Survey Control and Quality Assurance for Aerial Imagery and Elevation Models across NSW

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ABSTRACT

Spatial Services, a unit of the Department of Finance, Services & Innovation (DFSI), provides various imagery and elevation products as part of its ongoing custodial responsibilities to the NSW Foundation Spatial Data Framework. Survey accurate control underpins each of these imagery and elevation products. This paper briefly describes the various imagery and elevation products created by Spatial Services and the accuracy requirements for these products, before examining the survey requirements, processes and practices involved in providing survey control for these products with an emphasis on working in remote locations. Finally, this paper provides a case study on the survey control capture for a large DFSI project that will provide a digital surface model for Western NSW.

KEYWORDS: *Survey control, Digital Image Acquisition System (DIAS), Light Detection And Ranging (LiDAR), GNSS, digital surface model.*

1 INTRODUCTION

The purpose of this paper is to outline the requirements, processes and guidelines related to providing survey control and quality assurance for high-resolution imagery and elevation products captured and produced state-wide by Spatial Services, a unit of the NSW Department of Finance, Services & Innovation (DFSI). Accurate and reliable orthorectified aerial imagery and high-resolution elevation data is critical to effective planning, decision making, change monitoring and risks mitigation across NSW and is utilised by government, industry and the community. Reliable survey control is fundamental to ensuring the integrity of this data which forms part of the NSW Foundation Spatial Data Framework, contributing significantly to economic, social and environmental sustainability in NSW (LPI, 2015).

The state of New South Wales is approximately 800,000 km^2 in size and consists of greatly varied terrain and bioregional landscapes including lush rainforests, rugged mountains, sandy deserts and riverine plains (NSW Office of Environment & Heritage, 2017). Providing survey control and quality assurance for imagery and elevation products across NSW presents an abundance of unique and specific challenges in terms of access, availability of marks on public record in the Survey Control Information Management System (SCIMS – see Kinlyside, 2013), survey techniques, materials, weather and communications. A case study will be presented, outlining a specific survey that provided control and test points for imagery and elevation products, covering an area of approximately 38,000 km^2 in the Western Division of NSW.

2 BACKGROUND

The Survey Operations team functions within DFSI Spatial Services. The primary role of this team is to establish and maintain the State's fundamental survey control network via SCIMS, provide survey support to all internal aerial imagery, elevation and cadastral program and project work, and to liaise with and support other government agencies, the spatial industry and the general public.

A primary objective of the Survey Operations team is to capture, process and deliver survey control and test points to enable the processing and production of imagery and elevation products by DFSI Spatial Services. These products underpin the foundation of Spatial Data Infrastructure (SDI) in NSW and are integral for the generation of topographic maps and verification of spatial datasets within DFSI Spatial Services.

The Imagery and Elevation program and project work consists of:

- Digital Image Acquisition System (DIAS) program, which captures high-resolution 50 cm Ground Sample Distance (GSD) aerial imagery state-wide.
- Digital Town Imagery Capture (DTIC) program, which captures high-resolution 10 cm GSD aerial imagery over cities, towns and villages throughout NSW.
- Surface Model Enhancement (SME) Project, which utilises a variety of technology including aerial imagery and Light Detection And Ranging (LiDAR) to create a high-resolution, state-wide Digital Surface Model (DSM).
- LiDAR program, which captures highly accurate elevation data in high-risk areas across NSW.

3 SURVEY REQUIREMENTS FOR IMAGERY AND ELEVATION PRODUCTS

3.1 50 cm GSD State-Wide Aerial Imagery

3.1.1 Overview

DFSI Spatial Services has been undertaking aerial imagery capture cyclically across NSW since 1947, providing an invaluable dataset for the state of NSW. In order to capture NSW in a methodical and measured way, the State has been divided into 344 map sheets which are produced at a scale of 1:100,000 on A0 paper, whereby each map sheet covers 0.5º longitude by 0.5º latitude or about 54 km x 54 km (DFSI Spatial Services, 2017a), as illustrated in Figure 1. Aerial imagery is captured over 1:100,000 map sheets at a Ground Sample Distance (GSD) of 50 cm using a Leica ADS80 Airborne Digital Sensor mounted in a small aircraft.

As part of the current DIAS program, the Eastern and Central divisions of NSW are captured cyclically approximately every 7 years. As part of the SME Project, the Western Division of NSW is currently being captured with 50 cm GSD aerial imagery for the first time.

Accurate and reliable Ground Control Points (GCPs) are crucial to the orthorectification of the imagery and the accuracy of the resultant products. Orthorectified aerial imagery represents a true flat-earth image whereby each pixel represents the true X/Y/Z value on the ground at that point (Campbell and Wynne, 2011).

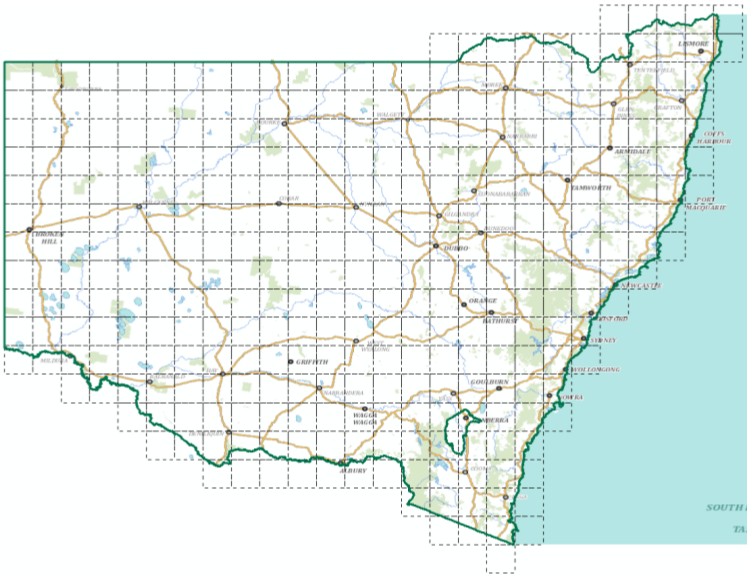

Figure 1: 1:100,000 map grid covering NSW.

Within DFSI Spatial Services, 50 cm orthorectified aerial imagery is primarily used to verify spatial data, for the creation of topographic maps and for the production of Digital Surface Models (DSMs). Externally, 50 cm orthorectified aerial imagery provides a valuable source of information for studying, monitoring, forecasting and managing natural resources, human activities and emergency events. The ongoing cyclical capture of aerial imagery across the State also provides a useful tool for viewing and comparing historical aerial imagery and verifying land uses over time.

3.1.2 Survey Control Requirements

GCPs are placed at the intersection of 1:100,000 map sheets (corners) and provide the ground control for the orthorectification of the aerial imagery. Two points are required for each corner: one primary mark which is a permanent survey mark as per the Surveyor General's Directions No. 1: Approved Permanent Marks (DFSI Spatial Services, 2016) (excluding pillars), and one secondary mark which is used for redundancy and can be a Galvanised Iron Pipe (GIP), iron spike or drill hole and is labelled as a 'CP' in SCIMS. Ideally, control points are placed within 3 km north/south of the corner and 1 km east/west of the corner to allow for the points to easily service all four map sheets.

GCPs are surveyed to an accuracy of 0.17 m horizontal (X/Y) and 0.25 m vertical (Z) with Geocentric Datum of Australia 1994 (GDA94 – see ICSM, 2014) coordinates and measured ellipsoidal height. The survey accuracy requirements are calculated based on providing control that is 3 times better than the stated accuracy of the derived products (0.5 m horizontal and 0.9 m vertical).

Processing of aerial imagery is initially performed using the panchromatic band, so a high-contrast, easily distinguishable target is critical, as illustrated in Figure 2. A 2.4 m x 2.4 m white target on a black background, placed in a cross formation and oriented true north, is placed over both survey marks. The target is oriented true north to correspond with the flight path of the plane and the resultant line of the pixels in the image which results in the target being clearly defined in the image. Targets which are not oriented true north will appear blurred in the aerial images. The size and shape of the target has been specifically chosen to be easily identifiable in the image and to allow the centre point to be accurately selected. The

materials used for the targets have been selected based on a number of factors including cost, weight, availability, ease of use and durability. Currently, targets are constructed from 3 mm whitecoat Masonite nailed over black weed mat – these materials are constantly being reviewed and alternatives discussed and evaluated.

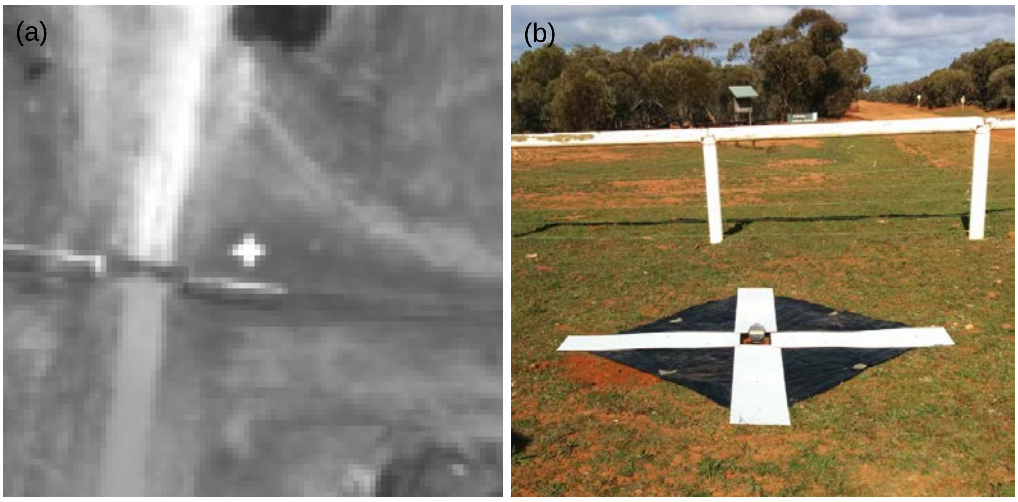

Figure 2: Ground control point (a) as viewed in 50 cm GSD aerial imagery processing software and (b) from the ground.

3.1.3 Test Points

A minimum of three Test Points (TPs) is required throughout each map sheet to check for gross errors in the orthorectification of the imagery. These TPs require an accuracy of 0.25 m horizontal and need to be identifiable in the imagery. Where possible, photo points are used for test points, i.e. existing points on the ground which are easily identifiable in an aerial image, such as the corner of a concrete slab, the corner of a large road marking (e.g. a 40 km/h sign) or the intersection of paths. Where a photo point cannot be found, a 3-wing 'T' shaped target can be placed over a survey mark, as illustrated in Figure 3. A 'T' shaped target has been selected to avoid confusion with GCPs while still being easily identified in imagery.

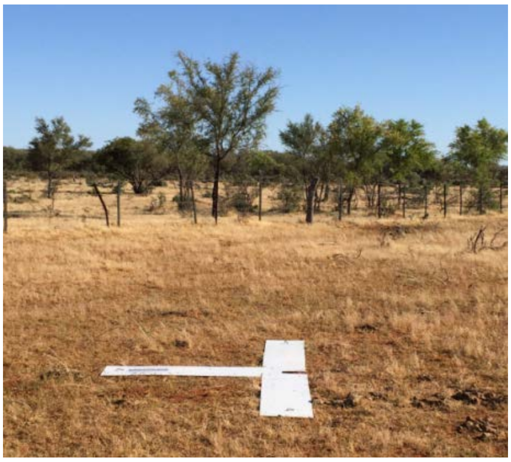

Figure 3: Example of a test point for 50 cm GSD imagery.

As is discussed in section 3.3.2, a number of test points are required to test the elevation models derived from the aerial imagery. These vertical test points can be paired with the imagery test points so that one point is able to serve two separate purposes.

3.2 10 cm GSD Town Aerial Imagery

3.2.1 Overview

As part of the Digital Town Imagery Capture Program, DFSI Spatial Services captures high-resolution digital aerial imagery for towns across NSW with a population of 400 people or greater and may capture smaller villages with significant growth or activity (Figure 4). Aerial imagery is captured over customised Areas Of Interest (AOI) at a Ground Sample Distance of 10 cm using a Leica ADS80 Airborne Digital Sensor mounted in a small aircraft. For high-population centres such as Sydney, Newcastle or Wollongong, DFSI Spatial Services may engage the private sector to assist with imagery capture and survey control to agreed specifications.

Figure 4: 10 cm GSD orthorectified aerial imagery.

The forward program for the capture of 10 cm GSD aerial imagery of towns and villages has been aligned with the capture of 50 cm imagery over 1:100,000 map sheets to allow survey work and imagery capture to be completed in one trip, and as such this imagery is updated approximately every 7 years. In areas of rapid growth or activity or where a specific request has been made, DFSI Spatial Services may elect to capture a town or village outside of this forward program. 10 cm GSD aerial imagery is a valuable resource for the whole of government and may not always be available to the general public. Local Government utilises this imagery for asset capture, planning and risk mitigation.

Due to the resolution of the imagery, it is integral that highly accurate and clearly identifiable GCPs are established for 10 cm GSD aerial imagery to ensure the usability of the resultant orthorectified imagery.

3.2.2 Survey Control Requirements

A minimum of 6 GCPs are required within the specified AOI for 10 cm aerial imagery, with one GCP per corner of the AOI (if possible) and an even distribution in the centre of the AOI. For larger towns, it is advisable to use more GCPs to provide redundancy and confidence in the end product.

Survey control for 10 cm aerial imagery requires a survey accuracy of 0.05 m horizontal (X/Y) and 0.07 m vertical (Z) with GDA94 coordinates and measured ellipsoidal height. As is the case with 50 cm GSD imagery, initial processing of the imagery is performed using the panchromatic band so a high-contrast, easily distinguishable target is critical (Figure 5). Targets for 10 cm GSD imagery are white 0.5 m x 0.5 m crosses oriented true north. Where possible, these GCPs are painted on roadways using a stencil and white exterior paint with a Galvanised Iron Nail (GIN) as the centre mark. Otherwise, a 0.5 m x 0.5 m target is constructed from whitecoat Masonite nailed over black weed mat or a photo point is selected.

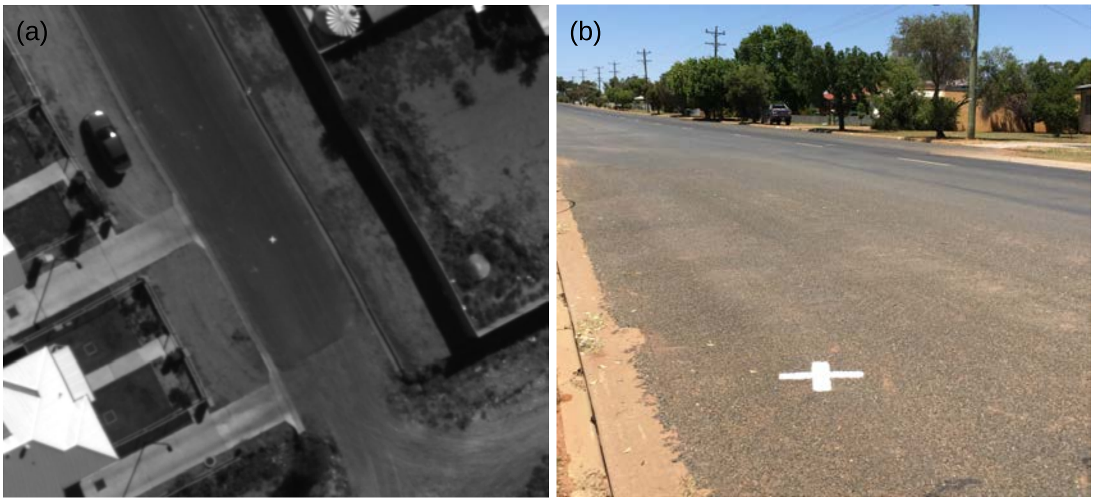

Figure 5: Ground control point (a) as viewed in 10 cm GSD aerial imagery processing software and (b) from the ground.

3.3 Surface Model Enhancement Project

3.3.1 Overview

The Surface Model Enhancement (SME) Project aims to deliver a high-resolution, state-wide Digital Surface Model (DSM) consistent with the Intergovernmental Committee on Surveying and Mapping (ICSM) Guidelines for Digital Elevation Data (ICSM, 2008). A Digital Elevation Model (DEM) will be derived from the DSM and will be used in the National Elevation Data Framework managed by ANZLIC, the Spatial Information Council (ANZLIC, 2017).

The SME Project commenced in 2014 after DFSI Spatial Services initiated a cost-benefit analysis, which identified the need for and immense benefits of a state-wide DSM. The SME Project will provide key benefits to Whole of Government including improvements in emergency services management, change detection, strategic development planning, compliance and insurance pricing, natural resource management, and law enforcement strategies.

The project integrates category 3 airborne LiDAR and surface models derived from 50 cm GSD aerial imagery to create the DSM to an accuracy of ±0.9 m Z (vertical) at 95% confidence interval and ±0.5 m horizontal at 95% confidence interval with a DEM being derived from this and output at an accuracy of 5 m. The DSM is processed and output using the 1:100,000 map sheet grid covering NSW as per 50 cm imagery (see section 3.1.1). The quality assurance of the DSM and DEM is a critical business function of the SME Project and is reliant on quality survey-accurate test points.

3.3.2 Test Points

The DSM and DEM produced are processed using ellipsoidal heights and applying a geoid model (currently AUSGeoid09) to derive the final products in the Australian Height Datum (AHD). A minimum of 6 test points are required per 1:100,000 map sheet with an even distribution across the sheet. As the geoid model is being utilised to derive an AHD product, it is critical that the accuracy of the geoid model is also tested in each map sheet. This is accomplished by establishing ‘measured’ AHD on a minimum of 3 test points per map sheet and comparing the values to the derived heights. These TPs require an accuracy of 0.25 m horizontal (X/Y) and 0.25 m vertical (Z). As these points are used to check the vertical accuracy of the DEM, they do not need to be identifiable in imagery and are simply an area of open, flat or uniformly sloping bare earth (Figure 6), which is located on the model using the horizontal coordinates of the point.

Figure 6: A typical test point used for testing the DEM produced for the SME Project.

Site selection is extremely important with test points used for quality assurance of elevation models as points selected near severe terrain changes or breaks in slope (e.g. culverts or structures) can result in the point being selected on the wrong side of the break line in the DEM.

3.4 LiDAR

3.4.1 Overview

Light Detection And Ranging (LiDAR) is an active remote sensing technology that uses light in the form of laser pulses to measure ranges (variable distances). Airborne LiDAR is used by DFSI Spatial Services to capture highly accurate elevation data over areas considered to be most at-risk within NSW with a particular focus on the coastline (Figure 7). It has also been utilised as part of the SME Project in areas of high vegetation or large elevation changes where the creation of a DSM from aerial imagery is impractical or where LiDAR has already been captured. LiDAR provides a superior DSM in comparison to other technologies, particularly in coastal, built up or highly vegetated areas. There are a number of limitations which prevent LiDAR technology being utilised as the sole technology for the creation of a state-wide DSM as part of the SME Project, with the major drawback being the cost of capture and the timeframe required for capturing and processing this data.

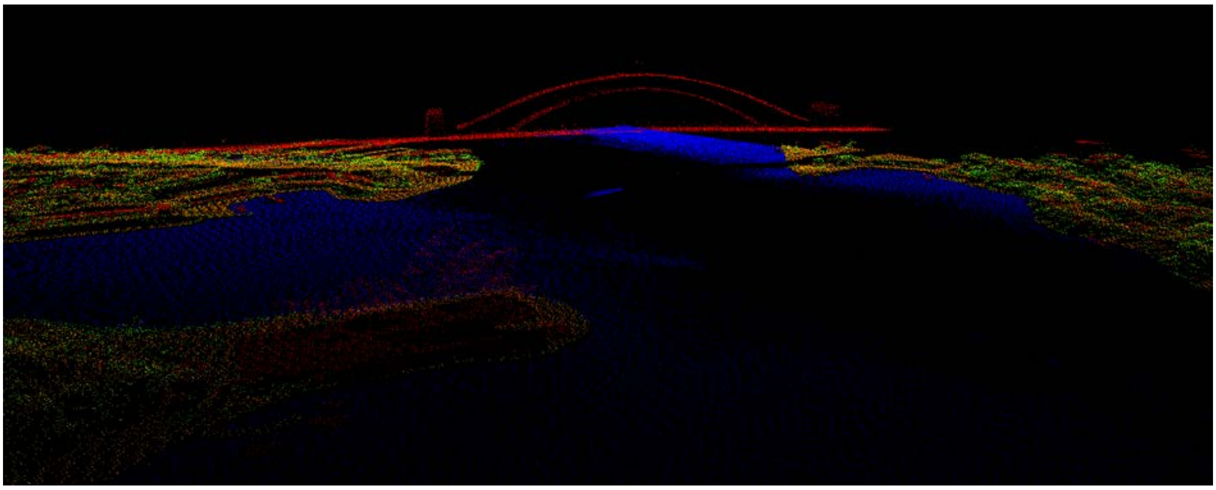

Figure 7: Classified LiDAR point cloud as captured over Sydney Harbour Bridge.

DFSI Spatial Services uses a Leica ALS50 Airborne LiDAR Sensor mounted in a small aircraft to capture point cloud data at a range of point densities and levels of classification in accordance with the ICSM Guidelines for Digital Elevation Data (ICSM, 2008). Category 1 LiDAR boasts a vertical accuracy of ±0.3 m at 95% confidence interval with one point captured per square metre and is primarily used for capturing elevation data over areas which have been identified as high risk. Category 3 LiDAR is captured at one point per four square metres which creates a DSM with vertical accuracy of ±0.9 m at 95% confidence interval and is utilised in the SME Project. Understandably, accurate and reliable test points are fundamental for determining the vertical accuracy of the LiDAR.

3.4.2 Test Points

Specifications for test points for category 1 LiDAR are given in the 'Elevation Products Data Specifications and Descriptions No. 2' written by DFSI Spatial Services in alignment with ICSM (2008). A minimum of 5 points per 1,000 km^2 with both an accurate AHD height (SCIMS Class B/LD or better) and measured ellipsoidal height. As is the case with SME Project test points, these points do not require any physical marking on the ground as they are testing a point cloud. Test points need to be in open, flat or uniformly sloping bare earth (see Figure 6), with a horizontal coordinate provided to an accuracy of 0.5 m used to locate the point in the cloud. The accuracy requirements for test points for category 3 LiDAR are the same as those required for the SME Project (see section 3.3.2).

4 CASE STUDY

4.1 Overview

As part of the SME Project, the Survey Operations team was tasked with providing survey control and test points for 1:100,000 map sheets being captured with 50 cm GSD aerial imagery in the Western Division of NSW. The area to be captured consisted of over 120 map sheets covering approximately 350,000 km^2 or 40% of NSW and included some of the most remote parts of the State.

The SME Project is a 5-year project that commenced in 2014, and the capture and processing of 50 cm GSD aerial imagery is an integral component to the success of the project. There are

a number of factors which affect the capture of imagery across the State and these had to be factored into a 4-year forward plan for providing the survey control, imagery capture and output within the set time frames. Key factors that were taken into account on this plan were:

- Solar altitude: In the Central and Western Division of NSW, aerial imagery can only be captured when the solar altitude is >35º and in the Eastern Division >40º in order to minimise shadows in the imagery. Consequently, a solar altitude map has been constructed to assist with planning (Figure 8).
- Longevity of GCPs: It is recommended that imagery is captured within 3 months of placing GCPs to guarantee the quality of the points. However, targets can last much longer in good circumstances.
- Weather: Aerial imagery can only be captured when there are no clouds in the sky so as to prevent shadows in the imagery. Due to the Western Division of NSW consisting of ‘dry weather only’ roads, the Survey Operations team is limited by weather with roads being closed in wet weather. For Work Health and Safety reasons, the Survey Operations team does not work in the far west of the State during summer due to extreme temperatures.
- Resources: Field work for survey control is captured over 2-week periods and is resource intensive in terms of team members, vehicles, equipment and materials, so this must be factored in during planning.

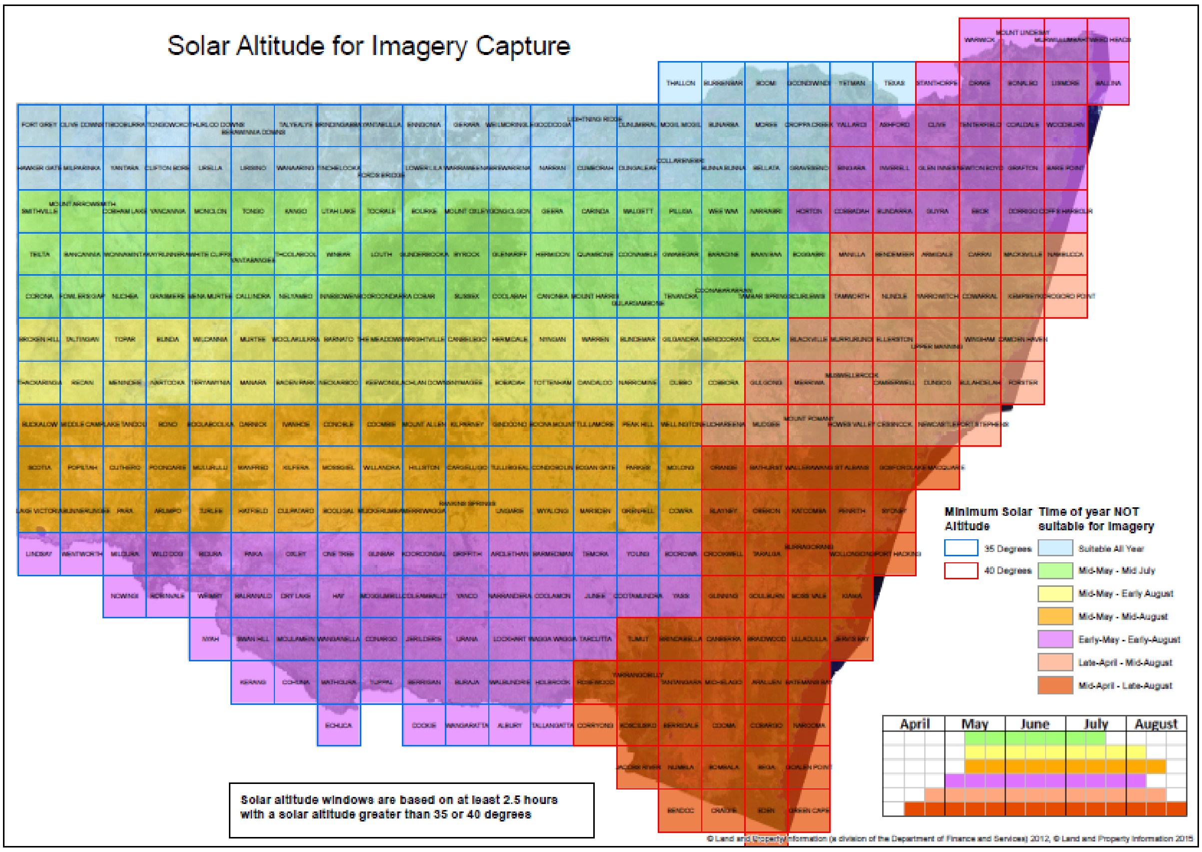

Figure 8: Solar altitude map for imagery capture over NSW.

The Survey Operations team, in co-operation with the Imagery and Elevation team and the SME Project team, created a preliminary forward plan for survey ground control and imagery capture which saw the area broken up into blocks of 10-12 map sheets to be captured in spring, winter or autumn. The forward plan (Figure 9) is flexible and has been amended as the project progressed. Where conditions such as weather, access and availability of resources

were ideal, more sheets were captured (up to 16 in one trip). High rainfall over the winter of 2016 resulted in delays for capturing survey control and imagery and as a result the plan has been amended to allow extra field work to be undertaken in 2017 within the deadlines of the project.

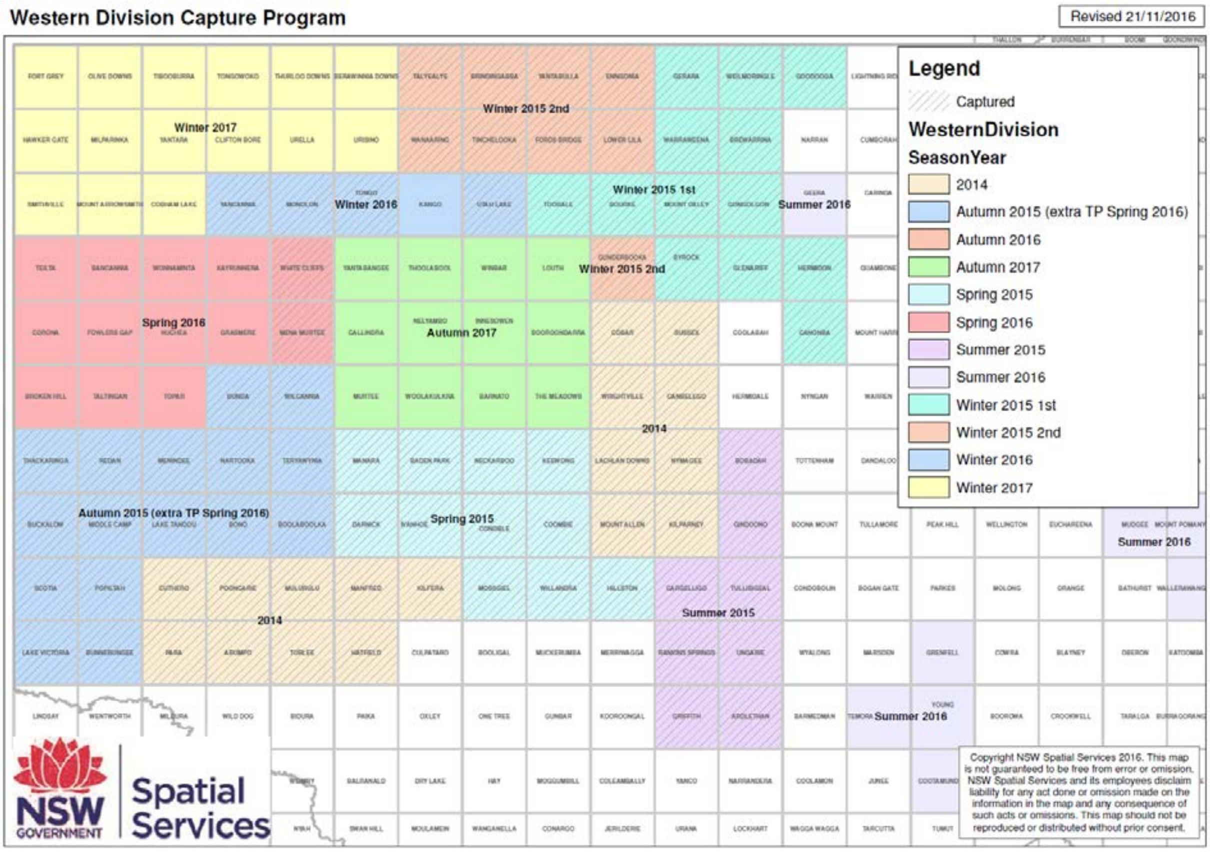

Figure 9: The Western Division Capture Program as of November 2016.

4.2 The Task

The job, labelled ‘Spring 2016’ in the ‘Western Division Forward Plan’ (see Figure 9), covered an area of approximately 38,000 km^2 and was located in the Unincorporated, Broken Hill and Central Darling Local Government Areas, including the townships of White Cliffs, Packsaddle and Broken Hill (Figure 10). The job was a day’s travel from the office in Bathurst and was completed using an 8-person survey crew with four vehicles.

The scope of the job was to provide ground control and test points for thirteen 1:100,000 map sheets to be captured with 50 cm GSD aerial imagery as well as providing test points for the derived DEM. In addition, the team was asked to provide survey control for one town to be captured with 10 cm GSD aerial imagery and to complete a Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) tie survey (Gowans and Grinter, 2013) whilst in the area.

Initially, the survey work was scheduled for September 2016 to align with the Aerial Survey Unit (ASU) schedule for imagery capture. However, this was delayed until November 2016 due to ongoing rainfall, resulting in many parts of the job being inaccessible.

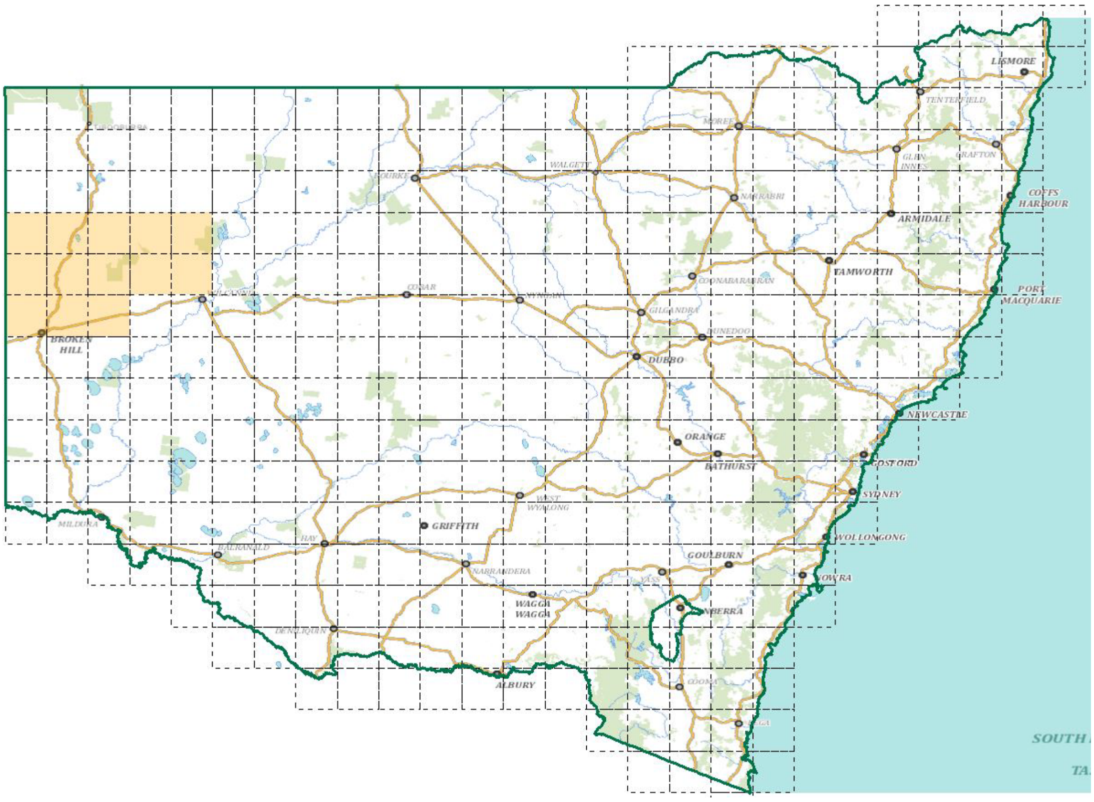

Figure 10: Location of the required survey control within NSW.

4.3 Survey Requirements

Due to the configuration of the 13 map sheets, there were a total of 22 corners requiring two ground control points each. Of this, 9 corners had not previously been surveyed, which meant that an existing survey mark would have to be located or Permanent Marks placed and surveyed for each of these corners. 18 of the corners were located on private property, so land owners had to be contacted and permission gained to access these locations. Static GNSS baselines from established marks and AUSPOS solutions (GA, 2017) were utilised for gaining horizontal position and ellipsoidal heights on new marks.

A minimum of 6 vertical test points were required for each map sheet to test the DEM to be derived from the imagery for the SME Project, which equated to 78 points evenly distributed throughout the job requiring measured ellipsoidal height. At least half of these also required measured AHD to verify the geoid model in this area. Three test points per map sheet also required physical marking on the ground that is identifiable in an aerial image to test the orthorectification of the imagery, equating to 39 marks with a 'T' shaped target.

The township of White Cliffs was identified as requiring 10 cm GSD aerial imagery as it had not been previously captured with high-resolution aerial imagery. Targets were placed by the aerial survey unit on a previous job, and as such only survey work was required for these points. The Real-Time Kinematic (RTK) GNSS technique was utilised for establishing these marks, using CORSnet-NSW's White Cliffs CORS as reference station.

Fowlers Gap CORS was constructed in October 2016 as part of the continuing expansion of the CORSnet-NSW positioning infrastructure (Janssen et al., 2016; DFSI Spatial Services, 2017). Due to the remote location of this CORS, it made sense to incorporate the local tie survey (to connect the CORS to existing surrounding ground control) into this job.

4.4 Planning

Due to the variety and scale of work to be undertaken as well as the remote location of the job, thorough planning and preperation was critical to undetaking the work in an efficient and safe manner whilst delivering within set time frames. A survey party leader was appointed the task of organising the planning, capture, processing and delivery of this job.

Initial planning of the job identified minimal survey control in the area, especially in horizontal position and with two map sheets having no AHD marks within them (Figure 11). Furthermore, 8 of the 13 map sheets contained ‘dry-weather only’ dirt roads and 2 of these did not contain any public roads. Gaining access to all of the required locations throughout the map sheets and establishing survey control to the accuracies required for 50 cm GSD imagery and the SME Project was the first consideration in planning this job, followed by predicted travel times to and between marks, required materials and resources.

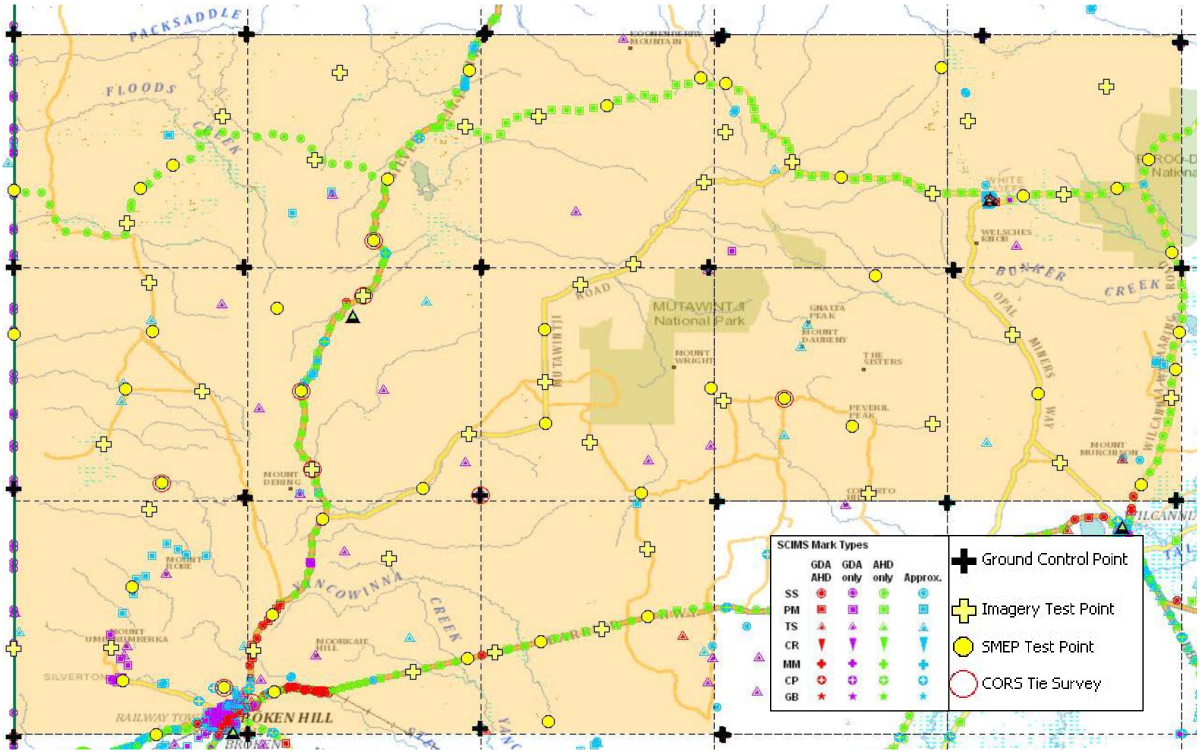

Figure 11: Planning location and survey for Ground Control Points and Test Points throughout the AOI.

Using ArcMap, a shapefile was created which identified desirable locations for GCPs and TPs, attribute data to be assigned to each point in regard to the survey required for it, whether it was on private property and, if so, contact details for the land owner. This file was used to create hard copy maps as well as being loaded on to ArcPad on tough book computers to be taken into the field and used for navigation.

The survey was designed utilising static GNSS baselines, AUSPOS solutions, RTK/NRTK and differential levelling. Each mark had different survey requirements depending on its use and location within the job.

A preliminary plan was designed to allow the survey control to be established in the safest and most efficient way. This was used to allow accommodation to be booked and land owners to be contacted and given expected dates of the work. The required paperwork included

Locality Sketch Plans, control point information, owner details and maps in order to allow for planning to be adapted during the course of the field trip as work progresses faster or slower than anticipated.

4.5 Resources

The job was undertaken in a 2-week window by an 8-person field party consisting of four Surveyors and four Survey Assistants, working in teams of two. Four vehicles were used, each equipped with long range fuel tanks, driving lights, HF radios and winches to allow work to be undertaken safely in remote locations (Figure 12).

Figure 12: Vehicles fuelling up in Packsaddle.

Each team was equipped with 5 GNSS receivers, 5 tripods, a spirit level, fixed tripod, levelling staff, bipod, hand tools, first aid kit, vehicle recovery kit, personal locator beacon, Toughbook computer and GPS navigator. Two brush cutters and two Satellite SPOT rovers were also taken and allocated to teams based on work requirements each day.

Materials were purchased prior to the trip and taken to the job in a trailer. This included 38 sheets of 3 mm Masonite cut into 300 1.2 m x 0.3 m ‘wings’, 4 rolls of weed mat, 4 boxes of 150 mm flat head nails, 120 star pickets for protecting survey marks, 80 Galvanised Iron Pipes, 12 cover boxes and 12 galvanised iron star pickets for placing Permanent Marks.

4.6 Setbacks and Challenges

Weather is a major concern when planning work in the Western Division of NSW as rain can result in road closures for several weeks and can leave properties inaccessible for much longer. The trip was initially scheduled for the start of October 2016, and 5-10 mm of rain was predicted in the first week of the trip. Fortunately, the rain arrived on the Sunday before the trip commenced and was much higher than expected, which resulted in road closures for over a week and several properties being inaccessible for up to a month. As a result, the trip was postponed until November – by then the roads had been re-graded and properties were accessible.

Placing ground control points within a few kilometres of the intersection (corners) of 1:100,000 map sheets often poses a challenge in terms of access as these corners can be located on private property, in protected areas (e.g. National Park or conservation area), in rugged terrain or high vegetation areas. Identifying land owners and gaining permission to place control points on private property is a critical step in planning for this type of work.

Within this job, there were two land owners that could not be contacted prior to the trip. In both cases, the solution was to call the neighbouring properties and ask for assistance in making contact with the land owners before going on the property.

As mobile phone reception is scarce in this part of the State, high-frequency (HF) radios are utilised for communication between the survey parties. Several days into the trip one of the radios malfunctioned and could not be repaired, resulting in one field team having minimal communications. In order to mitigate this issue, the team with minimal communications were tasked with work along major roads and in areas of known mobile phone reception, were given a SPOT satellite navigation unit (allowing them to be tracked and to send distress signals). Where possible, this team did not undertake survey work that required static GNSS baselines to other parties.

Issues with access to corners that have not been surveyed previously can often cause major delays as roads or tracks can be impassable, non-existent or extremely rough. One particular map sheet in this job had had new roads graded since the last topographic maps were made and as a result the roads that were shown on maps no longer existed, resulting in a 4-hour delay for one team as they navigated to the required points. Using HF radio communication with a nearby team, the impact of this delay was able to be minimised as work could be redistributed between teams.

Large numbers of wildlife and livestock on roads and tracks in the Western Division of NSW present a constant hazard when driving between survey marks (Figure 13). By ensuring that work is concluded before dusk each day and teams drive to the conditions and with caution, the likelihood of a collision with an animal is minimised. However, it is impossible to eliminate this risk. Unfortunately, during the course of this job, an emu hit a stationary vehicle causing cosmetic damages to the vehicle.

Figure 13: Animals present a constant hazard on roads in the Western Division of NSW.

Upon processing and performing a least squares network adjustment using the data collected on this job, it was found that there was a number of disagreements between established GDA94 horizontal marks and also between established AHD marks throughout the network. Further analysis and amended network design was utilised to identify survey marks which had suffered movement and no longer agreed with surrounding marks.

4.7 Deliverables

Due to favourable weather conditions, straight forward accesses, the ability to utilise survey work completed by DFSI Spatial Services staff earlier in the year and minimal equipment

malfunctions or other setbacks, the job was finished 4 days ahead of schedule. As a result, the field party was able to complete extra SME Project test points for 12 map sheets south of this job as well as a local tie survey for Ivanhoe 2 CORS. In total, 13 map sheets were provided with survey control for 50 cm GSD aerial imagery, 25 map sheets were provided with test points for quality assurance of the DEM for the SME Project, one town was provided with survey control for 10 cm GSD aerial imagery, and two local tie surveys were undertaken for newly built CORSnet-NSW stations.

Post-processing of survey data was carried out in the office using Leica Geomatics Office, and two least squares network adjustments were performed to establish and verify horizontal position, AHD height and ellipsoidal height for all GCPs and TPs. All 1+ hour GNSS sessions were submitted to AUSPOS (GA, 2017), and all 6+ hour GNSS sessions were submitted to be utilised in the national GDA2020 adjustment in order to contribute to Australian datum modernisation efforts (Gowans, 2017). A survey report was written, SCIMS was updated and the required results were delivered to the Imagery and Elevation team and the SME Project via a 'Control Point' database in ArcMap.

5 CONCLUDING REMARKS

On behalf of the Surveyor General, DFSI Spatial Services has a legislative, regulative responsibility to maintain the geodetic control network in NSW. Accurate and reliable survey control is essential to the production of high-resolution orthorectified imagery and high-accuracy elevation models produced by DFSI Spatial Services as part of the NSW Foundation Spatial Data Framework. Imagery and elevation products produced by DFSI Spatial Services are highly beneficial resources for both government and private stakeholders and are necessary for supporting analytical and planning functions across NSW.

The Survey Operations team, in conjunction with the Imagery and Elevation team, has developed standards and guidelines for delivering ground control points and test points in accordance with the ICSM guidelines to ensure the accuracy specification of imagery and elevation products is surpassed.

This paper has outlined that providing ground control points and test points across NSW for imagery and elevation programs and projects presents an abundance of unique and specific challenges, which can be addressed and mitigated through thorough planning and preparation. Capturing the Western Division of NSW with aerial imagery as part of the Surface Model Enhancement Project has allowed the Survey Operations team to develop a number of strategies for working in remote locations where communication, vehicular access and survey control are all limited and weather can cause significant setbacks.

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