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Photogrammetry UAV and terrestrial LiDAR, A comparative review in Volumetric surveys

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Contents

Abbreviations

AHD	Australian Height Datum
CAD	Computer Animated Drawing
DEM	Digital Elevation Model
DTM	Digital Triangle Model
EDM	Electronic Distance Measurement
EPA	Environmental Protection Authority
GCP	Ground Control Point
GPS	Global Positioning System
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Systems
GSD	Ground Sampling Distance
GSR	Ground Sampling Resolution
LiDAR	Light Detecting and Ranging
LAS	LASer 3D file format
LAZ	Variation of LAS format
MGA	Map Grid of Australia
SSM	State Survey Mark
TS	Total Station
TSS	Total Station Survey
TPS	Total Positioning System
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
RPAS	Remote Piloted Aircraft System

1 Abstract

This research paper will compare and analyse the survey from two methods of Remote Sensing techniques, Terrestrial LiDAR used as the base survey, and UAV Photogrammetry as the comparison survey for use in Landfill volume reporting.

Managing landfills generally requires adherence to local Environmental laws, and as such can include reporting on key metrics about the site including waste volume increase and remaining airspace in waste cells – important in end of cell life management and relaying on-costs to site users. These surveys have traditionally been recorded manually using GNSS GPS or Total Station techniques which can be dangerous to survey staff – oftentimes being exposed to the landfills harmful waste material. Remote sensing may be able to provide better data, faster, cheaper and eliminate exposure to harmful waste.

While extensive research has been undertaken in comparing UAV Photogrammetry to many other forms of survey, there is little research specific to the waste management context, and the advantages of remote sensing for workers.

This dissertation aims to research, test, and evaluate the suitability of UAV photogrammetry for the purpose of landfill volume survey for safety, cost, efficiency, and quality of delivered outcomes for their use in site management. Assessment of how the objectives are met will be done with quantitative analysis – providing a comprehensive cost-benefit analysis and quality assessment of each system output.

A control site was selected at the Albury Waste Management Centre – Operated by AlburyCity Council which are also the project sponsor. Two surveys were conducted on two separate time-series to build up a dataset able to produce a comparison of the methods.

UAV Photogrammetry – for its simplicity, low cost, and safety advantages, should be utilised by local government and landfill operators.

The study showed that UAV photogrammetry was able to survey far greater areas in a similar time, while significantly reducing time spent on site and drastically reducing exposure to the site waste.

For the great benefits and its demonstrated accuracy UAV photogrammetry can be deemed sufficient for volume survey in the waste management context.

The UAV method being less costly, still maintained a +/- 120mm relative accuracy to the base survey, which far exceeds the minimum EPA Waste Levy Guidelines of +/- 200mm.

Keywords. LiDAR, Laser scanning, Photogrammetry, UAV, Digital Elevation Model, Digital Surface Model, Topographic survey, Municipal Waste, Landfill Operations, Volumetric survey

2 INTRODUCTION

This chapter provides project Background and Idea Initiation as well as the Aims, Objectives and Scope. This background information is to provide context for the literature review, field testing, methodology and results. The expected Outcomes and Benefits of the project are also explored.

2.1 BACKGROUND AND IDEA INITIATION

Albury is a regional city located in southern New South Wales (NSW) on the border with Victoria. The AlburyCity Council operates the Albury Waste Management Centre which provides waste disposal and recycling facilities to nearby LGA's and approximately 200,000 people (Invest Albury Wodonga, 2021). The Council has a background in civil survey and design and has previously surveyed the landfill site in-house using traditional survey techniques.

AlburyCity Council is obligated by law to report various KPI's to the NSW EPA including the active landfill airspace progress to maintain the landfill license for the site. Previously, Council would utilise traditional survey techniques to survey and keep track of the waste-cells airspace, such as, theodolite, total station and GNSS GPS survey. These survey techniques are often time consuming, unsafe and provide limited data to management about the site.

Remote sensing data capture will no longer require staff members to physically traverse the hazardous open waste areas, being exposed to potentially harmful substances or the need to negotiate live compaction plant operating in the cell.

UAV photogrammetry survey techniques have been proposed on the site as an option for survey however, there has been no evaluation of the performance of this technique relative to current methods (i.e., terrestrial LiDAR) in this application.

Manual surveying provides limited data to the management team who make decisions about compaction rates, airspace volume calculations and the ultimate life cycle of the facility at current and future fill rates. The NSW EPA requires airspace data to have a minimum vertical accuracy of +/- 200mm (EPA, 2018) which is attainable by the three traditional survey techniques mentioned above. The minimum reporting requirements is one end of financial year survey and report completed before June 30.

The survey method selected for future use at this landfill site needs to:

- Meet the minimum survey requirements outlined by the NSW EPA,
- have this survey carried out over two large landfill cell areas of approximately 9 hectares combined and;
- incorporate any additional value adding activities that may provide benefit to the Council.

Additional value adding requirements for the survey include the need for the survey process to be cost effective, fast, repeatable, and accurate. This will enable quarterly data capture onsite to increase usability of the data for improving efficiency.

New measurement technology applicable to this site has emerged recently and has become common in the field of surveying. Such technologies include: laser scanners, terrestrial LiDAR, UAV LiDAR and photogrammetry, and digital laser levels. These methods of survey include an element of remote sensing capability which may address the needs of the airspace volumetric reporting required of AlburyCity in a local government waste management context. These new measurement techniques have also become cheaper and more accessible in the last few years (Bahuguna, PP, Kumar, D, Kumar, S, 2006).

Each of these new techniques of survey provide some improvement to the survey industry, however, none have been able to replace the Total Station as the most widespread method. This is partly due to the limitations of UAV's as the carrying platform and the inability to perform cadastral surveys.

Unmanned Aerial Vehicles (UAVs) offer modern surveyors a safe, fast, cost effective and accurate tool for survey of large areas of land. They accommodate a multitude of usable data outputs including aerial imagery, 3D mesh and Digital Elevation Models capable of deriving survey volumes more accurately than Total Station Survey (Arango, C & Morales C. A, 2015). Photogrammetry survey from various UAVs including fixed-wing drones and multi-copters have become incredibly useful due to their ability to capture high-resolution data quickly on large areas remotely.

Data will be collected by conducting surveys at the Albury Waste Management Centre Landfill site which will include the base scan using terrestrial LiDAR and UAV photogrammetry conducted by quadcopter. The methodology will include survey preparation, flight planning, survey setup, data collection, and then processing and analysis using specialised spatial software.

Data analysis will provide the council with valuable information about their fast-developing landfill site for current and future recycling projects including in-field compaction rates for landfill cells and current total airspace volume occupied. The data analysis will therefore inform a recommendation on which method of survey will suit their current and future landfill operations.

2.2 Aims Objectives and Scope

This dissertation aims to add value to the current academic world by researching, testing, and evaluating the suitability of UAV photogrammetry for the purpose of landfill volume survey. Assessment of how the objectives are met will be done with quantitative analysis. Field tests with both terrestrial LiDAR and UAV photogrammetry survey on a control site will be done, then providing a comprehensive cost-benefit analysis and quality assessment of each system output.

To achieve the aims above, the following objectives are proposed;

- Contact supervisor from sponsor organisation at AlburyCity Council and negotiate permission to conduct the research project including a budget.
- Approach a survey company, arrange a suitable time for survey with the Waste Management team and colleagues to assist with survey activities.

- Conduct the baseline survey using local survey company Walpole Surveyors and their company supplied Leica MS50 scanning Multi-station and 360 LiDAR scanner Lecia BLK360.
- Conduct a UAV comparison survey using a photogrammetry quad-copter DJI Phantom 4 V2.0 on the same day.
- Conduct a second survey 6 weeks later with both the terrestrial LiDAR scanner and the photogrammetry UAV.
- Verify UAV surveys against topographic survey and analyse accuracy using RStudio, Pix4D, ArcGIS and AutoCAD.
- Conduct cost-benefit analysis on each survey technique;
- and draw a conclusion and make recommendation on whether the photogrammetry survey technique is appropriate for landfill volume survey for local government. Further analysis will provide learnings about the process, ways to automate the tasks and improve accuracy. Suitability for the task will be assessed by comparing photogrammetry survey to LiDAR scanning to establish a benchmark for time, cost, and outputs.

The proposed scope of this dissertation is to conduct research and field-testing of two types of remote sensing survey techniques and compare results to derive the most efficient system for cost and time at a controlled Landfill site operated by the AlburyCity Council. The test survey site will be limited in size to keep the analysis data size small, however will include a range of technical features to test the capability of each method of survey.

The results of this research and field testing will provide a summary of the accuracy achievable by each technique, the potential benefits and limits, field survey and office processing times and an overall cost breakdown. The results will provide a tested comparison of these survey techniques in a real-life scenario and inform surveyors and AlburyCity Council on when to use each technique for survey. The study will also present if there is a leading option from a cost benefit perspective.

2.2.1 Outcomes and Benefits

This project will provide the greater academic world, network of modern surveyors and the AlburyCity Council with a comprehensive analysis of UAV photogrammetry survey compared to terrestrial LiDAR scanning and will provide the following expected outcomes;

- Better understanding of the way two different types of remote sensing survey work, their benefits and their drawbacks, for the wider academic network, the modern surveying network and for the AlburyCity Council.
- Build a database of information for the AlburyCity Council and their Albury Waste Management Centre - Landfill site including volume calculations, topography survey and updated cell airspace progress.
- Provide a tested comparison of these survey techniques in a real-life scenario and inform surveyors and AlburyCity Council on when to use each technique for survey and if there is a leading option from a cost benefit perspective.

2.3 Literature Review

This section of the dissertation will look at the literature review conducted for the project, reviewing recent advances and research conducted in relative fields to the dissertation topic "Photogrammetry UAV and terrestrial LiDAR, A comparative review in Volumetric surveys".

As such the following key areas will be looked at;

- Waste management EPA NSW guidelines survey requirements,
- UAV Definition and types,
- Brief History of Unmanned Aerial Vehicles,
- Recent developments of Survey UAVs,
- Modern UAV Applications,
- a theoretical comparison in terrestrial LiDAR and Photogrammetry technology,
- Data capture process and expected accuracies,
- Conventional Survey Techniques,
- Product Descriptions and Specification, and
- Conclusion

The research into industry literature within each of these segments will help establish survey data requirements, suitable UAV platforms and the methodology.

2.3.1 Waste management and Local Government

The Albury Waste Management Centre (AWMC) is located in the Hamilton Valley 5kms northwest of the centre of Albury, NSW. The landfill site was originally operated, like many others in the region, as an uncontrolled open fill general-waste landfill for many years. However, once EPA legislation developed around landfilling in regard to leachate capture, water quality, air quality, recycling requirements and reporting, many smaller sites were not feasible to be operated further and were closed permanently.

The AWMC site was developed to meet the new EPA requirements and now safely handles a wide variety of waste generated by the community and businesses. The redevelopment incorporates initiatives to increase diversion of waste from landfill. Currently the site boasts a drive-in push-pit general waste area as the last resort in the process for customers of the site, as they first need to drive through the weigh bridge gatehouse, recycle centre and then green waste areas.

As part of AlburyCity's ongoing commitment to providing industry leading waste management facilities to the community and the region, AlburyCity is looking at ways to invest in technology that will increase the efficiency and performance of the site in the long term. While the percentage of waste that comes through the gatehouse that ends up in landfill is decreasing each time a new recycling program or sorting facility comes online, there is still the requirement to report on the waste annually to the EPA.

The current method employed on site is weighing vehicles entering and exiting the site, and also by reporting on the current, available and used airspace that each landfill cell has been designed to accommodate. This airspace determines the percentage of space that has been occupied and therefore the actual in-field capacity of the landfill.

Performing airspace surveys regularly allows management to determine the in-situ compaction density of waste, which enables fine tuning of the compaction systems onsite to avoid wasting time, diesel, and plant hours.

Survey derived landfill fill rates are used to predict the long-term lifecycle of various cells on the site, which allow the Council to determine the net present value or true cost to landfill waste and can on-charge that cost to site users. The true cost can be determined by taking current rates for processing and compacting general waste, the cost to establish the landfill cell including the HDPE liner and Geo-synthetic clay lining systems, as well as the cost to process leachate and cap the landfill cell on completion. Many of these landfill cell management activities that are reported to the EPA rely on accurate survey of the site, which can often be large open cells of varying terrain and containing potentially hazardous waste material.

The nature of photogrammetry UAV survey and terrestrial laser scanning lend themselves well to the site constraints of a landfill and are able to provide the accuracy, coverage and remote sensing capability required of these sites. These techniques also offer the ability to conduct survey repeatedly in the same area, suitable for comparison surveys over time. All these characteristics and application provide the primary reason for justification for this research.

2.3.2 Types of UAVs and their characteristics

UAVs as part of an Unmanned Aerial System, including all other control equipment, come in a variety of formats. While sharing common componentry technology such as remote controls, batteries, cameras, gimbals, navigation systems like GNSS GPS, obstacle avoidance systems and sensors, motors and motor controllers, and landing gear. The main types of UAV include fixed wing UAVs, quadcopter & multi-copter UAVs (pertaining more or less propellers than 4).

A fixed-wing UAV resembles an airplane in geometry and is most similar in constriction to a hobbyist model aircraft however has been designed with utility as the number one priority. Fixed wing craft can operate at higher speeds than quadcopter UAVs, generally have longer battery life and range (higher efficiency due to glide) and have a greater redundancy as these UAVs can glide to safety in an emergency. However, since the fixed wing UAVs cannot hover in the air, this reduces their applicability to a narrow band of survey task. These fixed wing UAVs are more suited to open, larger sites that require more flight time. Modern fixed-wing UAVs operate largely autonomously with auto take-off and landing, and can fly with waypoint directions (senseFly, 2019).

Quadcopters are a Vertical Take Off and Landing (VTOL) craft that have four propellers working with opposed pairs of propellers to produce thrust. The electronic motor controllers can spin each motor independently using Inertia

Control Units to control pitch, yaw, heading and speed of the craft. Quadcopters offer the most versatility of modern crafts since they can hover, are unidirectional, and offer a range of payload and camera options on a full gimbal system (Chapman 2016). Quads have limited redundancy if you have a prop or motor failure, and they tend to drop out of the sky making them less safe than fixed wing UAVs. Quadcopters are not as efficient as fixed wing UAVs for the same size componentry and the maximum flight time achievable from the DJI Phantom 4 is around 30 mins (DJI, 2020).

Multicopter UAVs are technically a craft with more than one propeller, however relating more specifically to surveying drones, denote 6, 8 or more motors and propellers. These often larger, 8 motor UAVs, have many advantages such as greater payload, are less susceptible to wind gusts knocking them off course, and have built in redundancies. This makes them the perfect choice for heavy lift opportunities such as UAV agricultural spraying activities and operating larger more sophisticated hardware including RED Max cameras on movie sets, and a range of multi-spectral cameras and LiDAR units. When powering such units, they have a limited flying time and can be very noisy. Multi-copters such as the Matrice 300 equipped with the ZenMuse L1 have an advertised endurance time of up to 55 minutes (DJI, 2020).

2.3.3 Brief History of Unmanned Aerial Vehicles

The first iterations of UAVs were military offense and defence and non-military uses such as scientific research. These very first drones were launched by the Austrians in 1849, and were large weaponised air balloons armed with bombs and timers to detonate and take out the Italian city of Venice. Other uses of early drones were for military reconnaissance for spying and intelligence to record enemy operations. Nikola Tesla later developed remote control systems and implemented them in his remote-controlled ship and wireless controlled airship (Naughton, 2003).

Once the power of aerial missions by kite and balloon were realised, spy missions and aerial imagery operations were conducted in the 20th century. The crafts used ranged from kites to rockets to hot air balloons. As such in the 1970's tethered operations were undertaken where a large camera unit was fixed to gimbal and hung 9m below a large balloon, making use of the Hasselblad image sensors and radio control, to take images as high as 600m AGL to perform high level aerial imagery missions. In 1979 small scaled down aircraft were developed and used including a fixed wing UAV with a 3m wingspan. The craft needed a runway for take-off and hence was limited to what sites it could fly. Vibrations from the fuel engine caused blurry images and were not exceptionally good for aerial use.

2.3.4 Survey UAVs - Recent developments

With mass production and advanced manufacturing techniques, technology was getting cheaper, lighter and more advanced, as is the case with avionics componentry. Increases in battery energy density, increases in camera quality, development of electrical motors and sensors, and overall decrease in price point means UAVs are highly accessible to surveyors and suited to data collection - survey and mapping.

Custom-made UAVs were highly popular by large commercial companies for many years in Australia since flexibility of price, sensors and maintenance could all be achieved locally while the cost of off-the-shelf products were far too high or lacked desirable features.

Small ultra-light foam winged UAVs provided a cost-effective option for surveying large areas of land, originally taking form of remote-control model aircraft that had power adapters and mounts to support a camera being fixed to the body. Early versions had limited control over the camera settings and GPS functionality was later added-on. Modern fixed-wing drones utilise waypoint autopilot navigation, automatic take-off and landing, and users are assisted in all flight operations by smart design and software capabilities. An example of such foam-constructed fixed-wing UAV is the SenseFly eBee Classic, a 3-piece winged-UAV that can be boxed up and shipped into a carry case and transported in the back of a car easily. This UAV has high quality cameras and far greater endurance than its quad-copter counterparts (*senseFly - eBee Classic* 2019).

The Chinese drone manufacturer DJI currently owns a major market share in civilian drones for photography and videography and medium to heavy custom payload drones. Their market reach includes high end production videography and photography drones, agricultural spray drones and monitoring, and RTK enabled survey drones able to achieve down to 1cm accuracy on site (DJI, 2020).

Such large market share and reliance on a single company, specifically DJI in the civilian UAV market, has posed security questions around the gain of sensitive data or imagery and the gain which could be had by obtaining this information. The tiny flying intelligent devices are challenging for the security and privacy of data. The design of these small drones is yet not matured to fulfill the domain requirements. The basic design issues also need security mechanisms, privacy mechanisms and data transformations (Majeed et al, Drone security 2021).

GPS RTK technology, once reserved for surveying tasks on the ground, was eventually developed and packaged into Mobile Phones and navigation devices. High accuracy units were developed and made small with low enough power demands that they are applicable to drone use. While some UAV manufacturers have had basic GNSS capabilities in their drones for some years, the accuracy of the sensors could not be used for survey. This was not high enough accuracy to sort geotagged images across a survey site. Modern RTK units now achieve an accuracy of 1cm as a standalone system which suffices many survey requirements out of the box (DJI, 2020). Further accuracy can then be achieved by manual recording and incorporation of Ground Control Points (GCPs) which achieve finer accuracy by allowing the software to tie-in to the known ground levels.

Light Detection and Ranging (LiDAR) technology started around the 1970s as NASA began prototyping airborne, and eventually, space-borne sensors for recording of the earth’s surface for scientific research including arctic icesheets and ocean information. It was not until the mid-1980s when the demand for global positioning systems (GPS) and inertial measurement units (IMUs) increased the further development of the technology of LiDAR to begin being used for topographic survey uses. In the 1990s, laser-scanning technology developed and sensors were then able to produce 25k+ pulses per second and were being used for large-scale topographic survey, paving the way for LiDAR use as the future technology for dense accurate survey collection. With methods of capture similar to that of Photogrammetry, the technology could just be directly substituted, while offering better ground penetration through dense tree canopies and shrubs (Gaurav, 2018)

2.3.5 Modern UAV Applications

While UAVs have a long history with military and scientific uses, their modern commercial, and recreational uses are fast developing.

Armed military UAVs are still being used currently for reconnaissance missions, attack and defence, and enemy surveillance. Their civilian or recreation uses includes model RC planes, helicopters, and Drone Racing. Commercially, UAVs are having a huge impact in archaeology, agriculture, mining, volume surveying, aerial imagery, movie, film, emergency services, disaster relief and delivery services.

In particular, work has been done with UAV technology in the field of archaeology assisting in discovering ancient ruins and structures that years of foot survey and photography alone was not able to capture. During this project 'Archaeological surveying with airborne LiDAR and UAV photogrammetry: A comparative analysis at Cahokia Mounds' researchers conducted a comparison between publicly available LiDAR data and UAV photogrammetry. It was found that the LiDAR datasets done by light plane at a much higher elevation were of marginal quality, nevertheless that photogrammetry was deemed a satisfactory replacement to LiDAR in cases of low-lying vegetation for its simpler properties and lower cost (Vilbig, Sagan & Bodine 2020).

2.3.6 Photogrammetry and LiDAR theoretical comparison

Define Photogrammetry

Photogrammetry works by algorithmically solving pixel location triangulation in a series of photos taken a set distance apart with certain overlap of a subject to determine the depth of key frames of each image. As such computer programs can use these complex algorithms to build a 3D point cloud, 3D mesh model and other derivative outputs (contour, dxf) from the images (PIX4D, 2020)

Define LiDAR

Lidar works with angles and distance more similar to conventional total stations, but at hundreds of thousands of points per second. This means instead of being stationary, you can move the LiDAR unit around the subject area to record at high precision. Lidar works natively in point cloud format since this is how it records data and no conversion is required. Often a radar unit can be combined with a camera to derive what is called a photo-real point cloud. A LiDAR unit is an active sensor that sends infrared light pulses and a sensor measures the reflectance response, when this is combined with precise location information and velocity, highly detailed topographic maps can be created (Vilbig, Sagan & Bodine 2020).

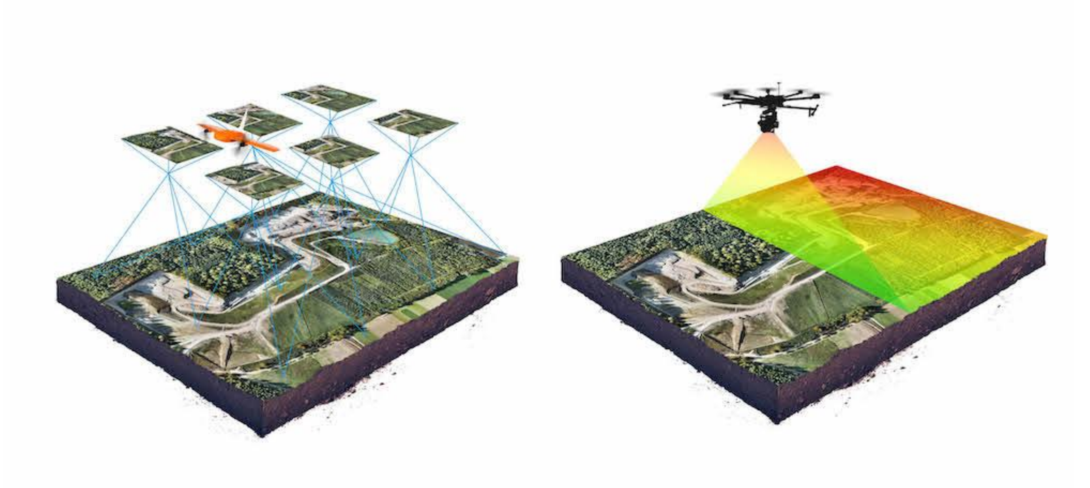

Figure 1. Graphic showing photogrammetry vs lidar (Wingtra, 2019)

2.3.7 Data capture process and expected accuracies

Photogrammetry

Flight software will be used to control the UAV, including take off, flight planning and image capture and landing. The software turns the input area into coordinates for the UAV to fly and take photos. Photos are downloaded and processed in the photogrammetry software such as Pix4D. Software and calculations are performed to the processed discussed in the "Mathematical Foundations of Photogrammetry" (Schindler K, 2014).

This process includes a range of assumptions to build a surface as the software reduces the point cloud based on observed pixels in each photo. Variability in light conditions across the site can cause errors as the software builds the surface. This can result in floating masses in the point cloud which can be easily cropped out. The expected accuracy in this method using GCPs and an open site without trees is 50mm vertical and 25mm horizontal accuracy relative to itself, which is the trusted accuracies of GNSS GPS systems.

LiDAR scanning

Points will be captured by a terrestrial LiDAR scanning total station which is setup in the same way as a regular total station and utilised coordinated pre-determined marks. The points captured will be discrete in nature as a measurement laser will record the distances and angles of points returned to the radar unit and typically achieve sub-millimetre accuracy while dome scanning.

Other uses across organisation

The council already owns a robotic total station, used for feature survey and cadastre survey, so council can upgrade to a scanning total station and still use device for current workload, or purchase a UAV.

A council owned UAV would allow council to regularly survey areas, and produce media shots for organisation or Asset condition checks and reports. Updated aerial imagery is a by-product of photogrammetry survey which can be greatly useful in design tasks.

2.3.8 Conventional Survey Techniques

During the field test component of this dissertation project, conventional survey techniques will be used to setup the 'control survey' or reference surface for comparison of all other techniques of survey. The AlburyCity Council will provide survey devices including a Theodolite or Total Station and a GNSS GPS system. The exact product specifications and expected accuracies of each system will be notated in the next section.

2.3.9 Product Descriptions and Specification

This section details the products used in the data collection part of the project.

2.3.9.1 Trimble R10 Integrated GNSS System

The project will utilise Council's own Trimble R10 GNSS rover, coupled with a TSC3 windows mobile handheld data recorder. The system accesses 4G internet via a sim card in the R10. Council also has access to the RINEX base geodesy service for live RTK corrections for the Albury area. This system will be used to setup site control, record ground control points and nominated accuracy checkpoints, as well as to establish control for survey company Walpole Survey who will undertake the lidar scanning.

Figure 2. Trimble R10 & TSC3 data collector (Geomatics Land Surveying, 2021)

Table 1. Trimble R10 technical specs

Max. Precision	Channels	Antenna	Received & transmit
8mm H / 15mm V	672	Integrated	UHF Radio

2.3.9.2 *Leica BLK360 Imaging Laser Scanner*

The Leica BLK360 is a laser scanner capable of conducting full 360-degree dome scans in under 3 minutes. The unit is compact, lightweight and suited for high detail short range modelling. This unit will be used by Walpole to conduct fill-in surveys in areas the larger unit cannot access.

Figure 3. Leica BLK360 shown inside construction project (Leica Geosystems, 2021)

Table 2. Leica BLK360 technical specs

Range	Accuracy	Scan rate	Capacity (Setups)
0.6m to 60m	4mm @ 10m / 7mm @ 20m	360,000 pts / sec	Battery: 40+ SD Card: 100+

2.3.9.3 Leica MS50

The Leica MS50 is the high-end total station offering from Leica Geosystems which is capable of 3D laser scanning 1000pts/s at up to 300m, and can scan points at up to 1,000m. The unit provides sub millimetre accuracy at 50m and is able to process 3D scans in true colour (Leica, 2013)

Figure 4. Leica Nova MS50 with SmartStation setup with GNSS receiver on top (Leica, 2013)

Figure 5. Leica Nova MS50 Scanning selection screen with polygon (Leica, 2013)

Table 3. Total station EDM accuracies

EDM mode	Standard deviation	Measurement Distance
GPR1 Prism	1mm + 1.5ppm (prism)	1.5m up to 10,000m
Any surface	2mm + 2ppm	1.5m up to 2,000m

Table 4. Total station scanning specifications

Range	Accuracy	Scan rate	Capacity (Setups)
Up to 1,000m	<1mm @ 50m	1,000 pts / sec @ 300m	Battery: 40+ SD Card: 100+

2.3.9.4 *DJI Phantom 4 V2.0 - Quadcopter drone*

The UAV utilised in this project will be Council's own DJI Phantom 4 V2.0

Figure 6 DJI Phantom 4 V2.0- Quadcopter UAV (DJI, 2020)

Table 5. DJI Phantom 4 V2.0- Quadcopter specifications (DJI, 2020)

Wingspan (diagonal width)	35 cm
Weight (incl. supplied camera & battery)	1.39 kg
Radio link range	7 km
Cameras (supplied)	1 inch CMOS Sensor 20MP
Cameras (optional)	None
Cruise speed	0-58 km/h (0-16 m/s)
Max. flight time	30 minutes

Max. flight range	12 km
Hand launch	Yes
Landing	Automatic, linear within 20 cm
Ground control points	Optional
Nominal coverage at 120 m (400 ft)	75 ha

2.3.10 Conclusion

This section of the dissertation looked at the literature review conducted for the project, reviewing recent advances and research conducted in relative fields to the dissertation topic "Photogrammetry UAV and terrestrial LiDAR, A comparative review in Volumetric surveys".

As such the following key areas were looked at;

Waste management and Local Government, UAV Definition and types, Brief History of Unmanned Aerial Vehicles, Survey UAVs - Recent developments, Modern UAV Applications, Photogrammetry and LiDAR theoretical comparison, Conventional Survey Techniques , Product Descriptions and Specification,

The research into industry literature within each of these segments will allow for better understanding of the overall topic and help better determine the methods of testing and analysis.

2.4 PROJECT FEASIBILITY

The feasibility of the selected project:

"Photogrammetry UAV and terrestrial LiDAR, A comparative review in Volumetric surveys",

is determined by a number of factors. Starting by evaluating the current research in the field and identifying the knowledge gap, understanding the resources required to make this advancement – both as student and supervisor time and costs or resources by the project sponsor. Once this is evaluated to ensure efficiency in each area, project feasibility can be established.

The field of surveying and UAV remote sensing is covered extensively in the academic world with technical reviews, research papers and journals, as well as many USQ students' reports over the years. There is a far reaching and vast application of remote sensing survey for many different industries such as forestry, land management, archaeological research, agriculture, volume analysis, topographic modelling and so on. However, in comprehensively understanding the scope of research of each project that was reviewed, it was found that there is little to no volume calculation comparison of UAV survey and ground based lidar in the municipal waste context such as the case with the AlburyCity Council and their Albury Waste Management Centre site.

This research project proposes to fill the gap in current research and provide a comprehensive review of photogrammetry UAV survey and ground-based LiDAR in the local government waste management context with regard to cell volume and airspace, while maintaining the minimum standards of the EPA Waste Levy Guidelines 2018. The results can then be applied by the Council and a decision based on the data and information provided.

In this instance the selected project aims to further develop research into the field of surveying, specifically regarding UAV photogrammetry with comparison to LiDAR scanning, and evaluate its use in landfill volume survey. The nature of the survey lends itself well to the characteristics of UAV survey, in accuracy, remote sensing capability, repeatability and cost. It was found that the research will allow for a greater understanding in this area, and thus should be continued forward.

Student, workplace, and supervisor time was evaluated for the demands of the project and as such, the student is required to complete the project in line with qualifying as a graduate from University of Southern Queensland with a Bachelor of Engineering Hons (Civil). The time required is estimated at between 350 and 450 hours for the project and will need to be balanced with work and private life, this however is deemed appropriate. The time required of the workplace AlburyCity Council (also the project sponsor) was approved by management and allowance made for the time required to complete the test survey flights during work hours. Project supervisor Craig Lobsey's involvement in the project is to guide myself through the course and ensure each part of the marking criteria is met and the journey of student lead learning and discovery meets the minimum academic requirements. His time is factored into the project as he manages a number of students and other projects in ENG4112 Final Year Research Project.

The costs associated with the project for hiring survey staff, providing time during work hours and all associated resources are covered by the project sponsor AlburyCity Council. Management kindly accepted the proposal to conduct research at their Albury Waste Management Centre which would aid in the completion of employee studies. The Council would therefore also gain the research into the method of survey for their future operations with demonstrated savings.

As a whole the project was deemed feasible and was successful in securing support in each aspect required to

3 METHODOLOGY

3.1 PROJECT PLANNING

The methodology for this project includes planning activities such as site planning, survey preparation, flight planning. Data collection activities such as LiDAR Scan survey, UAV Survey, and Processing and analysing the data using RStudio, Pix4D and ArcGIS Pro software.

The modelling process will be detailed at the end showing a step-by-step process of deriving the results.

3.1.1 Site planning

The project site selected is the Albury Waste Management Centre in the Hamilton Valley of the AlburyCity local government area. This is the major waste disposal site for the region. AlburyCity Council accepted the project proposal to conduct a Council funded research project to allow Council management to evaluate their landfill volume survey operations.

Arranging to have the site surveyed with a LiDAR UAV originally was proving to be difficult with limited suppliers and very high-end rental costs. When the LiDAR scanner rental option was selected, the availability outside of the major city centres; Melbourne and Sydney, and the high cost of renting a Trimble or Leica scanning unit, was not attainable on the limited budget. There was also a knowledge gap in using the machine and the cost of renting the device for these additional days to learn to use the device was not easily justified, even within other areas of the council such as the water and wastewater team looking to scan various water infrastructure and pump stations.

Figure 7. Northern Valley Landfill Cells – the most suitable site for volume comparisons at the AWMC (Site imagery, 2021)

3.1.2 Survey preparation

A calendar invitation was sent to all relative parties of the scan including key Council landfill management staff and survey staff, as well as Walpole survey to ensure everyone was well informed (Refer attached in Appendix). This allowed for coordination of the site staff and compactor operator to ensure works were on pause during the scans. While this worked well for the first survey scan, the second scan did not have this level of communication and a landfill operator was in the cell during the scan. This will be covered in higher detail in the results and discussions section.

3.1.2.1 Survey contractors – Walpole

In looking for survey companies to conduct the lidar scanning work, Walpole Survey in Albury was approached and happy to assist. And as such committed to the project and the site area was negotiated. The original area to be surveyed was the Southern Valley General waste landfill cell and is the most active cell on the site, which would lend itself to better data analysis. This would be challenging however since the site is so large it would be difficult to capture a meaningful survey over two instances since filling and compacting operations here are often sporadic. This area was too large to conduct survey cheaply by Walpole and another test site was identified. This site was the Northern Valley inert waste cells and is typically constituted of dry non-recyclable waste. This area is far less busy and less vast, such that all additional waste disposed of in the cell would be in a confined area, and can be considered less hazardous. This new project site allowed for the project budget to be met.

3.1.2.2 Site safety and induction processes

Survey personnel had to be inducted on site prior to work, using AlburyCity induction for AWMC. All minimum PPE and required operations procedures are to be followed to ensure the project went smoothly. Walpole utilised their standard practice survey procedures for the project.

3.1.2.3 Survey resources

Throughout the planning phase of the project, Permission was granted to use employer resources provided by the Council to complete the project, given the council was to receive a given output. These resources include those listed in Table 6. Survey and equipment requirements. It was agreed that the Team Leader Waste Management for AlburyCity, also the project sponsor, allowed to have the landfill cell surveys conducted on the site.

Figure 8. Survey Van (Onsite NV AWMC. 2021)

Figure 9. Supplied GPS Rover and paint supplies as part of cooperative research project (Tom Staats, 2021)

The following table includes a list of software and equipment required, where it will be sourced from, the attributed cost to the project (which differs to the cost for analysis reasons in comparison of the survey methods) and a note on each item.

Table 6. Survey and equipment requirements

Item	Quantity	Source	Cost	Note
Survey Equipment				
A survey vehicle (4x4)	1	Employer Supplied	Nill	ACC to supply 4x4 survey vehicle
Leica MS50	1	Walpole Survey	650/survey	Walpole Survey to supply
Leica BLK360	1	Walpole Survey	Inc above	Walpole Survey to supply
Trimble R10 GNSS Rover + Staff	1	Employer Supplied	Nill	ACC to supply GPS
Paint Cans	4	Employer Supplied	Nill	ACC to supply supplies
UAVs & Equipment				
Quad-Copter UAV	1	Employer Supplied	Nill	ACC to supply UAV
Landing Pad	1	Employer Supplied	Nill	ACC to supply landing pad
Carry Box	3	Employer Supplied	Nill	ACC to supply carry box
Car Charger	1	Employer Supplied	Nill	ACC to supply charger
240V charger	1	Employer Supplied	Nill	ACC to supply charger
iPad mini	1	Employer Supplied	Nill	ACC to supply iPad mini
Software				
Pix4D	1	Employer Supplied	Nill	ACC to supply software
ArcGIS Pro	1	Employer Supplied	Nill	ACC to supply software
AutoCAD Civil 3D	1	Employer Supplied	Nill	ACC to supply software

3.1.3 Flight planning

Flight planning according to CASA’s requirements and standard operating conditions was performed for the project, including a Job Safety Assessment, flight authorisation plan, and a flight plan including designated take-off, flight path and landing areas. As well, alternative landing sites and all potential site hazards need to be addressed, as seen in attached map in the appendix below.

3.2 Data collection

Data collection for this project consisted of conducting survey of the subject site with each survey technique, downloading the data from each device and reducing the data into a consumable format for ArcGIS to make comparison. For the Multi-station scanner (MSS), Walpole survey began with conventional topographic total station setup, tying into known points in the field (provided by GPS in-situ) and then beginning the scan to record all the features of the terrain in a comprehensive way to record a baseline survey as best as possible.

To download this data, a point cloud file was generated from the Leica processing software, which has been reduced from the angles, distances and known points, and the scan contextualised from these bearings. Edits or checks will need to be done to ensure the correct heights of instrument; target and pole are entered, as well as correct observation point names. The surveyor ensured the survey area is correctly entered into the MSS by means of an encompassing polygon (to which the device records the bounds by angle in vertical and horizontal sense) and sets the target point spacing at a set distance. This distance is chosen as an average of what the MSS will likely see over the scan.

Unlike traditional survey, there is no need for survey stringing software to join any codes and create a surface file, the array of points is so fine that often the triangulation will make little difference to the overall volume calculations. The surface file will be converted to a raster DEM file for comparison.

The data collection from the Photogrammetry UAVs includes conducting a photogrammetry UAV survey with a quad-copter Phantom 4 UAV. This system requires a CASA approved pilot to operate the drone to the Commercial Standard Operating Conditions outlined on the CASA website.

The survey will typically include arranging flight authorisation forms, pre- and post-flight checklists, risk assessments and using a GPS unit to record a series of Ground Control Points (GCPs). The survey is conducted with a pilot and an observer, using 3rd party software to the drone manufacturer which can be used to conduct flight planning, as below in Figure 10, flight planning in Pix4D.

To process the survey, this involves downloading a series of geo-tagged images from SD card from the UAV and putting them in a corresponding folder for processing. The processing software to be used is PIX4D since the Council already has two enterprise licenses. The GCP ".CSV" file will need to be loaded into Pix4D and at least three image matches to each GCP are required for successful geo-rectification of images and the resulting DEM files. The operator must then bring in the images and enter all the corresponding survey settings.

Figure 10. Flight planning screenshot (Onsite NV AWMC. 2021)

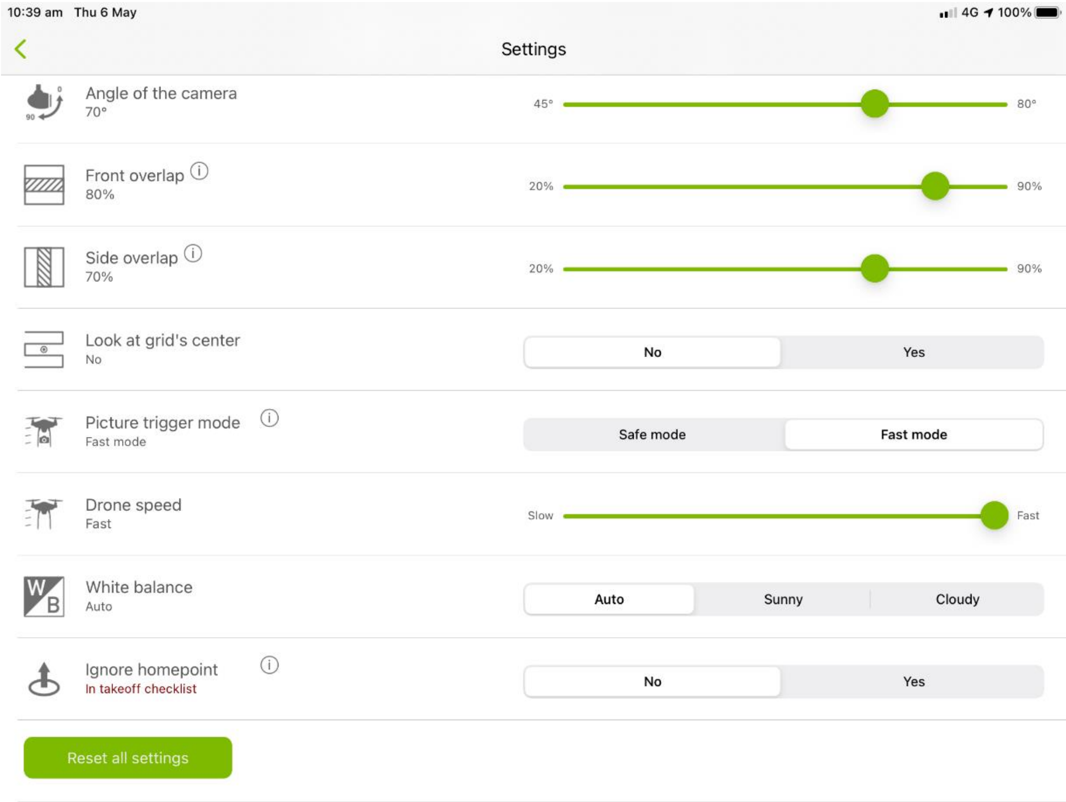

Figure 11. Survey settings in Pix4D Capture (ACC iPad screenshot Pix4D Capture, 2021)

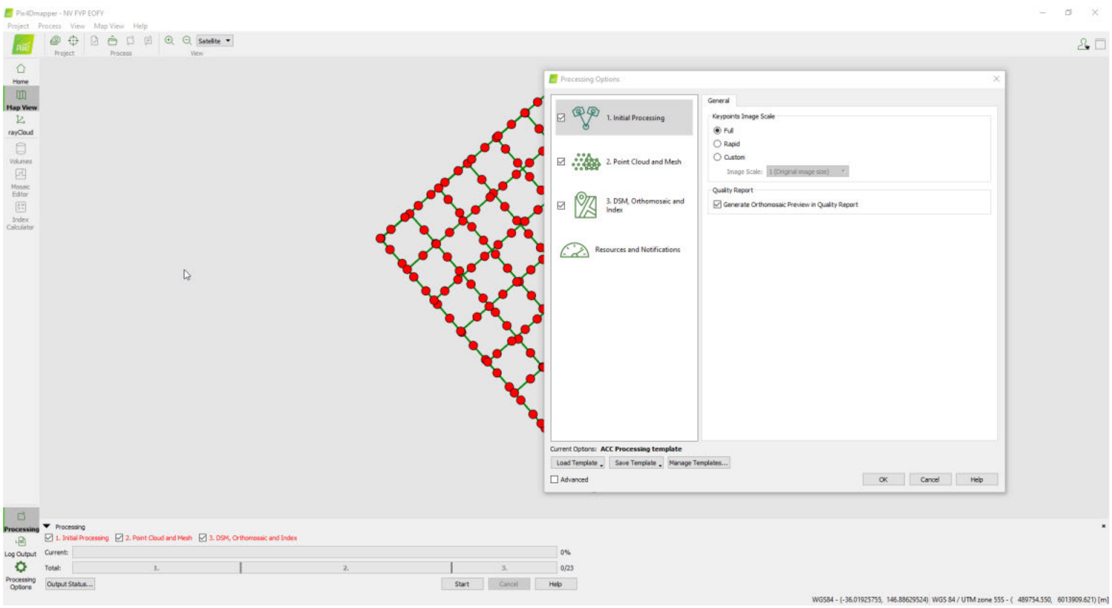

Figure 12. Photogrammetry processing settings

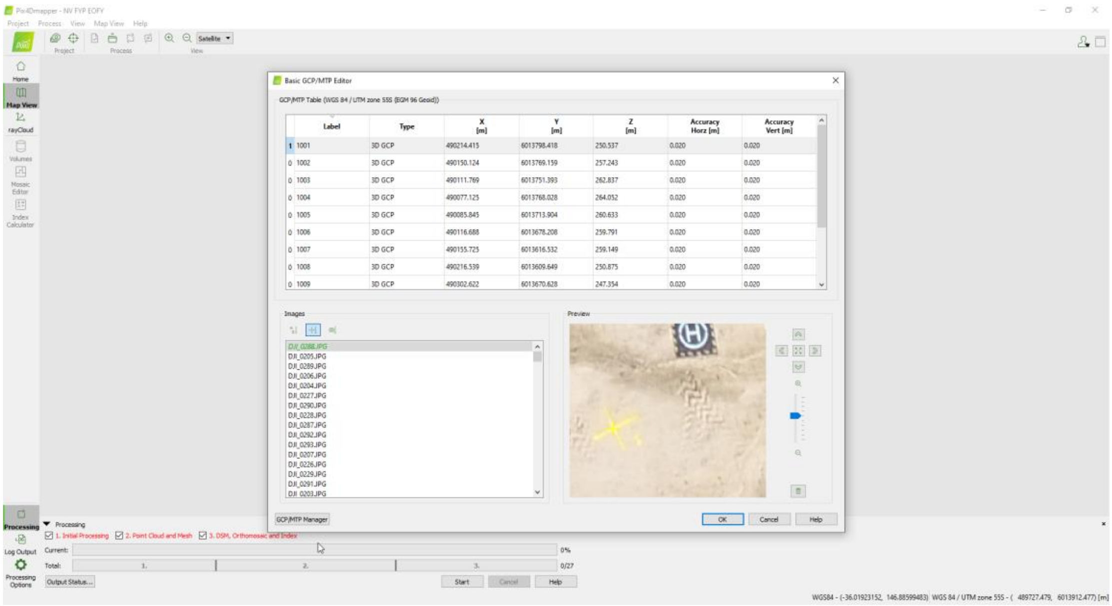

Figure 13. Pix4D GCP review – selecting the centre of each point to reference the survey

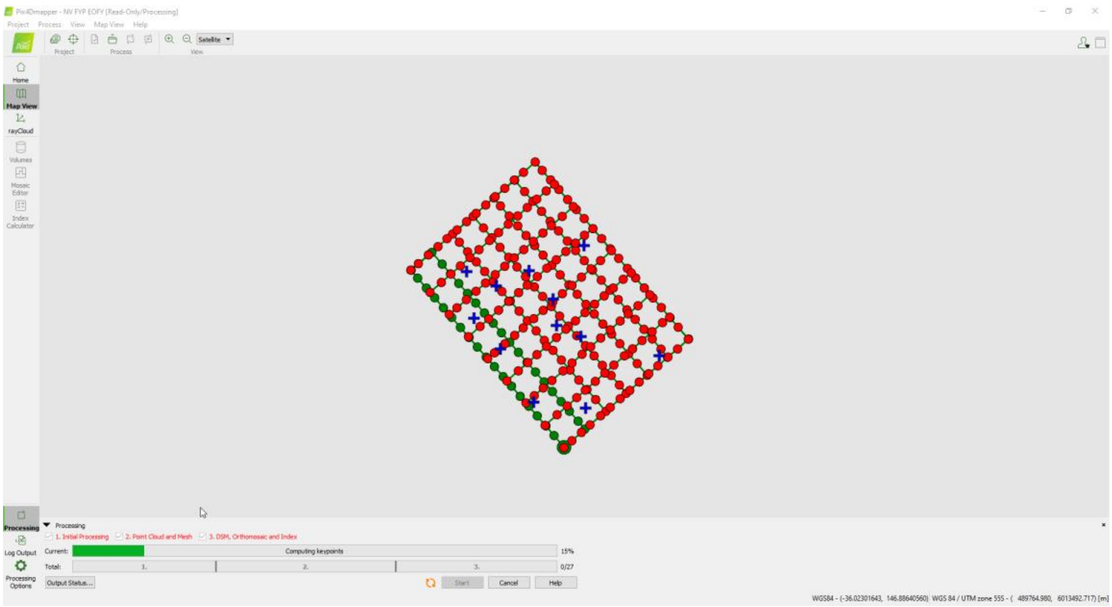

Figure 14. Pix4D processing each image displaying green, blue x's mark the GCPs

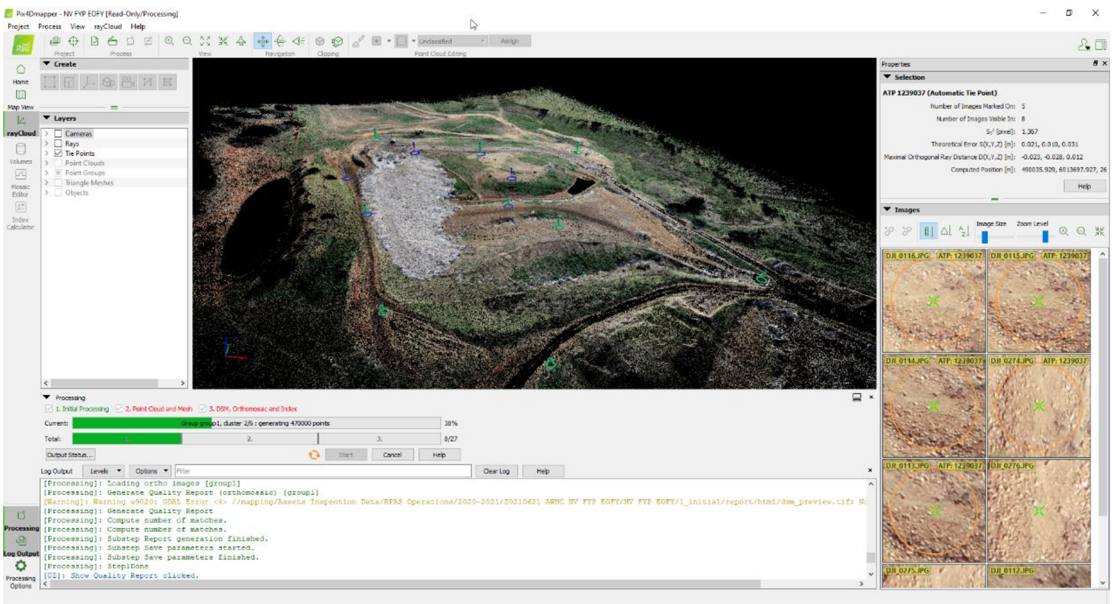

Figure 15. Completed key match points before full Point Cloud and DTM is generated

3.2.1.1 *LiDAR Scan survey*

To enable the most comparable survey, the method used to survey was to setup the GCP points while Walpole surveyors established the site with the MS50 Multi station, and then complete the UAV photogrammetry survey while the LiDAR scanner is in the process of scanning to reduce the time between surveys.

The MS50 was setup between 5-10 times to complete the scan without casting shadows. Where major shadows were identified and physical limitations did not allow for the MS50 to be setup, the smaller, faster BLK360 Leica dome scanner was geo-referenced and utilised to scan these areas. Survey was closed out by backsight checks performed by Walpole Survey, typical of EDM survey methodology.

Figure 16. Walpole Surveyors with the Multi-Station Scanner (Onsite NV AWMC. 2021)

3.2.1.2 *UAV Survey*

A standard methodology was followed for the photogrammetry survey including setting up GCP points, following the pre-flight checklists, briefing all staff involved with the activity on safety and operations, setting up the flight plan and flying maintaining 30m minimum distance to other members of the operation.

Figure 17. DJI Phantom 4 v2.0 on the landing mat (Onsite NV AWMC. 2021)

3.3 Data Processing and Analysis

To derive the final results, R Studio, Pix4D, ArcGIS and AutoCAD will be used to model the final results and as such provide the volume discrepancies and spatial differences in each technique of survey.

The model will be setup with a series of layers containing data from each survey and time-series. Inside the model there will be check-marks (GCPs) with known coordinates and height values. The software will be able to output the differences in heights of each of these surveys in one comprehensive comparison of data all generated for the purpose of comparison.

Understanding the core differences between the data sources allows us to understand where the data is critically different.

- LiDAR - discrete measured points from laser returns, angles & distance.
- Photogrammetry - key point algorithm calculated using assumptions

3.3.1.1 Photogrammetry:

The photogrammetry data processed in this project uses Pix4D software to output a range of deliverables, all of which are derived from imagery captured by the UAV.

- Point cloud ".las" – 3D point array
- DTM ".tif" – Digital Terrain Model raster format
- DSM ".tif" – Digital Surface Model raster format
- Contour shapefile
- Aerial Raster image

3.3.1.2 LiDAR data:

Outputs from the MSS are derived from angles and distance and include the following exports.

- Point cloud ".las" – 3D array

3.3.1.3 Assumptions and metrics

There will be a number of assumptions in the datasets:

- The data being compared is the same format GeoTIFF and density of points per sq.m pixel size is 250mm.
- The lidar scan will act as the ground truth surface in both cases.

The following metrics are used to justify the results:

- RMSE – Root Mean Square Error, showing spread of residuals around a best fit line.

These metrics can indicate the following trends about the two datasets:

- Biased or Unbiased, good for overall volume use, not good for individual locations,
- Precision or Imprecision, the relative grouping of datasets over a given area and checked by reference points on the project.
- An overall volume comparison showing increase or decrease of volume on the two sets of data

3.4 MODELLING OF RESULTS

Modelling and results methodology will be drawn from existing methods in cited literature, part of this is using control points to check data integrity. This is done by designating points as reference points over the given survey area, validation datapoints are then completely independent of the data process and objectively show what difference is present. This cross validation can be done using 4-5 points for independent checking, so they are not crucial in forming the survey process.

To conclude this section a summary to quantify the results will be included, proving merit method is indeed more accurate.

3.4.1 Modelling procedure

1. **Store all data from Survey company Walpole via email in file system (.las)**
2. **Store all data from photogrammetry model in file system (.las)**

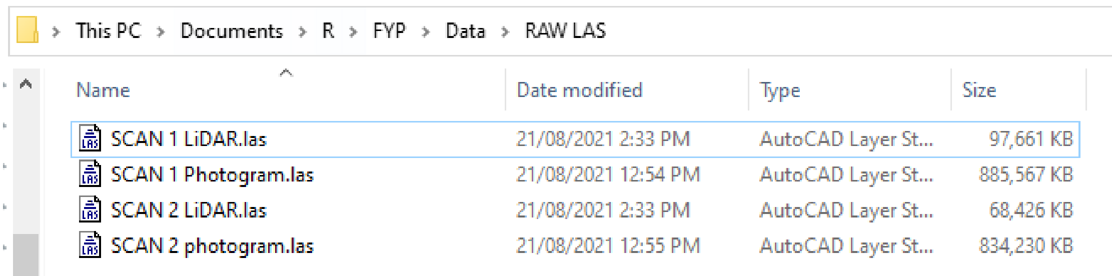

Figure 18. Storage of all raw LAS files into file system

3. **Import all LAS files into ArcGIS and view the data**

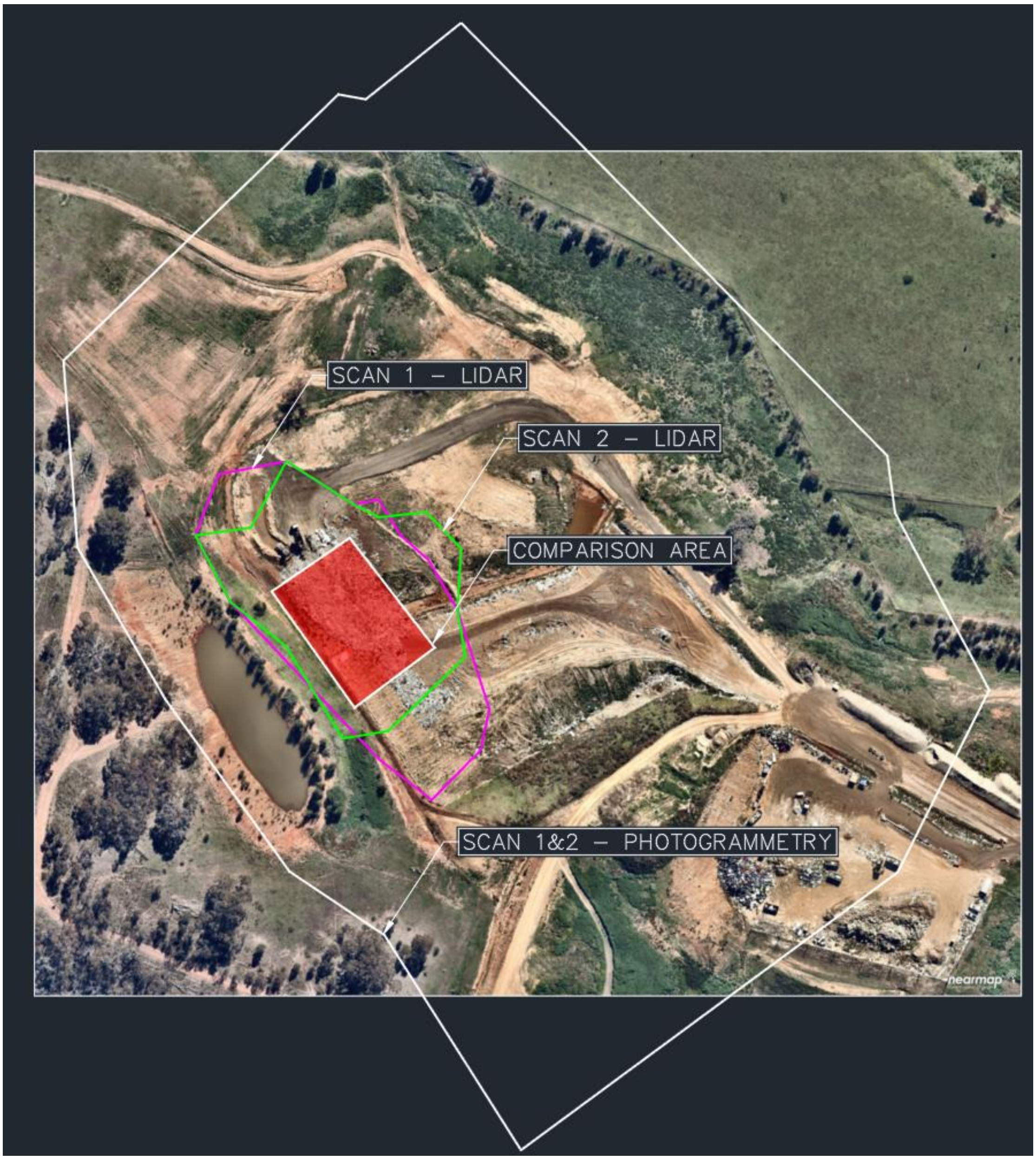

Figure 19. Extent of each survey – labelled

Viewing day 1's data, it can be seen in Figure 21 that the LiDAR survey has more gaps in the data which is caused by shadowing due to the perspective of the scanner close to the ground and its inability to capture points out of visual line of sight. Notably also, the presence of ghost points in the dataset due to a landfill compactor being present and driving through the site during the scan. This will require some point cloud editing and reclassifying to remove these points.

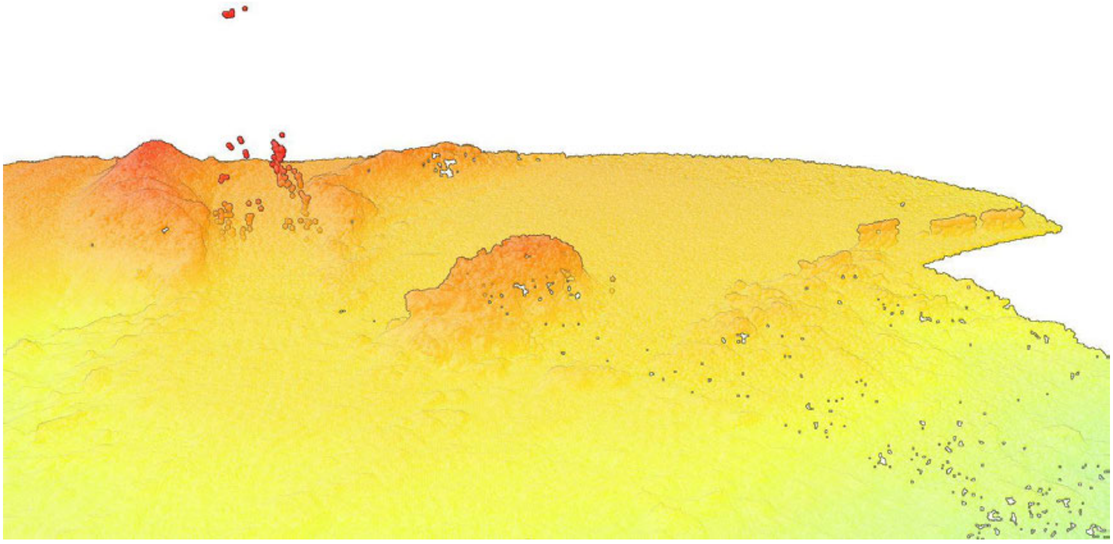

Figure 20. Day 1 Photogrammetry – good coverage and some ghost points

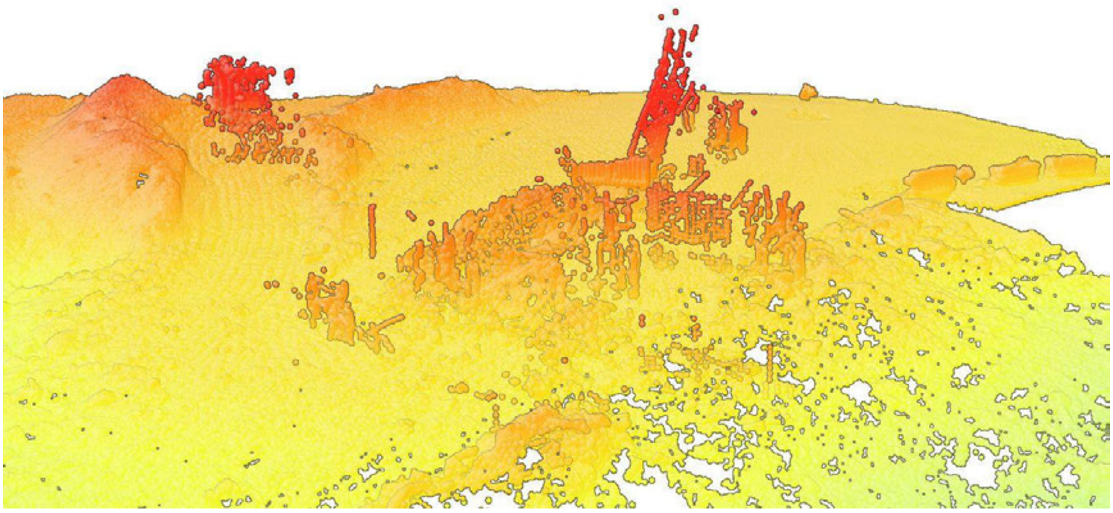

Figure 21. Day 1 LiDAR Scan – shadows and ghost points

Viewing the data from day 2's survey as in Figure 23 there is evidence of more shadowing through the survey. This is due to operator variance in the two surveys by not having the same survey marks. In future comparisons, permanent marks could be used for both the UAV survey and the LiDAR survey rather than using spray painted GCP points – any differences could be noted. The landfill compactor did not drive through the scanning area on day 2, and as such no point cloud modification will be required for this dataset since no ghost points were recorded.

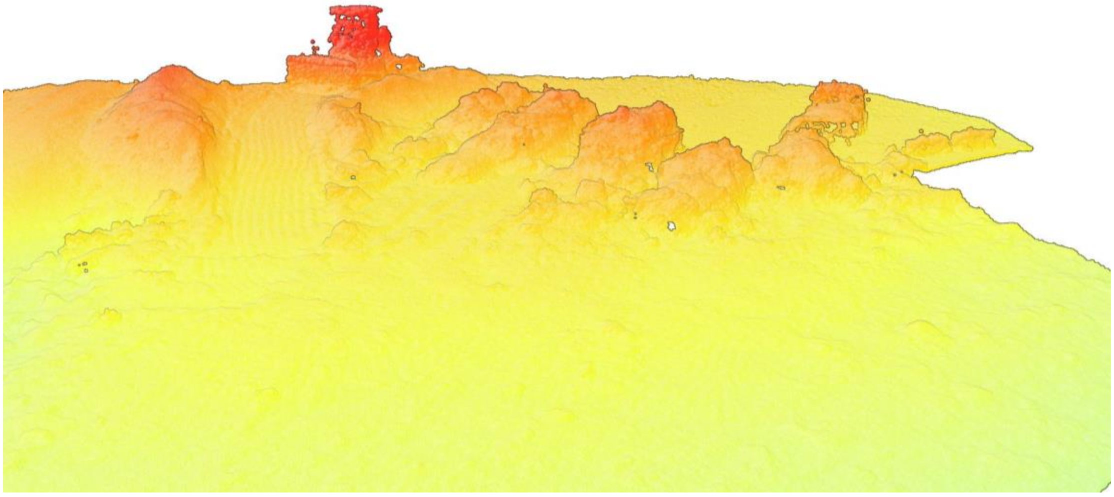

Figure 22. Day 2 Photogrammetry – no shadows and no ghost points

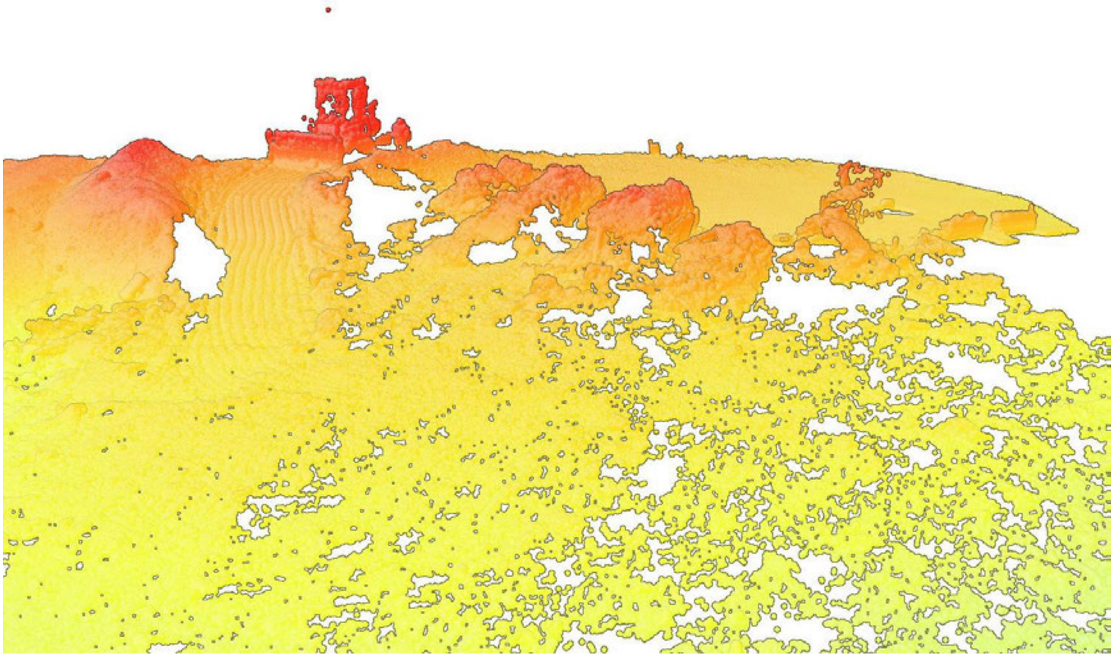

Figure 23. Day 2 LiDAR – heavy shadows and very minimal ghosting

4. Point cloud – trim by polygon to exclude ghost points

Other solutions here can be editing the point cloud, re-classifying ground points automatically or manually.

By just trimming the sample area down in this case enabled the problem areas to be excluded quickly without the need for timely modification of the point cloud. Manual classification can take some time to meaningfully exclude unwanted points. Automatic classification using ArcGIS Pro "Classify Ground" tool has a limit to 0.3m point density and as such excludes too much data for this type of analysis.

In future survey, making sure the survey path is clear of unwanted obstacles would solve this problem as well.

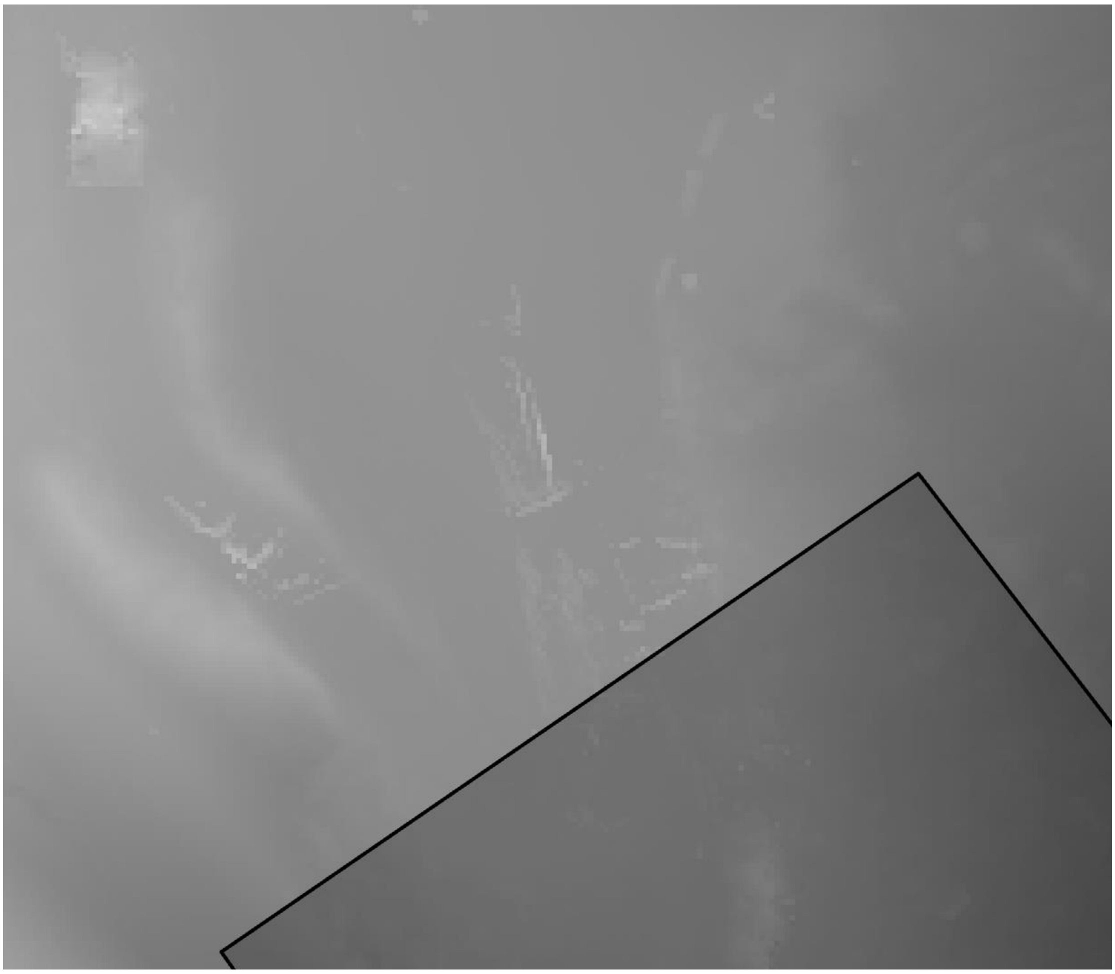

Figure 24. Polygon cropped area excluding unwanted ghost points.

5. Convert LAS point cloud to Raster TIFF

The parameters being used here is a 0.25m pixel size, a compromise on file size and quality, floating point data (to allow for decimal height data), a Z factor of 1 meaning z values will not be multiplied by any scale factor.

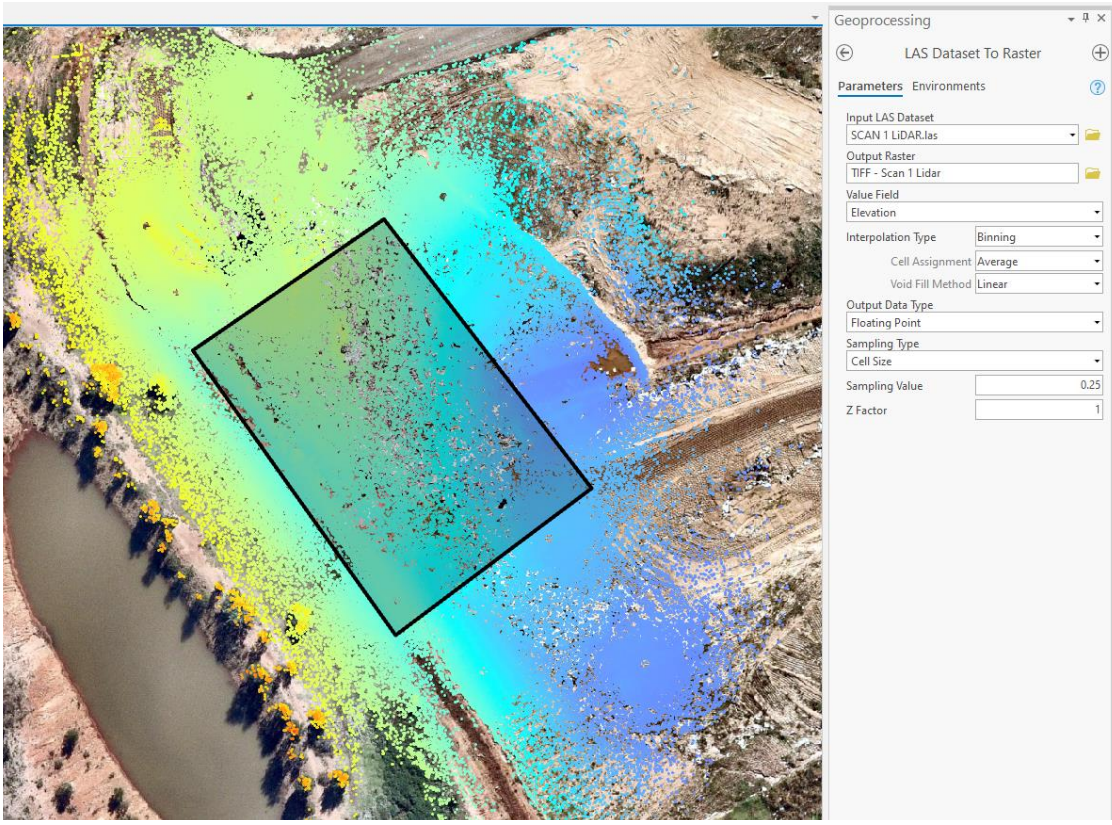

Figure 25. Converting LAS dataset to Raster TIFF.

The steps above were repeated for each LAS dataset and saved into the file system accordingly.

6. **Volume comparison of surfaces**

Since there are four generated comparison DSM surfaces, volume checks cam now be run in ArcGIS. It was found that the overlapping areas of the surveys were limited by the shape of Scan 2 LiDAR since it was the smallest footprint.

Initially there were some volume discrepancies over the two comparison surveys, as well as when these were cross checked. Live plant was present in the cell while the LiDAR scan took place and a stockpile was moved between instrument setups. This can be seen in Table 7.

7. **Refinement of cropped area to Polygon X1**

This maximised the comparable area in the given dataset, while removing known stockpiles and landfill machinery from the area. This is done in lieu of modifying the surface classification to extrapolate some results without spending too much time with postproduction editing. Polygon X1 is 3,946.762 m2. The volume checks will be covered in more detail following this section.

3.5 Key Tasks and Project Schedule

Key tasks for the project include:

- 1. Project Preparation;
  Prepare proposal document
  Prepare project Plan, Specification & Resources
  Arrange site access, vehicle & spotter
  Conduct sample data collection of control area
  Arrange rental of laser scanner
  Organise UAV spotter and arrange appropriate equipment.
  This step includes checking relevant drone usage standards from CASA including the Standard Operating Conditions (CASA, 2019)
- 2. Conduct field test and data collection - Baseline
  Conduct baseline survey with LiDAR scanner and UAV
  Perform GCP checks and data sanity
  Reduce and process UAV survey
- 3. Conduct field test and data collection – Comparison
  Conduct baseline survey with LiDAR scanner and UAV
  Perform GCP checks and data sanity
  Reduce and process UAV survey
- 4. Survey results comparison;
  Compare all datasets in CAD, ARCGIS, PIX4D
  Output data comparison
- 5. Write-up and present results
  Prepare draft dissertation
  Conclusion about cost, time, accuracy
  Present preliminary results PP2
  Complete dissertation and submit

ENG4111/4112 Research Project *Project Plan*

Thomas Staats' Research Project
Photogrammetry UAV and ground-based LiDAR; A comparative review in Volumetric surveys

ACTIVITY	PLAN START	PLAN DURATION	COMPLETE
1. Project Preparation			
Prepare proposal document	1	1	100%
Prepare project Plan, Specification & Resources	1	4	100%
Arrange site access, vehicle & spotter	10	1	100%
Conduct sample data collection of control area	10	1	100%
Arrange rental of laser scanner	6	1	100%
2. Conduct field test and data collection - Baseline			
Conduct baseline survey with LiDAR scanner and UAV	11	1	100%
Perform GCP checks and data sanity	11	2	100%
Reduce and process UAV survey	11	2	100%
3. Conduct field test and data collection - Comparison			
Conduct baseline survey with LiDAR scanner and UAV	18	1	100%
Perform GCP checks and data sanity	18	2	100%
Reduce and process UAV survey	18	2	100%
4. Survey results comparison			
Compare all datasets in CAD, ARCGIS, PIX4D	20	3	100%
Output data comparison	21	3	100%
5. Write-up and present results			
Prepare draft dissertation	4	31	100%
Conclusion about cost, time, accuracy	5	20	100%
Present preliminary results PP2	31	2	100%
Complete dissertation and submit	34	1	100%

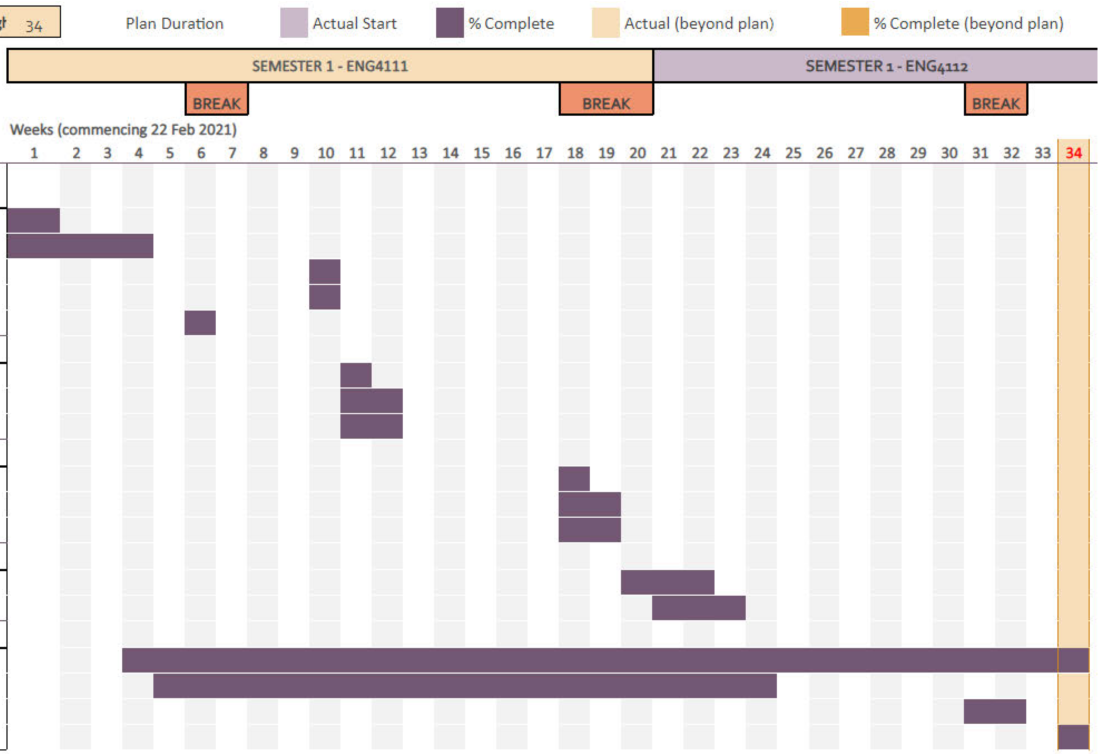

Figure 26. Proposed project plan for the dissertation project.

3.6 Risk Assessment

To conduct the survey activities expected in this research project, on a live Landfill site with a UAV, there are many risks and potential hazards that can cause harm to personnel, even when following workflow procedures. The risk assessment process involves itemising potential risks and hazards related to the workflow that are expected. Staff members note each risk and will include detail about its respective consequences if things went wrong. The risk score before any mitigation measures is recorded which informs staff of the severity of the risk. Works cannot proceed if the score in the risk matrix exceeds an allowable limit. As such, control measures and proposed risk mitigation activities are then listed. If the risk matrix output is a low-risk score as a result of the mitigation steps, staff members may sign off on the activity and proceed with the works. This process follows the risk mitigation hierarchy from elimination, to substitution, engineering controls, administrative controls to finally personal protective equipment.

For this project specifically there were a number of risks that were present due to working on a live landfill site. Working down the hierarchy of risk mitigation measures, potential risks were able to be identified and reduced and were able to continue with the base survey and consequently the comparison survey 3 months later.

All persons involved with the survey activities were inducted including Walpole Survey Staff members via AlburyCity Councils internal site induction process. This induction sets out many site-specific rules regarding landfill waste operations including prohibited activities like speeding on site, salvaging in the waste cells, exclusion areas, leachate storage and live plant operations. The induction also includes highlighting where first-aid kits are kept, eye washdown facilities and washdown showers are.

In addition to those, staff were briefed on the following items specific to each sub-heading:

Landfill Cells: Live plant operating areas and compaction zones, hazardous substances, sharps, infectious disease, wildlife and unstable surfaces.

Surveying: Trips and slips, heavy lifting, fitness for work, location of services (powerlines), Walpole Survey staff operate under their own risk assessment structure in addition to those on site.

UAV Survey: Following all CASA Standard Operating Conditions, as well as 30m exclusion zone & 1:1 elevation to distance ratio, alterative landing sites, spotter briefed on risks to low flying aircraft, aircraft in near vicinity, bird movement, sun angle, direct communication line through vocal means, pre and post flight checks, test flight in controlled circumstances.

Risk assessment: RPAS Flight

Likelihood	Consequence				
	1. Negligible	2. Minor	3. Moderate	4. Major	5. Catastrophic
5. Almost Certain	6 - Medium	7 - High	8 - High	9 - Extreme	10 - Extreme
4. Likely	5 - Medium	6 - Medium	7 - High	8 - High	9 - Extreme
3. Possible	4 - Low	5 - Medium	6 - Medium	7 - High	8 - High
2. Unlikely	3 - Low	4 - Low	5 - Medium	6 - Medium	7 - High
1. Rare	3 - Low	3 - Low	4 - Low	5 - Medium	6 - Medium

EXTREME	9, 10 - Task is not permitted. Risk controls are required to ensure residual risk is acceptable.
HIGH	7, 8 - Task is not permitted. Risk controls are required to ensure residual risk is acceptable.
MEDIUM	5, 6 - Task may proceed, however, risk must be reduced to 'as low as reasonably practicable' (ALARP).
LOW	0, 1, 2, 3, 4 - Task may proceed.

Figure 27. Proposed project plan for the dissertation project

Steps	Title	The Risk	The Consequence	Existing Controls	Risk Rating L (a)	C (b)	R (a+b)
001	Pre-planning/job prep	Incorrect data	Incorrect data	Follow operational procedures as outlined in the Operations Manual Double check and have someone else check charts, service locations, and project procedures	2	1	3
		Unfamiliar site/hazards	Unfamiliar site/hazards	Job site induction, review of JSA/checklists	2	2	4
		Unidentified overhead hazards	Unidentified overhead hazards	Inspect site before operations Consult council mapping systems for potential overhead assets Replan and reschedule operations	1	2	3
		Unqualified operator	Unqualified operator	Chief pilot to ensure pilot has correct & current licences. If not applicable then the standard operating conditions must be confirmed to be followed	2	2	4
002	Travel to and from site	Traffic accident	Traffic accident	Drive to conditions Follow RMS rules Concentrate on task	1	5	6
		Driver fatigue	Driver fatigue	Rest breaks Postpone job if affected by fatigue	1	5	6
		Poor understanding of vehicle	Poor understanding of vehicle	Complete fleet induction	2	2	4
003	Arrival & site set up/pack up	Plant & heavy machinery	Plant & heavy machinery	Training Avoidance & situational awareness Traffic management Separation of centre of operations from active areas Hi-vis clothing	1	5	6
		Hot weather/dehydration	Hot weather/dehydration	Wear appropriate clothing Bring plenty of water Reschedule operations if too hot	3	1	4
		Traffic & pedestrians	Traffic & pedestrians	Monitor job site Designate a centre of operations away from public access and active work sites	3	1	4
		Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		UV exposure/sun burn	UV exposure/sun burn	Wide brimmed hat, long sleeves, and sunscreen as required	2	2	4
		Manual handling	Manual handling	Team lifting Job rotation	2	2	4
		Snake bite	Snake bite	Wear long pants and boots Access to first aid kit and mobile phone/radio	1	4	5

Steps	Title	The Risk	The Consequence	Existing Controls	Risk Rating L (a)	C (b)	R (a+b)
004	Flight operations	Propeller strike	Propeller strike	Avoidance PPE Separation of persons from aircraft Clear communication from remote pilot stating aircraft movements	1	3	4
		Structural failure	Structural failure	Maintenance Pre/post flight checks	1	2	3
		Structural failure	Structural failure	Maintenance Pre/post flight checks	1	2	3
		Bird strike	Bird strike	Manoeuvre to evade/avoid birds Land ASAP if strike seems likely or has occurred Reschedule	1	2	3
		Engine failure	Engine failure	Pre/post flight inspection Maintenance Separation from public/do not fly over populous or built up areas Recovery/manual control training Failsafes	1	3	4
		Collision with persons on landing	Collision with persons on landing	Avoidance Communication and instruction from remote pilot Barriers Follow correct procedures outlined in the operations manual	1	3	4
		Other aircraft	Other aircraft	Check active NOTAMs Operate within standard operating conditions Use of a spotter Do not fly within approach/take-off splays or within 3nm (5.5km) of airport movement area or over 400ft/120m above ground level Descend RPA if aircraft spotted nearby	1	5	6
		Pedestrian/public	Pedestrian/public	Planning Awareness Exclusion Notification Monitoring	2	1	3
		Battery fire	Battery fire	Storage/LiPo bags Quarantine area Monitor batteries Maintenance Pre/post flight checks Follow manufacturers battery guidelines Fire extinguisher	1	4	5
		Loss of control	Loss of control	Instruction Mission planning Failsafes Awareness Follow procedures outline in operations manual	1	3	4
		Operator unaware of nearby buildings or overhead services	Operator unaware of nearby buildings or overhead services	Defined exclusion zones Keep constant visual contact with RPA to ensure RPA does not move into exclusion zones Awareness Pre flight meeting with all persons involved in operations to ensure understanding and location of hazards	1	3	4
		Poor weather	Poor weather	Check wind and weather forecasts prior to flight and confirm while on site Reschedule if too windy, raining or storms. Do not fly in thunder, low cloud, or conditions that would otherwise restrict visual line of site with the aircraft	1	3	4

Figure 28. Risk assessments from AlburyCity Council used in survey activities

Steps	Title	The Risk	The Consequence	Existing Controls	Risk Rating L (a)	C (b)	R (a+b)
001	Load equipment in to vehicle	Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
002	Travel to work area	Traffic accident	Traffic accident	Drive to conditions Follow RMS rules Concentrate on task	1	5	6
		Poor understanding of vehicle	Poor understanding of vehicle	Complete fleet induction	2	2	4
003	Arrive at site	Traffic & pedestrians	Traffic & pedestrians	Monitor job site Designate a centre of operations away from public access and active work sites	3	1	4
004	Park vehicles in required area	Insufficient space available for unloading safely	Insufficient space available for unloading safely	Keep vehicles & equipment away from traffic and environmentally sensitive areas	2	1	3
005	Inspect areas where work to be carried out	Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		Poor understanding of scope of works	Poor understanding of scope of works	Review instructions from supervisor	1	2	3
		Traffic - serious injury, crushing, death	Traffic - serious injury, crushing, death	Hi-vis clothing Signage Traffic cones Awareness	1	5	6
006	Conduct site induction	Lack of task understanding	Lack of task understanding	Site supervisor to induct staff on all site and council WH&S procedures	2	2	4
007	Unload equipment	Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		Eye damage	Eye damage	Safety glasses	1	3	4
		Cuts, abrasions, and crushing	Cuts, abrasions, and crushing	Wear gloves, safety boots, and keep limbs clear of pinch points	2	2	4
		UV exposure/sun burn	UV exposure/sun burn	Wide brimmed hat, long sleeves, and sunscreen as required	2	2	4
		Pedestrian/public	Pedestrian/public	Planning Awareness Exclusion Notification Monitoring	2	1	3

Steps	Title	The Risk	The Consequence	Existing Controls	Risk Rating L (a)	C (b)	R (a+b)
008	Site set up	Incorrect TCP or TCP not on site	Incorrect TCP or TCP not on site	Cease work and contact supervisor	2	2	4
		Incorrect signage	Incorrect signage	Complete TCP checklist	1	2	3
		Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		UV exposure/sun burn	UV exposure/sun burn	Wide brimmed hat, long sleeves, and sunscreen as required	2	2	4
		Hot weather/dehydration	Hot weather/dehydration	Wear appropriate clothing Bring plenty of water Reschedule operations if too hot	3	1	4
		Cuts, abrasions, and crushing	Cuts, abrasions, and crushing	Wear gloves, safety boots, and keep limbs clear of pinch points	2	2	4
		Legal liability	Legal liability	Use competent and ticketed personnel only	1	3	4
		Manual handling	Manual handling	Team lifting Job rotation	2	2	4
		Lack of task understanding	Lack of task understanding	Site supervisor to induct staff on all site and council WH&S procedures	2	2	4
		Traffic - serious injury, crushing, death	Traffic - serious injury, crushing, death	Hi-vis clothing Signage Traffic cones Awareness	1	5	6
		Entrapment	Entrapment	Establish escape route	1	5	6
009	Clean up rubbish	Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		Broken bottles - cuts/lacerations	Broken bottles - cuts/lacerations	Gloves	1	2	3
		Syringes/needle stick injury	Syringes/needle stick injury	Do not touch syringe Use long handle tongs, lift from barrel, place in sharps container and seal Gloves	1	3	4
		Snake bite	Snake bite	Wear long pants and boots Access to first aid kit and mobile phone/radio	1	4	5

Steps	Title	The Risk	The Consequence	Existing Controls	Risk Rating L (a)	Risk Rating C (b)	Risk Rating R (a+b)
010	Establish control points and complete survey	Overhead powerlines - electrocution	Overhead powerlines - electrocution	Keep staff at a 3m clearance of overhead power lines at all times	1	5	6
		Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		Incorrect levels	Incorrect levels	Use competent personnel	3	1	4
		Tripod trip hazard	Tripod trip hazard	Cones to be placed around tripod legs	2	2	4
		Laser - eye damage	Laser - eye damage	Do not look into or point laser at persons eyes Set up signage as required	2	1	3
011	Pack up equipment	Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		Eye damage	Eye damage	Safety glasses	1	3	4
		Cuts, abrasions, and crushing	Cuts, abrasions, and crushing	Wear gloves, safety boots, and keep limbs clear of pinch points	2	2	4
		UV exposure/sun burn	UV exposure/sun burn	Wide brimmed hat, long sleeves, and sunscreen as required	2	2	4
		Pedestrian/public	Pedestrian/public	Planning Awareness Exclusion Notification Monitoring	2	1	3
012	Remove signage	Slips, trips, sprains, strains, breaks	Slips, trips, sprains, strains, breaks	Correct footwear Watch out for uneven surfaces and loose gravel	2	2	4
		Cuts, abrasions, and crushing	Cuts, abrasions, and crushing	Wear gloves, safety boots, and keep limbs clear of pinch points	2	2	4
		Pedestrian/public	Pedestrian/public	Planning Awareness Exclusion Notification Monitoring	2	1	3
		Traffic - serious injury, crushing, death	Traffic - serious injury, crushing, death	Hi-vis clothing Signage Traffic cones Awareness	1	5	6
013	Travel back to office	Traffic accident	Traffic accident	Drive to conditions Follow RMS rules Concentrate on task	1	5	6

Figure 29. Proposed project plan for the dissertation project

3.7 Quality Assurance Plan

To make sure the overall quality of this dissertation research project is held to a high standard, measures and checks will be implemented, including:

- All survey data accuracies will be independently checked to ensure the survey was conducted properly. A full range of data audits and physical site checks will be used to validate the data by referencing the GCPs on site and the reference survey.
- All surveys will be undertaken by professional surveying staff following industry standard code of practice for surveying. This will be signed off by a registered survey to confirm all practices and workflows comply with industry standard.
- All instrumentation will be calibrated and checked prior to use on the project to ensure that no accumulative error occurs on the project.

Before submission of the final dissertation a draft submission will be provided to USQ and ACC supervisors to review and provide critical feedback. During the project, there will be opportunities and also regular reviews undertaken after each critical project phase. All feedback and advice received during these reviews will be taken into account in preparing the final document.

3.8 CONCLUSION

In conclusion the aim of this dissertation is to assess the measuring abilities of UAVs and verify against the control survey using a terrestrial LiDAR total station to provide a comparison of the systems accuracy, precision, limitations and advantages as a survey instrument.

As previously highlighted, the surveying industry has seen many technological improvements over the last 2 decades, with the rise of GNSS survey units and laser scanners, each having their own niche and adding to the whole industry, however not replacing the total station. The remote sensing capabilities of UAVs means less survey time for surveyors, larger areas can be surveyed quickly, and provide safe remote sensing to users in sensitive or dangerous areas such as hazardous landfill waste site or steep unstable terrain.

As such, UAV photogrammetry survey will be compared to terrestrial LiDAR survey in the following ways in this report; Time, cost, area surveyed, difference in volume, overall cost-benefit analysis for use in municipal landfill waste volume surveys.

4 RESULTS

4.1 INTRODUCTION

All data was reduced to .las point cloud format, as well as GeoTIFF raster imagery format

Day 2 lidar scan data was interrupted by live plant in the scan area during survey due to communication error. Better communication would be necessary for the future. These points while not usable, could be removed for the necessary survey comparisons to be completed.

Survey data was compared in RStudio open source GIS

4.2 VOLUME COMPARISON

To assess the change in volume over the two survey instances, a volume comparison tool was used created by Nathan Duncan at AlburyCity Council. It is a custom tool created using Python coding within ArcGIS Pro to subtract one raster image from another and report on the difference over a given shapefile comparison area.

A range of variations of the surfaces and comparison areas were used, and the final 0.39Ha area for comparison removed some surface noise and maximised comparison area over the four surveys. Other edits include point cloud re-classification and trimming of errant points (created in error when processing some water puddles in photogrammetry) to create this final comparison.

Table 7. Iterations of comparison surfaces

VOLUME SURFACE.	VOLUME CHECKS				
	Base	Comparison	Boundary	Cut	Fill
1	TIFF_Scan1Lidar.tif	TIFF_Scan2lidar.tif	"Boundary" - 0.26	18.1	2,144.10
2	TIFF_Scan1Lidar.tif	TIFF_Scan2photog.tif	"Scan1Lidar" - 0.99	85.2	5,387.70
3	TIFF_Scan1photog-1.tif	TIFF_Scan2photog.tif	"Boundary" - 0.26	21.7	1,973.80
4	TIFF_Scan1photog-1.tif	TIFF_Scan2photog.tif	"Scan1Lidar" - 0.99	132.8	4,339.70

5	TIFF_Scan1photog-1.tif	TIFF_Scan1Lidar.tif	"Boundary" - 0.26	49.3	79.7
6	TIFF_Scan1photog-1.tif	TIFF_Scan1Lidar.tif	"Scan1Lidar" - 0.99	232.2	227.7
7	TIFF_Scan2photog.tif	TIFF_Scan2lidar.tif	"Boundary" - 0.26	1.9	285.6
8	TIFF_Scan2photog.tif	TIFF_Scan2lidar.tif	"Scan1Lidar" - 0.99	65.7	1,429.30
9	TIFF_Scan1photog-edit.tif	TIFF_Scan2photog.tif	"Boundary" - 0.26	21.7	1,957.40
10	TIFF_Scan1photog-edit.tif	TIFF_Scan2photog.tif	"Scan1Lidar" - 0.99	128.6	4,411.80
11	TIFF_Scan1photog-edit.tif	TIFF_Scan1Lidar.tif	"Boundary" - 0.26	49.4	63.6
12	TIFF_Scan1photog-edit.tif	TIFF_Scan1Lidar.tif	"Scan1Lidar" - 0.99	209.2	281.2

The above table shows the iterations of various boundaries cropping the comparison areas as well as slightly edited surfaces to eliminate noise and parts of the survey that were not consistent from each time series. The below table then shows the final iteration of the comparable area, Polygon X1: 0.39Ha and the final surfaces used to derive the results.

Table 8. Final four comparisons used in analysis

VOLUME SURFACE.	VOLUME CHECKS				
13	TIFF_Scan1photog-edit.tif	TIFF_Scan2photog.tif	"Polygon X1" - 0.39	1.2	3,400.10
14	TIFF_Scan1Lidar.tif	TIFF_Scan2lidar.tif	"Polygon X1" - 0.39	10.8	3,046.50
15	TIFF_Scan1photog-edit.tif	TIFF_Scan1Lidar.tif	"Polygon X1" - 0.39	83.1	44.1
16	TIFF_Scan2photog.tif	TIFF_Scan2lidar.tif	"Polygon X1" - 0.39	6.4	459.5

Volume comparison 13-through-16 will provide the data for commentary below.

4.2.1 Results – Cumulative volume checks

Cumulative volume checks for the site resulted in the following:

Table 9. Excerpt from volume checks – cumulative.

VOLUME SURFACE	VOLUME (M^3)
Volume 1-P: UAV Photogrammetry (13)	3,400.10 m^3

Volume 2-L: LiDAR scan (14)	3,046.50 m^3

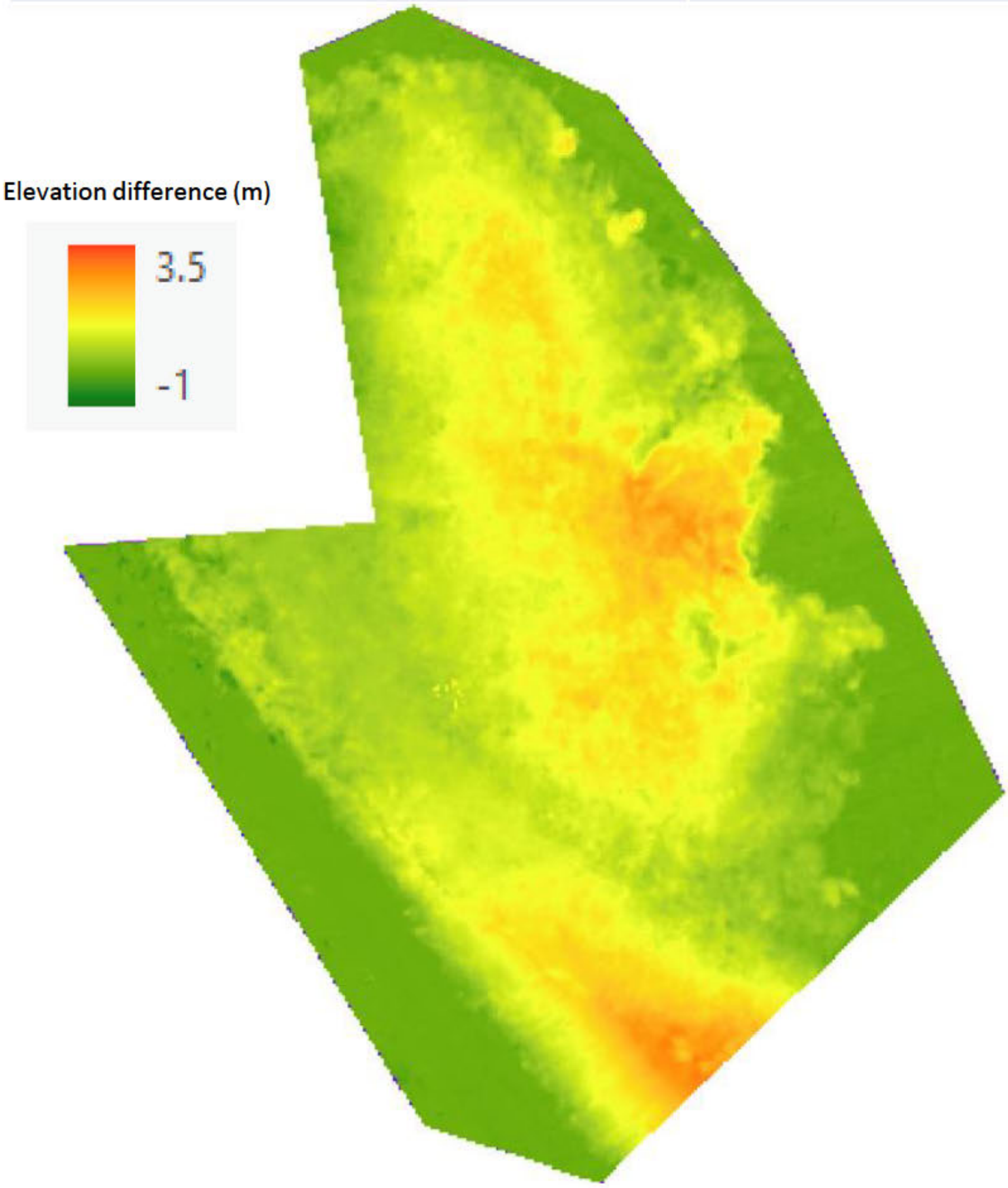

Figure 30. Volume 1-P – Photogrammetry volume surface over two surveys

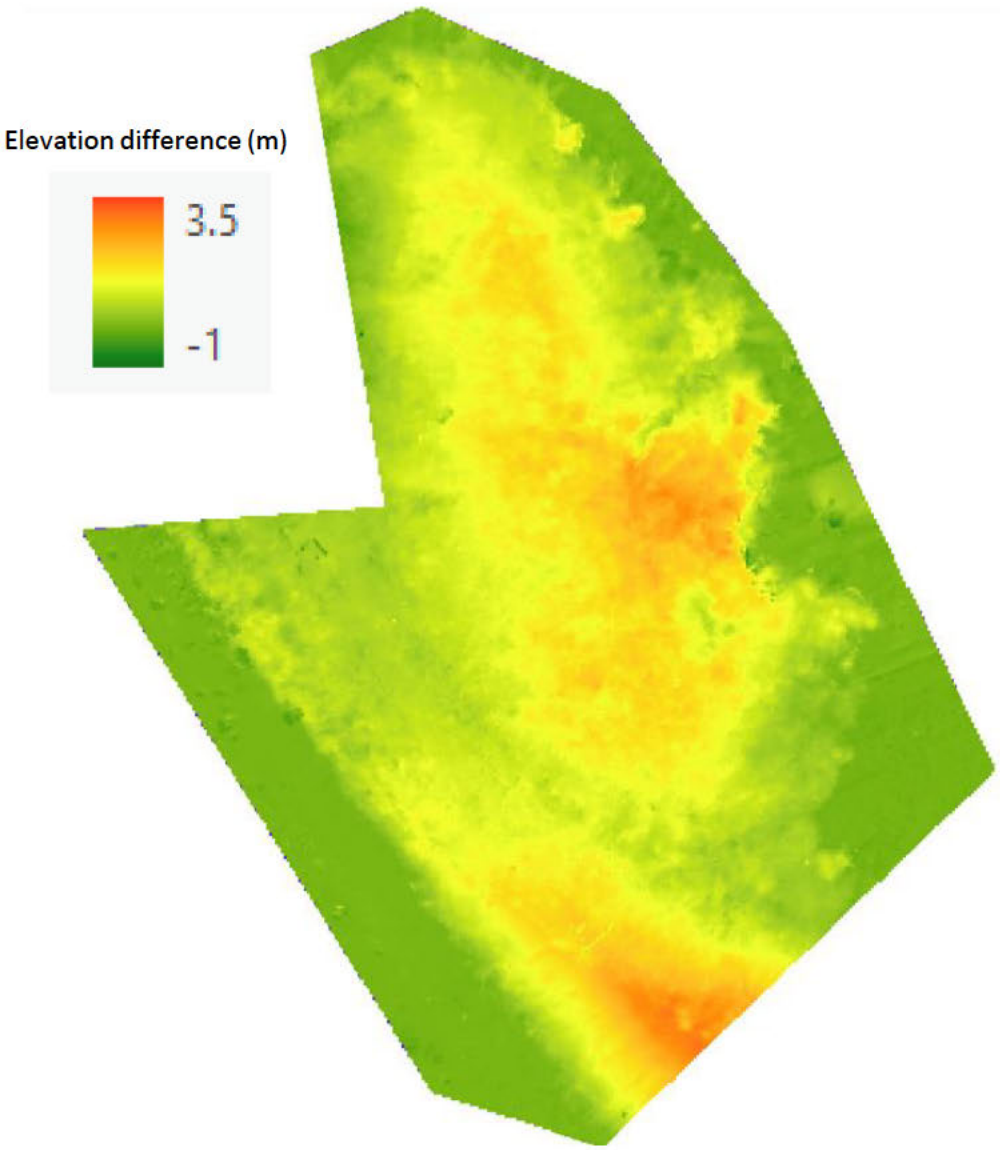

Figure 31. Volume 2-L - LiDAR volume surface over two surveys

The comparison highlighted a difference of 353.60 m^3 (nearly 10%) over the 0.39 Ha site. This works out to be a 90mm / m^2 average error over the site which is less than the +/- 200mm EPA 2018.

It should be noted that the LiDAR Scan did not have as close correlation to unchanged surface heights from the 1st to the 2nd survey as the Photogrammetry did. The lighter green surrounding the LiDAR scan compared to the deeper green reflected a higher difference. The Photogrammetry scan was between 5mm-50mm different in these areas, whereas the LiDAR scan came back with 10-100mm difference in the same areas (lighter green).

4.2.2 Results – Relative accuracy checks

Relative accuracy checks for the site resulted in the following:

Table 10. Excerpt from accuracy checks – relative.

VOLUME SURFACE	VOLUME (m^3)	Tolerance
Volume 3-1: Day 1 Check	44.1 m^3	10mm/m^2
Volume 4-2: Day 2 Check	459.5 m^3	120mm/m^2

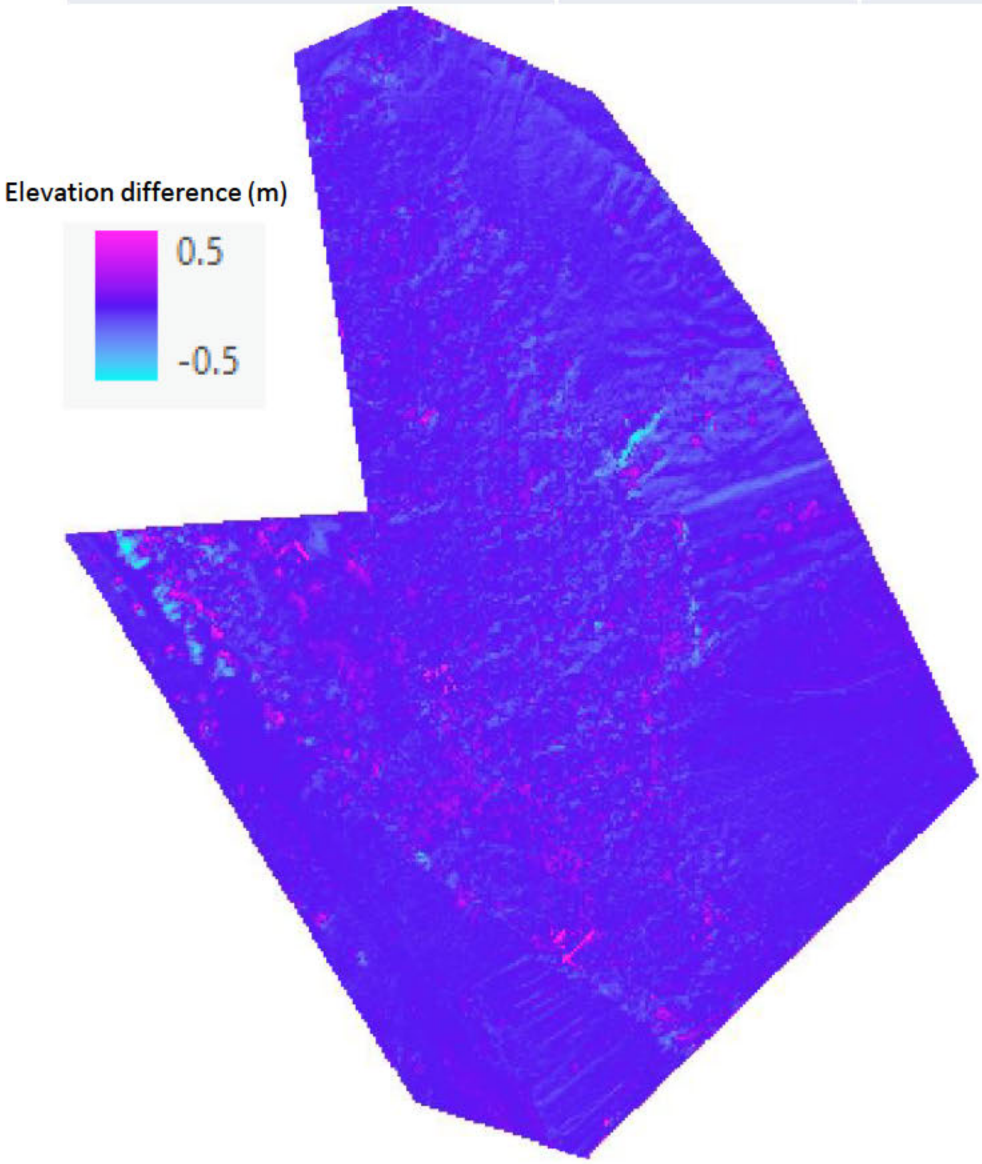

Figure 32. Volume 3-S1 – Day 1 comparison surface

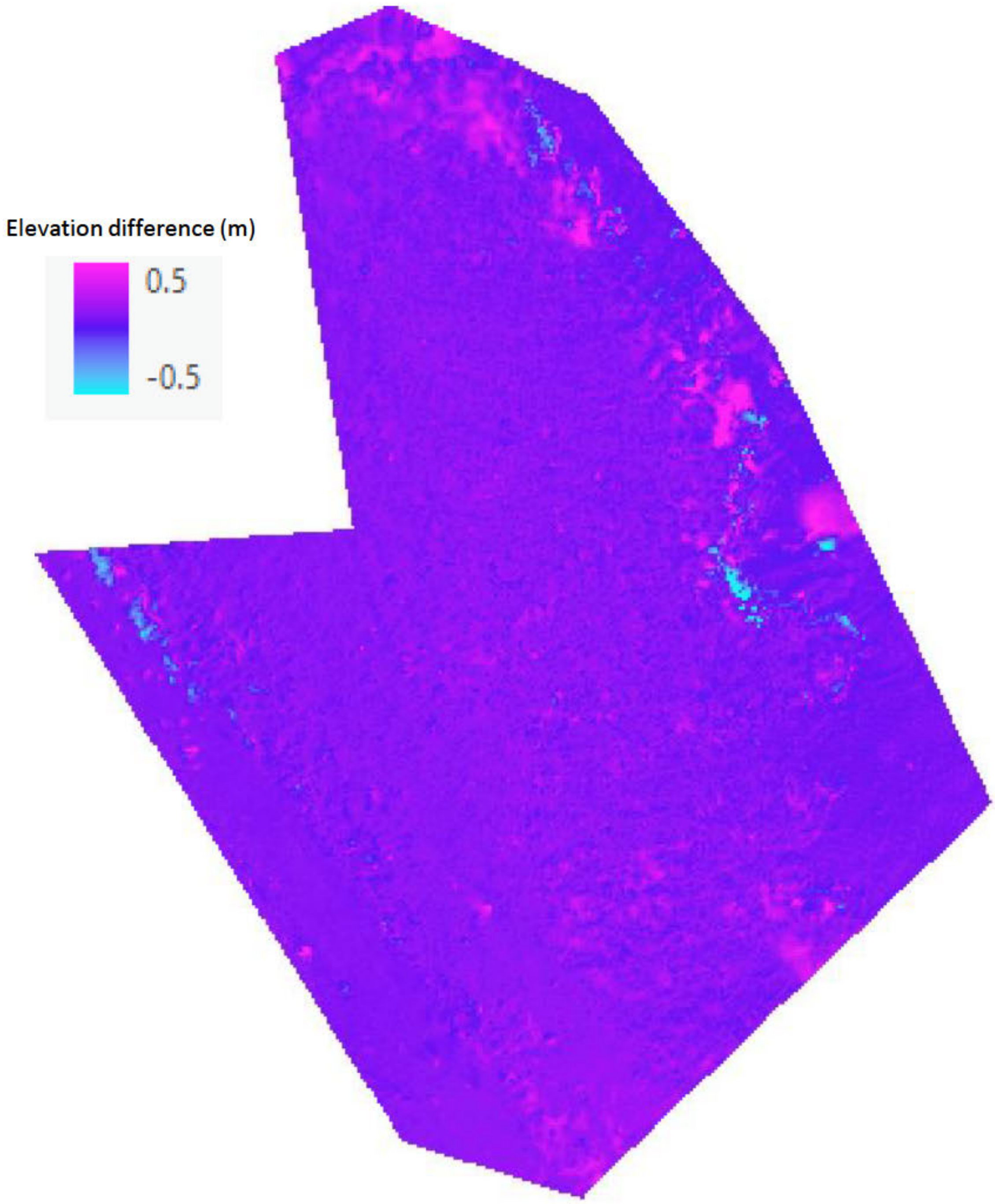

Figure 33. Volume 4-S2 – Day 2 comparison surface

The relative checks for the site resulted in the following, and should be as close to zero difference as possible to show good correlation.

The first surface **Volume 3-S1** is the day 1 survey check which compares Photogrammetry and LiDAR on the first day of survey to check the difference in the site. This yielded a 44.1 m^3 difference or 10mm/square meter average over the 0.39 Ha site. This is a very close correlation, showing the two methods have been setup and processed with minimal error.

The second surface **Volume 4-S2** is the day 2 survey check which compares Photogrammetry and LiDAR on the second day of survey to check the difference in the site. This yielded a 459.3 m^3 difference or 120mm/square meter average over the 0.39 Ha site. There is a larger error here with less correlation between the surfaces – illustrated by the lighter colour of the surface to Volume 3-S1. The two methods have been setup and processed in the same way as the with minimal error.

There is an approximate 10 times difference over the second survey, However, All variances still come within the 200mm tolerance specified by NSW EPA

4.3 Statistical Analysis

The following three statistical analysis calculations were selected to describe the datasets in relation to each other: Mean error, Standard deviation error and Root mean square error.

Table 11. Analysis of Photogrammetry and LiDAR points against GCPs (Survey 2)

	GPS Recorded	Photogram	Residuals (P)	LiDAR	Residuals (L)
GCP2	257.243	257.306	-0.063	257.28	-0.037
GCP3	262.837	262.872	-0.035	262.897	-0.06
GCP4	264.052	264.086	-0.034	264.185	-0.133
GCP5	260.633	260.63	0.003	260.745	-0.112
GCP6	259.791	259.774	0.017	259.888	-0.097
GCP11	254.656	254.706	-0.05	254.806	-0.15
GCP12	256.542	256.608	-0.066	256.616	-0.074

Table 12. Analysis of each metric for Photogrammetry and LiDAR

RMSE_P	RMSE_L	ME_P	ME_L	SDE_P	SDE_L
0.04392	0.10183	-0.03257	-0.09471	0.02947	0.03740

When compared to the GCPs, Photogrammetry was seen here to have a two times lower RMSE, indicating the bias and precision are both better than LiDAR.

The mean error indicates there is less bias in the photogrammetry survey. In the standard deviation error however there is a similar amount of imprecision in both survey methods. Some of the bias seen here in the LiDAR survey could be attributed to the shadowing affect seen in the point cloud analysis, where it may miss some of the detail in the highly undulating section of the site.

While Photogrammetry survey appears to be more precise and less biased, it should be noted that the GCP points are what the photogrammetry algorithm uses to pin down the table cloth as it were and results should be expecting as close to zero as possible in these regions. Both surveys utilise the points to calibrate their surface to the known ground points – such that it would be preferential to suggest future studies utilise additional GCPs out of the processing of the surfaces to perform independent checks. The analysis performed on these point should provide a more meaningful check as a cross-point validation. The method and approach was industry standard and utilising LiDAR as the control was believed to be the most appropriate – the results so happened to find that in this case photogrammetry survey compared better in each check.

Table 13. Analysis of Photogrammetry against LiDAR points as the control.

RMSE_of P		ME_P		SDE_P	
0.082	m	0.062	m	0.054	m

4.3.1 Mean Error (ME)

The mean error of Photogrammetry when compared to the LiDAR scan was seen to be a positive 62mm which is an acceptable tolerance, which is placed midway the results when compared to the GCP points above. This shows a relatively small bias from the control surface.

$$ME = \sum\left(z_{f_i} - z_{o_i}\right) \qquad \text{Eqn 1.}$$

4.3.2 Standard Deviation Error (SDE)

The way the bell curve may be distributed is described here by the Standard Deviation Error taking the residuals in this case from the difference of the Photogrammetry surface and the control LiDAR surface. The result shows just 54mm meaning the check dataset is more precise and less bias since it is less spread-out.

$$SDR = SD\left(z_{f_i} - z_{o_i}\right) \qquad \text{Eqn 2.}$$

4.3.3 Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) was selected to be used to determine the relationship between the various surfaces produced from the timeseries scans – to the volume surfaces, to determine the fitment between them.

RMSE is a prediction of errors found by taking the standard deviation of the residuals – a measure of how far from the regression line data points are. RMSE is a measure of how spread out these residuals are. In other words, it can identify how well fit the data is to the prediction surface.

$$RMSE = \left[\frac{\sum_{i=1}^{N}\left(z_{f_i} - z_{o_i}\right)^2}{N}\right]^{\frac{1}{2}} \qquad \text{Eqn 3.}$$

Where $\sum$ is the summation of, $\left(z_{f_i} - z_{o_i}\right)^2$ the differences of the forecasted and observed squared, divided by N the sample size and square rooted to find RMSE – Root Mean Squared Error.

Using RStudio a script was written up to import and run the desired datasets and derive the error values. The 3 error numbers to compare include:

- Day 1 survey discrepancy (For both survey methods)
- Day 2 survey discrepancy (For both survey methods)
- Overall Volume discrepancy (both methods, over both timeseries)

The analysis in RStudio began with importing the necessary libraries to code using raster datasets. Then the working directory was set containing the data files, and each raster was imported and given a shortened code name such as L1 – for "Scan 1 Lidar.tif".

A simple function was developed using samples on the internet (Maas, R & Ommeren W V 2015) to derive the RMSE as a function of X & Y. Once defined, values for X & Y could be substituted as the raster images being compared.

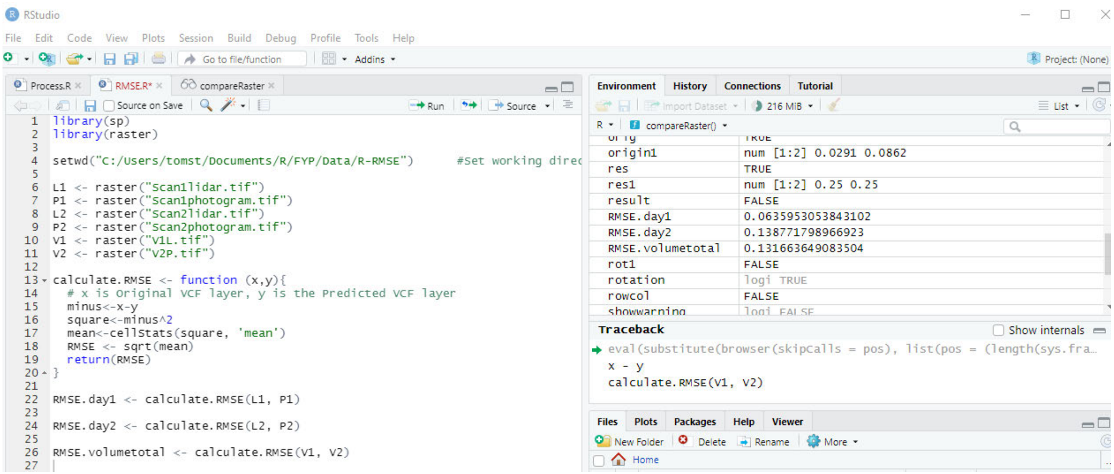

Figure 34. Excerpt of RStudio code calculating RMSE on 3 cases

The three RMSE error outputs from RStudio are as follows (in same unit as DV):

Table 14. Key metrics from the entire surface comparisons

RMSE Day 1:	0.062m	(LiDAR against Photogrammetry)
RMSE Day 2:	0.139m	(LiDAR against Photogrammetry)
RMSE Volumetric	0.132m	(Volume surfaces)

Day one RMSE of 62mm shows that the surfaces were closer overall than where the GCPs were located, however relatively consistent with these previously compared metrics.

Day two RMSE results came in at just over two times the day one figures at 139mm which shows there is some variance in the surveys here. It was noted in the methodology section that the photogrammetry scans overestimated the volume from the control by approximately 400 cubic meters, shown here in the additional variance.

The volume comparison RMSE was 132mm which is similar in amplitude to the Day two results. The inherent error identified in the residuals and the previous metrics would therefore also be pronounced here in the volume checks – confirmed by visual analysis of the difference in colour of the resultant volume check GeoTIFFs.

4.4 Cost Benefit Analysis

A cost benefit analysis was chosen as the method to compare the two survey techniques since all the required metrics are available, and the resulting score will enable decision-makers to see where the options compare for long term use and applicability to the Council.

Important to note, the LiDAR survey scan was done by a local surveying company to assist the Council and this thesis as a research project. Although this was the only price confirmed in the quotation process, it represents relatively good value for the works that were required. Future studies could include further analysis, but due to the resulting difference in cost, no further checks were made.

The formula explored is the Benefit-Cost Ratio which will allow for numerical scoring of each option which is a product of the net present value of all the Expected Benefits divided by the net present value of all the Associated Cost.

$$\mathrm{BCR} = \frac{\sum PV\ of\ all\ Expected\ Benefits}{\sum PV\ of\ all\ Associated\ Cost} \qquad \text{Eqn 4.}$$

Where BCR is Benefit Cost Ratio, $\sum PV$ will be the sum of Expected Benefits, divided by $\sum PV$ of all associated costs for the project.

All benefits will be referenced back to the productivity of the two methods, with a reference rate of a hypothetical GPS survey put into the comparison as well.

Table 15. Table of hours attributed to the survey tasks – Day 1

Task	Time for LiDAR Survey scan 1		Time for UAV Survey scan 1		Time for GPS Survey 1	
	hours	Staff	hours	Staff	hours	Staff
Travel to site	0.5	2	0.5	2	0.5	2
Induction	0.5	2	0.5	2	0.5	2
Survey setup	0.5	2	0.5	2	0.5	2
Survey	1.5	2	0.25	2	1.5	2
Travel: return to office	0.5	2	0.5	2	0.5	2
Processing survey	1.5	1	1.5	1	0.5	1
Total survey time	5	8.5	3.75	6	4	7.5
Total area surveyed	**9,930.84**	m2	**112,776.70**	m2	**8,000.00**	m2
	Time for LiDAR Survey scan 2		**Time for UAV Survey scan 2**		**Time for GPS Survey 3**	
	hours	Staff	hours	Staff	hours	Staff
Travel to site	0.5	2	0.5	2	0.5	2
Induction	0.5	2	0.5	2	0.5	2
Survey setup	0.5	2	0.5	2	0.5	2
Survey	1.5	2	0.25	2	1.5	2
Travel return to office	0.5	2	0.5	2	0.5	2
Processing survey	1.5	1	1.5	1	0.5	1
Total survey time	5	8.5	3.75	6	4	7.5
Total area surveyed	**7,946.41**	m2	**114,776.70**	m2	**8,500.00**	m2

Table 16. Table of costs attributed to the various survey tasks

Cost	LiDAR Survey		UAV Survey		GPS Survey (Hypothetical)	
Travel - vehicle (30km return)	$24.00		$24.00		$24.00	
Travel - time (2x workers)	$170.00		$170.00		$170.00	
Survey & Processing	$1,275.00		$1,000.00		$1,105.00	
Total	$1,469.00		$1,194.00		$1,299.00	
Comparison area (Ha)	**0.39**	"Polygon X1"	**0.39**	"Polygon X1"	**0.39**	"Polygon X1"
Price($)/Area(Ha)	$3,722.04		$3,025.26	123%	$3,291.31	
Comparison area (Ha)	0.79		11.28		0.85	
Price($)/Area(Ha)	$1,848.63		$105.87	1746%	$1,528.24	

The total survey time was recorded by both the tested methods of survey, and reference rates used to estimate the GPS survey time. The fastest total survey time is the UAV method, closely followed by the GPS survey. Although for this analysis, the GPS would have only provided an approximate 1pt / 10 square meters, far less than the 400pts / 10 square meters of the other two methods.

The total surveyed area includes the entire usable area of survey captured by the techniques, as such the UAV was able to cover over 11x the survey area covered by the GPS and LiDAR scans in a similar duration.

The costs derived from these total times comes in close with LiDAR being the cheapest, then GPS, then LiDAR. The comparable area selected for the final analysis “polygon X1” encapsulated the maximum comparable area without the need for any major post processing – providing a solid dataset for analysis without needing to delve into post processing in detail (although talked about in the methodology section).

The final cost analysis shows again that for the 0.39Ha comparison area, each survey method is within approximately 10% of each other. Where the UAV survey really comes into its own is the vast area it was able to capture at over 17X cheaper than LiDAR and 15X cheaper than GPS per Ha of survey captured. Important to note is the time to process larger surveys only differs for the number of GCPs used in the survey and the survey can be left to process in the background and an alert notified when it is complete, freeing up staff during processing time.

5 Discussion and Recommendation

This section will host discussion, then touch on the difficulties, shortcomings, and successes of the project as a whole, as well as possible consequences, implications and ethics around the use of UAV technology, photogrammetry and remote sensing in a civilian and research context.

5.1.1 Discussion

The aims of the research project were met by researching, testing, and evaluating the suitability of UAV photogrammetry for the purpose of landfill volume survey. That's not to say there are things that couldn't have been done differently within the methodology such as ensuring the survey site was free of landfill compactors during survey times (successfully organised on the second scan) and ensuring adequate GCPs were used to enable independent cross-validation.

The use of this modern UAV technology is highly suitable to landfill cell surveys due to the importance of personnel safety the method delivers, as well as cost effectiveness, efficiency, and quality of delivered outcomes for their use in site management. An additional output of UAV survey is a full resolution ortho-mosaic for consumption in CAD and other GIS programs allowing for great visualisation of the data, as well as the 3D point cloud for use in design tasks.

The objectives were met using quantitative analysis – which showed how UAV survey is between 15 and 17 times cheaper per hectare surveyed than GPS and LiDAR methods respectively. UAV photogrammetry was also able to maintain a relative accuracy to the base survey of below the +/- 0.2m accuracy required by the NSW EPA.

The UAV method can be a challenge to operate legally in built-up areas located near to airspace restrictions such as airports or military areas. By following the correct operating procedures and abiding by local civil aviation law, or employing a company with the correct approvals, UAV survey can be applicable to a large number of sites.

5.1.2 Recommendations

It is therefore recommended that the Council and other companies reporting on Landfill waste volumes use Photogrammetry survey in preference over GPS survey and Total Station survey. UAV Photogrammetry also works out to be more efficient than terrestrial LiDAR survey due to being cheaper to purchase, taking less time to survey and having other positive uses for the.

To ensure the best survey accuracy for UAV Photogrammetry, the best practice was observed using additional GCPs in the survey scattered according to the 5-on-a-die layout rule (Awasthi, B et al 2019). To then perform data checks on points independently, additional points can be used for the ground truth to ensure ongoing survey accuracy.

It also goes without saying to ensure all policy and procedure is up to date, as well as operating the UAV in good weather and to the CASA standard operating conditions.

5.1.3 Successes, difficulties, and shortcomings.

This section explores the following headings based on experimental experience and research.

5.1.3.1 Difficulties

- Funding: Securing sufficient project funding to cover the original project scope was a challenge. This resulted in a reduction of scope for the scan area while still allowing for successful survey technique comparison.
- Data collection: Surveying with live plant proved difficult due to live obstacles in the survey area. Timeliness of LiDAR scan meant obscure data.

5.1.3.2 Successes

- Funding: A budget allocation increase was approved by AlburyCity senior management which allowed for rental of survey gear for the revised scope. This enabled as part of the project, the provision of 2 staff members from Walpole survey Albury to conduct the survey scans.
- Project outcome: Successful project data collection scans on both occurrences, resulting in two complete datasets prepared for assessment.

- Volumetric analysis: Successful comparison of surfaces from both scans undertaken and analysis and comparisons complete.

5.1.3.3 Shortcomings

- Survey size was smaller than originally planned, which reduced the need to perform post processing activities (this would be appropriate for future scope).
- Not enough GCPs to make the most of accuracy checks within the survey site of the LiDAR scanner. As such common points within the survey selected.
- LiDAR scanner data had ghost points in the main cell area from live plant, this had to be cropped out and comparison was still conducted.

5.1.4 Ethics, Implications and Consequences

This section will detail the ethics, implications, and consequences regarding the use of UAV and terrestrial LiDAR.

5.1.4.1 Ethics

- Use of images captured from using a UAV system, from a high elevation carries a risk of breach of privacy, or personal gain from aerial imagery, survey, or surveillance. Ensure all site images are stored on secure server systems with access control. Ensure all processed outputs are screened before public use.
- Potential for pilots to gain access to restricted information recorded by the UAV, pilot’s ethical decision around their future action with that new information. This may breach privacy or company policy.
- Purchase of mass-produced technology such as UAV Phantom 4, risk of underpaid work, unfair work manufacturing environments. While large company such as DJI is a world leader in UAV sales with approx. 70% market share. The company is private and not open to public investment which means it doesn’t need to consider the opinion of investment stakeholder.
- The use of UAVs or LiDAR scanners reduces exposure to potentially hazardous and difficult to access remote locations, increasing worker safety and reducing potential for injury to workers required to gain this information.

5.1.4.2 Implications

- Legal implications around breach of privacy if survey images capture private details not normally visible to the public at regular viewing angles (from the street / google maps). This can lead to a loss of trust by the public, a loss of employment and a loss of drone license.
- Less site survey using traditional survey techniques, often these methods are associated with cadastre survey and a registered surveyor. This is less of an implication when using a scanning multi-station due to having the functionality of a regular total station with additional survey capabilities.
- Accidental or aggravated UAV collision. Drone impact with staff or site personnel, plant and machinery or low flying aircraft. This may cause damage to property or personal injury. Specific insurance can be held to reduce the financial penalty for accidental collision.
- Creation of jobs for UAV pilots, providing solutions in new technology sectors not previously achievable such as high resolution, repeatable multi-spectral scans of areas.
- Wide variety of modern solutions to remote surveillance and imagery which can assist in asset condition assessments of difficult to reach locations such as bridge columns and underneath of decks, roof tops, emergency response for police and firefighting and agriculture. This could lead to the disruption of many sectors providing people with cheaper more effective options.

5.1.4.3 Consequences

- The use of a UAV system discourages site staff to walk around survey site less, which could lead to less health and fitness and less observation of site.
- Potential cause of distrust with the public with regard to the possibility for breach of privacy, resulting in negative views of drones and UAVs despite their positive uses.
- Loss of skill in the field of surveying due to reduction in regular use of specialised survey equipment. This may not be the job of the drone pilot to engage in surveying activities outside of those required for an Aerial Survey. Additional training can be provided to ensure survey pilots maintain that skillset. You can be proficient in both skillsets simultaneously.

- The production of hyper-realistic 3D model enables site snapshot and all site details to be recorded and analysed in greater depth than traditional surveys. Details can be shared, and measurements and comments can be made directly on the app to inform design or maintenance activities.
- A variety of deliverables and outputs associated with LiDAR and Photogrammetry surveys such as point clouds, textured mesh files, DEM and DTM files are highly usable and consumable in a range of common surveying software.

Thanks for reading – T.S.

6 References

Awasthi, B Karki, S Regmi, P Singh D, D Thapa, S & Panday, U S 2019, *Analyzing The Effect of Distribution Pattern & Number of GCPs on Overall Accuracy of UAV Photogrammetry Results,* October 2019, Conference: International Conference on Unmanned Aerial System in Geomatics 2019, April 06-07, 2019, IIT Roorkee At: Roorkee, India, viewed online 28/03/2021 <https://www.researchgate.net/publication/336278707>

Arango, C & Morales C. A 2015, *Comparison between Multicopter UAV and total station for estimating stockpile volumes*, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-1/W4, 131–135, https://doi.org/10.5194/isprsarchives-XL-1-W4-131-2015, 2015.

Alonzo, M, Dial, RJ, Schulz, BK, Andersen, H-E, Lewis-Clark, E, Cook, BD & Morton, DC 2020, *Mapping tall shrub biomass in Alaska at landscape scale using structure-from-motion photogrammetry and lidar*, Remote Sensing of Environment, vol. 245, no. 111841.

Australian Civil Aviation Safety Authority 2020, *Remotely piloted aircraft systems - licensing and operations' Civil Aviation Safety Authority*, Advisory Circular, viewed 3 October 2020, <https://www.casa.gov.au/standard-page/casr-part-101-unmanned-aircraft-and-rocket-operations>

Bahuguna, PP, Kumar, D, Kumar, S 2006, *Modern Survey Instruments and their use in Mine Surveying*, Department of Mining Engineering, Indians School of Mines, Dhanbad – 826004

Chapman, A 2016, *Types of Drones: Multi-Rotor vs Fixed-Wing vs Single Rotor vs Hybrid VTOL - AUAV*, AUAV, viewed 5 October 2020, <https://www.auav.com.au/articles/drone-types/>.

DJI 2020, *PHANTOM 4 PRO V2.0 Visionary Intelligence Elevated Imagination*, viewed 4 October 2020, <https://www.dji.com/au/phantom-4-pro-v2>

DJI 2020, *The World Leader in Camera Drones/Quadcopters for Aerial Photography*, DJI Official Website, viewed 5 October 2020, <https://www.dji.com/au/phantom-4-rtk/info#specs>.

Ellis, N 2013, *Inspection of power transmission lines using UAVs,* Undergraduate Research Project, University of Southern Queensland, Toowoomba.

Gaurav, S G 2018, *Brief History of LiDAR, Its Evolution and Market Definition*, BBC Research Editorial Blog Website, viewed 5 October 2020, <https://blog.bccresearch.com/brief-history-of-lidar-evolution-and-market-definition>.

Geomatics Land Surveying 2021, *Trimble R10 Price*, viewed 20 May 2021, <https://geomaticslandsurveying.com/wp-content/uploads/2018/11/trimble-r10-price.jpg>

Grimm, D E, Zogg, H 2013, *White tech paper: Leica Nova MS50*, Specification and feature list publication for Leica Nova MS50 Multi-station, Published by Leica Geosystems AG Switzerland, viewed 15 April 2021, <https://w3.leica-geosystems.com/downloads123/zz/tps/nova_ms50/white-tech-paper/leica_nova_ms50_tpa_en.pdf>

Invest Albury Wodonga 2021, *Economic and Demographic Profile*, published by eco-development Albury Wodonga, online article with economic and populous data for Albury Wodonga, viewed 2 February 2020, <https://investalburywodonga.com.au/real-estate/commercial>

Jayathunga, S, Owari, T & Tsuyuki, S 2018, The use of fixed–wing UAV photogrammetry with LiDAR DTM to estimate merchantable volume and carbon stock in living biomass over a mixed conifer–broadleaf forest, International Journal of Applied Earth Observation and Geoinformation, vol. 73, pp. 767–777.

Leica Geosystems, 2021, *BLK360*, Specification and data sheet for Leica Laser scanner BLK360, published by Leica Geosystems, viewed 21 March 2021, <https://leica-geosystems.com/products/laser-scanners/scanners/blk360>

Long, D 2013, *A.R Drone vision-guided searching*, Undergraduate Research Project, University of Southern Queensland, Toowoomba.

Majeed, R, Abdullah, N, Mushtaq, M & Kazmi, R 2021, *Drone Security: Issues and Challenges*, International Journal of Advanced Computer Science and Applications. 12. 10.14569/IJACSA.2021.0120584

Metcalfe, P J (2013), *Evaluation of remotely piloted aircraft in surveying applications*, Undergraduate Research Project, University of Southern Queensland, Toowoomba.

Maas, R & Ommeren W V 2015, *Assignment Lesson 7 - 2.4 Calculate RMSE between predicted and original rasters,* This Rpub Document includes the assignment of Geo-Scripting Lesson 7. In this Lesson LandSat bands are used to predict the tree cover with a linear regression model, viewed online 3 October 2021 <https://rstudio-pubs-static.s3.amazonaws.com/53631_ce77e4e53bfc4fa2b210f719c301d11d.html>

Naughton, R 2003, *Remote Piloted Aerial Vehicles: An Anthology*, in H McDaid, D Oliver, B Strong & K Israel (eds), www.ctie.monash.edu.au, Monash University Melbourne, viewed 4 October 2020, <http://www.ctie.monash.edu.au/hargrave/rpav_home.html#Teleautomata>.

NSW EPA 2018, *Waste Levy Guidelines*, State of NSW and the NSW Environment Protection Authority, viewed report online 12 March 2021

NSW EPA 2016, *Environmental Guidelines Solid waste landfills,* Second edition 2016, viewed report online 11 March 2021

NSW Government 2019, *Surveyor-General's Direction No.5: Calibration of Electronic Distance Measuring (EDM) Equipment*, Surveyor-General of NSW, viewed 3 October 2020, <https://www.spatial.nsw.gov.au/surveying/surveyor_generals_directions>

Pix4D 2019, *Pix4Dcapture: Free drone flight planning mobile app*, viewed 4/10/2020, https://www.pix4d.com/product/pix4dcapture

Schindler K, 2014, *Mathematical Foundations of Photogrammetry*, Computer Science, Article detailing the algorithmic mathematic principles behind 3D Photogrammetry, Handbook of Geomathematics pp 1-14, Springer Link, Corpus ID: 15302500, available online and viewed 24/08/2021 <https://ethz.ch/content/dam/ethz/special-interest/baug/igp/photogrammetry-remote-sensing-dam/documents/pdf/math-of-photogrammetry.pdf>

Sofonia, J, Shendryk, Y, Phinn, S, Roelfsema, C, Kendoul, F & Skocaj, D 2019, *Monitoring sugarcane growth response to varying nitrogen application rates:*

A comparison of UAV SLAM LiDAR and photogrammetry, International Journal of Applied Earth Observation and Geoinformation, vol. 82, no. 101878.

Solazzo, D, Sankey, J B, Sankey, T Ts & Munson, S M 2018, Mapping and measuring aeolian sand dunes with photogrammetry and LiDAR from unmanned aerial vehicles (UAV) and multispectral satellite imagery on the Paria Plateau, AZ, USA, Geomorphology, vol. 319, no. 101878, pp. 174–185.

Torres, G 2019, *Drone photogrammetry vs. LIDAR: what sensor to choose for a given application*, Wingtra website, viewed 5 October 2020, <https://wingtra.com/drone-photogrammetry-vs-lidar/>.

Trimble Geospatial 2021, *Products and solutions – R10*, viewed 05/07/2021, <https://geospatial.trimble.com/products-and-solutions/r10>

United States Naval Academy 2018, DTM/DSM and Other Lidar Grids, Last revision 6/27/2018, viewed 21/08/2021, https://www.usna.edu/Users/oceano/pguth/md_help/html/dtm_dsm.htm

Wilson, B 2010, *Development of an unmanned aerial vehicle for use during disaster situations*, Undergraduate Research Project, University of Southern Queensland, Toowoomba.

Vilbig, JM, Sagan, V & Bodine, C 2020, Archaeological surveying with airborne LiDAR and UAV photogrammetry: A comparative analysis at Cahokia Mounds, Journal of Archaeological Science: Reports, vol. 33, no. 102509.

7 APPENDICES

7.1 TECHNICAL DETAILS

Appendix A

ENG4111/4112 Research Project

Project Specification

For	Thomas Staats
Title	Comparative review of Photogrammetry UAV and terrestrial LiDAR for Volumetric surveys.
Major	Civil Engineering (BCIVHon)
Supervisor	Craig Lobsey
Sponsorship	Andrea Baldwin – Team leader Resource Recovery, AlburyCity Council
Confidentiality	Written permission provided from Council to use AWMC landfill site and resources
Enrolment	ENG4111 – EXT S1, 2021 ENG4112 – EXTS 2, 2021
Project Aim	To compare LiDAR and UAV photogrammetry and evaluate the most effective remote sensing data capture method for Municipal waste volume surveys at a local council, while abiding by the EPA Waste Levy Guidelines 2018 for minimum accuracy requirements. A cost benefit break-down will be developed including initial cost outlay, running costs, and time to perform each survey, as well as practicality for use in volume analysis

Programme: Version 1, 24 February 2021

1. Research background information relating to ground-based LiDAR and Photogrammetry
2. Conduct high resolution initial baseline survey with the two survey techniques.
3. Conduct high resolution comparison survey 3 months post baseline.
4. Analyse field data and provide it in a comparable format (GeoTIFF) required for analysis
5. Analyse survey capture variance and comment on the differences between the results.
6. Evaluate why such differences occur.
7. Provide a summary on the two survey methods and their relative effectiveness to conduct remote sensing, cost and time requirements, other skillset requirements and make recommendation to which technique is most suitable to volume analysis in a local government and waste management context.

If time and resources permit:

8. Modify the test parameters and increase/decrease the intensity of the data capture rate for each technique.
9. Provide a summary and recommendation on the iteration curve which changes make the most beneficial improvements or time savings.

8 APPENDIX OF FIGURES

9 APPENDIX OF TABLES

10 APPENDIX OF ATTACHMENTS

List of all attachments relevant to the dissertation project:

ACC Risk assessment for field survey

Credit ACC (cited within paper)

ACC Risk assessment for UAV survey

Credit ACC, Nathan Duncan (cited within paper)

ACC Job Safety Assessment

Credit ACC

RPAS OPERATIONAL PROCEDURES (LIBRARY)

APPENDIX 5 - JOB SAFETY ASSESSMENT

Company	AlburyCity Council	Date	06-05-2021
Task: Location:	UAV Aerial Survey AWMC - Northern Valley	Check the following and address as needed	

Maps and charts available and checked	Yes, outside 3NM
Weather, within limits for RPA and operation	Mostly sunny. Light winds. – Max 24 C
Airspace classification and requirements	Class D
NOTAMs	Checked
Possibility of public moving into area	bollard area off
Footpath/right of way	bollard area off
Landing area including alternate	Yes, on plan
Ability to maintain 30M of public	Yes
Obstructions (buildings, trees) ('Return to Home' height setting)	Set to 400ft AGL
Possible interference (Powerlines/antennas)	Test flight before
Ability to maintain visual line of sight	Yes
Remote Pilot's ability matches location/task	Yes
Permission of any landowners	Yes, council land AWMC
Privacy	clear
Local restrictions/by laws	clear
Signage placement	Place on day
Jobs specific threat and error management	Risk assessments

RP	Tom Staats	Signature [redacted]		
Crew	Nathan Duncan			

Comments:

Ensure survey area is free of people, setup in areas inaccessible to public and away from active plant. Conduct 1 flight of the northern valley active fill area for use as base survey. Ensure Road and sorting pad area is not flown over and monitor weather conditions on-site and reschedule activity if rainfall or high winds occur.

Albury City Council T/A AlburyCity RPAS Operational Procedures	Document No.: ACC-RPAS-02	Revision No.: 1
Release Date: 24/04/2020	Uncontrolled If Printed	Page 26 of 32

ACC Flight Authorisation Form

Credit ACC, Nathan Duncan

RPAS OPERATIONAL PROCEDURES (LIBRARY)

APPENDIX 1 - FLIGHT AUTHORISATION FORM

Task		
Date 06/05/2021	Location AWMC NV	RPAS System APOLLO - P4 V2.0
Task Description Standard ACC landfill survey Flight control software to be used to create a single grid of images to produce survey plan, and output DEM & Ortho-mosaic. Tower radio frequency 123.25 to be tuned in and monitored		
RP T. STAATS	2nd RP N. DUNCAN	Observer / Crew N. DUNCAN

Operation details		
Local Area Frequencies 123.25	Emergency Contact Number Ben Van Kesteran 0401 948 627	
Notes (special operational procedures, permissions, etc.)		

Flight Authorisation		
Chief Remote Pilot		Date
Remote Pilot	[redacted]	Date 4/5/2021

Albury City Council T/A AlburyCity RPAS Operational Procedures	Document No.: ACC-RPAS-02	Revision No.: 1
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ACC Pre-Post flight check forms
Credit ACC, Nathan Duncan

Screenshot: Pix4D flight software flight planning

Meeting invite to RPAS pilot, RPAS spotter, AWMC site supervisor, AMWC team leader & Walpole survey company

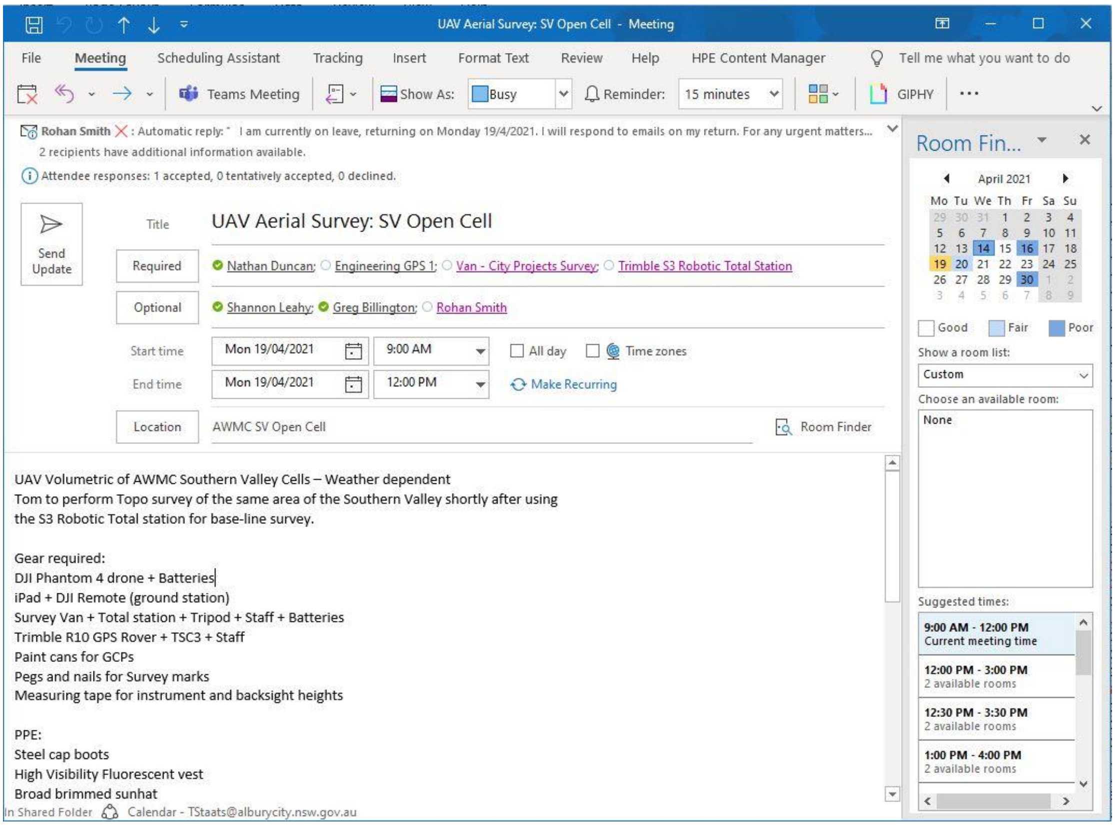

Figure 35. Calendar event for the 1st drone flight (Tom Staats, 2021)