

University of Southern Queensland
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3D Hydrologic Features Mapping with Imaging Rover

A dissertation submitted by
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in fulfilment of the requirements of
ENG4111 and ENG4112 Research Project
towards the degree of
Bachelor of Spatial Science (Honours) (Surveying)
Submitted October, 2016

ABSTRACT

Severe weather events and flooding have damaged waterways in Toowoomba in the summer of 2011; however with the aid of flood mapping, the damage can be greatly reduced. Flood mapping has always been of major importance to local councils and communities as it identifies flood prone areas and allows the authorities to mitigate the risk to reduce damage. New technology has emerged that can accurately create 3D image models of flood prone sites in an attempt to map hydrological features and the potential risks. The Trimble V10 Imaging Rover can create a spatially accurate image model and point cloud that can later be processed and measured off to create flood mitigation solutions. The aim of the project is to see whether the Trimble V10 Imaging Rover is a viable solution for flood mapping and hydrologic feature modelling within small catchments and creeks.

A section of West Creek in the centre of Toowoomba was selected for the site and a survey using the Trimble V10 and R10 GNSS receiver was completed. The data was processed in Trimble Business Centre to create a useable model. The automatic tie-point method was selected for the registration of the images to create an image model and later, a point cloud was generated.

This research proposal identifies that the creation of an image model within Trimble Business Centre allows simple analysis of the hydrological features. Areas and distances can be accurately measured; however a point cloud is required for a more detailed analysis of the features. The point cloud was poorly generated and was extremely patchy and unreliable which made it virtually unusable. The horizontal coordinates of the models were similar however the heights were significantly different. The research project is useful to councils and local governments to try and mitigate flood risks and damages.

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ACKNOWLEDGEMENTS

I would like to acknowledge that the research was performed under the supervision of Dr. Xiaoye Liu. Her continued assistance has been extremely valuable.

I would also like to acknowledge the assistance and technical support provided by Luke Czaban on the operation and processing of data of the Trimble V10.

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CHAPTER 1 – INTRODUCTION

1.1 Introduction

3D modelling is fairly old news in the world of spatial science however it is progressively becoming more accurate and cost effective (*MacLeod 2014*). Arguably the most common form of 3D modelling is laser scanning with many survey firms offering scanning solutions of their own; however other areas include UAV's and photogrammetry. The surveying industry is moving away from traditional surveying practices in favour of 3D point cloud technology (*Jones 2013*) as it provides a much more in-depth model of the environment. Similar to terrestrial laser scanning instruments, Trimble has developed an imaging rover which takes 360 degree images of the terrain rather than millions of 3D points. From these images, spatially accurate points can be extracted and used in later applications. Due to the added benefit of having a visual representation of the terrain as well as data points, the Trimble V10 Imaging Rover was chosen to use for my research project.

Although the V10 imaging rover is essentially an advanced form of terrestrial photogrammetry, there is very limited research on the topic as was discovered by completing a literature review. It differs to traditional terrestrial photogrammetry because it captures 360 degree imagery (*Trimble, 2015*) from a single station compared to a single image from a single station. The V10 should allow for a more complete model that includes numerous similar points within the images; which should ultimately lead to a more accurate three-dimensional model.

Severe weather events and flooding have damaged waterways in Toowoomba in the summer of 2011; however with the aid of flood mapping, the damage can be greatly reduced. Flood mapping has always been of major importance to local councils and communities as it identifies flood prone areas and allows the authorities to mitigate the risk to reduce damage. West Creek in Toowoomba experienced heavy floods during this period (*Brown, 2011*) and was the obvious choice for the survey site.

Floods occur due to poor planning and rainwater management; however the objects that contribute to the flood are not always known. Mapping the hydrologic features within the site provides documentation and a model to identify flood hazards such as bridges and culverts. Once identified, the features can be removed or redeveloped to mitigate the flood hazard depending on their impact. Hydrologic feature modelling provides a key resource in an attempt to rectify the past floods.

1.2 Aim, Objectives and Scope

Although there are already flood mapping systems in place, they mainly deal with larger areas and do not identify the source of the flood. The aim of the project is to see whether the Trimble V10 Imaging Rover is a viable solution for flood mapping and hydrologic feature modelling within small catchments and creeks. The objectives that are hoped to be achieved within the project are:

- To determine how accurate the Trimble V10 Imaging Rover is and whether it is suitable for the application of mapping/modelling hydrological features.
- To calculate the volume of the selected site using the point cloud and determine how much water it can handle during severe weather events.
- To determine whether the point cloud/image model is a sufficient dataset to use for future applications related to the site.

This technology can be applied to large catchments and entire creeks/streams, but to keep it within the scope of an undergraduate thesis it was decided to survey a small stretch of West Creek between The Warrego Highway and Herries Street. The roads provide a structural boundary for the survey and the chosen section of creek includes a bridge and water calming devices. The site is easily accessible and has limited trees to allow for good satellite connection. Although the section is quite long, it is essentially without obstructions so it should allow for a quick and fairly simple

survey process. The site is suitable for the necessary scope and it should meet the requirements of the project.

1.3 Conclusion

Toowoomba and West Creek in particular have been subjected to severe floods in the past, and with the aid of hydrologic feature mapping using the Trimble V10 Imaging Rover, there is hope to identify flood hazards and mitigate the risk. The model should provide a detailed analysis of the site's features which can be used to isolate the hydrologic features. The dissertation features five chapters which include the introduction, literature review, methodology, results and discussion, and conclusion. Research and investigation into the current flood mapping methods as well as the applications of the Trimble V10 is performed in the literature review which provides reasoning for the selection of the research project.

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction

The purpose, aim and objectives of the project were discussed in Chapter 1. In this chapter, a literature review is performed to identify the existing knowledge on photogrammetry and the Trimble V10 in order to better understand how the technology can be applied to modelling hydrologic features. The purpose of the literature review was to gather information about:

- Terrestrial photogrammetry and the theory behind it
- Geo-referencing of images and point clouds to create 3D hydrological features
- Data selection and filtering for optimum information

2.2 What is Photogrammetry?

Photogrammetry is the use of photography in fields such as surveying and mapping to create a 3D model which measurements can be extracted from (*Walford 2007*). Through taking multiple photos of an object or site, images can be stitched together through geo-referencing of similar points within the images, to form a survey accurate 3D model. Photogrammetry has a wide array of applications and can be used on engineering projects through to medical applications. The improvement in technology results in fast and efficient survey solutions whilst being able to record data to use at a later date.

2.3 Types of Photogrammetry

2.3.1 Aerial Photogrammetry

In aerial photogrammetry, a camera or sensor is mounted in an aircraft. The type of aircraft can range from a fixed wing plane through to a multi-rotor copter or UAV. The camera is generally mounted to the underside of the aircraft and takes images of the ground below (*Walford 2007*). The detail and quality of the survey depends on the aircraft's altitude and the amount of image overlap. Image overlap is required to view a pair of images in stereo-view. Stereo-view allows the viewer to see the images in 3D and thus provide a more detailed view of the images. These photos are also used for Digital Elevation Model (DEM) creation.

2.3.2 Terrestrial Photogrammetry

Terrestrial photogrammetry is also known as close-range photogrammetry as the camera is typically close to the subject object. The camera is generally handheld or on a tripod, however it can also be mounted on a vehicle for ease of mobility (*Walford, 2007*). Terrestrial photogrammetry is not concerned with producing topographical maps; it is more concerned with creating 3D models of objects, point clouds and generating measurements. The cameras used for terrestrial photogrammetry are often much more affordable than those found in aerial photogrammetry as they do not require the inclusion of numerous sensors. A simple digital camera can be used for close-range photogrammetry and still produce accurate results; however an appropriate camera positioning will need to be adopted to generate suitable overlap (*USQ SVY3202 Study Book, 2015*).

2.4 Trimble V10 Imaging Rover Properties

The Trimble V10 imaging rover is a new piece of technology which captures panoramic images through 12 cameras. Compared to traditional digital cameras, the V10 images have full central perspective properties (*Haefeli-Lysnar*), meaning the position of the images are known and can be stitched together to create a single panorama. The images are overlapped when they are stitched together based on the exterior calibration of the cameras. Each camera has its own projection centre (*Haefeli-Lysnar*) allowing for accurate panoramas.

The V10 can be integrated with a Trimble R10 GNSS Receiver or S6 Total Station to give accurate positions (*Trimble, 2016*). The V10 sits on a range pole with a special tip that limits the impact on the pole to ensure the cameras do not go out of calibration. The power source for the V10 is located on the pole and travels through connections in the pole to supply power for the instrument (*Trimble, 2016*), this limits the weight of the head and balances the weight of the instrument to avoid it being too top heavy.

2.5 Image Registration

2.5.1 Aerial Image Registration

There are a number of factors that need to be known in order to register aerial images such as flying height and photo capture angle. The image registration relies on fiducial marks and ground targets. The fiducial marks are exposed within the camera onto the film and are used to define the frame of reference needed for spatial measurements (*Sun, 1997*). The ground targets are used in the same way as terrestrial photogrammetry, therefore there should be a number of targets visible in multiple images to effectively stitch the images together and form a tight control network (*USQ SVY3202 Study Book, 2015*). Image overlap is also required for stereoscopic viewing, meaning the overlapped images can be viewed in 3D,

highlighting features within the images. The more overlap between images, the better the stereoscopic pair (*USQ SVY3202 Study Book, 2015*).

2.5.2 Terrestrial Image Registration

Creating a 3D model requires multiple images to be stitched together. Assuming that a suitable amount of overlap is achieved during the survey, a number of like-points in the overlapping images need to be selected to create a model. These points can either be reference points such as targets placed in the images, or natural points within the images such as corners of windows, concrete joints etc. As long as the overlapping images contain at least 3 like-points (*USQ SVY3202 Study Book, 2015*) the images can be stitched together. The points identify both the scale and position of one image in relation to another overlapping image. If the object is very high or wide, the exposure of the object or site must be divided into multiple individual models. The image registration is performed using software programs and modern programs will identify like-points in the images automatically to create the model; however reference marks provide an important check to ensure accuracy.

Although a model has been created through the use of reference marks, it may not necessarily have a relationship with reality. The scale of the model can be determined by physically measuring the distance between reference marks, or alternatively a reference unit (levelling staff/ruler) can be exposed in the photographs (*USQ SVY3202 Study Book, 2015*). A mixture of the two methods is generally preferred as it provides a check.

2.5.3 Trimble V10 Image Registration

The Trimble V10 is different to traditional terrestrial photogrammetry as it captures 360 degree panoramas from 12 cameras, compared to singular photos (*Trimble, 2016*). A GNSS receiver or a laser target can be installed on top of the V10 to provide accurate positioning which eliminates the need for a scale. The images are imported into the Trimble Business Centre software and an automatic or manual tie point adjustment can be performed. The automatic adjustment processes the images

and automatically identifies points that are present in multiple photo stations and stitches the images together (*Trimble, 2016*). The more like-points identified, the greater the registration accuracy. The manual adjustment relies on the user to identify these like-points to complete the same outcome. Photo targets can be used to provide easier adjustment and stitching, however if the site is heavily populated with features, there is little need for them.

It can be seen that the image registration of the Trimble V10 is similar to traditional terrestrial photogrammetry however the process is fully automated and results in minimal user error.

2.6 Current Applications of Photogrammetry

Photogrammetry is not necessarily a new technology, however new technology is starting to emerge which makes photogrammetry more user friendly and accessible to the general population. The current applications span across numerous sectors including both public and private areas.

2.6.1 Engineering Applications

There are a vast number of photogrammetry applications within the engineering sector including volume calculation of spoil heaps, tunnel profiling, deformation surveys of dams and measurement of road surfaces to determine roughness to name a few (*USQ SVY3202 Study Book, 2015*). With technology advancing rapidly the applications will continue to grow.

2.6.2 Police Applications

Photogrammetry provides a non-intrusive method of documenting crime and accident scenes and can be used for a wide range of different investigation types

(DCM Technical Services, 2013). The result is an accurate representation of the scene which measurements can be extracted from to aid the investigation.

2.6.3 Medical Applications

Photogrammetry in relation to medical applications generally relates to the creation of surface models of bodies, particularly the face, back and torso (Mitchell, 1995). It can be used for applications such as modelling a face prior to and after reconstruction surgery as well as measurement of an amputated limb for creation of a prosthetic piece (USQ SVY3202 Study Book, 2015).

2.6.4 Archaeology Applications

Photogrammetry provides archaeologists with a new way to document excavations and artefacts (Prins & Adams, 2012). It also aids archaeologists by documenting the process of the dig at different stages and making it easier to digitise the image and eliminates the hand-drawing error previously present.

2.7 Flood Mapping

Current flood identification methods consist of using information extracted from GIS systems and remote sensing (Haq et al. 2012). These methods have greatly improved flood identification and monitoring, as remote sensing provides accurate levels across large areas whilst being time and cost efficient. Remote sensors collect data by emitting energy and calculating the time before the energy returns to the sensor (NOAA, 2015). This time difference allows the sensor to calculate the point heights of the natural surface. The output maps identify which areas are vulnerable to flooding depending on severe weather events including Q50 and Q100 storms, meaning storms that only occur once every 50/100 years. The flood maps identify areas that are vulnerable and this allows the council to improve infrastructure to mitigate the risk and perhaps lower the risk of a Q50 storm to a Q100. For the application of this project, remote sensing is not within the scope of price or

achievability, and it also would not achieve the level of accuracy required for this study.

Hydrological feature modelling is important for flood mapping as it identifies the features which may be contributing to the flood problem. A bridge may be too low and when it floods, the bridge goes beneath the surface. This may then trap debris which causes even more damage and water displacement. If the feature was modelled, calculations could be performed to see if it has any impact on the flooding problem and the feature could be removed or redeveloped.

2.8 Modelling Hydrological Features

A hydrologic model is a software tool that simulates the behaviour of water along a river system (*MDBA, 2016*). Hydrologic models are concerned with the movement of water through the river system as well as flood plains and wetlands. They investigate the losses and gains of the river system as the water moves through the landscape and it helps determine how the storage, use and supply of the water can be managed.

The models consider a range of input data including rainfall figures, evaporation rates, temperature and stream flows for certain periods of time (*MDBA, 2016*). These models later use mathematical calculations in order to simulate the behaviour of a river system depending on the input data and conditions experienced. Whilst these systems have been widely implemented over the last 40 years and can be utilised to identify the consumption of water throughout varying climatic conditions, they do not necessarily identify flood hazards. Hydrologic models are mainly concerned with water resource management.

Through including an accurate 3D model of the river system, the hydrologic models could become an even more important tool in not only assessing resource management, but also identifying and minimising the risk of floods.

2.9 Application of Trimble V10

Traditional photogrammetry relies on taking photographs at multiple different imaging stations. The distance of the stations away from the desired object is generally constrained depending on the size of the object and a certain amount of overlap between images needs to be present. This overlap is needed to tie the images together through a series of related points present in the different images and thus a 3D model can be formed.

The Trimble V10 imaging rover works in a similar manner however instead of taking a single image at each station; it takes a 3D panoramic image of the landscape surrounding the station via its 12 high quality cameras. This process allows for a significant increase in both imagery and related points in the images, meaning that a more accurate and comprehensive three-dimensional model can be created. The integration of the Trimble R10 GNSS Receiver allows for the real-world position of the V10 to be known, whilst traditional photogrammetry would need to have a survey control established previously to obtain known positions of the photograph stations. This allows for a much quicker field-work time and more integrated package.

Once the field work is completed, the collected data can be imported into the Trimble Business Centre software package to be analysed and corrected. The TBC software recognises like points within the images and automatically geo-references the images to create a 3D model of the site (*Trimble, 2016*). This process can also be done manually by selecting like points within the images. Once the model is created, a point cloud can be overlaid over the images to create a mesh with millions of known positions. This process allows for users to measure between the desired objects and manages the data.

It is inevitable that the surrounding environment will also be captured within the images during the field survey. The unwanted data can be deleted either by setting the survey parameters to not measure outside a certain area/distance or by simply deleting the unwanted data once it is in the software package; which results in keeping only the vital information.

2.10 Conclusion

Flood mapping and modelling will always be of importance and as the population of the earth continues to grow, so will the need for improved flood and disaster prevention. Using the Trimble V10 Imaging Rover in conjunction with the Trimble R10 GNSS Receiver should allow for a three-dimensional model of the subject watercourse integrated with accurate real-world coordinates.

Photogrammetry provides broad image capture of the site which allows for analysis of the model at a later date. Compared to traditional surveying, important information is always missed and needs to be picked up later. Not only does this save time and money in a real-world scenario, but it also serves as a historical record of the site that can be referred back to at a later date. The inclusion of images within the model only enhances the usefulness because users can visualise the site in perfect clarity without even having visited the site before. This means that anyone can easily understand the data and manage it without too much trouble.

CHAPTER 3 – METHODOLOGY

3.1 Introduction

The current applications of photogrammetry and the importance of modelling hydrological features were identified in Chapter 2. This chapter aims to identify the location of the site whilst discussing the reasoning and importance behind the selection of the study area. The survey field procedure is discussed in detail including the issues and problems encountered during the survey process.

3.2 Study Area

The study area chosen for the purpose of the dissertation is located in the city of Toowoomba within Queensland, Australia. Toowoomba is located 125km west of Queensland's capital city, Brisbane, with an estimated population of 165,168. Toowoomba is Australia's second largest inland city, after Canberra.



Figure 3.1. Location map of Toowoomba (WhaTech, 2015)

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The survey site is located in Central Toowoomba. The site is a stretch of West Creek between Herries Street and James Street.



Figure 3.2. Satellite Image of the survey site (*NearMap, 2016*)

The approximate length of the site is 460m derived from satellite imagery. For the purpose of the dissertation, the site had to be a significant waterway affected by the 2011 Toowoomba floods. This particular stretch of West Creek has recently been redeveloped, so it serves as a good site to determine whether the changes are beneficial.

The site is easily accessed as there is a pathway running parallel to it and as it is a public area, permission to survey the site is not an issue. The site contains a number of hydrological features including bridges and basins of varying materials; therefore it will serve as a good test to see how the Trimble V10 reacts to imaging varying surfaces. The creek itself consists of a small concrete channel with grass surrounding both sides. A retaining wall is located on the Eastern side with a batter slope leading to buildings located on the Western side.

3.3 Equipment

The required resources will all be provided either by myself or the University of Southern Queensland (Toowoomba Campus). The resources needed are:

- 1 x Trimble V10 Imaging Rover
- 1 x Trimble R10 GNSS Receiver
- 1 x Trimble Tablet Rugged PC
- 1 x Trimble Bipod
- Access to the stretch of West Creek between the Warrego Hwy and Herries Street
- Computer with appropriate software

The Trimble V10 is an imaging rover that can generate survey accurate positions from images. It includes 12 calibrated cameras which are able to capture 60mp panoramic images.



Figure 3.3. Trimble V10 Imaging Rover (Trimble, 2016)

3D Hydrologic Features Mapping with Imaging Rover

The V10 can be integrated with the Trimble R-series GNSS receiver and Trimble S-series total stations to enhance positioning accuracy. For the purpose of this dissertation, the V10 will be integrated with a Trimble R10 GNSS receiver.

The V10 is positioned using a range pole and stabilised with a tripod. The range pole features a power supply near the base of the pole, and feeds the imaging rover via the pole; however external additions such as a GNSS receiver or tablet require an independent power source.

The data recorder that is used for the study is a Trimble Tablet Rugged PC. The tablet features a Microsoft operating system, allowing users to do calculations in the field if need be. The software used is Trimble Business Centre.



Figure 3.4. Trimble V10 range pole setup (*Trimble, 2016*)

3.4 Method

The process of the project can be divided into separate areas which include the field procedure, office processing and hydrological feature extraction.

3.4.1 Field Procedure

3.4.1.1 Control Survey

Although the site is essentially in the centre of Toowoomba, there are limited Permanent Survey Marks (PSM) in close proximity to the site that have both accurate height and position. The survey marks adopted for the survey control were PSM 651, PSM 178775 and PSM 12517. PSM 651 and 178775 both have datum coordinates with GPS (4th order) fixed heights whilst PSM 12517 has derived coordinates with a spirit levelled (3rd order) fixed height. This means that PSM 651 and 178775 have accurate coordinates ($\pm 10\text{mm}$) with approximately 25mm vertical uncertainty. PSM 12517 on the other has considerable horizontal uncertainty with accurate height.



Figure 3.5. Location map of permanent survey marks used for control (Google Earth, 2016)

The selection of survey marks was the best available and provided good separation and geometry as they surrounded the site to minimise potential error.

3D Hydrologic Features Mapping with Imaging Rover

A Trimble R8 GNSS receiver was utilised for the base station. It was not possible to connect to all three PSM's and survey the site with the Trimble V10 with only one base station set-up due to signal interference caused by infrastructure. The set-up location of the base station was chosen to be an arbitrary point for simplicity, however a fair amount of trial and error was performed in order to measure and connect to all three PSM's in a single base station set-up.

The first base station set-up was next to the bridge in the centre of the site. PSM 178775 and 12517 were easily connected to with good signal strength, however as PSM 651 was approached, the base station signal dropped out. The signal loss was potentially caused by interference by the buildings and perhaps powerlines surrounding PSM 651. Although this base station location was the easiest and most practical, it was imperative to connect to all PSM's for redundancy.

The second base station set-up was on the Eastern side of West Creek, along James Street. A survey peg with a nail was placed in the ground (later called **Check 01**) so the location could be revisited if need be. This provided a line of site to PSM651 however once again, PSM 178775 and 12517 could be connected to, but the signal was lost once near PSM 651.

The third base station set-up was on top of PSM 12517 and yet again PSM 178775 was within range but the signal was lost once near PSM 651. It was realised that there was something interfering with the signal and decided to cross James Street to get closer to PSM 651 and hopefully eliminate the interference.

The fourth and successful base station set-up (**Base 20**) was on the Southern side of James Street, between PSM 651 and 12517. There was concern that the base station may have been too far away from PSM 178775 however the base managed to connect to all three PSM's successfully. Once the PSM's were measured, the location of the peg where the second base station attempt was (**Check 01**), was measured as well as a bolt of the handrail on the edge of the footpath (**Base 21**). The bolt would be the base station location for the actual site survey and the peg would act as a check shot to check the accuracy of the shift.

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Once back in the office, the coordinates of the PSM's, peg and bolt were extracted. Due to the base station only being operational for a short period of time, the positioning was not exact and therefore a block coordinate shift was needed to get the bolt and peg on the correct datum (real world coordinates). The three PSM's have real world coordinates, therefore the difference in Easting, Northing and Elevation between the known and measured coordinates were found. It can be seen in Table 3.1 that the difference in height between the known and measured coordinates of PSM 651 was 1mm, and the difference in Eastings and Northings of PSM 651 and 178775 were extremely similar.

Table 3.1. Coordinate Block Shift

Point	Easting	Northing	Height	Form Easting	Form Northing	Form Height	ΔE	ΔN	ΔRL	Shift Easting	Shift Northing	Shift Height
Base 20	396342.203	6950151.657	603.359							396341.938	6950151.600	603.358
Base 21	396147.560	6950354.817	595.523							396147.295	6950354.760	595.522
Check 01	396145.685	6950203.214	598.079							396145.420	6950203.157	598.078
PSM 651	396541.225	6950149.179	608.246	396540.960	6950149.122	608.245	-0.265	-0.057	-0.001	396540.960	6950149.122	608.245
PSM 12517	396260.863	6950188.502	600.393	396257.447	6950188.341	600.429	-3.416	-0.161	0.036	396260.598	6950188.445	600.392
PSM 178775	395882.632	6950430.885	601.502	395882.370	6950430.811	601.453	-0.262	-0.074	-0.049	395882.367	6950430.828	601.501

The difference in Easting and Northing between the known and measured coordinates of PSM 12517 was substantial; however it was to be expected with the high uncertainty of the known coordinates. What is unexpected is the variation in height across the three survey marks, differing up to 85mm. The large variation could not be explained and although PSM 12517 has the best vertical uncertainty, the mark may have been disturbed.

Due to the uncertainty in height and positioning, PSM 651 was adopted as the best mark to perform the block shift around. From performing the block coordinate shift, real world coordinates for Base 21 and Check 01 were established which can be seen in Table 3.1. The shift allows the survey of the site to be on a real world datum and creates less office processing once the survey is complete.

3.4.1.2 Site Survey

The base station was set up on Base 21 on the side of the footpath using the coordinates derived from the block shift. The base station location is in the centre of

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the site to ensure good coverage and signal throughout the survey. Once the Trimble V10 was established and connected to the base, PSM 178775 and 12517 as well as Check 01 were measured to tie the survey into the control.

The survey was started at the James Street end of West Creek and gradually worked throughout the day towards Herries Street. From prior testing of the Trimble V10 Imaging Rover, the range and scope of imagery was able to be determined,. Three station set-ups for each section of the creek was found to be a suitable amount to accurately measure all of the present features. Where there was more detail, such as the bridge, culverts and basins, extra stations were incorporated to ensure sufficient image capture.

The bridge was the most difficult feature to map as it has so many dimensions; therefore a number of set-ups were used around and on top of the bridge. Another difficult feature to map was the large concrete mounds which are assumed to be designed to slow the flow of water. Measuring these required a set-up on top, as the ground stations could not get sufficient imagery alone.

Once the base station and V10 were initialised, the measuring process was quite simple and efficient. A minimum of 20 seconds was adopted to occupy each set-up to allow for accurate GNSS positioning. Once the position was stored, the Trimble V10 created a panorama via the 12 cameras and stated that it was acceptable to move to the next station. This process was repeated for all of the stations and resulted in a streamlined process. The battery of the base station had to be changed once during the survey, however it did not prove to be an issue and once the base was reinitialised, the survey continued as expected. Overall there were 87 photo stations and 1044 images.

At the completion of the survey, PSM 178775, PSM 12517 and Check 01 were reconnected to in an attempt to ensure nothing changed throughout the duration of the survey and to provide a critical check on the coordinates and control.

3.4.2 Post Processing

The post processing is handled in Trimble Business Centre (TBC). TBC is used to process data from all Trimble instruments, and thus is an extremely capable software suite. The software has recently been upgraded to include a Trimble V10 workflow tab to streamline data processing and make the overall process as simple as possible for the user.

The first step was to extract the data from the Trimble Rugged Tablet PC and upload the raw data file (.job) into TBC. The photos from the survey are stored in a known location so TBC can access and import them into the program along with the .job file. It is important to note that the directory that the photos are stored in cannot be changed as TBC will no longer recognise the location and thus will not be able to import them. Once the data is imported, a basic layout of the survey can be seen with the spatial positions of the PSM's, check shots and photo stations.

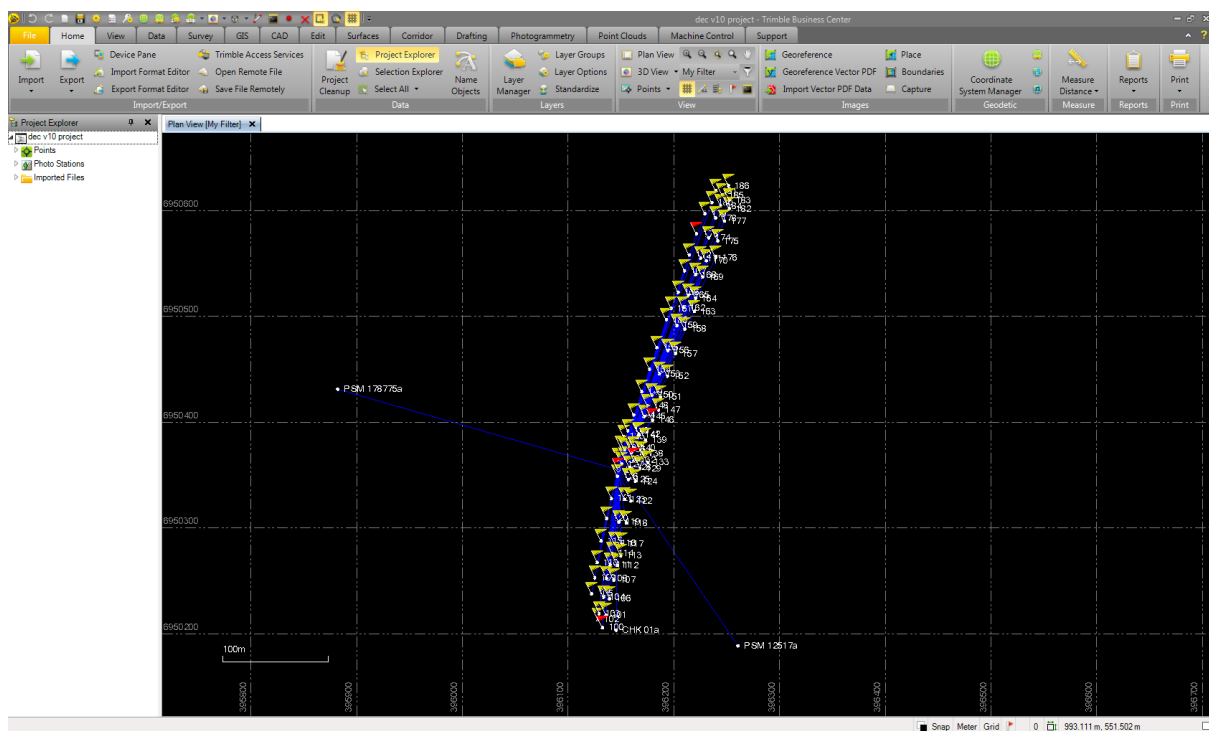


Figure 3.6. Layout of photo stations within TBC

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The next step was to adjust the photo stations using the automatic tie point adjustment. The full orientation adjustment method was chosen as it adjusts the compass and tilt value of the photo stations whilst maintaining the 3D coordinates. The automatic tie point adjustment works through each photo station and identifies common points between stations and creates a series of tie points. These tie points allow the program to stitch the images together to form a single, coherent image model that is not disjointed. The better the station geometry and feature mapping, the more tie points and redundancy. The automatic tie point adjustment goes through a number of steps including matching feature points (tie points), removing blunders and forming the model. Due to the large number of photos taken during the survey, the automatic tie point adjustment took approximately 48 hours on a standard specification PC. The sheer amount of data and processing time has caused problems for the project as it was difficult to source a PC capable of both handling the workload and doing it in an acceptable timeframe.

Once the automatic adjustment was complete, a total of 10,411 automatic tie points were created. The model was essentially seamless and after careful analysis, the images were stitched together well. Due to the fact that the images of each station were taken at different times, the contrast and light between each capture varied slightly. The 'Process Panoramas' feature was used to balance the exposure of the images as well as blend the edges between adjoining images. The feature also gives the option to create a .jpeg panorama deliverable of each photo station. The process took approximately 2 hours to complete.

The photo station view allows the user to view the images captured by the V10 as well as the location of the surrounding photo station set-ups. The overlap of images can be seen as well as the connection vector back to the GNSS base station.

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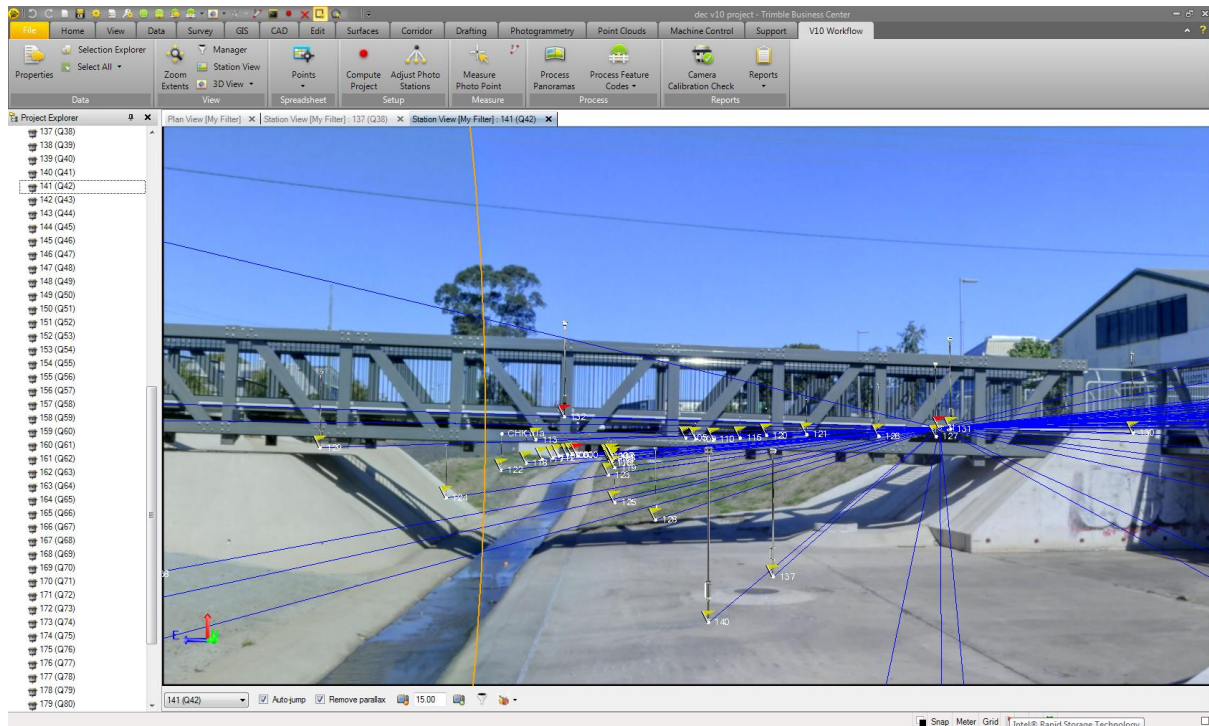


Figure 3.7. Photo station view in TBC

The adjustment of the model is now complete; however there is limited analysis that can be performed in its current state. Although individual points and features can be created from the photo model through a process similar to the tie point creation, the analysis is extremely limited and it would take too long to obtain the appropriate results. This is where the creation of a point cloud comes into consideration. TBC allows users to create a point cloud from the photo model. Similar to the automatic tie point creation, the process identifies features within the photo model and creates thousands of spatial points to form a single point cloud.

The 'Create Point Cloud' feature was chosen and all 87 photo stations were selected. The option to specify the extents of the point cloud was offered; however this had the potential to accidentally exclude important data, so it was decided to leave the extents open. The creation of a point cloud from the image model takes a considerable amount of time due to the dramatic amount of processing required and thus the point cloud took approximately 4 days to create. The point cloud was created as a separate .las file and imported into TBC and the model. The benefits of having a separate .las file are that it can be imported into external software such as

Autodesk 3DS Max, which has the ability to analyse and handle the point cloud data much more efficiently.

3.4.3 3D Hydrological Feature Extraction

The hydrological features present within the survey site are bridges, culverts, basins, water diverters and a channel. These features can be extracted from the image model either by identifying multiple key points within the image model, or through creating a point cloud and isolating the features. The image model allows the user to pick a point, such as the handrail of the bridge, from multiple photo stations (the more photos, the better the coordinates). A coordinate for the point is calculated and added into the image model. If there are multiple points created then it is possible to measure between these points and get the horizontal and vertical differences.

The point cloud option is a much more visual and comprehensive option as the hydrological features are made up of thousands of spatial points; all of which can be selected for dimensions and 3D positions.

Once the point cloud is created from the image model, it can be manipulated to create cross sections of the hydrological features. This is especially useful to calculate the volume of the creek at particular sections as well as viewing the features in different viewports.

3.5 Conclusion

A few problems arose during the survey of the site relating to the limited selection of PSM's and underestimating the processing time; however the process was rather straight forward and user friendly. The Trimble V10 workflow was efficient and provided sufficient capture of the site in a short amount of time. The actual field work component is definitely less time consuming compared to traditional surveying, but the office processing limits the practicality of the V10. The results analysis of the

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model captured by the imaging rover is limited in the image model; however the point cloud provides a much more in depth view into the site and the hydrological features.

CHAPTER 4 – RESULTS AND DISCUSSION

4.1 Introduction

The survey of the site went to plan and the data was processed to create a spatially accurate image model. A point cloud was created in TBC through automatically identifying surfaces and features within the image model. The image model allows simple hydrological feature analysis whilst the point cloud should allow for more complicated and in depth analysis. The point cloud was created in a number of steps to limit the processing power required by the computer and placed together to create a uniform point cloud.

4.2 Analysing Features in the Image Model

The image model allows users to select spatial points out of the photo stations. The automatic or manual tie point adjustment needs to be previously completed to ensure accurate image registration.

A bolt was selected on the bridge's hand rail as it was easy to locate and replicate in multiple images. Four photo stations were used to create the point (Point 2500) as they had the best view of the point and were not too far away. The closer the photo station and the less angle of the photo, the more accurate the points coordinate. Once the point is generated, it can be seen within the photo model, along with connecting vectors to the stations which it was selected in. This allows the user to identify which stations are related to each photo point.

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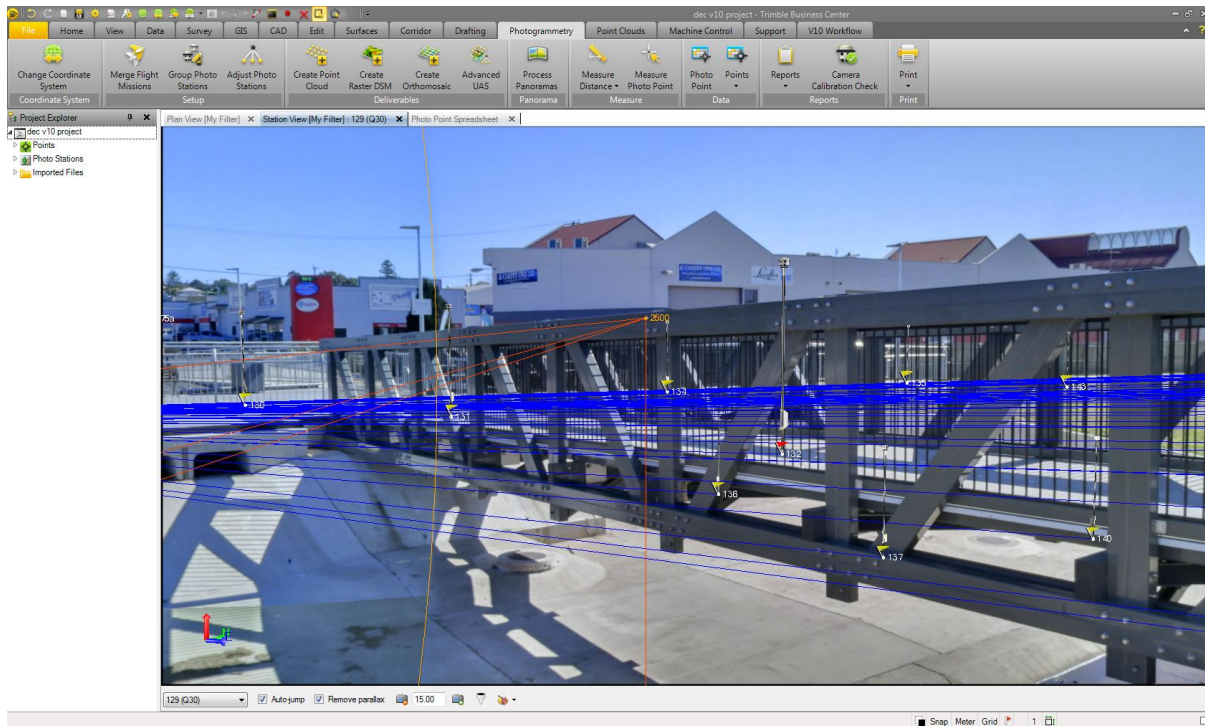


Figure 4.1. Photo point displayed in photo station view

The photo point attribute data can be seen within the photo point spreadsheet. This provides information on the strength of the point (how accurate the coordinates are), the amount of connected photo stations, the bearing and distance from each connected photo station as well as whether the photo point is resolved or not.

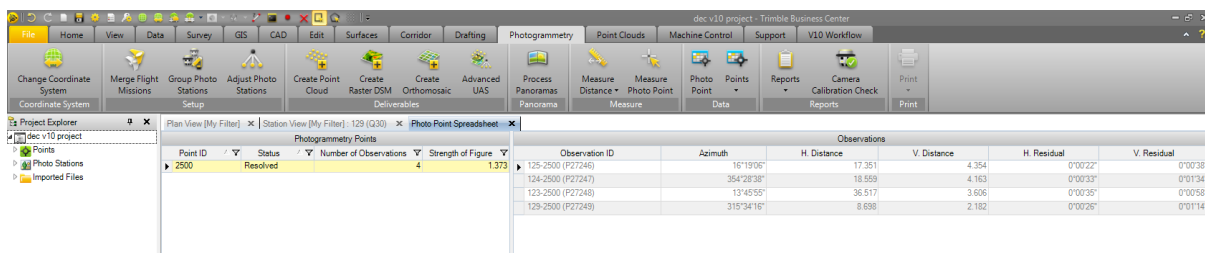


Figure 4.2. Photo points attribute data

If multiple photo points are created, the differences between them can be analysed. This feature is useful to measure the dimensions of the hydrological features such as the height of the bridge above the channel. Two photo points need to be chosen and the inverse feature calculates a number of measurements including bearing, distance, change in height, ellipsoid and ground distance. This feature makes it easy to analyse photo points and saves a significant amount of time that would be spent on manual calculations.

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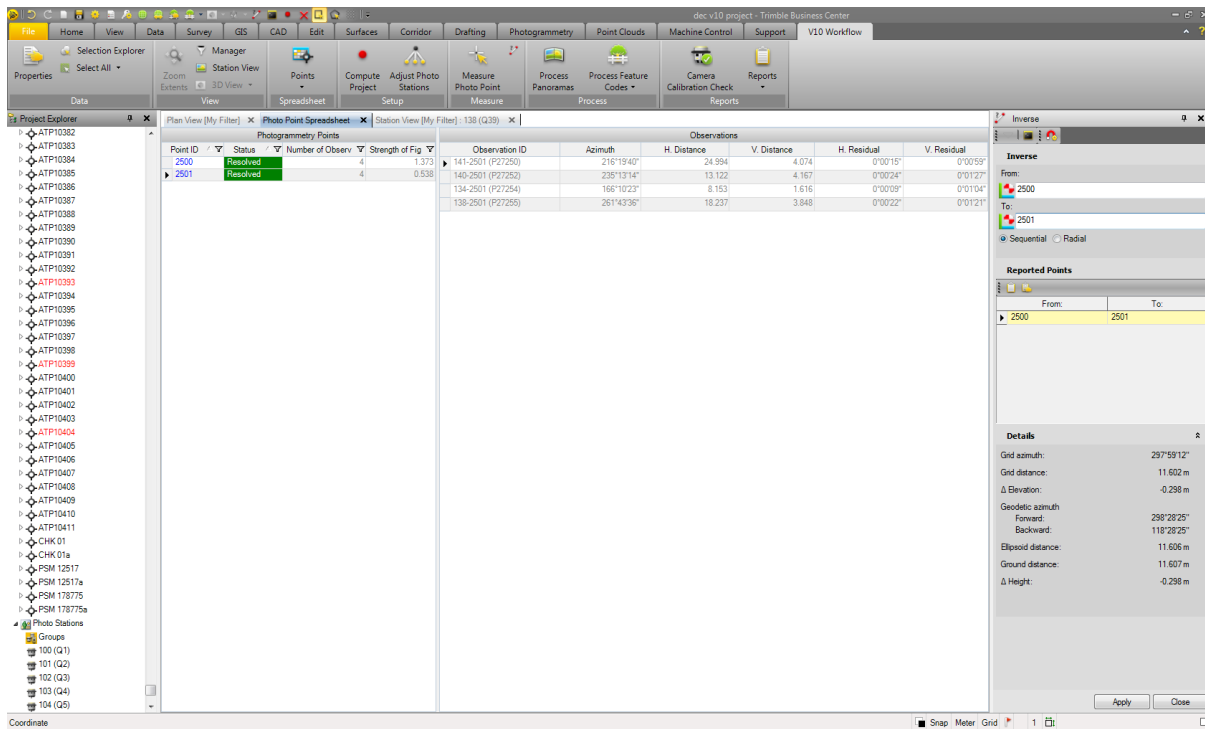


Figure 4.3. Inverse function in TBC

Using the process mentioned above, two points on either side of the bridge were selected to determine the length of the bridge over the waterway. The results displayed that the suspended section of the bridge is 20.703m long and has an approximate grade of 2.5%. The height of the bridge above the channel is 2.376m. This analysis was extremely simple to complete and only took a few minutes. A more detailed analysis can be performed by creating more points along the plane and getting a cross-section area under the bridge. This would determine the amount of water that could flow beneath the bridge before the bridge became unusable.

Culverts also play a major part in the waterway structure and potentially have the biggest impacts on flooding if they are blocked or overwhelmed. The culvert on the norther end of the site was selected to be analysed as it is downstream and is most likely to get blocked.

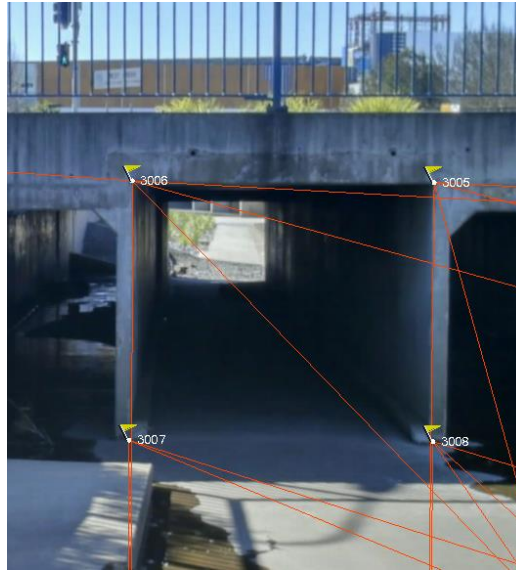


Figure 4.4. Analysis of eastern culvert

Four corners of the culvert were selected using the aforementioned process in order to determine the size. Each point was selected from a minimum of four photo-stations to ensure accuracy. Because of the sharp edges, the points were easy to replicate in all photo-stations. The inverse function calculated the left side to be 2.365m high, the top to be 2.701m wide, the right side to be 2.327m high and the bottom to be 2.745m wide. Accounting for user selection error, it can be assumed that the culvert's size is 2.70m x 2.35m. This results in an area of 6.345m². Water flow analysis can be tested on the site to determine the flow rates experienced in a storm; which then can be tested against the culverts to determine whether they can handle the flow. The same process of analysis can be applied to the rest of the image model to model the hydrological features, however with the generation of a point cloud; a much more in depth analysis should be theoretically possible.

4.3 Analysing Features in the Point Cloud

The point cloud consists of millions of spatially accurate points, each with their own coordinates. The point cloud is automatically created within TBC and the coverage and ability to generate each particular point cloud is an unknown factor. The program utilises a process that analyses the photo stations and identifies various points that are present within multiple photo stations. This is done through a process of intersecting the like points from multiple photos to create a single point in the cloud. The more photos used to intersect the point, the more accurate the coordinates of the point will be.

As mentioned previously, the creation of the point cloud was extremely taxing on the computer that was used and a number of issues were encountered. The computer with 8GB of RAM that was used to adjust the photo stations and create the automatic tie points for the image model was inadequate to generate the point cloud. The process took approximately 4 days but would fail 95% of the way through. Thinking that it was a storage/RAM issue with the computer, hard drive space was freed up and the process was restarted; however was met with the same result. Trimble Business Centre offered no explanation as to why or at which part the point cloud generation failed, making it difficult to locate the problem. Due to time restrictions, it was not viable to continue using the computer so the use of a much higher specification computer with 32GB of RAM was sought.

The new computer processed the data much faster and cut the processing time down to under a day; however the point cloud generation still failed so it was decided to process the point cloud in sections. Five sections were selected. This was finally successful and the point clouds were generated with a .las file created for each section; with the exception of a single section. Through trial and error it was found that one station was failing and thus resulted in the entire point cloud to fail. It is unknown as to why the photo station was failing to generate within the point cloud as TBC did not offer an explanation.

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The impact that the failed station had on the final point cloud was minimal as there is sufficient coverage of the site from the other stations and an adequate coverage of points was still created.

Once all five of the point cloud sections were created, they were imported into Maptek I-Site. Maptek I-Site is a software program that efficiently deals with spatial and point cloud information through a range of useful features. The point cloud sections were created on MGA coordinates so they were dragged and dropped into the Maptek software on the same coordinate system.

The point cloud that was generated for the project turned out to be extremely inconsistent and a significant amount of detail was excluded from the final model. A number of hydrological features were either completely missed or poorly generated. The point cloud was inconsistent throughout with ground coverage and grass being represented well in some sections and completely non-existent in others.

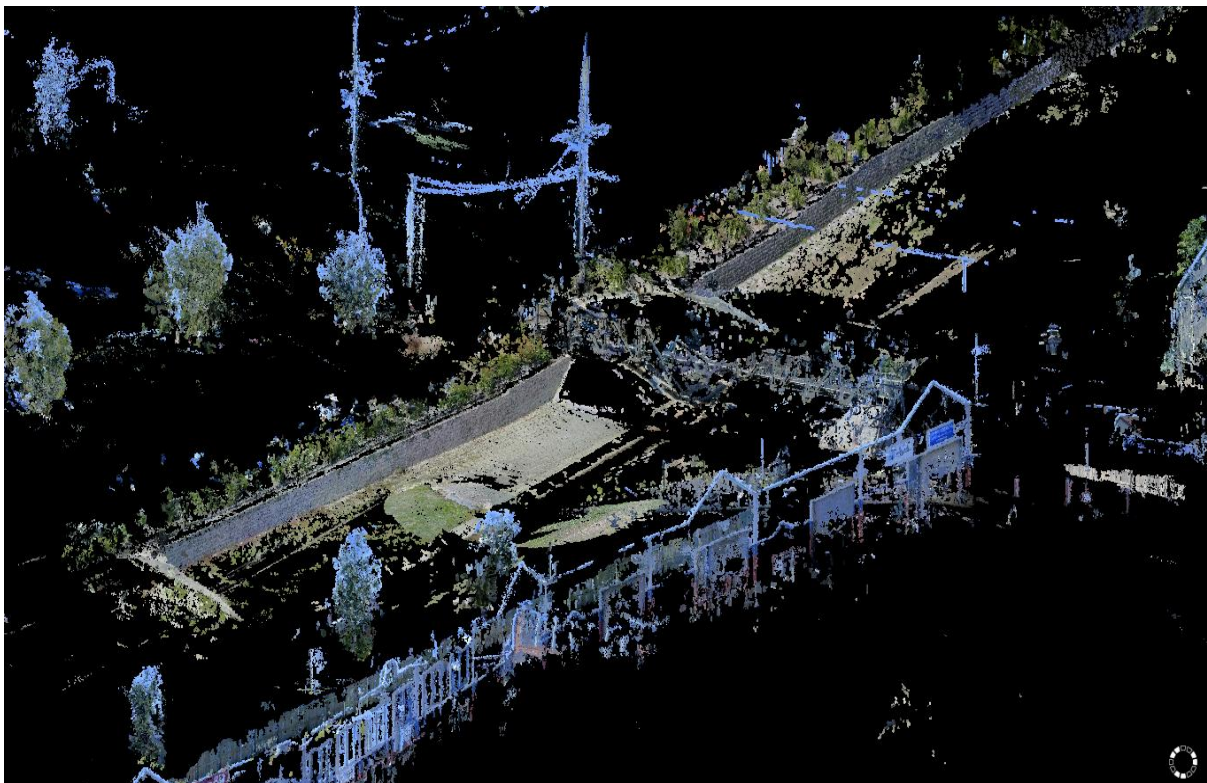


Figure 4.5. View of the point cloud showing inconsistency of data generation

The point cloud has failed to identify the channel running through the middle of the site and the main hydrological feature, the bridge, has large sections missing. The surrounding building facades and trees have been represented well for the most part but that was not the investigation of this project.

The hydrological features, where they are generated, can still technically be analysed within the point cloud as each point has a unique coordinate. Programs such as Maptek and Autodesk 3DS Max have features that can create Digital Terrain Models (DTM) and contours. They can also create rendered surfaces and cross sections. The original plan was to create a DTM and run a series of cross sections throughout the model to measure the maximum volume of the waterway at different chainages. This would identify how much water the waterway could handle before breaking its banks as well as damaging the bridge. Due to the poor, and in most areas, non-existent creation of surface points (and various other points) this is not possible and limited analysis of the point cloud is able to be performed.

4.4 Viability of the Point Cloud

The capability of the point cloud generated within Trimble Business Centre is extremely limited. It can be seen that a significant amount of detail has not been generated and a number of hydrological features present within the site are either not represented or poorly generated. Some analysis of the hydrological features can still be performed, but compared to a complete point cloud, the analysis is restricted. As stated previously, surface models and rendered objects could be created if the point cloud was complete which would open up numerous other analysis options.

The hydrological features included in the site can be seen in the images below. Some features were generated better than others; however all of the features are fairly poor and could be generated a lot better.

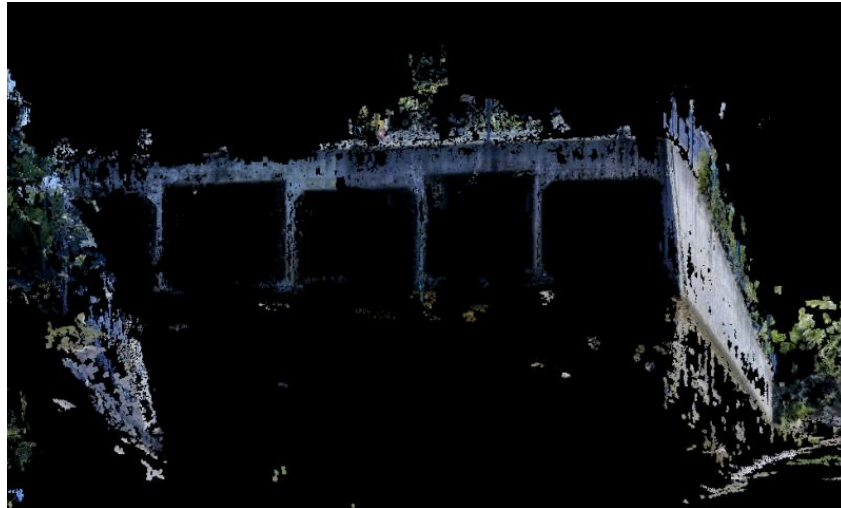


Image 4.6. Northern culvert in the point cloud

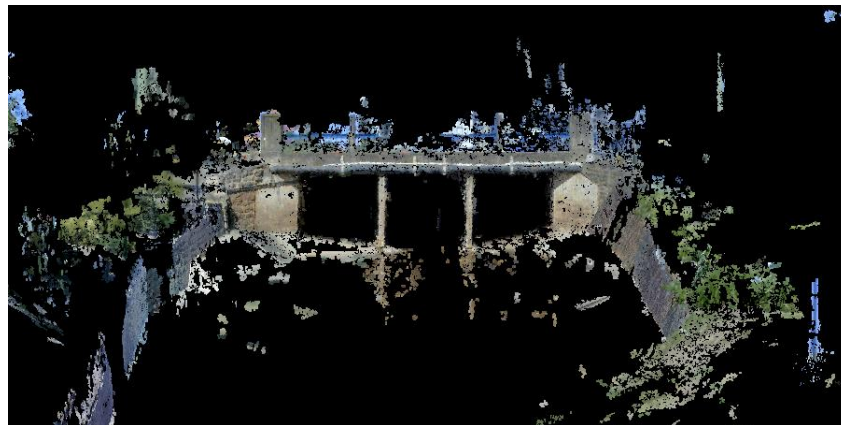


Image 4.7. Southern culvert in the point cloud

The culverts are represented quite well as they consist of sharp edges and it is easy for TBC to differentiate between the surfaces and create points. The channel on the other hand is essentially non-existent even though the grass and concrete offer completely different textures. It can be seen in both images that there are no points on the ground, making it extremely difficult to gather information regarding areas, volumes and heights.

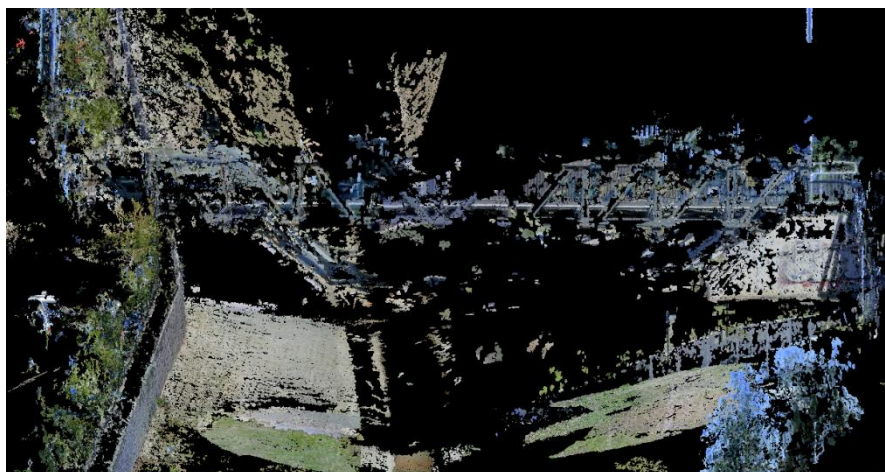


Figure 4.8. Point cloud representation of the bridge in the centre of the site

The image shows how sporadic the point coverage of the bridge is and the amount of detail that is missing. The opposite handrail of the bridge is virtually non-existent. A small amount of ground cover can be seen which consists of pavers and grass. It is interesting how TBC generates some patches of grass but ultimately leaves the majority of the ground surface out. There is not enough information to model or render the hydrological features and there is limited need for a point cloud to be generated if it is similar to this one.

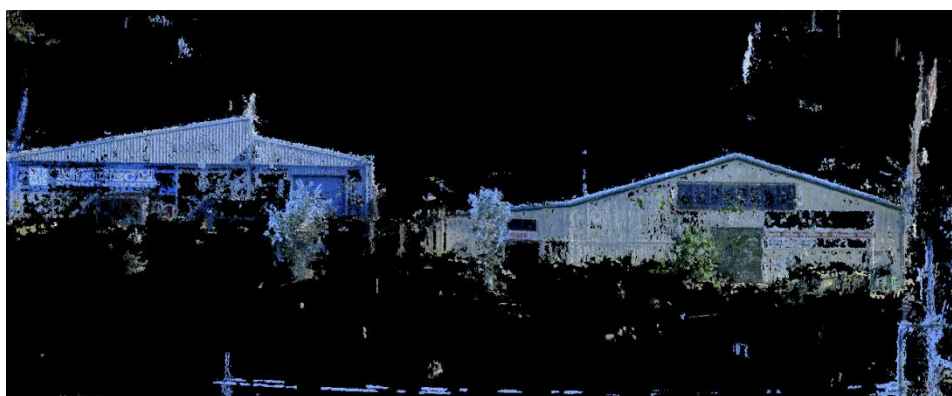


Figure 4.9. Building facades in the point cloud

The building facades were easily the most comprehensive features displayed within the point cloud. This is most likely due to the wide range of textures and detail present on the buildings. The buildings were outside the selected site, yet they were

still captured well, which leads me to believe the Trimble V10 Imaging Rover would be more suited to building mapping rather than contour/detail surveys.

4.5 Generation of the Point Cloud

There are a range of possible reasons behind the poor generation of the point cloud of the site. There is confidence that the survey planning and photo-station geometry is sound and provides more than enough coverage to generate a satisfactory point cloud. The problem lies within Trimble Business Centre and the process behind the creation of the point cloud.

The building facades were represented surprisingly well considering that they were not the intended features to be captured. The ground surface was poorly represented with the majority of the site not having any points. A possible explanation of this outcome could be that the grass is too much of a uniform surface and TBC cannot differentiate between the different blades, and thus not creating any points. The user manual for the Trimble V10 does state that smooth surfaces that are lacking texture, such as glass or white walls, will not be represented; however it was thought that grass would have sufficient texture. What was surprising was that the concrete channel running down the centre of the site was essentially non-existent in the point cloud. There is a distinct line between grass and concrete and it is reasonable to believe that TBC should be able to differentiate between the two surfaces, so it is concerning as to why it did not.

The bridge in the centre of the site was mostly modelled, but it is quite patchy and large sections of the handrail and path are missing. Once again there is a distinct difference between the bridge and the surrounding objects, so it was expected that it would be represented much better than it is. It cannot be explained as to why TBC has generated some sections of the bridge, but failed to generate the whole feature. The culverts at both ends of the site have been generate quite well and the size and shape can be clearly seen, but the ground surface is lacking.

The program has a significant task to complete in generating a point cloud from images and although some features are represented well, the fact is that majority are not. TBC has problems in differentiation between features and surfaces which resulted in the hydrological features of the site either being poorly represented or not represented at all. This restricts the capability of the point cloud and essentially eliminates a range of applications for the Trimble V10 such as detail surveys and other survey applications where ground detail is important. It may be possible to utilise a different photogrammetry program to create a point cloud, and a better result may be seen, however this was not within the project specification.

4.6 Comparison of Models

The image model and point cloud both serve a purpose and even though the point cloud generation was rather poor, some hydrological features can still be analysed. The image model is useful for simple data analysis and measuring a small number of points whilst the point cloud is useful for more in depth data analysis and the points are already created for the user to measure.

The models are created similarly with the image model consisting of images being stitched together through a series of automatic tie points and the point cloud being created by intersecting points from the images. This means that both of the models should have similar coordinates for the same points/objects. The table below analyses a series of points that are selected out of both models to compare the coordinates of the generated points. This will determine the differences between creating manual photo-points in the image model and automatically created points in the point cloud. Due to the limited amount of features in the point cloud, simple objects such as screws etc. were chosen for the comparison points as they could be replicated in both models easily.

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Table 4.1. Coordinate comparison between image model and point cloud

Point	Location	Image Model			Point Cloud			Difference			
		Easting	Northing	RL	Easting	Northing	RL	Easting	Northing	RL	
1001	Bridge	396155.795	6950366.962	596.652	396155.809	6950366.973	597.172	-0.014	-0.011	-0.520	
1002	Bridge	396158.073	6950366.581	596.721	396158.081	6950366.607	597.227	-0.008	-0.026	-0.506	
1003	W Culvert	396130.464	6950200.934	597.300	396130.461	6950200.914	597.796	0.003	0.020	-0.496	
1004	W Culvert	396125.425	6950201.651	597.282	396125.407	6950201.581	597.750	0.018	0.070	-0.468	
1005	W Culvert	396132.716	6950200.590	598.464	396132.727	6950200.580	598.968	-0.011	0.010	-0.504	
1006	W Culvert	396123.040	6950202.755	596.484	396123.035	6950202.780	596.989	0.005	-0.025	-0.505	
1007	E Culvert	396254.267	6950629.682	592.696	396254.258	6950629.705	592.679	0.009	-0.023	0.017	
1008	E Culvert	396259.652	6950627.576	592.453	396259.657	6950627.554	592.464	-0.005	0.022	-0.011	
1009	E Culvert	396256.707	6950628.732	592.458	396256.694	6950628.742	592.438	0.013	-0.010	0.020	
1010	M Culvert	396151.520	6950361.417	594.289	396151.517	6950361.438	594.792	0.003	-0.021	-0.503	
								Average	0.001	0.001	-0.348
								St Dev	0.011	0.031	0.246

The table shows that across 10 randomly selected points, the difference in Eastings and Northings between the image model and the point cloud is minimal. The heights are significantly different with the majority of the points being 500mm apart. The standard deviation is also quite acceptable for the Eastings and Northings.

There is some error in selecting the points within the two models because the image model is only as accurate as the pixel size and it is difficult to select a single point in the point cloud as it loses all detail when zoomed in on. This user error can explain the differences between the Eastings and Northings however it cannot explain the differences in height. The difference in height is most likely related to the process that TBC uses to create the point cloud. The table shows us that the horizontal coordinates are quite accurate between the models however depending on the adopted model, the heights may be unreliable. A simple fix to this problem would be to measure a few known ground points within the site to compare to the image model or point cloud to obtain the correct heights.

With the poor generation of the point cloud for the site, there is not much practical use for it. The majority of the hydrological features cannot be modelled or analysed due to patchy coverage or non-existence within the cloud and there is not much benefit over the image model. The image model has acceptable measurement features included and although a little more time consuming, the results are a known variable and are reliable.

4.7 Conclusion

Both the image model and the point cloud offer a range of tools to analyse the hydrological features however the point cloud generation was extremely inconsistent and resulted in majority of the features not being represented. The image model offered an easy option to create points within the model that had coordinates and could be measured between. This allowed area calculations of the culverts and measurement of the hydrological features.

Although the image model is not as advanced as the point cloud in terms of its ability to analyse the features, it is a reliable model which allows a range of spatial points to be created. The point cloud is too unreliable and important points may be missed in the processing. This is potentially caused by Trimble Business Centre having trouble differentiating between surfaces and not recognising features. Overall the image model offers a sufficient amount of options to analyse the hydrological features and if a point cloud is needed for further analysis, it would be more beneficial to measure the site with a laser scanner.

CHAPTER 5 – CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The research project aimed to investigate the mapping of hydrological features using the Trimble V10 Imaging Rover. The subject site was mapped and the data was processed to determine whether it can be used to analyse hydrological features. There were issues with processing due to the large data files and although a point cloud is a more comprehensive modelling tool, the image model was the most useable model. The V10 is capable of mapping hydrological features effectively and efficiently, however Trimble Business Centre needs to advance before the true capabilities are discovered.

The research project successfully achieved the aim of identifying whether the Trimble V10 Imaging Rover is a viable instrument for hydrological feature mapping. The data captured by the V10 is significant in size and causes processing problems for TBC. The amount of time required for a standard specification computer to process a small survey is substantial. The added possibility that the processing will fail without explanation means it is unpredictable and a risk for businesses. With the use of a computer that can handle the processing, the task is actually quite user friendly and is essentially fully automated.

The image model provides a tool to capture an entire site in a few hours and measure points later. This is beneficial over traditional surveying methods because if something is forgotten, the surveyor does not need to go back out to the field. Creating photo-points within the model is simple and providing that the survey station geometry is acceptable, accurate results can be achieved. The points can be measured between to get distances of the hydrological features and analysis such as the calculation of areas and volumes is possible.

The point cloud turned out to be quite patchy and a significant amount of detail was excluded. The majority of hydrological features were either non-existent or poorly

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represented within the model. There was extremely limited surface coverage of the site and the channel in the centre of the site was not generated. This limits the applications of the Trimble V10 as it is not viable to use for detail surveys or other purposes where surface coverage is needed. If the point cloud was generated well, it would prove to be a capable tool for analysing the hydrological features through the creation of cross sections, areas, volumes and object rendering.

Comparing the coordinates of random points within each model, it was found that the horizontal coordinates are similar whilst the heights are significantly different. This could be due to the processing procedure that TBC adopts whilst generating the point cloud.

The image model does provide a decent amount of analysis tools to model the hydrological features but it is limited to the manual creation of photo-points. A better outcome for the point cloud was expected and unless the processing can be improved to create better coverage of points, a laser scanner would be a more viable option.

The Trimble V10 Imaging Rover is still new technology and has the potential to become the industry standard in mapping and site capture. There are issues with processing and the creation of point clouds however with minor software revisions, these problems could be eliminated. Being able to visually capture an entire site in a short amount of time and later measuring the image model is an attractive feature.

The V10 is capable of mapping hydrological features and analysing them within the image model, however a working point cloud is needed for comprehensive modelling. The accuracies of the V10 are acceptable for this application and as long as the survey is relatively small, standard computers should not have too many problems with processing the data. Further research is needed to determine if the station geometry or survey method affected the outcome of the point cloud, as well as whether a different photogrammetry software suite is capable of a better outcome.

5.2 Further Research and Recommendations

The research project only investigated a single application of the Trimble V10 Imaging Rover, and it was found that it can efficiently map water corridors to produce a workable image model. Further research on this topic would be to investigate whether different photogrammetry software is more capable of producing a better point cloud. The issue may not be caused by the V10 itself, rather by Trimble Business Centre. The problem may also lie within the image registration, so it would be interesting to investigate the results of a fully constrained survey with manual targets compared to a survey that relies on the automatic creation of tie points.

With a workable point cloud, it is possible to create a rendered model. This opens up numerous opportunities for volume calculations and simulations. Using game engines, there is the potential to create a flood simulation that runs through the model. This would allow the user to specify flow rates for storms and visually see the impact that the floods have on the hydrological features.

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3D Hydrologic Features Mapping with Imaging Rover

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Appendix A – Project Specification

ENG4111/ENG4112 Research Project

Project Specification

For: Declan Pettersson

Title: 3D Hydrologic Feature Mapping with Imaging Rover

Major: Surveying

Supervisors: Dr. Xiaoye Liu

Enrolment: ENG4111 – ONC S1, 2016
ENG4112 – ONC S2, 2016

Project Aim: To determine whether the Trimble V10 Imaging Rover is a viable solution for flood mapping and modelling within small catchments and creeks.

Programme: Issue A, 16th March 2016

1. Search for current applications of 3D mapping instruments and how they apply to real world situations.
2. Learn how to operate the Trimble V10 Imaging Rover and perform survey on the selected site.
3. Download the survey data and create a 3D point cloud of the site. This will require a lot of data filtering and selecting what data points are useful for the study.
4. Utilise the point cloud to extract information that directly applies to the study, and thus determining the flow capacity of the selected site. This will decide whether the study is viable.

If time and resources permit:

5. Create and run a water flow simulation through the model to provide a visual representation of the captured data.
6. Alter the simulation for different flow scenarios and present findings/recommendation.

Appendix B – Risk Assessment and Quality Assurance

Risk Assessment

Risk assessment plays a major role within the project as I will be working in some dangerous places whilst undertaking field measurements. I have included a basic risk assessment table below which identifies the levels of risk present and what justifies each risk. The table also outlines how to deal with the risks and what precautions should be taken depending on the level of risk.

Table 5.1. Qualitative Risk Analysis Matrix – Level of Risk

LIKELIHOOD	CONSEQUENCE				
	Insignificant 5	Minor 4	Moderate 3	Major 2	Catastrophic 1
A - Almost Certain	H	H	E	E	E
B - Likely	M	H	H	E	E
C - Possible	L	M	H	E	E
D - Unlikely	L	L	M	H	E
E - Rare	L	L	M	H	H

Extreme	Extreme risk, immediate action required, works must not proceed at this level.
High	High risk, acceptable to proceed only with strict controls.
Moderate	Moderate risk, acceptable to proceed with suitable controls
Low	Low risk, acceptable to proceed

The main risks involved within the project are related to working in close proximity of road and water channels. These risks are only present during the field work stage and all other aspects of the project are **low risk**.

Table 5.2: Personal Risk Assessment

Hazard	Risk	Minimisation
Injury by being hit by a vehicle when near road	H	<ol style="list-style-type: none"> 1. Adhere to relevant traffic regulations 2. Wear fluorescent safety vest 3. Limit exposure to busy roads
Drowning or injury during field work in water corridor	M	<ol style="list-style-type: none"> 1. Do not enter water corridor when raining 2. Wear fluorescent safety vest 3. Notify appropriate person when working

Special Requirements

There are no special requirements such as confidentiality restrictions or intellectual property issues associated with the project. Any data or equipment provided by USQ remains the property of USQ and will not be released to a third party without their prior approval.

Quality Assurance Plan

Quality assurance plays a major part in the surveying profession as the career is directly related to accuracy and precision. There will be a number of quality assurance checks in relation to the field work and data collection phase, as well as at a few other key stages in the project:

- Ensure Trimble R10 GNSS Receiver is calibrated to ensure accurate position measurements
- Connect survey to known permanent marks to ensure accuracy of the position of imaging stations and thus accuracy of geo-referencing

3D Hydrologic Features Mapping with Imaging Rover

- Ensure that appropriate field checks are undertaken as well as assessing the reliability of the permanent marks surrounding the site
- As mentioned previously in the project schedule, project reviews will be undertaken at three separate times throughout the project to identify any problems

With a suitable quality assurance plan in place, it creates a reputable and accurate project that has been checked for errors to produce the best possible result.

Appendix C – Supporting Documentation



Survey Control Mark Report

ADMINISTRATIVE			
Mark Number	651	Town	TOOWOOMBA
Alternate Names	TCC166	Local Authority	TOOWOOMBA REGIONAL
Locality Description	JAMES/RUTHVEN STS		
Related Information			

DETAILS				
Mark Type	STAND	Connections	IS255185	19-Jan-2015
Installed By	AB YEATES		IS232768	26-Oct-2010
Installed Date	01-Jan-1956		SP210886	27-Feb-2009
Mark Condition	GOOD		IS207754	11-Dec-2006
Last Visited	19-Jan-2015		SP164275	09-Sep-2003
Sketch Available	Yes		(11 connections)	

GDA94 COORDINATES			
Lineage	Datum	Horizontal Uncertainty	0.012m
Latitude	27° 34' 06.87671" S	Vertical Uncertainty	0.025m
Longitude	151° 57' 06.97209" E	MGA94 Point Scale	0.99973212
Ellipsoidal Height	650.628m	MGA94 Grid Conv	-0° 29' 06.35"
MGA94 Easting	396540.960m	Fixed By	GPS
MGA94 Northing	6950149.122m		
MGA94 Zone	56		
Published	27-Jun-2016		
Adjustment	QLD ANJ 16.06		

AHD HEIGHT			
Lineage	Datum	Vertical Uncertainty	Class C / 3rd ORDER
Height	608.245m	Fixed By	SPIRIT LEVELLING
Published	16-Mar-1992	NLN Section	204-219
Origin Mark			
Source			

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3D Hydrologic Features Mapping with Imaging Rover

SCS000651 V0 Page 1 of 1 Not To Scale

FORM 6
Regulation 161
P.A.
04/01/11

QUEENSLAND REGD. No. 651

THE SURVEY CO-ORDINATION ACT OF 1952
TOOWOOMBA C. C. BM NO. 168

PERMANENT MARK SKETCH PLAN

TYPE STANDARD TYPE OF SURVEY CADASTRAL

Parish of DRAYTON City or Town of TOOWOOMBA

Local Authority TOOWOOMBA CITY COUNCIL Map 1:2500 9242-11244

NOTE—Measurements are to be shown from the permanent mark to as many nearby survey marks, buildings, fence posts, banks, etc., as practicable. Up to six measurements are desirable. Measurements are in Links (that necessity to scale.)

Line	Surveyor	Date	Plan No.

Installed by A. J. Yeates, Auth. Surv. Date 10. 2. 2016 Plan No. D. 10. 226

Shown on D. 10. 226, D. 10. 268 Sh. 2 & P/N D. 10. 317 Sh. 2 RP 176745, RP 180050, RP 179613, RP 189653, RP 15477

Reduced level (i) 600.245m (ii) AHD Prov'd. N.S. File 31
(iii) 1994.93 ft 608.055 m Datum State L Book No.

Levelled by Toowoomba City Council Date 1863 Plan No. File 294/149

Levelled from (i) Toowoomba (219) - Warwick (204) National Level Adjustment
(ii) State H. M. No 22

Adopted R.L. of Datum 1957.25 ft 596.570m Correction for State Datum

I certify that the permanent mark shown in this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952" and that the information shown hereon is correct.

(Signature) *A. J. Yeates*
(Date) 15th June 19 2016
SURVEY OFFICE
Public Authority

651

The Queensland Survey Control Register is the authoritative source for coordinate and height information. The coordinate and height information contained on this document may not be the current information regarding this mark.



Survey Control Mark Report

ADMINISTRATIVE

Mark Number	12517		
Alternate Names	TCC449	Town	TOOWOOMBA
		Local Authority	TOOWOOMBA REGIONAL
Locality Description	JAMES/WATER STS		
Related Information			

DETAILS

Mark Type	STAND		
Installed By	AB YEATES	Connections	IS207754 11-Dec-2006
Installed Date	01-Jun-1959		SP185496 01-Sep-2006
Mark Condition	GOOD		SP177893 21-Apr-2005
Last Visited	15-Jan-2007		SP177021 05-Oct-2004
Sketch Available	Yes		IS176829 30-Oct-2002
			(12 connections)

GDA94 COORDINATES

Lineage	Derived		
Latitude	27° 34' 05.52418" S	Horizontal Uncertainty	CLASS PE / NO ORDER
Longitude	151° 56' 56.64626" E		
Ellipsoidal Height		Vertical Uncertainty	
MGA94 Easting	396257.447m	MGA94 Point Scale	0.99973285
MGA94 Northing	6950188.341m	MGA94 Grid Conv	-0° 29' 11.11"
MGA94 Zone	56		
Published	19-Jan-2007	Fixed By	GPS
Adjustment	HAND HELD GPS		

AHD HEIGHT

Lineage	Datum		
Height	600.429m	Vertical Uncertainty	Class C / 3rd ORDER
Published	16-Mar-1992	Fixed By	SPIRIT LEVELLING
Origin Mark		NLN Section	204-219
Source			

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FORM 6
(Regulation 16)

QUEENSLAND
REGD. No. 12517
TCC. 449

THE SURVEY CO-ORDINATION ACT OF 1952

PERMANENT MARK SKETCH PLAN

TYPE STANDARD TYPE OF SURVEY CADASTRAL
 Parish of DRAYTON City or Town of TOOWOOMBA
 Local Authority TOOWOOMBA CITY COUNCIL Map I: 2500 9242-11244

NOTE—Measurements are to be shown from the permanent mark to as many nearby survey marks, buildings, fence posts, kerbs, etc., as practicable. Up to six measurements are desirable. Measurements are in links (this necessarily to scale.)

ADDITIONAL CONNECTIONS			
Line	Surveyor	Date	Plan No.

12517
SCS012517

Installed by A. B. Yeates, Auth. Surv. Date June, 1959 Plan No. D. 10. 263 Sh. 1
 Shown on D. 10. 263 Sh. 1, S. R. P. 107946 SRP. 131516, RP 180000 & P/N
R.P. 178531, RP 199653, RP 194771 RP 178745

Reduced level (i) 800.420m (ii) 1969.26' (iii) 600.230m Datum (i) AHD (ii) State NLN File L Book No.

Levelled by Toowoomba City Council Date Plan No. File 284/148
 Levelled from (i) Toowoomba (219) - Warwick (204) National Level Adjustment (ii) State B.M. No. 22, Toowoomba

Adopted R.L. of Datum 1957.25' 526.570 Correction for State Datum

I certify that the permanent mark shown in this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952" and that the information shown hereon is correct.

(Date) 22nd September, 19 66

(Signature) [Signature]
 [Signature]
 SURVEY OFFICE
 Public Authority

The Queensland Survey Control Register is the authoritative source for coordinate and height information. The coordinate and height information contained on this document may not be the current information regarding this mark.



Survey Control Mark Report

ADMINISTRATIVE

Mark Number	178775		
Alternate Names	BORE 4223 1655	Town	TOOWOOMBA
	GOGG STREET BORE	Local Authority	TOOWOOMBA REGIONAL
	GOGG STREET PARK		
Locality Description	GOGG ST PARK TOOWOOMBA		
Related Information			

DETAILS

Mark Type	MINI MARK		
Installed By	GJ	Connections	IS251053 05-Sep-2014
Installed Date	05-Jan-2009		SP249049 02-Mar-2012
Mark Condition	GOOD		RC249046 02-Mar-2012
Last Visited	05-Sep-2014		
Sketch Available	Yes		

GDA94 COORDINATES

Lineage	Datum		
Latitude	27° 33' 57.54153" S	Horizontal Uncertainty	0.010m
Longitude	151° 56' 43.04491" E		
Ellipsoidal Height	643.826m	Vertical Uncertainty	0.024m
MGA94 Easting	395882.370m	MGA94 Point Scale	0.99973381
MGA94 Northing	6950430.811m	MGA94 Grid Conv	-0° 29' 17.27"
MGA94 Zone	56		
Published	27-Jun-2016	Fixed By	GPS
Adjustment	QLD ANJ 16.06		

AHD HEIGHT

Lineage	Derived		
Height	601.453m	Vertical Uncertainty	Class A / 4th ORDER
Published	18-Feb-2009	Fixed By	GPS
Origin Mark	NLN Section		
Source	TOOWOOMBA CITY BORES JAN2009		

Form 6
Survey and Mapping Infrastructure Act 2003
DEPARTMENT OF NATURAL RESOURCES & WATER

PERMANENT MARK SKETCH PLAN

REGD NO. 178775
'Gogg Street Park'

Bearings are Magnetic (Magnetic, MGA) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document:
"Completion of Permanent Mark Sketch Plans"

178775
Mini Mark in Conc Bore Surround
(Bore No. 42231655)

GOGG STREET

TOINTON STREET

Mark Type Mini Mark in Concrete Bore Surround
Not to Scale

Suited to GPS	SCDB DETAILS ON REVERSE ARE TO BE COMPLETED	
Yes/No- Yes	I certify that the permanent mark sketch has been prepared in accordance with the "Survey and Mapping Infrastructure Act 2003".	
Date 10/02/2009	Date <u>19-2-2009</u>	Signature

The Queensland Survey Control Register is the authoritative source for coordinate and height information.
The coordinate and height information contained on this document may not be the current information regarding this mark.

3D Hydrologic Features Mapping with Imaging Rover

Project file data		Coordinate System	
Name:	C:\Users\lu1046366\Desktop\dec v10 project.vce	Name:	Australia/GDA94
Size:	9 MB	Datum:	GDA94
Modified:	8/08/2016 9:33:23 AM (UTC:10)	Zone:	Zone 56
Time zone:	E. Australia Standard Time	Geoid:	AUSGeoid09 (Australia)
Reference number:		Vertical datum:	
Description:			
Comment 1:			
Comment 2:			
Comment 3:			

Additional Coordinate System Details

Local Site Settings			
Project latitude:	?	Ground scale factor:	1
Project longitude:	?	False northing offset:	0.000
Project height:	670.000	False easting offset:	0.000

Terrestrial Bundle Adjustment Report

Adjustment Group 'All Terrestrial Photo Stations'

Adjustment date: 8/5/2016 7:35:40 PM **Number of tie points:** 10411
Number of stations: 87 **Station setup type:** Standard Resection

Passed stations: 87					
100 (Q1)	101 (Q2)	102 (Q3)	103 (Q4)	104 (Q5)	105 (Q6)
106 (Q7)	107 (Q8)	108 (Q9)	109 (Q10)	110 (Q11)	111 (Q12)
112 (Q13)	113 (Q14)	114 (Q15)	115 (Q16)	116 (Q17)	117 (Q18)
118 (Q19)	119 (Q20)	120 (Q21)	121 (Q22)	122 (Q23)	123 (Q24)
124 (Q25)	125 (Q26)	126 (Q27)	127 (Q28)	128 (Q29)	129 (Q30)
130 (Q31)	131 (Q32)	132 (Q33)	133 (Q34)	134 (Q35)	135 (Q36)
136 (Q37)	137 (Q38)	138 (Q39)	139 (Q40)	140 (Q41)	141 (Q42)
142 (Q43)	143 (Q44)	144 (Q45)	145 (Q46)	146 (Q47)	147 (Q48)
148 (Q49)	149 (Q50)	150 (Q51)	151 (Q52)	152 (Q53)	153 (Q54)
154 (Q55)	155 (Q56)	156 (Q57)	157 (Q58)	158 (Q59)	159 (Q60)
160 (Q61)	161 (Q62)	162 (Q63)	163 (Q64)	164 (Q65)	165 (Q66)

3D Hydrologic Features Mapping with Imaging Rover

166 (Q67)	167 (Q68)	168 (Q69)	169 (Q70)	170 (Q71)	171 (Q72)
172 (Q73)	173 (Q74)	174 (Q75)	175 (Q76)	176 (Q77)	177 (Q78)
178 (Q79)	179 (Q80)	180 (Q81)	181 (Q82)	182 (Q83)	183 (Q84)
184 (Q85)	185 (Q86)	186 (Q87)			

Failed positions: 1					
173 (Q74)					

Scoring

Station geometry: (9.0 / 10)



Observation accuracy: (9.2 / 10)



Tie point distribution: (9.9 / 10)



Tie point geometry: (7.6 / 10)



Tie point redundancy: (2.5 / 10)



General

Number of equations:	52733	Reference factor:	0.89
Number of unknowns:	31755	Chi square test:	Non-optimal weighting
Redundancy:	20978	Number of iterations:	4

The reference factor, also known as the standard error of unit weight, is the ratio of the a-posteriori residuals to the a-priori error estimates. A value in the range 0.95 to 1.05 is desirable. An overall reference factor is given in the General section above, but a more useful reference factor is given in the Group Statistics section. For example, if the reference factor for photogrammetry is greater than 1, it indicates the back projection residuals are larger than the anticipated value specified in Project Settings > Default Standard Errors > Photogrammetry > Pixel picking error. Optimal weighting is achieved when reference factors in the Group Statistics are close to 1, which, in the example, means increasing the pixel picking error setting.

Group Statistics

Group	Reference factor	A priori scalar	Redundancy
Photogrammetry	0.90	1.00	20486.34
Position	0.67	1.00	230.72
Tilt	0.03	1.00	260.94

Station Connections

Total Tie Points	Station	Shared Tie Points @ Connected Station
137	130 (Q31)	1 @ 129 (Q30), 1 @ 138 (Q39), 1 @ 135 (Q36), 1 @ 143 (Q44), 2 @ 122 (Q23), 4 @ 126 (Q27), 4 @ 125 (Q26), 4 @ 137 (Q38), 4 @ 140 (Q41), 5 @ 128 (Q29), 9 @ 134 (Q35), 13 @ 132 (Q33), 51 @ 136 (Q37), 68 @ 127 (Q28), 82 @ 131 (Q32)

3D Hydrologic Features Mapping with Imaging Rover

179 (Q80)	0.001 m	0.002 m	0.000 m	0.67
180 (Q81)	0.001 m	0.002 m	0.000 m	0.75
181 (Q82)	0.001 m	0.002 m	0.000 m	0.80
182 (Q83)	0.001 m	0.002 m	0.000 m	0.79
183 (Q84)	0.012 m	0.018 m	0.000 m	0.77
184 (Q85)	0.001 m	0.002 m	0.000 m	0.75
185 (Q86)	0.001 m	0.002 m	0.000 m	0.77
186 (Q87)	0.001 m	0.002 m	0.000 m	0.79

Station Statistics

Station	Geometry score	Distribution score	Redundancy
100 (Q1)	6.00 / 10	10.00 / 10	109.2
101 (Q2)	6.87 / 10	10.00 / 10	267.5
102 (Q3)	6.72 / 10	10.00 / 10	148.9
103 (Q4)	8.15 / 10	9.78 / 10	232.3
104 (Q5)	8.47 / 10	10.00 / 10	337.3
105 (Q6)	10.00 / 10	10.00 / 10	178.1
106 (Q7)	10.00 / 10	10.00 / 10	198.9
107 (Q8)	6.95 / 10	10.00 / 10	293.4
108 (Q9)	8.06 / 10	10.00 / 10	308.5
109 (Q10)	10.00 / 10	10.00 / 10	181.1
110 (Q11)	10.00 / 10	10.00 / 10	188.2
111 (Q12)	8.65 / 10	10.00 / 10	294.3
112 (Q13)	7.79 / 10	10.00 / 10	309.5
113 (Q14)	10.00 / 10	10.00 / 10	293.0
114 (Q15)	7.67 / 10	10.00 / 10	361.1
115 (Q16)	10.00 / 10	10.00 / 10	119.1
116 (Q17)	7.26 / 10	10.00 / 10	288.9
117 (Q18)	8.65 / 10	10.00 / 10	326.0
118 (Q19)	8.55 / 10	10.00 / 10	187.4
119 (Q20)	7.02 / 10	10.00 / 10	254.1
120 (Q21)	10.00 / 10	10.00 / 10	149.3
121 (Q22)	10.00 / 10	10.00 / 10	148.2
122 (Q23)	8.52 / 10	10.00 / 10	243.7
123 (Q24)	7.16 / 10	10.00 / 10	258.3
124 (Q25)	9.79 / 10	10.00 / 10	211.8
125 (Q26)	8.05 / 10	10.00 / 10	317.0
126 (Q27)	9.89 / 10	10.00 / 10	223.5

3D Hydrologic Features Mapping with Imaging Rover

127 (Q28)	10.00 / 10	10.00 / 10	284.5
128 (Q29)	8.14 / 10	10.00 / 10	330.7
129 (Q30)	10.00 / 10	10.00 / 10	234.9
130 (Q31)	10.00 / 10	10.00 / 10	103.7
131 (Q32)	10.00 / 10	10.00 / 10	329.8
132 (Q33)	10.00 / 10	10.00 / 10	357.8
133 (Q34)	10.00 / 10	10.00 / 10	140.2
134 (Q35)	10.00 / 10	10.00 / 10	185.9
135 (Q36)	10.00 / 10	10.00 / 10	236.5
136 (Q37)	10.00 / 10	10.00 / 10	242.2
137 (Q38)	10.00 / 10	10.00 / 10	329.3
138 (Q39)	10.00 / 10	10.00 / 10	197.4
139 (Q40)	10.00 / 10	10.00 / 10	241.6
140 (Q41)	10.00 / 10	10.00 / 10	291.1
141 (Q42)	10.00 / 10	10.00 / 10	344.4
142 (Q43)	9.37 / 10	10.00 / 10	316.2
143 (Q44)	10.00 / 10	10.00 / 10	243.9
144 (Q45)	10.00 / 10	10.00 / 10	204.3
145 (Q46)	9.05 / 10	10.00 / 10	229.4
146 (Q47)	10.00 / 10	10.00 / 10	179.6
147 (Q48)	10.00 / 10	10.00 / 10	263.5
148 (Q49)	9.14 / 10	10.00 / 10	356.4
149 (Q50)	10.00 / 10	10.00 / 10	195.2
150 (Q51)	7.83 / 10	10.00 / 10	296.8
151 (Q52)	9.58 / 10	10.00 / 10	244.0
152 (Q53)	8.33 / 10	10.00 / 10	262.5
153 (Q54)	7.03 / 10	10.00 / 10	291.9
154 (Q55)	10.00 / 10	10.00 / 10	157.5
155 (Q56)	9.87 / 10	10.00 / 10	230.5
156 (Q57)	7.62 / 10	10.00 / 10	251.8
157 (Q58)	8.52 / 10	10.00 / 10	223.9
158 (Q59)	9.30 / 10	10.00 / 10	269.1
159 (Q60)	7.26 / 10	10.00 / 10	269.8
160 (Q61)	9.89 / 10	10.00 / 10	190.1
161 (Q62)	9.81 / 10	10.00 / 10	203.6
162 (Q63)	8.56 / 10	10.00 / 10	293.5
163 (Q64)	10.00 / 10	10.00 / 10	213.9
164 (Q65)	8.57 / 10	10.00 / 10	238.6

3D Hydrologic Features Mapping with Imaging Rover

165 (Q66)	8.65 / 10	10.00 / 10	215.6
166 (Q67)	10.00 / 10	10.00 / 10	181.4
167 (Q68)	10.00 / 10	10.00 / 10	129.3
168 (Q69)	7.64 / 10	10.00 / 10	277.0
169 (Q70)	8.94 / 10	10.00 / 10	279.3
170 (Q71)	8.07 / 10	10.00 / 10	296.7
171 (Q72)	8.15 / 10	10.00 / 10	258.3
172 (Q73)	10.00 / 10	10.00 / 10	101.4
173 (Q74)	10.00 / 10	10.00 / 10	139.9
174 (Q75)	8.41 / 10	10.00 / 10	244.3
175 (Q76)	9.80 / 10	10.00 / 10	317.5
176 (Q77)	10.00 / 10	10.00 / 10	237.8
177 (Q78)	9.94 / 10	10.00 / 10	311.7
178 (Q79)	8.57 / 10	10.00 / 10	299.7
179 (Q80)	10.00 / 10	10.00 / 10	140.6
180 (Q81)	10.00 / 10	10.00 / 10	238.3
181 (Q82)	10.00 / 10	10.00 / 10	174.8
182 (Q83)	10.00 / 10	10.00 / 10	282.4
183 (Q84)	10.00 / 10	10.00 / 10	227.8
184 (Q85)	8.38 / 10	10.00 / 10	362.8
185 (Q86)	8.11 / 10	10.00 / 10	269.7
186 (Q87)	8.33 / 10	10.00 / 10	87.2

Station Status

Station	Setup type	Adjustment	Position	Orientation
100 (Q1)	Standard Resection	Passed	Enabled	Enabled
101 (Q2)	Standard Resection	Passed	Enabled	Enabled
102 (Q3)	Standard Resection	Passed	Enabled	Enabled
103 (Q4)	Standard Resection	Passed	Enabled	Enabled
104 (Q5)	Standard Resection	Passed	Enabled	Enabled
105 (Q6)	Standard Resection	Passed	Enabled	Enabled
106 (Q7)	Standard Resection	Passed	Enabled	Enabled
107 (Q8)	Standard Resection	Passed	Enabled	Enabled
108 (Q9)	Standard Resection	Passed	Enabled	Enabled
109 (Q10)	Standard Resection	Passed	Enabled	Enabled
110 (Q11)	Standard Resection	Passed	Enabled	Enabled
111 (Q12)	Standard Resection	Passed	Enabled	Enabled
112 (Q13)	Standard Resection	Passed	Enabled	Enabled