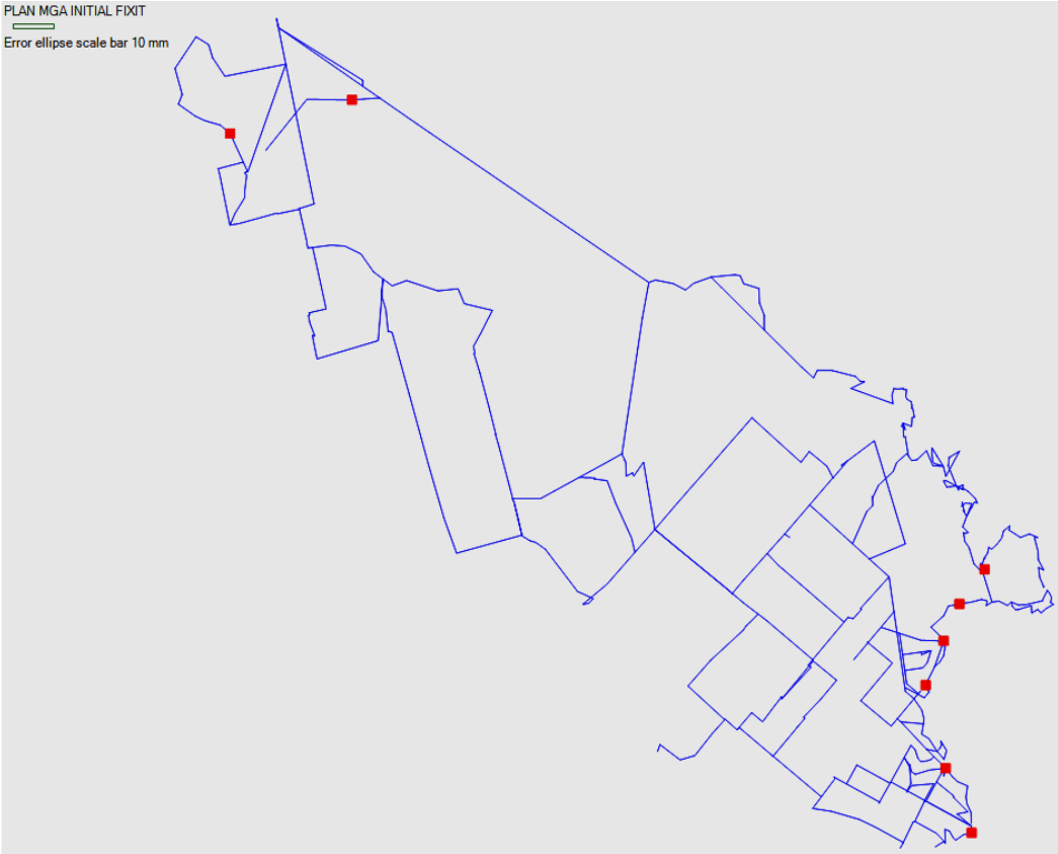


Figure 20: Closed loops in the adjustment with the 8 selected control marks (red) held fixed.

Furthermore, the geometry has been enhanced by finding traverse lines which were straight. Adding angle observations of 180°, with a very small standard deviation (0.1”) maintains the original intention of the surveyor. In the subject survey plan, many traverse lines follow straight boundaries, but the traverse lines themselves zig-zag. One key example where straight lines can be locked occurs at the northern end of the plan, and given the considerable length of the lines involved (>2 km), it is important to retain these as straight lines with no bends (Figure 21).

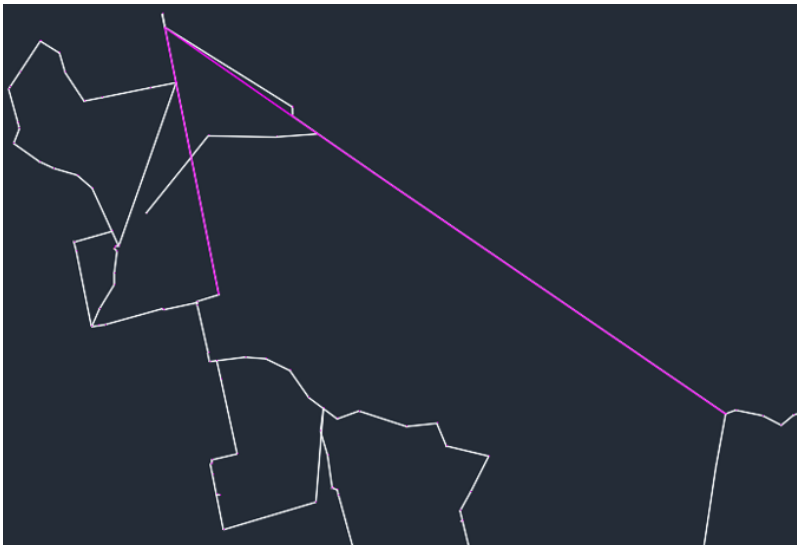


Figure 21: Straight lines preserved in the north-west corner of the survey.

6.1 Least Squares Output

The least squares network adjustment output is shown in Table 3. The final model shifts the coordinates from their starting position by up to 0.440 m, as expected from Table 2. The coordinates of the final solution have an average 95% confidence ellipse of 0.151 m. The variance factor is 1.02, with group variance factors for plan bearings and horizontal distances being 0.95 and 1.02, respectively.

Table 3: Output of the least squares network adjustment.

2D adjustment: ➢ 0 directions ➢ 578 distances ➢ 3 Easting point position (EPP) observations ➢ 3 Northing point position (NPP) observations ➢ 588 plan bearings ➢ 5 angles
There are 1094 coordinate parameters, 1 orientation parameters and 1177 observations
4 Iterations ➢ Iteration: 1 had a max shift in a coordinate = 435.0mm ➢ Iteration: 2 had a max shift in a coordinate = 7.7mm ➢ Iteration: 3 had a max shift in a coordinate = 0.0mm ➢ Iteration: 4 had a max shift in a coordinate = 0.0mm
Plan orientation / swing - 5.2 Seconds +/- 1.3 secs
After iteration 4 the Variance Factor is 1.02 [n-u = 82, Ave redundancy = 0.07]

While the histogram of ‘v/s’ shows that the input ‘s’ is large (Figure 22), this is due to the occurrence of many ‘perfect’ bearing and distance observations which were in fact derived, not surveyed.

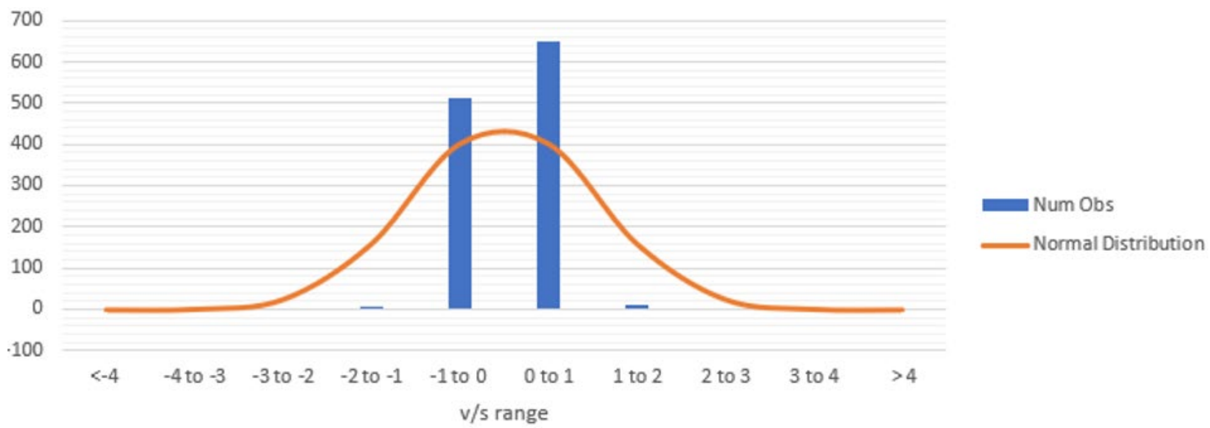


Figure 22: Histogram of v/s from the least squares network adjustment output.

7 DISCUSSION: PLAN QUALITY AND COMPARISONS

The DCDB for Ryde has been obtained from the GIS section at City of Ryde Council. That information is sourced from DCS Spatial Services. It is understood that this model is regularly updated, and is also in beta, but the differences in spatial accuracy between versions are negligible. The DCDB is used for most of Council’s purposes, including management of infrastructure, as well as civil and landscape design.

Whilst the 1883 survey covers land in Hunters Hill Council and Hornsby Council, this is outside of the Ryde Council jurisdiction, and discussion and comparison of the results is restricted to within Ryde LGA (Figure 23). Analysis of a set of about 50 marks, which are common between the 1883 Crown Plan and the modern DCDB (Figure 24), reveals an average discrepancy of 0.350 m. The largest discrepancy was 0.814 m, while the smallest discrepancy was 0.058 m.

At this stage, with the current available data, it is possible to compare the distance between some points that are far apart. Traverses of this size have not been undertaken in the area for many years, so this is a rare opportunity to test the DCDB against ground survey data. In summary, there is a general agreement between the distances on the plan and on the DCDB, which shows that over very large distances the relative accuracy of the DCDB is quite good. However, without further information on the absolute positional accuracy, it is difficult to determine whether the DCDB is inaccurate or Crown Plan 15.440 is inaccurate, or a mixture of both scenarios.

Figure 23: Crown Plan 15.440 overlaid on DCDB.

Figure 24: Common points between DCDB and Crown Plan 15.440.

To verify the positional accuracy of the model, it is possible to compare the results with several independent boundary fixes carried out by the City of Ryde survey team (Figure 25). The jobs selected for comparison have been conducted on MGA2020, using the best available marks according to the hierarchy of survey evidence, and connections to stable and reliable SSMs. A direct cadastre comparison can then be carried out (Figure 26).

Figure 25: Some of the Council-surveyed boundaries (shown blue) overlaid on the DCDB.

Figure 26: Direct comparison at the intersection of High Street and The Strand.

Analysis of a further subset of about 20 locations, which have both fixed boundaries and intersection points with Scrivener's survey, can be found in Appendix B. A summary of these results is shown in Table 4.

Table 4: Summary of results of comparison between least squares output, DCDB and City of Ryde survey.

	Average (m)	Max (m)	Min (m)
Distance between surveyed boundary point and DCDB point	0.444	0.964	0.162
Distance between surveyed boundary point and least squares model of Scrivener's survey	0.286	0.437	0.094

This corresponds to an average improvement of 35.6% in spatial accuracy, and in 83.3% of cases, the least squares model was found to be an improvement over the existing DCDB. The largest discrepancy between a surveyed boundary and the least squares output was reduced to less than 0.45 m.

Thus, it may be concluded that there is merit in applying this process to upgrade the DCDB. One of the interesting aspects, as well as benefits, of implementing this approach is that the solutions generated for a given street are derived from survey control points that are kilometres away and still have a comparable, if not better, precision than the DCDB. In some cases, the improvements are up to 0.5 m.

Another advantage of overlaying this plan is that it exposes where the DCDB has been distorted to fit and maintain inferior data. For example, Moncrieff Drive and Wolfe Road at East Ryde form the old boundary of portions 245 through to 256. By investigating DP 31252 and DP 31253, it is apparent that these roads should remain as continuous straight lines. However, this is not the case in the DCDB (Figure 27). Overlaying the 1883 Crown Plan also exposes where the road reserve now varies in width and becomes irregular. Further opportunities for cadastral upgrades are shown in Appendix C, where Scrivener's road boundaries extend for long distances throughout the cadastre.

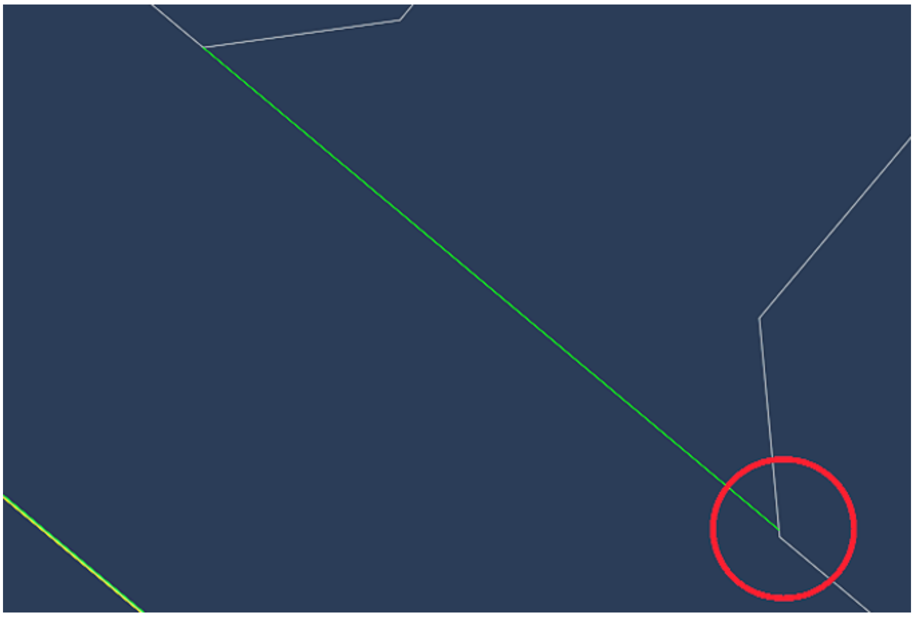


Figure 27: Steps in road boundaries as seen in the DCDB.

In undertaking this survey adjustment, there are still opportunities for further improvement and development of the approach. First and foremost, the search for physical survey marks is incomplete. Appendix D shows the location of two potential boundary marks in Cherrybrook and Pennant Hills respectively, that form the long line connecting the northern and central parts of the survey. It also shows ridgetop trig stations J12, O12 and P12, which exist but have not formed part of this study due to their location in dense bushland. Future traverse by total station is an option to determine accurate coordinates for these marks.

Appendix E shows that the south-west finial of St Anne's Church in Ryde has given coordinates. Although the roof has been replaced it is possible to re-establish the location of the mark from surveys in surrounding streets. A search of field book documents from the NSW State Archives has not yet yielded results, however, connections to the old kerb and gutter lines have been noted.

Appendix F shows a diagram of present-day Thompson's Corner in West Pennant Hills, where several observations were made to buildings and structures by Scrivener. Searching through 1943 aerial imagery shows that one such privately owned stone building has remained, and both the south and north-east corners of the structure were recorded by Scrivener.

More broadly, the case study makes it clear that it is important to be more selective with the data entry. In this study, the traverse table was copied in its entirety. In the plan itself though, there are many instances of a traverse following the road patterns in a zig-zag shape, with occasional radiations to boundary marks. The survey can be further simplified by first calculating the boundaries to use as input data into the adjustment. Furthermore, the direct input of boundaries will make it easier to add constraints. Figure 28 demonstrates how several lines of data entry can be reduced to just one line when the straight-line boundary is used.

Figure 28: Detail from Crown Plan 15.440 (sheet 4), showing divergence between the traverse lines and the straight-line boundary (green).

Further improvements are possible by drawing from data in Scrivener's alignment plans and Crown Plan 386.2030 to fill missing gaps and create more redundancy. Unlike the addition of modern Deposited Plans, the integration of such survey data with the current model is easier due to the consistency of surveyor, instruments and survey marks placed. Investigation into the relationship between this plan and aligned streets is also warranted. The many alignment stones within City of Ryde (de Belin, 2014) will further strengthen the solutions generated by Scrivener's plan from 1883.

8 CONCLUDING REMARKS

Opportunities exist to fix original road alignments and portion boundaries in their original positions. There will be areas of hiatus and overlap between the modern DCDB and the old cadastre of Ryde, which has been based on Scrivener's original Lands Department subdivisions. There is an opportunity to predict where such discontinuity may occur and therefore prepare for such clash points. The current notion of leaving all the cadastral discrepancy within the road reservation may finally come to an end.

Upgrading the spatial accuracy of the cadastre can be a tedious task. The method presented in this paper, which involves utilising older large-scale survey data, is just one of many possible solutions that can be used. This study demonstrates that positional uncertainty of <0.5 m can be achieved over a large area without significant back-capture required. In the case study presented, this method does add some value, in most cases reducing the discrepancy between true boundary positions and the DCDB boundary.

Therefore, it is suggested that this approach is useful in areas prone to large errors or more remote areas. For urban areas in which much modern survey work has been undertaken and the cadastre is relatively stable, there are still benefits in examining older plans such as Crown Plan 15.440, including their usefulness in providing checks that help to bind the cadastre together. The primary advantage of utilising older survey data over other methods is that it is far easier to interpret the intentions of the original surveyor and use road patterns to lock lines in place. In this form of adjustment, there is ultimately still a strong link between the coordinated cadastre and the land titles which underpin it. In principle this method uses a 'whole to the part' approach, which nudges the DCDB away from the conventional role of the cadastral surveyor, which is to fit their subject land within just the surrounding properties.

As it stands, most government agencies in Australia have accepted the importance of the spatial accuracy of the DCDB. Undeniably, a comprehensive back-capture of all survey plans is still the most thorough approach. The current undertaking by the Victorian Government (VIC Government, 2021) suggests that public demand has made this a viable option, where previously the level of resources required was considered too great. However, that is not to say that there are other suitable proposals for different places with different needs, including the use of Crown Plan data. Regardless of the method of improving boundaries, the challenge that follows is the integration of spatial improvements into the DCDB itself. How will this data and metadata be managed? What is the best way to implement a system that can incorporate accuracy and precision values within the DCDB?

The end goal is allowing users to quickly and conveniently locate legal property boundaries and know what kind of accuracy they are working with. This starts with having a solid and stable cadastral framework on which we can build better boundaries.

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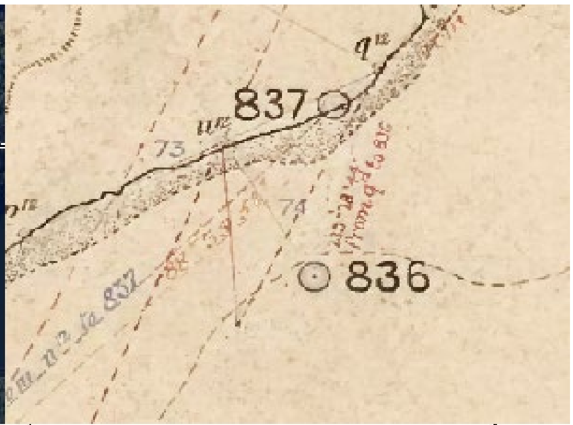
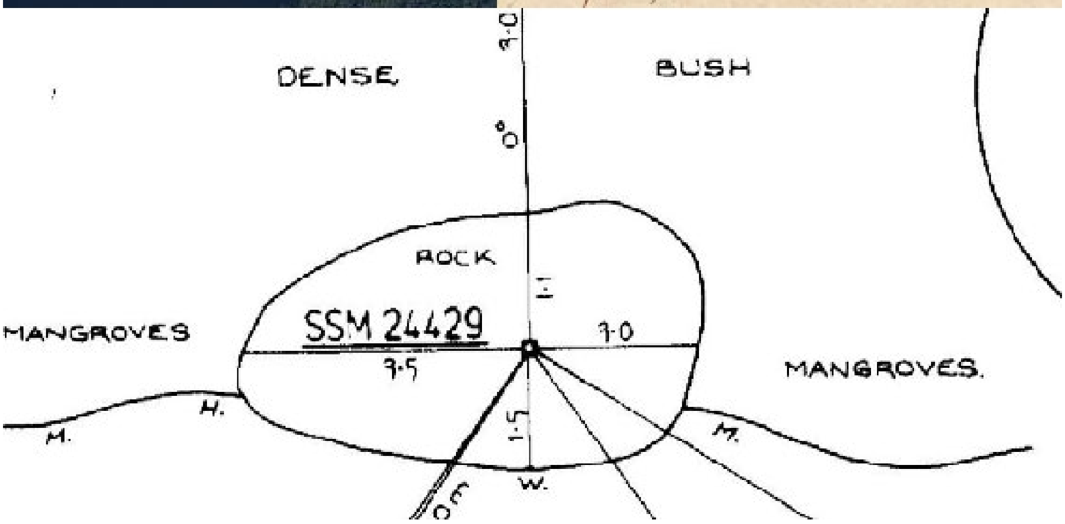
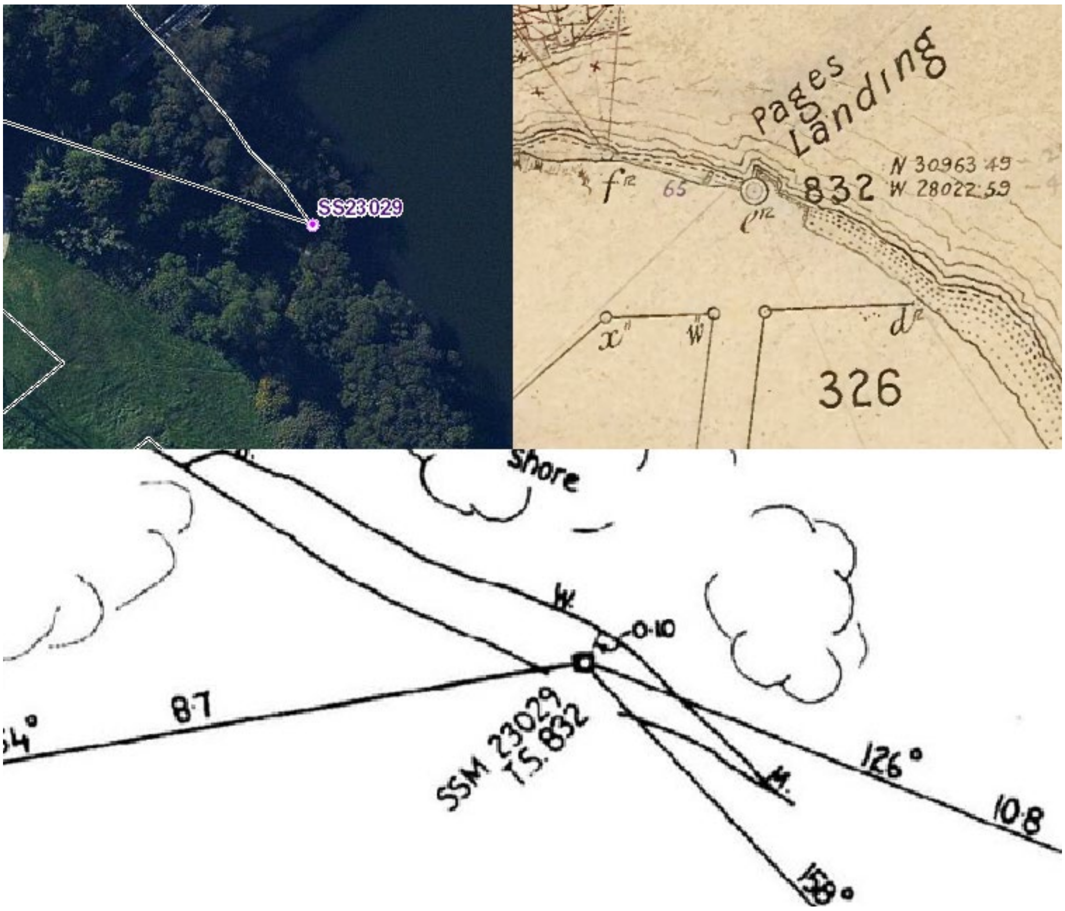
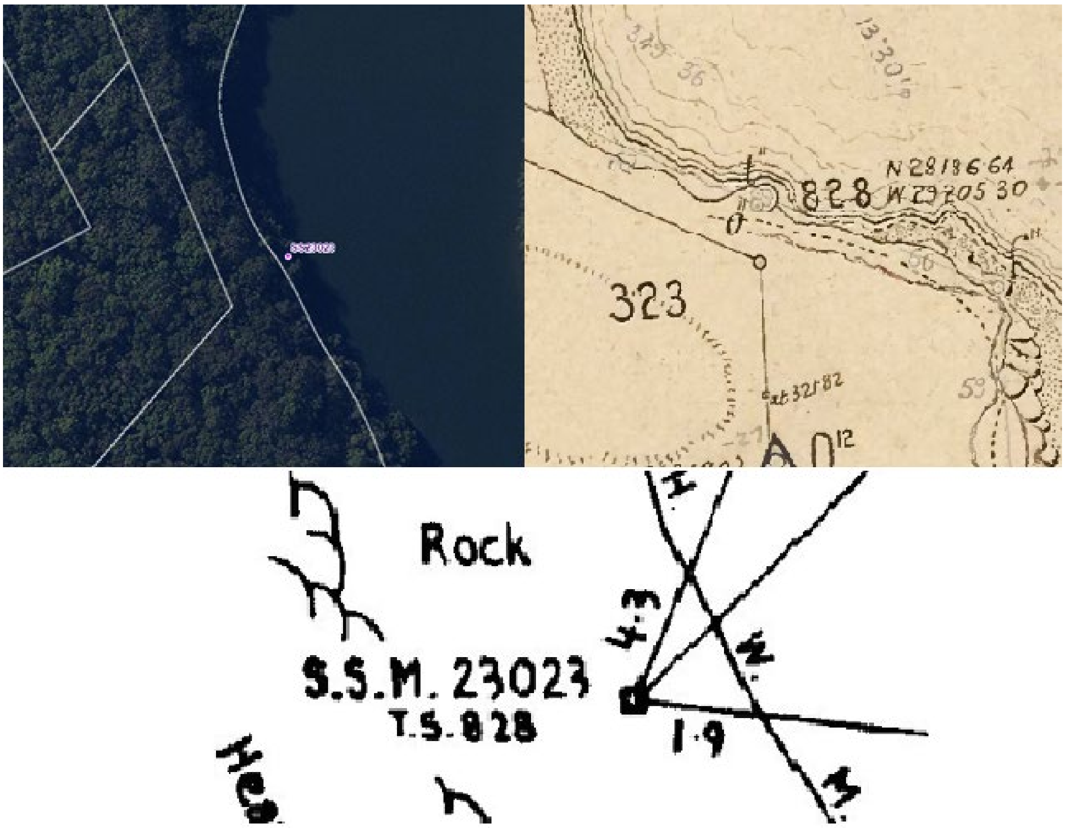
APPENDIX A

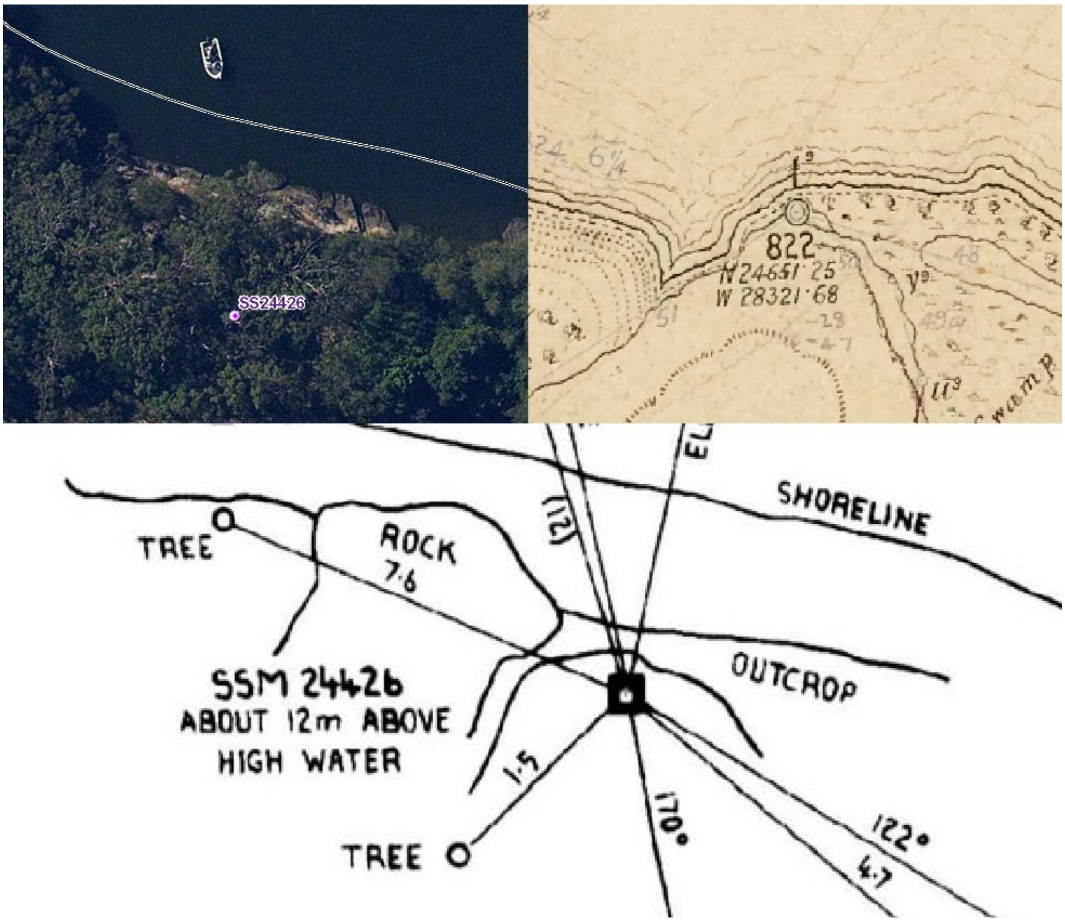
Details of several historical survey marks that were used as the sites for SSMs in 1979 and 1980 by the Maritime Services Board of NSW, in connection with hydrographic surveys of the Lane Cove River. Detail from Crown Plan 15.440 is shown along with detail and locality sketch from SIX Maps/DCDB. TS2276 GORDON has only two bearing connections to Scrivener's survey (to trig stations 013 and P13). The SCIMS coordinates for this mark have an unknown source and as such were considered unreliable.

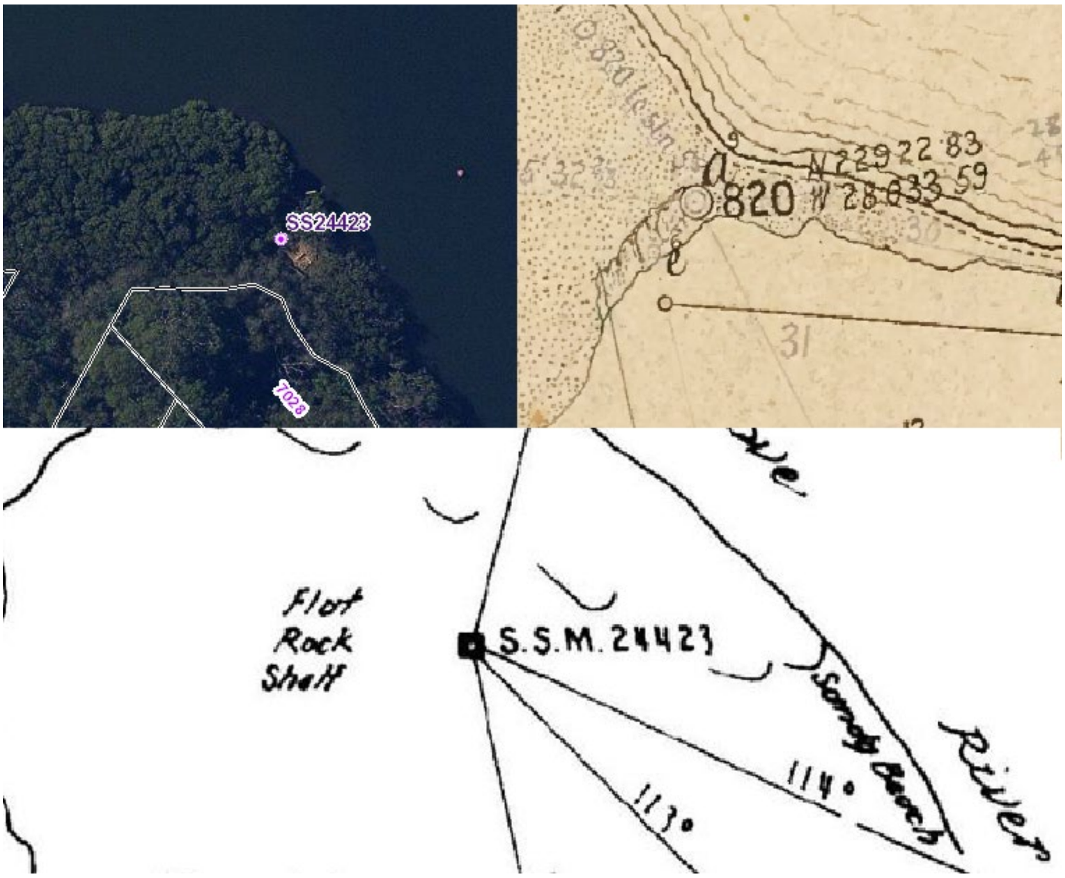


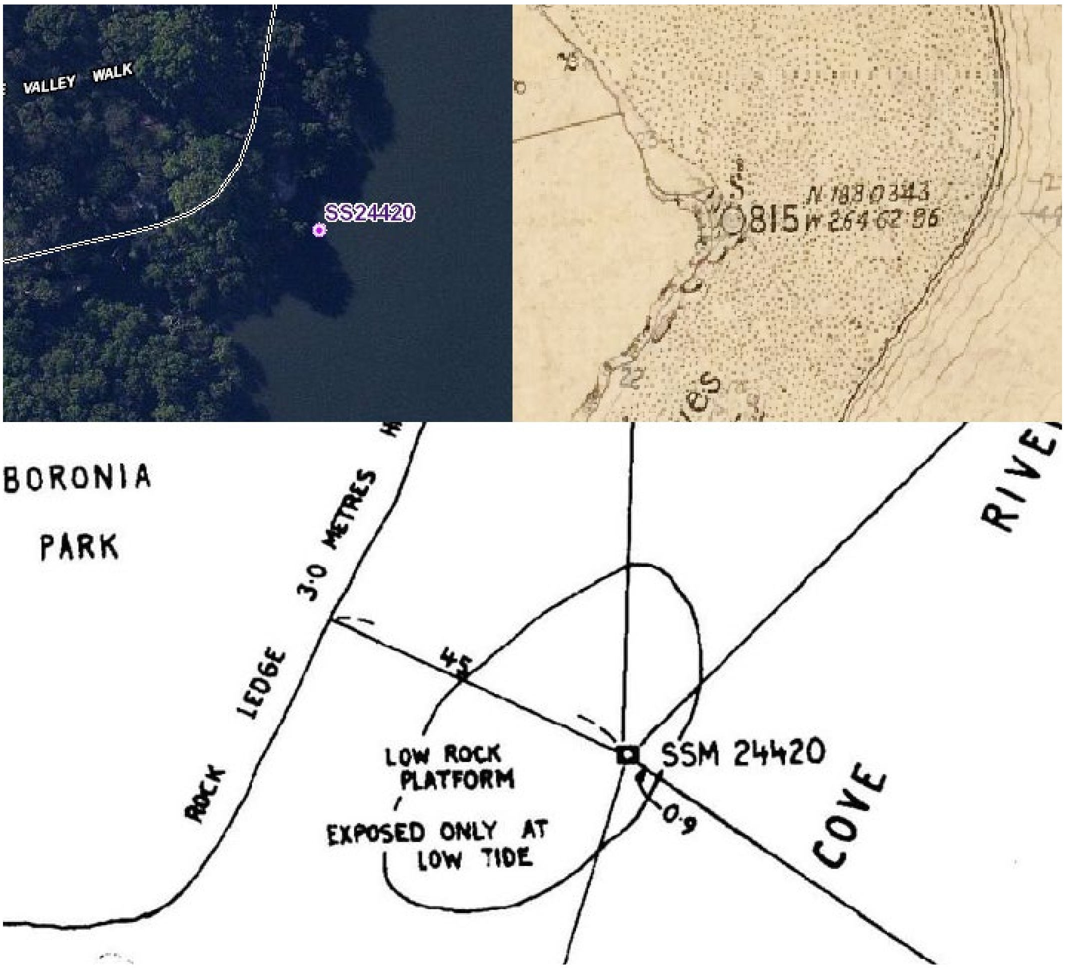


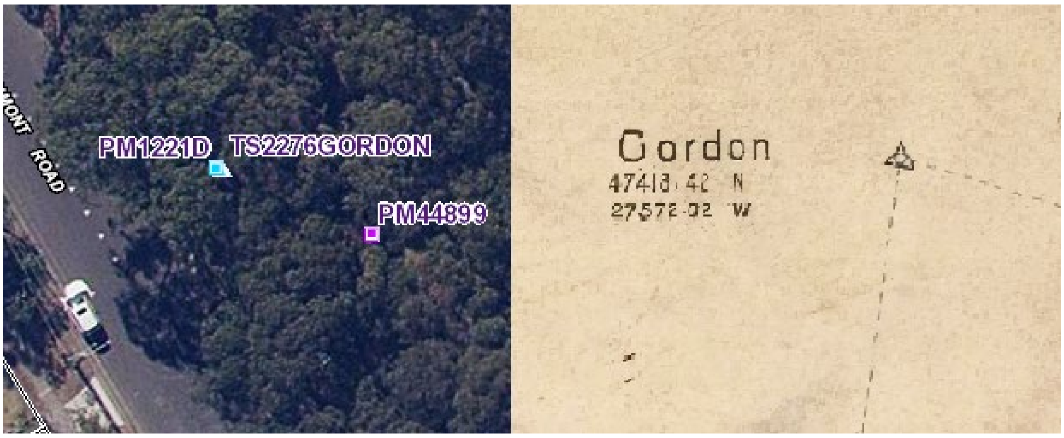

SS23029
Pages Landing
832
N 30963 49
W 28022 59
326
Shore
0·10
8·7
SSM 23029
T.S.832
126°
10·8


828
N 28186 64
323
Rock
S.S.M. 23023
T.S. 828
4·3
1·9


SS24426
822
N 24651·25
W 28321·68
SHORELINE
TREE
ROCK
7·6
OUTCROP
SSM 24426
ABOUT 12m ABOVE
HIGH WATER
1·5
TREE
170°
122°
4·7


SS24423
7028
820
N 22922·83
W 28033·59
31
Flat
Rock
Shelf
S.S.M. 24423
114°
113°
Sandy Beach
River


VALLEY WALK
SS24420
815
BORONIA
PARK
3·0 METRES
ROCK LEDGE
45
LOW ROCK
PLATFORM
EXPOSED ONLY AT
LOW TIDE
SSM 24420
0·9
COVE


ROAD
PM1221D
TS2276GORDON
PM44899
Gordon
47418·42 N
27572·02 W

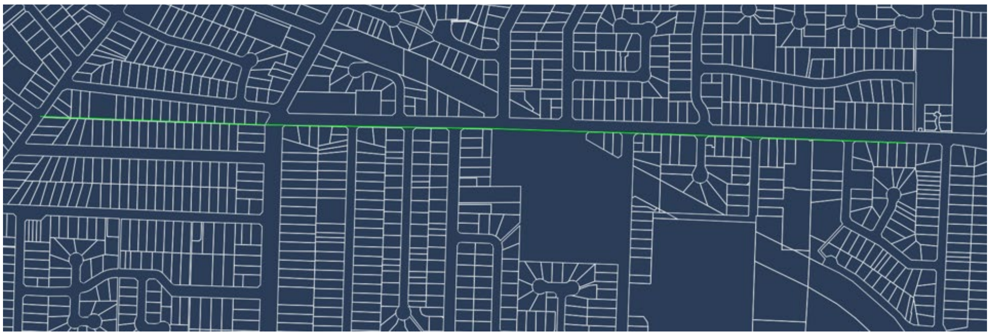
APPENDIX B

Results of the comparison analysis of a subset of 18 locations, which have both fixed boundaries and intersection points with Scrivener's survey.

Location	Distance between boundary as surveyed and DCDB (m)	Distance between boundary as surveyed and least squares model (m)
Moncrieff Dr & Pate Ave	0.431	0.098
Moncrieff Dr	0.192	0.094
Wolfe Rd	0.602	0.363
Blue Gum Dr	0.692	0.375
Cox's Rd & Cressy Rd	0.427	0.221
Cox's Rd & Cressy Rd	0.245	0.212
Cressy Rd & Magdala Rd	0.183	0.135
Cressy Rd & Pittwater Rd	0.381	0.211
Magdala Rd & Pittwater Rd	0.184	0.186
Magdala Rd & Pittwater Rd	0.311	0.241
Monash Rd & Thompson St	0.162	0.158
Westminster Rd & Thompson St	0.597	0.407
Westminster Rd & High St	0.873	0.434
Westminster Rd & High St	0.351	0.437
High St & The Strand	0.641	0.395
High St & Short St	0.399	0.398
High St & Pittwater Rd	0.357	0.406
Cox's Rd	0.964	0.381

APPENDIX C

Two examples showing where Scrivener's straight boundary line (shown in green) sits in the modern DCDB as a road boundary.



APPENDIX D

Location of two potential boundary marks in rock on Boundary Road in Cherrybrook and Azalea Grove in Pennant Hills respectively, that form the long line connecting the northern and central parts of the survey.

Ridgetop rock-mark trig stations J12, O12, and P12 exist, but these have not formed part of this study due to their location in dense bushland.

APPENDIX E

SIX Map/DCDB detail showing the pinnacle of St Anne's Anglican Church, Ryde, has existing coordinates.

APPENDIX F

Diagram of present-day Thompson's Corner in West Pennant Hills, where several observations were made to buildings and structures by Scrivener. Highlighted is a remaining sandstone building.