Roche MINING

COMMODORE MINE

3DM CALIBCAM AND ANALYST PACKAGE REPORT

Prepared by
Nicholas Pascoe

EXECUTIVE SUMMARY

The aim of this report is to evaluate the software package offered by ADAM Technology for the purposes of terrestrial photogrammetry. This report is based on a number of trials undertaken at the Commodore mine. Features of the 3DM software package include:

- Support for both digital cameras and scanned images
- High accuracy
- Relative-only and absolute orientation of any number of images
- Automatic DTM generation
- Stereo viewing
- Line feature definitions
- 3D point and line digitising, image draping for 3D viewing
- Output to a variety of formats to suit a number of other CAD packages such as AutoCAD, Vulcan and Terramodel

A number of possible applications for the 3DM software package at Millmerran were examined, including;

- highwall coal seam mapping
- dump profiling
- blast profile mapping

Requirements of the system are:

- digital camera, preferably a Single Lens Reflex type and additional memory cards
- high end computer with 1Gb or so of RAM, good graphics card
- tripod, tribrach, mount for camera to keep position of camera consistent and measurable

The results of the initial trial at Millmerran indicate that point accuracy to within 100mm is easily achievable, and literature from other trials indicates that point accuracy of around 20mm is achievable, depending on equipment and techniques. The results can be seen below.

Camera	Deviation (mm)		
	x	y	z
Cannon 10D	0.174	-0.272	0.116
Canon IXUS400	0.725	-0.427	0.283
Sony DSC-P100	0.252	-0.280	0.096
Canon A70	0.212	-0.262	0.100

Comparison of GPS survey with both laser and photogrammetric survey yields results within 2%. Thus photogrammetric survey is comparable with accuracy from conventional survey techniques and laser scanning. The results of the comparison can be seen below.

Elev Range (m)	Survey (m^3)	Laser Difference to GPS (m^3)	Laser Difference to GPS (%)	Photo Difference to GPS (m^3)	Photo Difference to GPS (%)
375.000 > 380.000	0.00	0	0.0%	0	0.0%
380.000 > 390.000	88,582.98	-1,766.78	-2.0%	-1,063.28	-1.2%
390.000 > 400.000	79,094.86	-289.64	-0.4%	407.83	0.5%
400.000 > 403.243	17,883.56	-117.60	-0.7%	75.74	0.4%
TOTAL	**185,561**	**-2,174**	**-1.2%**	**-580**	**-0.3%**

Time taken for the entire process typically ranged between 3 to 5 hours, depending on the complications encountered. With a more efficient technique and expertise born of practise, far less time would be needed.

ADAM Technology's software package, 3DM CalibCam and Analyst is accurate, robust and easy to use. Results compare favourably with laser scanning and conventional survey techniques. Utilisation of the 3DM software package would be extremely useful at Millmerran for applications such as blast profiling for dozer push, highwall coal seam mapping and waste dump mapping.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

.

1.0 INTRODUCTION

Fast, accurate and safe surveying for mine sites is becoming increasingly important as mine sites become larger and survey more rigorous, to allow better tracking of production. There are a number of alternatives available from the age-old theodolite and staff to total station, GPS surveying, aerial photogrammetry and terrestrial photogrammetry.

The aim of this report is to evaluate the software package offered by ADAM Technology for the purposes of terrestrial photogrammetry. This report is based on a number of trials undertaken at the Commodore mine.

The software offered by Adam Technology includes two components; **3DM CalibCam** block adjustment software and **3DM Analyst** which is used for generating 3D images. The features of the software package are:

- Support for both digital cameras and scanned images
- High accuracy
- Relative-only orientation of any number of images
- Absolute orientation of any number of images
- Automatic DTM generation
- Stereo viewing
- Line feature definitions
- 3D point and line digitising
- Image draping for 3D viewing
- Output to a variety of formats to suit a number of other CAD packages such as AutoCAD, Vulcan and Terramodel

It is proposed to compare results with GPS survey and Laser scanning, where possible, to allow a comparison of accuracy and time requirements for a variety of tasks. The potential applications examined include:

- Stockpile models
- Waste dump scheduling
- Blast profile mapping
- Highwall mapping

Of particular interest to the Commodore mine are highwall coal seam mapping, waste dump mapping for dump scheduling and blast profile mapping for use in GPS dozer push applications.

2.0 SCOPE

The purpose of this trial is to measure the accuracy and time requirements, test some of the features of the software and thus determine if it satisfies the requirements of Roche Mining, that is:

- Seam and lithology mapping capabilities
- Dump surveying at Commodore mine
- Blast profile mapping for dozer push applications
- Low time and personal requirements

Comparison with GPS surveying and Laser scanning was to provide a degree of confidence in the accuracy of the package and not to find the better method. Orica blasting services provided the laser scans from pre and post blast scans.

Also part of the trial was to determine if a Single Lens Reflex type camera was necessary to provide suitable results. It is desired that, if employed, sites be able to use 3 mega pixel or higher consumer grade digital cameras instead of the more expensive semi-professional and professional quality Single Lens Reflex type cameras.

This report makes no effort to compare the cost of this system with other similar survey methods such as laser surveying.

3.0 PROCEDURE

The basic process for undertaking a survey using the 3DM software follows. This is intended to be a brief narrative detailing the procedure followed during the trial at Millmerran. Much more detailed information can be found in the users manuals supplied with **3DM CalibCam** and **3DM Analyst**.

Hardware

Equipment for field work:

- Digital camera
- Survey equipment (GPS equipment preferably)
- Suitable targets
- Tripod
- Tribrach

Equipment for image analysis:

- Quality computer with 1 GB or so of RAM and good graphics card

Additional requirements:

- Additional memory cards
- Second person to assist with survey
- Favourable weather conditions

Planning

A basic idea of the layout of the area to be photographed is essential. It is necessary to know the dimensions of the area to be photographed and a rough distance from the photograph station to the area being photographed. Using the spreadsheet supplied with **3DM CalibCam** (or a modified spreadsheet) allows calculation of the necessary details for establishing the layout. A screenshot of the calculation spreadsheet is shown below. It is important to input the correct details for the camera that is being used. Required inputs are the name of the model of camera, focal length range, image resolution and image sensor size. This data can be obtained from the manufacturer's handbook that was supplied with the camera or from a reputable website such as www.dpreview.com.

The important details to take from the spreadsheet are the distance between camera stations and the desired target size. The number of targets necessary is not addressed in the spreadsheet and is approximate, however two targets each end of the section of highwall and three in between were used in the initial trials on a 250m section of highwall.

If the area to be photographed is not a straight section, such as a highwall, some modification to the technique is necessary. Refer to the user manuals supplied with **3DM CalibCam** and **3DM Analyst** for more detailed information regarding photography other than strip photography.

Object Distance Calculation Spreadsheet

Camera Name: Canon IXUS 400

Camera Details	Width		Height	
Number of pixels:	2272	x	1704	
Image sensor dimensions:	7.176	x	5.319	mm
Actual focal length of lens x adapter:	7.9		mm	
Equivalent 35mm camera focal length:	40		mm	
Size of each pixel in CCD array:	3.16	x	3.12	um

Image size:	3.9 megapixels
Field of View Crop/Lens multiplier:	5.0 x 4.5

	PW		PH
3DM Analyst camera calibration settings:	0.00316	x	0.00312

Required Conversion: Distance -> Pixel Size

Model Details				
Desired object distance:	130			m
Ground coverage of each Image:	118.1	x	87.5	m
Ground pixel size:	5.2	x	5.2	cm
Desired target size:	31			cm
Desired target + border size:	83			cm

Accuracy Estimates	
Estimated image accuracy:	1.0 pixels
Distance between camera stations:	47.2 m
Object distance/base ratio:	2.8 : 1
Estimated plan accuracy:	5.2 cm
Estimated distance accuracy	14.3 cm
Estimated overall accuracy	16.1 cm

Area Details for Strip Planning					
Width and height of area:	300	x	31 m	Distance between camera stations:	47.2 m
Desired horizontal overlap:	60%	=	70.9 m	Number of images per strip:	8
Desired vertical overlap:	20%	=	17.5 m	Number of strips:	1
Captured images to used images ratio:	1	:	1	Total number of images:	8

Figure 1: Object Distance Calculation Spreadsheet screenshot

Establish layout

Layout of targets or control points is important. As mentioned previously, the number of targets and their locations is approximate. In ideal circumstances the number of targets may be reduced to even a single target, however when not using a fixed lens camera this may be asking too much and in any case, redundant control points can only strengthen camera calibrations. The next step is the layout of the camera stations. The camera stations are laid out with the first station being level with the first control point (in a highwall situation) as shown below. The locations of the control points must be surveyed. It is recommended that the locations of the camera stations be surveyed; however it is possible for the software to determine the locations of some of the camera stations without surveying all of them.

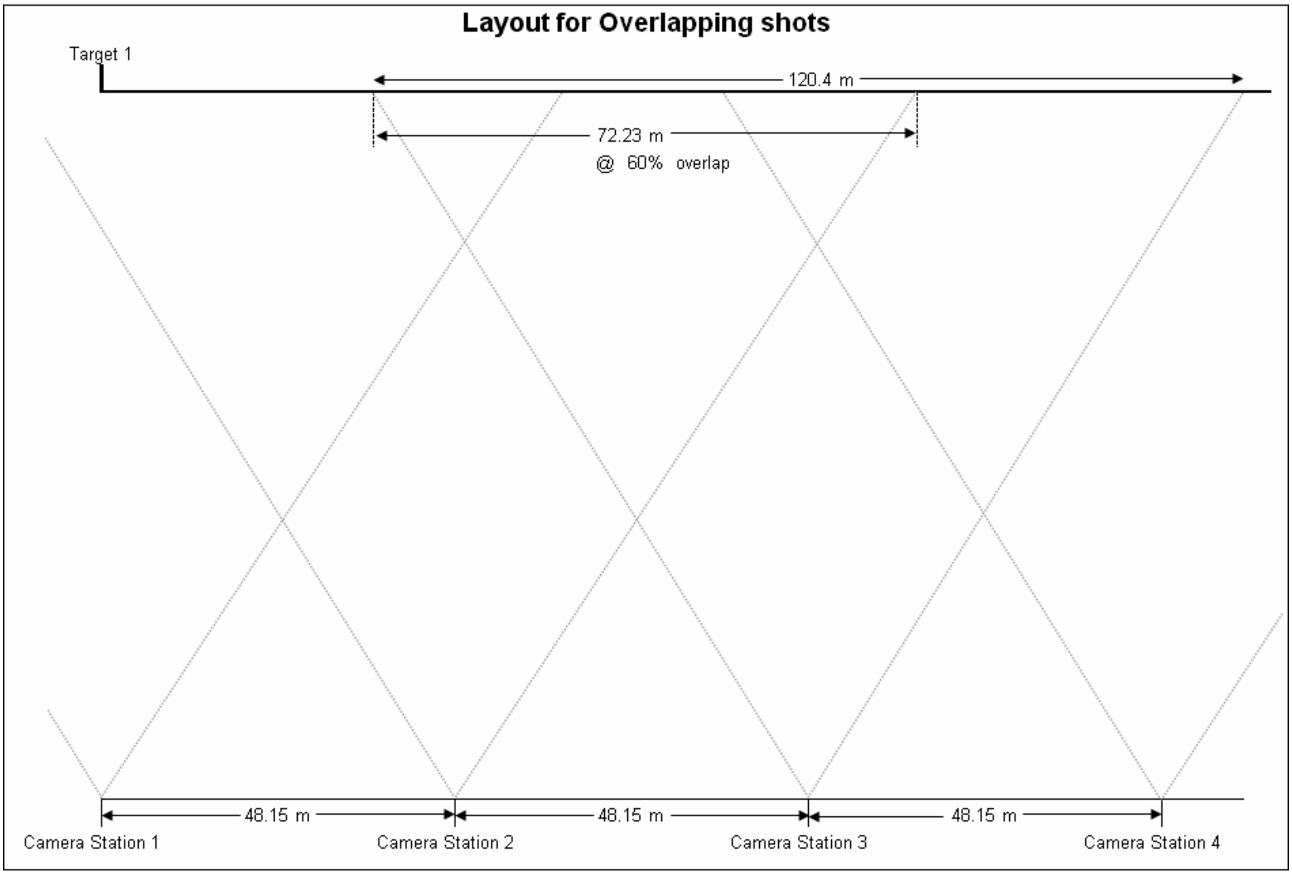


Figure 2: Layout diagram of control points and camera stations

Having established the layout it is recommended that a sketch of the layout be taken to record the approximate location of each point in relation to the other points and any major geological features that may help when digitising points in **3DM CalibCam**. This also serves to help prevent major errors in selecting points that will prevent **3DM CalibCam** from completing a block adjustment.

Take photographs

Use a tripod or similar take the photographs from the surveyed camera stations. It is important to use a tripod to ensure a consistent, measurable height when taking photographs and to help obtain a clear image. Manufacture of a bracket to mount a camera to a tribrach and tripod has been completed by some users to ensure the centre of the lens is consistently in the same spot for taking images.

For each photograph it is important to take each photograph directly at the desired area and allow for overlap. Generally if using the Object Distance Calculation Spreadsheet the overlap will be correct. Underexposure or overexposure of the image or major changes of perspective will render the process much more difficult or even impossible.
This is the last of the field work.

Establish location and orientation of camera stations

A text file of the 3 dimensional coordinates obtained when surveying the control points and camera stations is necessary. Using these allows the software to accurately determine focal lengths. Throughout the trials at Millmerran the method of survey was a Trimble GPS survey unit. It is not necessary to provide all the control points or all the camera stations as **3DM CalibCam** is capable of determining some of these points using reference to other points however it is recommended that these points be supplied for the purpose of initial camera calibrations.

Calibrate Camera

Each camera used must be calibrated for the focal length that it is used at. For more information on this procedure refer to the user manual supplied with **3DM CalibCam**. Alternatively refer to the document titled: 3DM CalibCam & Analyst Basic User Manual that runs through a typical calibration and model generation process.

Generate models

Following calibration of the camera in **3DM CalibCam**, model generation is accomplished in **3DM Analyst**. Output is a DTM that can be exported into AutoCAD or Vulcan using a number of formats. For more information on this procedure refer to the user manual supplied with **3DM Analyst**. Alternatively refer to the document titled: 3DM CalibCam & Analyst Basic User Manual that runs through a typical calibration and model generation process.

4.0 INITIAL TRIAL

The initial trial undertaken at Commodore mine was on the 23/11/04. Present were Steven McAtee: ADAM Technologies, Michael Granger: Senior Surveyor, Bruce Highlands: Survey/Machine Control, Brendan Davies: Commodore Mine Project Engineer/Surveyor and Nicholas Pascoe: student mining engineer. This trial was part of the training offered by Adam Technologies and the data provided by this session has been used in this report.

The trial consisted of 13-15 pictures taken of a 250 metre section of highwall using a range of cameras. The cameras used include:

- 6.3 mega pixel Canon EOS 10D digital SLR camera
- 3.9 mega pixel Canon IXUS400 digital camera
- 5.0 mega pixel Sony DSC-P100 digital camera
- 3.1 mega pixel Canon Powershot A70 digital camera (Commodore Camera)

These four camera types were evaluated to determine if purchasing of a single lens reflex type camera was necessary or if a standard digital type camera available on a mine site would be suitable.

Parameters

For the planning of this trial see *Appendix A: Initial Trial Planning*. The characteristics of this trial were:

- Approx 130m from camera stations to targets
- 250m of highwall
- 60% horizontal overlap between pictures
- Cameras set on highest picture quality
- 8 targets, 4 white on black, 4 black on white
- 7 surveyed stations, 1 unsurveyed
- 15 images, ≈ 2 per station

The layout of control points and camera stations is as shown in Figure 3: Initial Trial layout sketch.

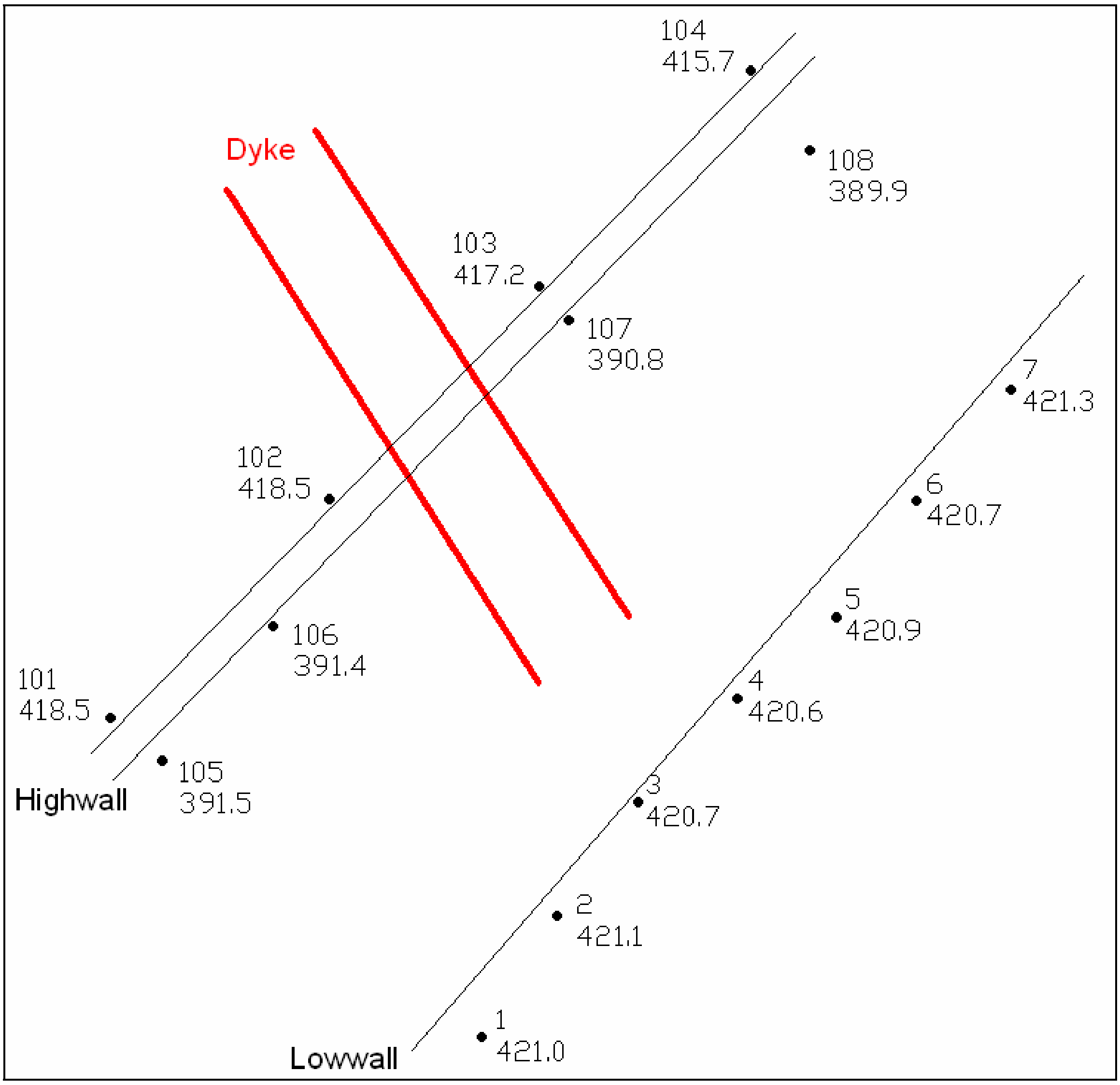


Figure 3: Initial Trial layout sketch

Accuracy

From the bundle adjustment produced in **3DM Analyst** accuracy estimates typically falls in the range 0-150 mm for points in the model. A summary of the average accuracy can be seen in Table 1: Estimation of ground point accuracy.

Table 1: Estimation of ground point accuracy

Camera	Average (m)		
	x	y	z
Cannon 10D	0.087	0.081	0.041
Canon IXUS400	0.108	0.091	0.330
Sony DSC-P100	0.140	0.128	0.044
Canon A70	0.128	0.109	0.077

The accuracy estimate produced by the bundle adjustment in **3DM Analyst** is produced by using the image coordinates alone to determine the ground coordinates.

As the accuracy estimate is similar to assuming no image error and pushing all the error into the ground coordinates, it was deemed necessary to obtain a more concrete measure of the accuracy of the software. To this end a separate run of calibrations and a block adjustment was run during which the coordinates of one of the control points was withheld and then a point for the centre of the target digitised to obtain the 3 dimensional coordinates of the point. This method of accuracy estimation was suggested by Jason Birch of Adam Technologies.

The control point numbered '106' was removed from the data set and a relative only point digitised in the centre of the target. For this trial the calibration file generated in the previous runs were used. Following the block adjustment process the coordinates of this point were recorded and a comparison to the surveyed coordinates made. Two tables summarising the results can be seen below.

Table 2: Results of accuracy check

Camera	Survey Coordinates			Measured Coordinates		
	x	y	z	x	y	z
Cannon 10D	328,589.329	6,907,561.389	391.790	328,589.155	6,907,561.661	391.674
Canon IXUS400	-	-	-	328,588.604	6,907,561.816	391.507
Sony DSC-P100	-	-	-	328,589.077	6,907,561.669	391.694
Canon A70	-	-	-	328,589.117	6,907,561.651	391.690

Table 3: Deviation from actual coordinates

Camera	Deviation		
	x	y	z
Cannon 10D	0.174	-0.272	0.116
Canon IXUS400	0.725	-0.427	0.283
Sony DSC-P100	0.252	-0.280	0.096
Canon A70	0.212	-0.262	0.100

The data above shows that a point result of within 100mm is easily possible. The data also shows that the y-axis results deviate more from the actual value than other values. This is probably a reflection on the spread of control points for this trial, that is, the control points have a varied range of x and z coordinates but a more restricted range of y coordinates leading to greater error.

Also due to the target centroiding tool not working for most images in this trial, error may be attributed to digitisation of the centre of the control point. Ronaszeki (2004) suggests that error in this part may cause up to 20mm of error alone. Furthermore during Ronaszeki's trials survey of the centre of control points was accomplished using a total station which is more appropriate for survey of the target centre than the GPS survey unit used in the trials at Commodore mine.

The software shows extremely good accuracy given the small amount of time spent doing the accuracy check.

Time Taken

Of particular importance is the time taken for the process to be completed. This is important as the DTM's are only relevant when they are current and also to prevent this process from taking too much of site personnel's time. The entire process should take under two hours, however, difficulty getting the GPS to work or taking satisfactory photographs will dramatically extend the time taken for field work and unsatisfactory photographs will increase the time needed for model generation (or make it impossible). During the trial the time breakdown estimation was as follows:

Table 4: Initial trial time breakdown

Item	Time (mins)
Setup targets	30
Survey targets	20
Push slots	30
Take photos	40
Survey camera stations	-
Load to computer	15
3DM CalibCam process	60
3DM Analyst process	30
Total	225

It should be noted that during the trial the process was new and procedures probably took longer than they would in normal circumstances. Also, during the photography stage there were four photographers instead of one, which would increase the time taken for this step.

It is suggested that a more detailed process for the procedure be compiled to ensure time is used most effectively and the process is consistent.

Outputs

For each camera type, a number of models were generated of the section of highwall. These models were run through the batch processing to change the data into a DTM. The DTM's can be viewed in Terramodel or a similar CAD program. Following are some views of one of the models output by Analyst. Each model is comprised of two images.

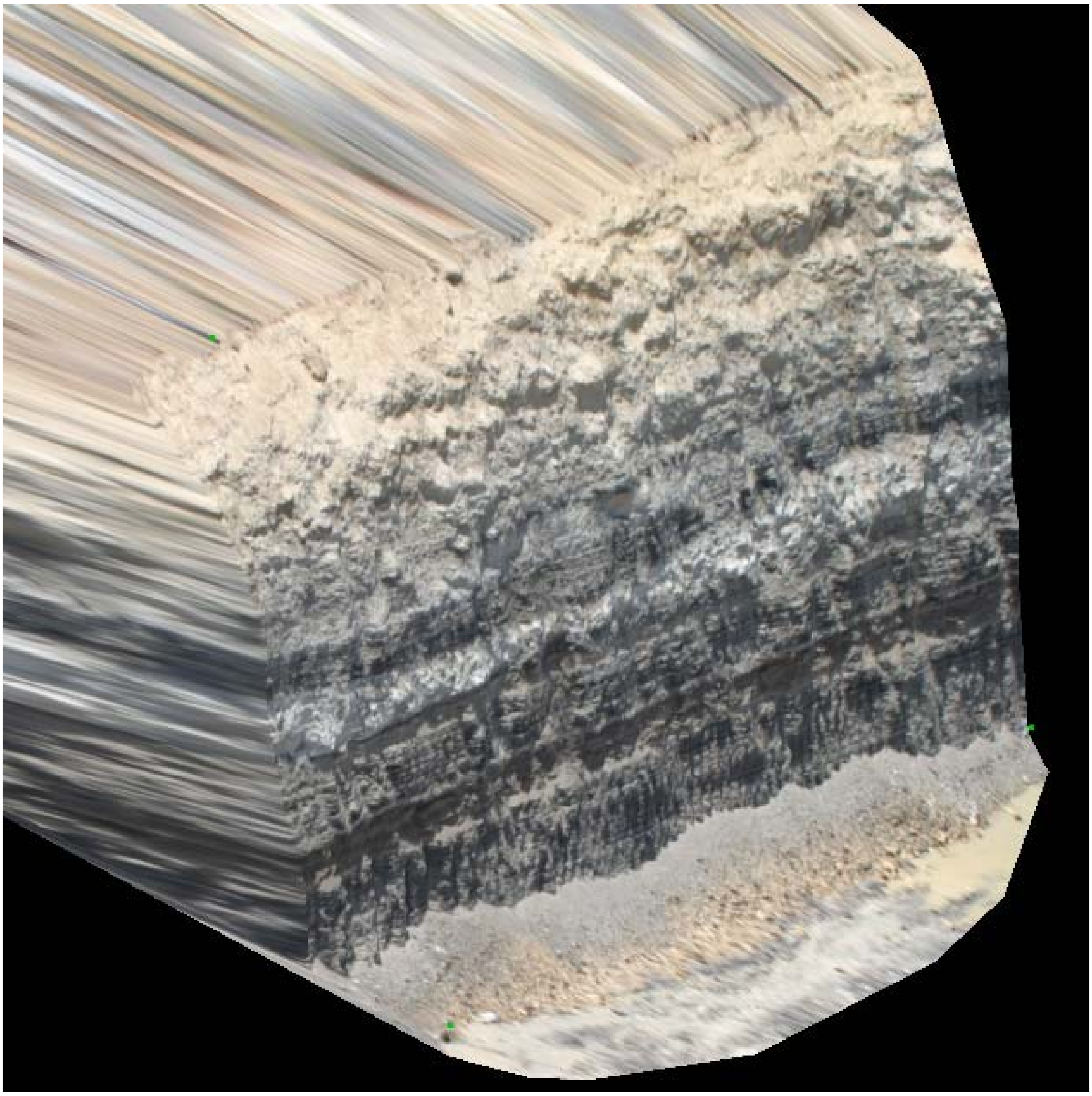


Figure 4: View of textured face of one model DTM in Analyst

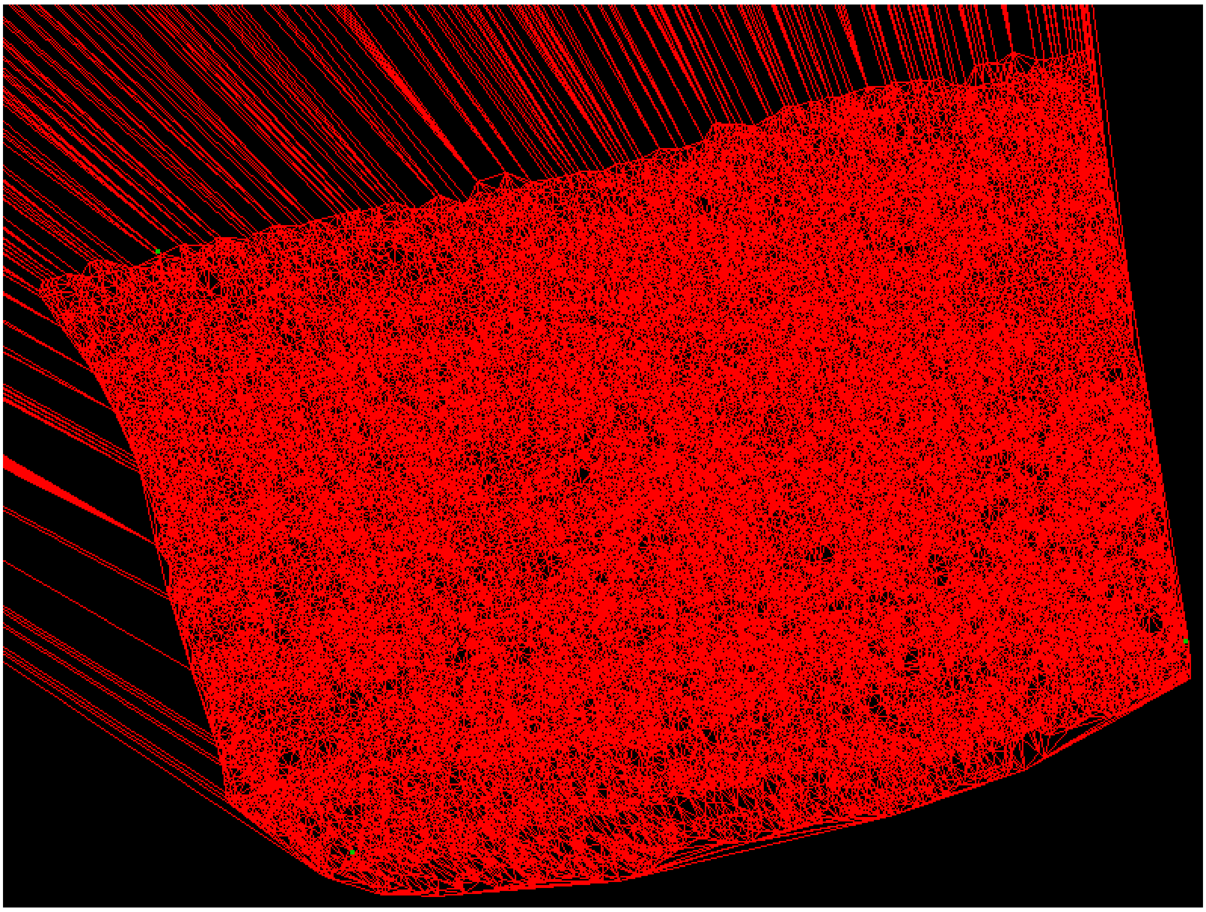


Figure 5: View of triangulated DTM for one model in Analyst

Once a model has been generated for each pair of images they can be turned into a DTM's using a batch process. Each model (pair of images) is output separately to other models.

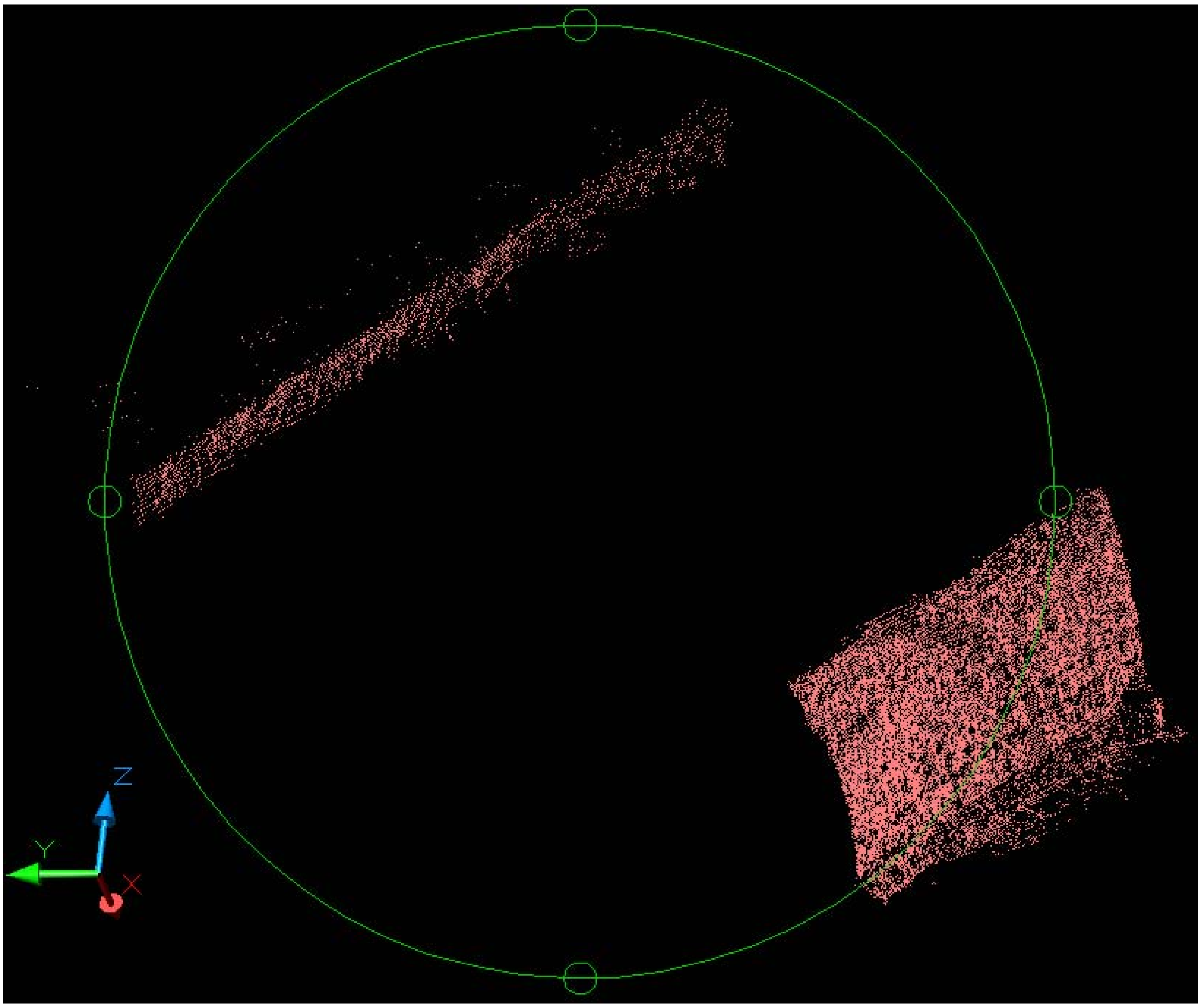


Figure 6: 3D view of exported point data for one model

Discussion

This trial was part of the training given by Adam Technology. The data gathered during the training was used as the basis for the above section of the report. After the training was over the process was repeated to try to obtain the best results for each camera. Then the accuracy checks were run, however not as much time went into the accuracy checks as did the model and DTM generation. It is felt that with more favourable conditions and with expertise born of practice that better results could be obtained.

The target centroiding tool which is an important factor in the accuracy of 3DM CalibCam did not work for more than two control points taken with the Canon EOS 10D camera and none with other cameras. This lead to greater error than should have been the case. Steve McAtee (2004) indicated that this was due to the targets used rather than the software as the targets were manufactured on short notice and with a very arbitrary guide from the Camera Object Distance Calculation spreadsheet. With improved targets the accuracy of results should improve.

The results of the accuracy check indicate that the Canon EOS 10D SLR yields more accurate results than the other cameras, but in the case of the Canon Powershot A70 it is by a very small margin. The major difference in the cameras lies in the clarity of images and the associated ease in digitising points. A number of screenshots taken at 1x magnification show the difference in image clarity for each camera. See *Appendix B: 1x Zoom Image Clarity Screenshots* and *Appendix C: 2x Zoom Image Clarity Screenshots*. This clarity is most likely linked to the resolution of the photograph, whereas accuracy may be more a combination of a better lens and higher image resolution. Therefore the higher the image resolution of the camera the greater the clarity and the accuracy. This is discussed further in 9.0 DISCUSSION.

5.0 STOCKPILE MODEL

To assess the ability of the software to generate models of stockpiles a topsoil dump was selected. Present were Nicholas Pascoe: student mining engineer and Mark Perquin: Commodore mine Coal Quality Engineer. This was not an important requirement for Roche Mining; this was merely a test of the software's capability.

For this trial two stockpiles were surveyed by GPS surveying and then setup for photogrammetry. The photographs were taken with the sites digital camera, the Canon Powershot A70.

Parameters

For the planning of this trial see *Appendix D: Stockpile Model Planning*. The parameters of this trial were:

- Canon Powershot A70 digital camera
- Approx 55m from camera stations to targets
- Approx 100m x 40m x 4m (l x w x h)
- ≈ 60% horizontal overlap between pictures
- Camera set on highest picture quality
- 8 targets, 4 white on black, 4 black on white
- 17 surveyed stations
- 25 images

Both of the stockpiles surveyed had similar parameters.

Accuracy

No models were able to be generated using **3DM CalibCam** and/or **3DM Analyst** for either stockpile surveyed.

Time Taken

Below are tables showing the time breakdown for each of the two stockpile models.

Table 5: Stockpile 1 time breakdown estimation

Item	Time (mins)
Setup targets	20
Survey targets	30
Take photos	27
Survey camera stations	-
Load to computer	10
3DM CalibCam process	90
3DM Analyst process	10
Total	187

Table 6: Stockpile 2 time breakdown estimation

Item	Time (mins)
Setup targets	20
Survey targets	30
Take photos	137
Survey camera stations	-
Load to computer	10
3DM CalibCam process	90
3DM Analyst process	10
Total	297

.

Outputs

No outputs from **3DM CalibCam** or **3DM Analyst**.

Discussion

In both cases for the stock pile models no output was possible. This is due to a number of problems, both with the software and with the survey technique.

- Stockpile 1 had vegetation growing on 30-40% of the stockpile. This made picking up points in **3DM CalibCam** extremely difficult.
- Both stockpiles were low lying structures and photos were taken from ground level in most cases resulting in an incomplete view of the structure.
- The second stockpile had photographs taken from dumps lying beside it however this resulted in a change in perspective from the majority of shots taken from the ground and resulted in few points being able to be digitised.
- The texture of the stockpile material was homogeneous and at 50m it was not possible to distinguish any details.
- Sunlight in some shots (as the camera stations made a complete circle) rendered them useless.
- Camera stations were too far apart. This is due to inexperience and the idea that survey of a stockpile would be similar to survey of a strip of highwall. In order to avoid major changes of perspective it is necessary to increase the number of survey stations used in this circumstance.

Thus the software has a problem with vegetation, lack of texture and major changes of perspective. Survey technique must be modified for stockpiles; however this was not considered an area of interest for Roche except perhaps for coal stockpiles.

The first stockpile was surveyed with a single person and the second with two people. The process was much simplified and expedited using two people.

6.0 PRE-BLAST MODEL

To compare the results of the software package a section of Pit A was photographed and on the day that it was to be blasted, laser profiled by Orica. The control points used were the same and this allows an effective base for comparison.

The photographs were taken with the sites digital camera, the Canon Powershot A70.

Parameters

For the planning of this trial see *Appendix D: Stockpile Model Planning*. The parameters of this trial were:

- Canon Powershot A70 digital camera
- Approx 195m from camera stations to targets
- Approx 300m section of highwall
- 60% horizontal overlap between pictures
- Camera set on highest picture quality
- 7 targets, 3 white on black, 4 black on white
- 6 surveyed camera stations
- 16 images, 6 normal, 10 fanned

Accuracy

The DTM's generated by 3DM Analyst were imported into Terramodel, as well as the DTM's generated by the laser scanner. By importing both laser scanner and photogrammetry models they can be compared with conventional GPS survey. A boundary was laid out to provide a bench section for comparison between the survey methods and cut off at the 380.00RL.

Table 7: Volume comparison by 10m bench

Elev Range (m)	Survey (m^3)	Laser (m^3)	Photo (m^3)
375.000 > 380.000	0	0	0
380.000 > 390.000	88,582.98	86,816.20	87,519.70
390.000 > 400.000	79,094.86	78,805.22	79,502.69
400.000 > 403.243	17,883.56	17,765.96	17,959.30
TOTAL	**185,561**	**183,387**	**184,982**

Table 8: Volume difference by 10m bench

Elev Range	Laser Difference		Photo Difference	
(m)	(m^3)	(%)	(m^3)	(%)
375.000 > 380.000	0	0.0%	0	0.0%
380.000 > 390.000	-1,766.78	-2.0%	-1,063.28	-1.2%
390.000 > 400.000	-289.64	-0.4%	407.83	0.5%
400.000 > 403.243	-117.60	-0.7%	75.74	0.4%
TOTAL	**-2,174**	**-1.2%**	**-580**	**-0.3%**

There is only a marginal difference between survey results and both laser and photogrammetry results. The laser scanned and photogrammetric results are with 2% of each other for each of the 10m benches and within 2% for the total result. This suggests that both are quite accurate, however photogrammetric survey results are closer to survey.

Time Taken

A breakdown of the time taken is shown below.

Table 9: Pre-blast model time estimation

Item	Time (mins)
Setup targets	20
Survey targets	30
Take photos	25
Survey camera stations	-
Load to computer	10
3DM CalibCam process	120
3DM Analyst process	30
Total	235

Outputs

DTM's were output from 3DM Analyst. Some screenshots can be seen in *Appendix E: Pre-blast Output Screenshots*. The screenshots of the photogrammetric outputs show the texture of the face out put by the Adam Technology software, as compared with the smooth faces output from GPS survey and Laser scanning.

Discussion

A lot of problems were had getting this trial to work. Initially there was some mistakes with the sequence of images input into 3DM CalibCam. Adam Technology staff were able to find and fix some of the problems with the trial and allow some results to be generated.

Adam Technology staff suggested that there were discrepancies between the coordinates surveyed for the camera stations and the actual coordinates that the photos were taken from. This resulted in large sigmas for block adjustments and means there is a relatively large amount of error in the results. This means that although the results are relatively accurate, a fair degree of improvement can be expected.

7.0 OTHER TRIALS

A number of other trials were completed to further test the software and to refine time estimates. These trials included modelling a section highwall in Pit B and digitising the uppermost seam (G seam) for use in Vulcan, a dump model to test its ability to deal with a large range of control point coordinates, and a post blast model of the same strip as in the pre-blast trial.

All trials were successful, except in the case of the highwall section. Photos taken were dramatically underexposed and a lot of difficulty was had, however a number a models were generated and the seam digitised successfully. These models were imported into Vulcan.

It is suggested that Adam Technology staff would have been able to resolve the issues with this project and that the only real problems with this project could be fixed by a more experienced user.

8.0 RISK ASSESSMENT

A number of risks are associated with purchase of the software and the physical process involved with taking the photographs. A basic risk assessment was completed. This risk assessment does not seek to satisfy statutory requirements, it was completed to identify areas of risk and to demonstrate what had been considered. The risk assessment can be found in tabulated format in *Appendix F: Risk Assessment*.

9.0 DISCUSSION

Although not spelled out in the training, it is possible to specify the accuracy of the results. A document produced by Adam Technology entitled Laser Scanning vs. Digital Photogrammetry and based on some work by Derek Lichti and Stuart Gordon from Curtin University in Western Australia, goes into a great deal of detail showing the differences, strengths and weaknesses of laser scanning and photogrammetry.

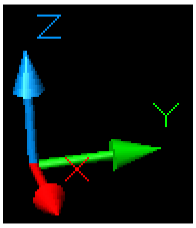


Figure 7: x, y, z axis directions

As touched on in Section *4.0 INITIAL TRIAL - Discussion*, the accuracy of the image is dependant on the amount of ground covered by a single pixel. The amount of ground covered by a single pixel is determined by the distance from the target, focal length of the lens and the image resolution. The Planimetric accuracy (spatial accuracy in y and z axis) is determined to about 1/3 of a pixel in the plane parallel to the image.

The base to distance ratio is the ratio of the base (distance between camera stations) to the distance (distance between camera and targets). The base to distance ratio effectively determines the depth accuracy (spatial accuracy in the x axis). The depth accuracy is determined by multiplying the base to distance ratio by the planimetric accuracy. Hence a base to depth ratio of 2:1 is half as accurate as a base to depth ratio of 1:1.
(Laser Scanning vs. Photogrammetry, 2005)

Below in *Table 10: Camera ground pixel size* the ground pixel size of the cameras used in the initial trial.

Table 10: Camera ground pixel size

Camera	Lens Focal Length (mm)	Ground Pixel Size x (mm)	y (mm)	Planimetric Accuracy (mm)
Cannon 10D	28	34.3	34.3	11.4
Canon IXUS400	7.4	55.5	55.5	18.5
Sony DSC-P100	7.9	45.5	45.5	15.2
Canon A70	5.8	58.8	58.8	19.6

Based on this table the most accurate camera is the Cannon 10D, followed by the Sony DSC-P100, the Cannon IXUS400 and the Canon A70.
In *Table 11: Depth accuracy and base to distance ratio* the base to distance to depth accuracy is calculated.

Table 11: Depth accuracy and base to distance ratio

Camera	Base (m)	Distance (m)	Ratio 1 : x	Planimetric Accuracy (mm)	Depth Accuracy (mm)
Cannon 10D	37.2	130	1 : 3.5	11.4	40.0
Canon IXUS400	37.2	130	1 : 3.5	18.5	64.7
Sony DSC-P100	37.2	130	1 : 3.5	15.2	53.0
Canon A70	37.2	130	1 : 3.5	19.6	68.5

Once again the sequence of most accurate camera is the same.

Had these determining parameters been known about earlier in the trial, a better result for the accuracy may have been possible by planning each trial better.

A number of characteristics of this software were found. These include:

- Problems digitising points with vegetation cover

- Lighting is critical
- The automatic centroiding tool worked on only two targets. These were taken during the initial trial with the EOS 10D camera. It is suggested that a higher quality camera makes processing the images easier.
- Time taken varies depending on circumstances.

The software package is quite accurate (<100mm), and is known to be far more accurate (<20mm) as in the Ronaszeki report.

10.0 RECOMMENDATIONS AND CONCLUSION

As a result of the trials undertaken at Millmerran a number of recommendations for improvement can be made. These include:

- if high accuracy is required, selection of a suitable Single Lens Reflex type digital camera
- manufacture of a suitable cradle to mount off a tripod and tribrach to ensure camera centre is constant and position measurable at all stage of photograph stage
- sourcing of a high specification computer with a large amount of RAM and a good graphics card to expedite processing of images
- a more defined camera location process to ensure consistency with images taken and use of equipment
- manufacture of larger and more effective targets

ADAM Technology's software package, 3DM CalibCam and Analyst is accurate, robust and easy to use. Results compare favourably with laser scanning and conventional survey techniques. Use of expensive hardware is not required unless a high degree of accuracy is needed. Use of the 3DM software package would be extremely useful at Millmerran for applications such as blast profiling for dozer push, highwall coal seam mapping and waste dump mapping.

11.0 ACKNOWLEDGEMENTS

Steve McAtee, Jason Birch and Kevin Ha at Adam Technologies for their product training and support.
Mark Perquin and Brendan Davies for assistance and advice.

12.0 REFERENCES

(In order of appearance)

3DM CalibCam User's Manual

3DM Analyst User's Manual

www.dpreview.com

Pascoe, N. 2004. 3DM CalibCam 2.2 Alpha 8 & Analyst 2.2 Alpha 4 Basic Users manual. December 2004.

Jason Birch, 2005. Personal Communication, 27 January.

Ronaszeki, J. 2004. Abridged report on field test of new safe highwall mapping technologies for BMA, Goonyella mine 10 march 2004 (BMA Internal Report)

Steven McAtee, 2004. Personal Communication, 22-24 November.

Jason Birch, 2004 Personal Communication, 2-3 December.

Adam Technology, 2005. Laser Scanning vs. Digital Photogrammetry.pdf, Adam Technology, February 2005

13.0 APPENDIXES

Appendix A: Initial Trial Planning

Canon EOS 10D

Object Distance Calculation Spreadsheet

Camera Name: Canon EOS-10D

Camera Details	Width		Height	
Number of pixels:	3072	x	2048	
Image sensor dimensions:	22.7	x	15.1	mm
Actual focal length of lens x adapter:	28	mm		
Equivalent 35mm camera focal length:	44	mm		
Size of each pixel in CCD array:	7.39	x	7.37	um

Image size:	6.3 megapixels	
Field of View Crop/Lens multiplier:	1.6 x 1.6	
	PW	PH
3DM Analyst camera calibration settings:	0.00739 x	0.00737

Required Conversion: Distance -> Pixel Size

Model Details		
Desired object distance:	130	m
Ground coverage of each Image:	105.4 x 70.1	m
Ground pixel size:	3.43 x 3.43	cm
Desired target size:	21	cm
Desired target + border size:	55	cm

Accuracy Estimates		
Estimated image accuracy:	1.0	pixels
Distance between camera stations:	42.2	m
Object distance/base ratio:	3.1 : 1	
Estimated plan accuracy:	3.4	cm
Estimated distance accuracy	10.6	cm
Estimated overall accuracy	11.6	cm

Area Details for Strip Planning				
Width and height of area:	200 x	31 m	Distance between camera stations:	42.2 m
Desired horizontal overlap:	60% =	63.2 m	Number of images per strip:	6
Desired vertical overlap:	20% =	14.0 m	Number of strips:	1
Captured images to used images ratio:	1 : 1		Total number of images:	6

Canon IXUS400

Object Distance Calculation Spreadsheet

Camera Name: Canon IXUS 400

Camera Details	Width		Height	
Number of pixels:	2272	x	1704	
Image sensor dimensions:	7.176	x	5.319	mm
Actual focal length of lens x adapter:	7.4	mm		
Equivalent 35mm camera focal length:	37	mm		
Size of each pixel in CCD array:	3.16	x	3.12	um

Image size:	3.9 megapixels	
Field of View Crop/Lens multiplier:	5.0 x 4.5	
	PW	PH
3DM Analyst camera calibration settings:	0.00316 x	0.00312

Required Conversion: Distance -> Pixel Size

Model Details		
Desired object distance:	130	m
Ground coverage of each Image:	126.1 x 93.4	m
Ground pixel size:	5.55 x 5.55	cm
Desired target size:	33	cm
Desired target + border size:	89	cm

Accuracy Estimates		
Estimated image accuracy:	1.0	pixels
Distance between camera stations:	50.4	m
Object distance/base ratio:	2.6 : 1	
Estimated plan accuracy:	5.5	cm
Estimated distance accuracy	14.3	cm
Estimated overall accuracy	16.3	cm

Area Details for Strip Planning				
Width and height of area:	200 x	31 m	Distance between camera stations:	50.4 m
Desired horizontal overlap:	60% =	75.6 m	Number of images per strip:	5
Desired vertical overlap:	20% =	18.7 m	Number of strips:	1
Captured images to used images ratio:	1 : 1		Total number of images:	5

Sony DSC-P100

Object Distance Calculation Spreadsheet

Camera Name: Sony DSC-P100

Camera Details	Width		Height	
Number of pixels:	2594	x	1944	
Image sensor dimensions:	7.176	x	5.319	mm
Actual focal length of lens x adapter:	7.9	mm		
Equivalent 35mm camera focal length:	40	mm		
Size of each pixel in CCD array:	2.77	x	2.74	um

Image size:	5.0 megapixels			
Field of View Crop/Lens multiplier:	5.0	x	4.5	
	PW		PH	
3DM Analyst camera calibration settings:	0.00277	x	0.00274	

Required Conversion: Distance -> Pixel Size

Model Details				
Desired object distance:	130			m
Ground coverage of each Image:	118.1	x	87.5	m
Ground pixel size:	4.55	x	4.55	cm
Desired target size:	27			cm
Desired target + border size:	73			cm

Accuracy Estimates		
Estimated image accuracy:	1.0	pixels
Distance between camera stations:	47.2	m
Object distance/base ratio:	2.8 : 1	
Estimated plan accuracy:	4.6	cm
Estimated distance accuracy	12.5	cm
Estimated overall accuracy	14.1	cm

Area Details for Strip Planning						
Width and height of area:	200	x	31 m	Distance between camera stations:	47.2 m
Desired horizontal overlap:	60%	=	70.9 m	Number of images per strip:	6
Desired vertical overlap:	20%	=	17.5 m	Number of strips:	1
Captured images to used images ratio:	1	:	1	Total number of images:	6

Canon Powershot A70

Object Distance Calculation Spreadsheet

Camera Name: Canon Powershot A70

Camera Details	Width		Height	
Number of pixels:	2048	x	1536	
Image sensor dimensions:	5.371	x	4.035	mm
Actual focal length of lens x adapter:	5.8	mm		
Equivalent 35mm camera focal length:	39	mm		
Size of each pixel in CCD array:	2.62	x	2.63	um

Image size:	3.1 megapixels			
Field of View Crop/Lens multiplier:	6.7	x	5.9	
	PW		PH	
3DM Analyst camera calibration settings:	0.00262	x	0.00263	

Required Conversion: Distance -> Pixel Size

Model Details				
Desired object distance:	130			m
Ground coverage of each Image:	120.4	x	90.4	m
Ground pixel size:	5.88	x	5.88	cm
Desired target size:	35			cm
Desired target + border size:	94			cm

Accuracy Estimates		
Estimated image accuracy:	1.0	pixels
Distance between camera stations:	48.2	m
Object distance/base ratio:	2.7 : 1	
Estimated plan accuracy:	5.9	cm
Estimated distance accuracy	15.9	cm
Estimated overall accuracy	17.9	cm

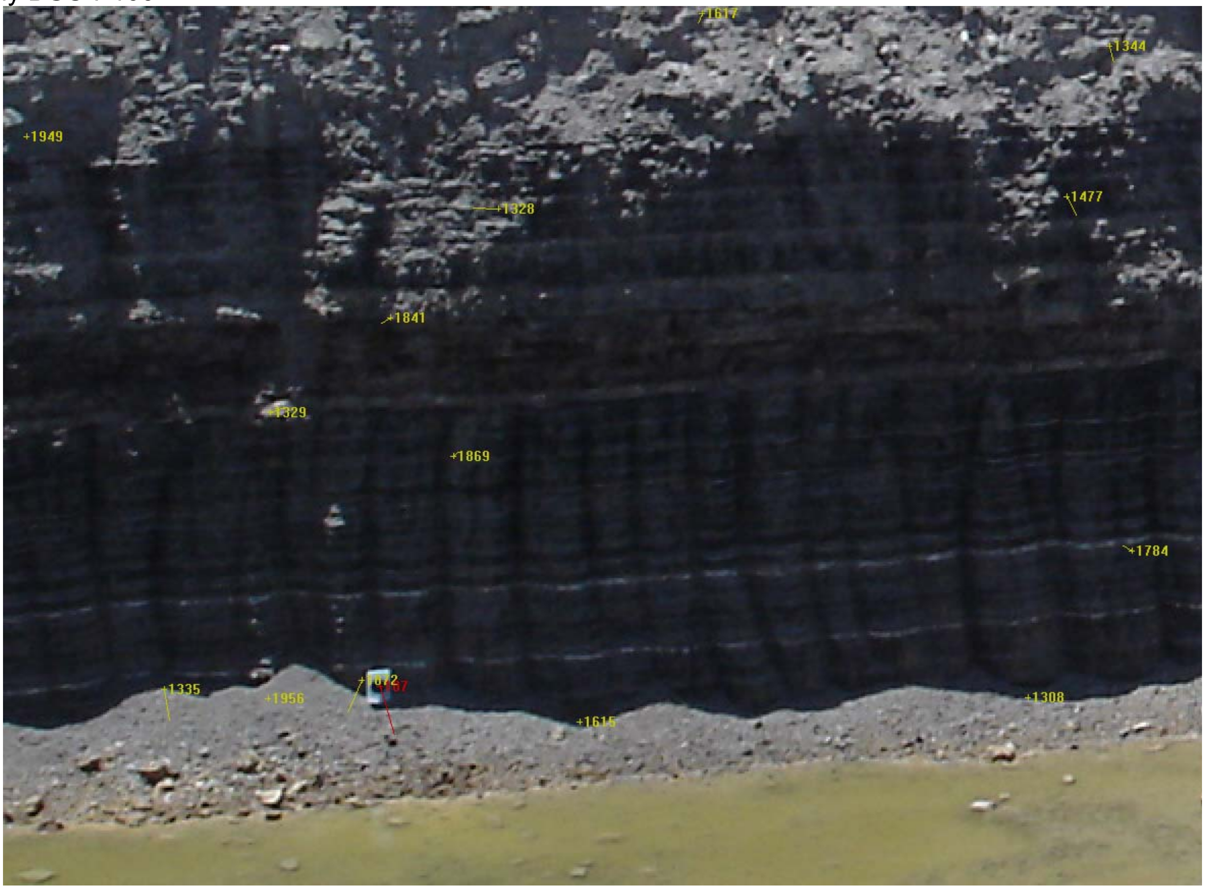
Area Details for Strip Planning					
Width and height of area:	200	x	31 m	Distance between camera stations:	48.2 m
Desired horizontal overlap:	60%	=	72.2 m	Number of images per strip:	6
Desired vertical overlap:	20%	=	18.1 m	Number of strips:	1
Captured images to used images ratio:	1	:	1	Total number of images:	6

Appendix B: 1x Zoom Image Clarity Screenshots

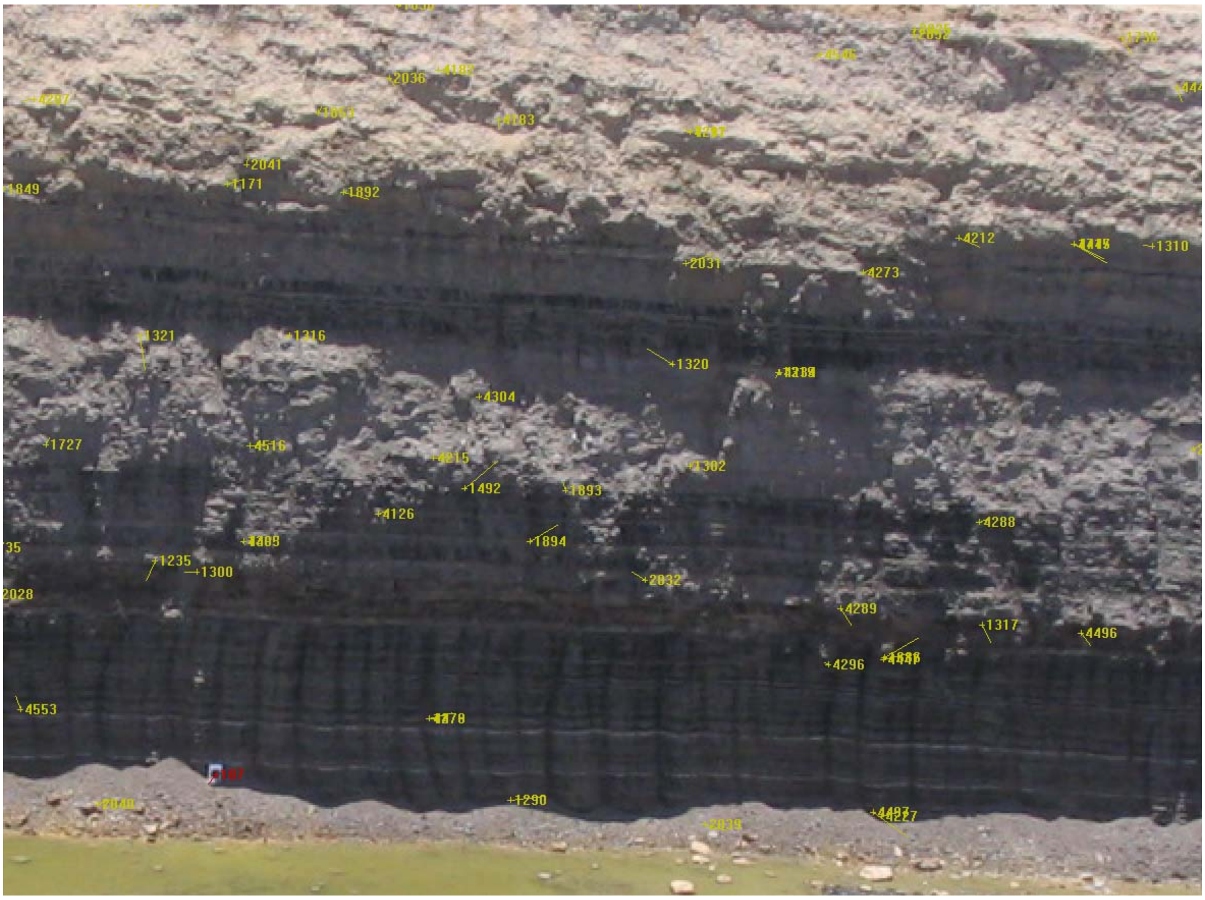
Canon EOS 10D

Canon IXUS400

Sony DSC-P100



Canon Powershot A70



Appendix C: 2x Zoom Image Clarity Screenshots

Canon EOS 10D

Canon IXUS400

Sony DSC-P1000

Canon Powershot A70

Appendix D: Stockpile Model Planning

Object Distance Calculation Spreadsheet

Camera Name: Canon Powershot A70

Camera Details	Width		Height	
Number of pixels:	2048	x	1536	
Image sensor dimensions:	5.371	x	4.035	mm
Actual focal length of lens x adapter:	5.8	mm		
Equivalent 35mm camera focal length:	39	mm		
Size of each pixel in CCD array:	2.62	x	2.63	um

Image size:	3.1 megapixels	
Field of View Crop/Lens multiplier:	6.7 x 5.9	
	PW	PH
3DM Analyst camera calibration settings:	0.00262 x	0.00263

Required Conversion: Distance -> Pixel Size

Model Details					Accuracy Estimates		
Desired object distance:	55			m	Estimated image accuracy:	1.0	pixels
Ground coverage of each Image:	50.9	x	38.3	m	Distance between camera stations:	20.4	m
Ground pixel size:	2.49	x	2.49	cm	Object distance/base ratio:	2.7 : 1	
Desired target size:	15			cm	Estimated plan accuracy:	2.5	cm
Desired target + border size:	40			cm	Estimated distance accuracy	6.7	cm
					Estimated overall accuracy	7.6	cm

Area Details for Strip Planning						
Width and height of area:	100	x	8	m	Distance between camera stations:	20.4 m
Desired horizontal overlap:	60%	=	30.6	m	Number of images per strip:	6
Desired vertical overlap:	20%	=	7.7	m	Number of strips:	1
Captured images to used images ratio:	1	:	1		Total number of images:	6

Appendix E: Pre-Blast Model Planning

Object Distance Calculation Spreadsheet

Camera Name: Canon Powershot A70

Camera Details	Width		Height	
Number of pixels:	2048	x	1536	
Image sensor dimensions:	5.371	x	4.035	mm
Actual focal length of lens x adapter:	5.8	mm		
Equivalent 35mm camera focal length:	39	mm		
Size of each pixel in CCD array:	2.62	x	2.63	um

Image size:	3.1 megapixels	
Field of View Crop/Lens multiplier:	6.7 x 5.9	
	PW	PH
3DM Analyst camera calibration settings:	0.00262 x	0.00263

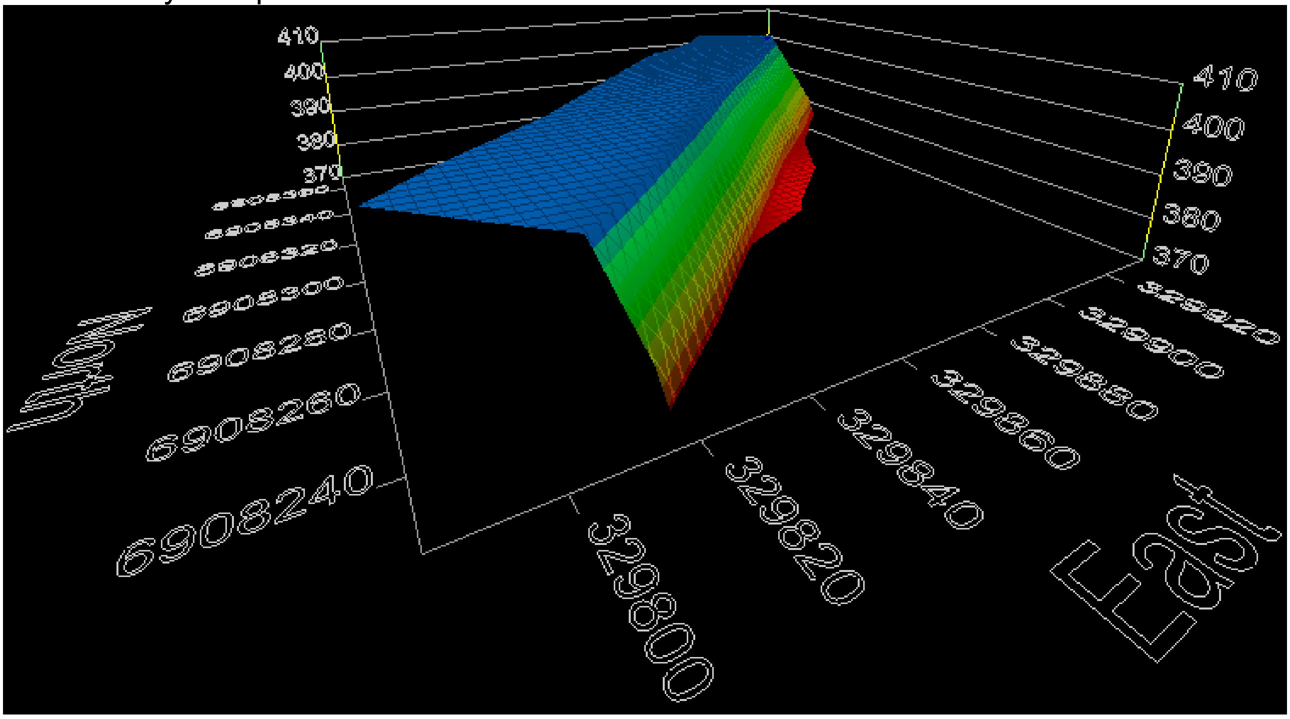
Required Conversion: Distance -> Pixel Size

Model Details					Accuracy Estimates		
Desired object distance:	195			m	Estimated image accuracy:	1.0	pixels
Ground coverage of each Image:	180.6	x	135.7	m	Distance between camera stations:	72.2	m
Ground pixel size:	8.82	x	8.82	cm	Object distance/base ratio:	2.7 : 1	
Desired target size:	53			cm	Estimated plan accuracy:	8.8	cm
Desired target + border size:	141			cm	Estimated distance accuracy	23.8	cm
					Estimated overall accuracy	26.9	cm

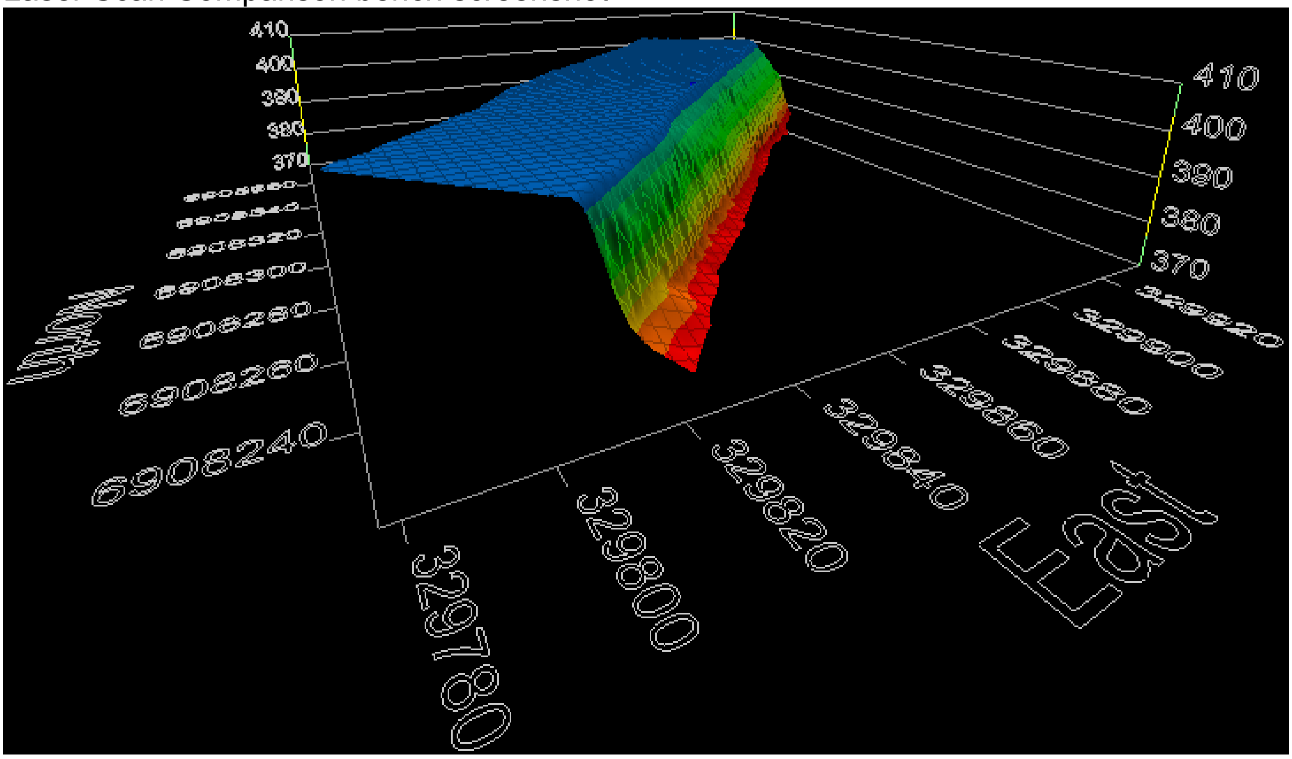
Area Details for Strip Planning						
Width and height of area:	300	x	31	m	Distance between camera stations:	72.2 m
Desired horizontal overlap:	60%	=	108.3	m	Number of images per strip:	6
Desired vertical overlap:	20%	=	27.1	m	Number of strips:	1
Captured images to used images ratio:	1	:	1		Total number of images:	6

Appendix E: Pre-blast Output Screenshots

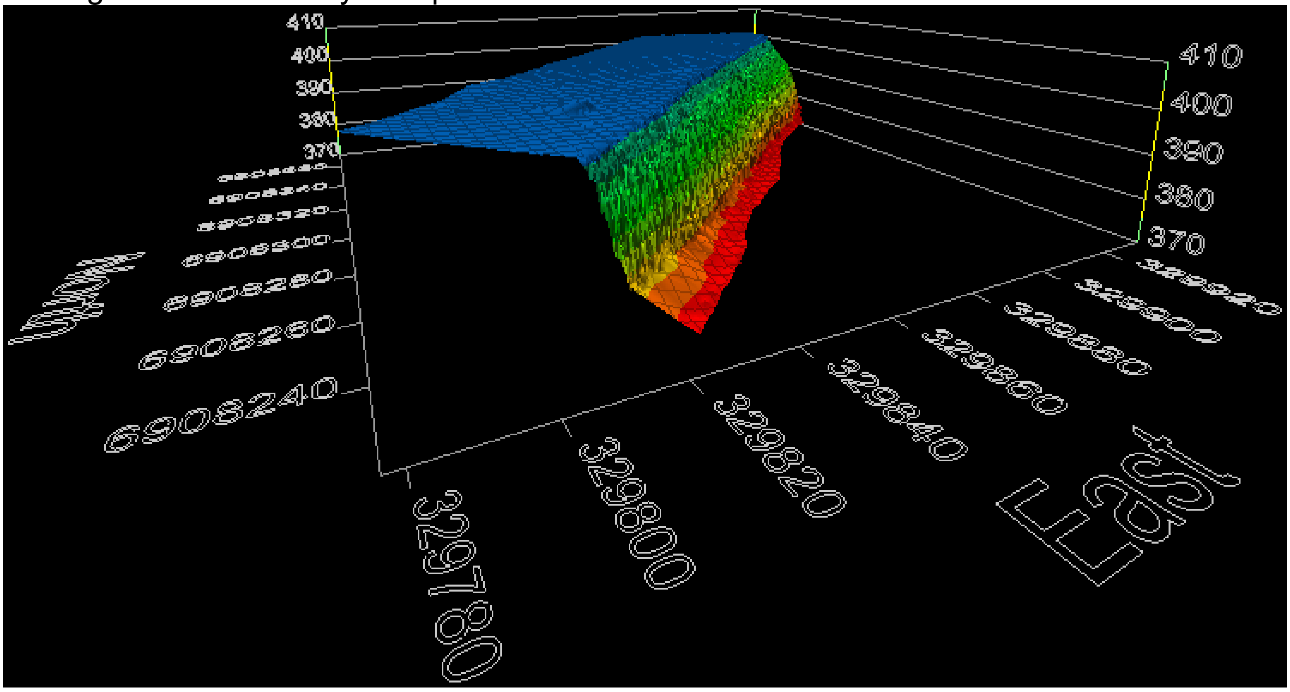
GPS Survey Comparison bench screenshot



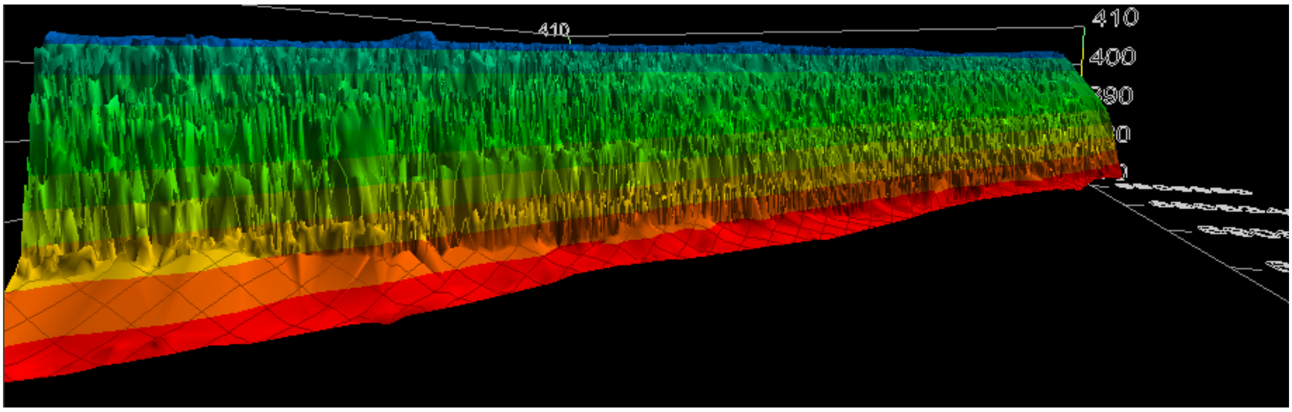
Laser Scan Comparison bench screenshot



Photogrammetric Survey Comparison bench Screenshot



Photogrammetric Survey face texture close-up



Appendix F: Risk Assessment

Risk	Consequence	Rating	Probability	Control	Commentary
Technical Factors					
Accuracy Issues	Incorrect data	High/Med	Medium	Test thoroughly	
Capability shortfall	Can not complete the required jobs	Med	Low	Test thoroughly	
				Find third party evaluations	
				Read product literature	
				Communicate with Adam Technology	
Excessive time	Take too much time of personal	High	High	Test thoroughly	
	Require additional personal	Med	High	Evaluate	
	Ineffective data	High	Medium	Evaluate	
Excessive cost	Not value producing for Roche	N/A	Low	Not in scope of assessment	
	Requires additional equipment, personal	High	High	Evaluate to determine actual requirements	
	More effective method not considered	Low	Medium	Compare with GPS survey and laser	
Hazards					
Heights	Fall from highwall	High	Medium	Maintain rill on highwall crest	
				Work with assistant	
				Maintain distance from edge	
				Consult OCE to locate danger areas	
Falling debris	Injuries from falling rock under highwall	High	Medium	Use spotter when working under highwall	
				Wear PPE	
Slips, trips, falls	Limb damage	Low	High	Take care on uneven terrain	
Equipment damage	Damage to GPS, camera etc	Medium	Medium	Take care on uneven terrain	
				Work with assistant	
Heat exhaustion	Heat exhaustion	High	High	Carry water	
				Ensure adequate sun protection	
	Fatigue	Medium		Carry water	
				Take breaks	
	Dehydration	High	High	Carry water	
				Take breaks	
				Wear cooling clothing	