University of Southern Queensland

Faculty of Engineering and Surveying

Bathymetric Survey of Flooded Open Cast Mine Workings

A dissertation submitted by

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ABSTRACT

This dissertation analyses bathymetric surveying techniques and applies them to the mining industry as traditionally this area of speciality was isolated to estuaries, lakes and oceans.

As an open cast mine reaches its economic limit many companies are deciding to leave a void up against the final high wall which subsequently fills up with water and deposited material. Sedimentation and deposited material build up in flooded open cast mine workings and is not being accounted for in the future mine plan and cost modelling phase of these areas. To understand this anomaly of additional overburden removal and pumping requirements, a bathymetric sounding survey is required so that overburden and coal extraction productivity rates can be more accurately determined.

Bathymetry data can be collected using a wide variety of sensors including: lead lines, single beam and multi beam acoustic depth sounders, as well as airborne laser sensors, but are usually collected as a series of cross section lines. Bathymetric techniques will be analysed to determine whether inexpensive bathymetric equipment coupled with Real Time Kinematic (RTK) Global Positioning System (GPS) technology can provide a high level of precision, accuracy and what effect different transect and point spacing have on the accuracy of the volumes of deposited material. Only lead line, single and multi beam acoustic techniques will be considered due to the remoteness and cost constraints for this project.

A low cost digital single beam echo sounding system unit coupled with RTK GPS for positioning and navigation, temporarily installed in an over – the - side configuration on a small fibreglass boat, was employed for this project along with recommendations with respect to the logistical suitability of this method and its ability to achieve desired accuracy and precision.

This research project validated that RTK GPS coupled with inexpensive digital bathymetric sounding equipment may be utilised effectively, is a viable solution to this problem and has identified possible further research.

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TABLE OF CONTENTS

Contents **Page**

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

NOMENCLATURE, ACRONYMS AND ABBREVIATIONS

The following abbreviations have been used throughout the text and bibliography:-

BCM	Bulk Cubic Metre
CEE	Ceeducer Pro Raw Data File
CPR	Ceeducer Pro Processed File
DGPS	Differential Global Positioning System
DTM	Digital Terrain Model
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
LOM	Life of Mine
RL	Reduced Level
RPM	Revolutions Per Minute
RTK	Real Time Kinematic
TSC1	Trimble Survey Controller 1
UTM	Universal Transverse Mercator
WGS84	World Geodetic Spheroid of 1984

CHAPTER 1

INTRODUCTION

"Understanding the hydrologic characteristics and how those characteristics have changed over time is essential for the effective management of valuable resources." (Sebree, 2003).

1.1 Introduction

The above statement suggests the need for further research into resource management and recovery. As mining reserves dwindle and become more costly to mine, alternative solutions for resource recovery are necessary.

Traditionally, bathymetric surveying techniques were isolated to estuaries, lakes and oceans, not the mining industry. As an open cast mine reaches its economic limit, which is usually determined in tender/bid phase or from the Life of Mine (LOM) design, many companies are deciding to leave a void up against the final high wall, so that future mining can occur once the economic climate improves. Over time this void subsequently fills up with water and deposited material.

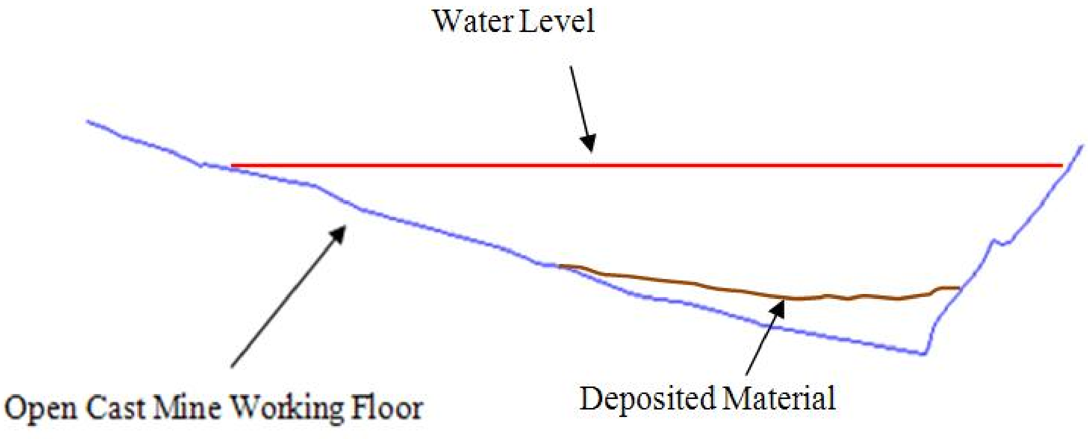

Figure 1.1 *Deposited Material in Flooded Open Cast Mine Workings*

Accordingly, bathymetric techniques will be analysed to determine whether inexpensive bathymetric equipment coupled with RTK GPS technology can provide a high level of repeatable accuracy to provide a volume of this deposited material. This will allow greater scope for future bathymetry surveys in comparison to more expensive techniques for achieving the same repeatable accuracies. The purpose and scope of this study is detailed in Section 1.3: Research Aim and Objectives.

1.1.1 Satui Mining Operation

In June 2000, Thiess Indonesia secured the long term mining operational contract for the Satui coal mine located in South East Kalimantan Indonesia with client PT Arutmin. In 2003, the alliance was extended for the LOM where Thiess Indonesia is the sole contractor responsible for mine operation with total mining services that include, mine planning, clearing of pre-mining vegetation, final rehabilitation of disturbed areas, topsoil stripping, overburden removal, coal preparation, crushing, transportation and loading onto a barge. The barges are towed down river to a major port facility, unloaded onto large ocean going vessels, bound for China.

The mining operations are segregated into three mining areas (Appendix B); Bukit, Kintap and Mulia with current onsite annual coal production of 9 million tonnes per annum from 70 million Bulk Cubic Metre (BCM) of overburden removal. The mining areas of Bukit and Kintap cover a bituminous coal formation across 35km of strike with the southern area of Mulia in sub-bituminous coal formations. The total work force is over 2,359 employees, which includes administration, mining operations and maintenance personnel, with a further 494 subcontract personnel also engaged on site.

1.2 Justification

Satui mine has been operating since the early 1980's and as a result there are several old open cast mining areas across their large mining lease as shown in Appendix B. A large number of these mining areas have not been rehabilitated. As the coal commodity price increases, these old mining areas become re-economical to mine.

Sedimentation and deposited material build up in flooded open cast mine workings, (as shown in Figure 1.1), over time and is currently not being accounted for in the future mine plan and cost modelling phase. To understand this anomaly of additional overburden removal and pumping requirements, a bathymetric sounding survey is required so that overburden and coal extraction productivity rates can be more accurately determined.

1.3 Research Aim and Objectives

The aim of this research is to conduct a bathymetric survey of a flooded open cast mine workings at Satui mining operation. The objectives are to determine, recommend and prepare the following:

a. Conduct a comprehensive literature review to determine whether RTK GPS technology coupled with bathymetric equipment may be utilised effectively;
b. Determine if inexpensive bathymetric equipment can achieve a high level of repeatable accuracy;
c. Determine what effect different transect and point spacing have on the accuracy of the deposited material volumes;
d. Make recommendations with respect to the suitability of this method and its ability to achieve desired accuracy and precision; and
e. Prepare a dissertation to a suitable standard.

See Appendix A for Project Specification.

1.4 Conclusions: Chapter 1

This dissertation aims to design and validate the use of bathymetric surveying techniques at Satui mining operation to estimate the quantity of deposited material in flooded open cast mine workings to an accuracy that will allow decisions to be made about the viability of re-mining.

This research project is expected to result in the validation that RTK GPS coupled with inexpensive digital bathymetric sounding equipment is viable solution to this problem and to identify solutions and alternatives that have been tried and proven for similar applications researched in detail in Chapter 2: Literature Review.

CHAPTER 2

LITERATURE REVIEW

“Knowledge is of two kinds: We know a subject ourselves, or we know where we can find information about it.” Samuel Johnson (1709-1784).

“Acquire new knowledge whilst thinking over the old, and you may become a teacher of others.” Confucius (BC551-BC479).

2.1 Introduction

The above statements suggest that a comprehensive literature review is necessary to increase ones knowledge and the knowledge of others.

This chapter will review literature to establish parameters and proven practice for bathymetric RTK GPS single beam surveys with the outcome laying the foundation for the methodology design phase.

Without a comprehensive literature review, the discovery of literature sources would be incomplete by not allowing the project to critically review sources effectively and evaluate the topic. This ultimately has a flow on effect to the design phase when developing an approach to solving the problem.

The literature review will look at the history of bathymetric surveying, the data acquisition techniques and technology available today and the errors associated when selecting a suitable method.

2.2 Bathymetric Surveying

The pioneering expedition of HMS Challenger from United Kingdom’s Royal Navy 1872-1876 and later the United States Coast and Geodetic Survey Steamer ‘Blake’ laid the foundation for all future hydrographic surveys, as they were the first systematic bathymetric surveys conducted. Sigsbee (1880) reported that their innovative sounding techniques such as wire rope for sounding increased the operational life of sounding apparatus. The German ship *Meteor* (1920's) conducted the first echo sounding survey.

Bathymetry data is usually recorded as z point data, and can be used to generate depth contours (line and area vector data) as well as digital terrain models (DTM) (California Marine Habitat Task Force, 1999). Bathymetry determines the depth of water, bottom topography, heights and the location of fixed objects for survey and navigation purposes relative to sea level and/or a designated datum along transect line to produce a section. Sectioning consists in obtaining a record of the undulations of the ground surface along a particular line (Clarke, 1972).

When depth values are displayed on a chart or map it is usually as a contour or point height and may be either portrayed as a negative or positive number but should be generally understood to be a negative number.

2.3 Data Acquisition Techniques

Bathymetry data can be collected using a wide variety of sensors including: lead lines, single beam and multi beam acoustic depth sounders, as well as airborne laser sensors (California Marine Habitat Task Force, 1999), but usually collected as a series of cross section lines (Sebree, 2003). Only lead line, single and multi beam acoustic techniques will be considered due to the remoteness and cost constraints for this project.

2.3.1 Lead Line

Lead line techniques were used by early hydrographic teams and involved measuring depths using a hand held line, usually made of rope or lines with graduated depth markings with a lead weight attached at the end (Figure 2.1).

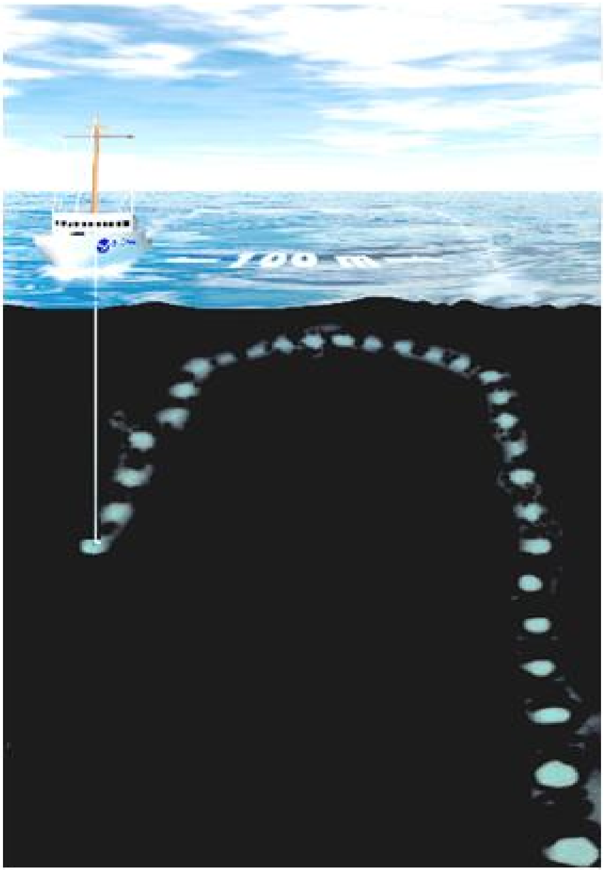

Figure 2.1 *Lead Line Data Density*

The weight of the line needed to measure great depths exceeded that of the end weight, making it difficult to tell when the weight hit the bottom (Gardner *et al.*, 2000).

A lead line sounding was usually taken from a slow moving vessel with positions determined by three point sextant fixes from mapped reference points. With the introduction of GPS satellite navigation in the 1990's the positioning of depth recordings can be improved (Dost, 2008).

Lead lines were labour intensive and a time consuming process. The soundings may have been accurate but they were limited in number. Sigsbee (1880) reported that coverage between the individual soundings were sparse.

2.3.2 Single Beam

Single beam acoustic depths are almost always derived by relating the speed of an acoustic pulse to the distance from the transmitter to a point below it on the lake, reservoir or ocean floor back to a receiver (Figure 2.2).

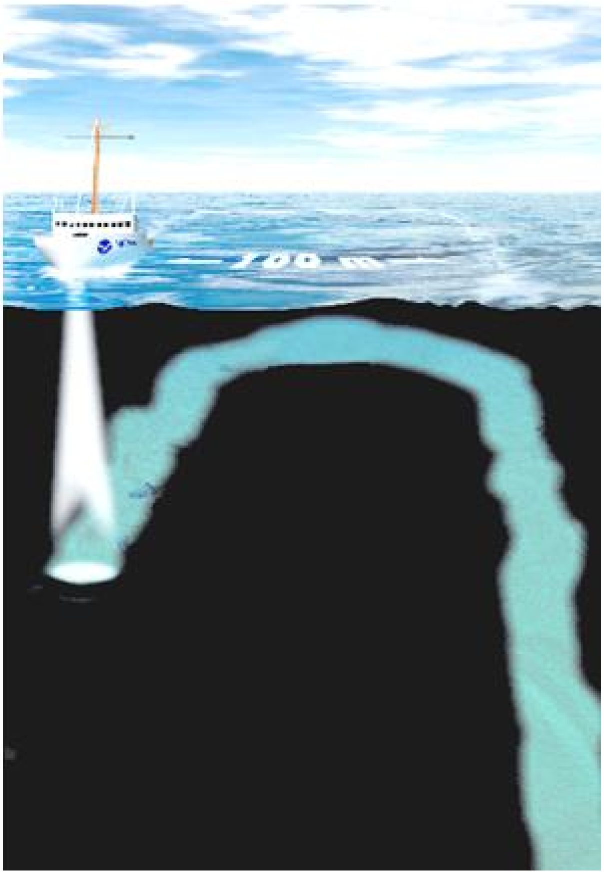

Figure 2.2 *Single Beam Data Density*

In its simplest form, a sound pulse is transmitted from the echo sounder (transducer) at the water surface, bounced off the underwater 'floor' and received back at the transducer (Gardner *et al.,* 2000). All that is required is an accurate value for the speed of sound through the intervening water column (California Marine Habitat Task Force, 1999).

This travel time is then converted to a depth based on a variety of estimations of the signal speed through the water column and may vary based on salinity and temperature. The error in the measurement of the soundings is primarily due to inadequate sounder calibration and errors in recorded positions (Gibbings, 2004). Length of time depends on the depth of the water and the speed of sound through water, which is about 4,800 feet per second (Hughes & Taube, 2000), or approximately 1500 metres per second of time is commonly used.

The advantages of single beam acoustic depth sounders are that it is reliable; the equipment is of a relatively low cost and does not require highly skilled operators (Todd, 2006). One disadvantage of single beam acoustic depth sounders is the beam will spread outwards from the transmitter as the depth increases smoothing over possibly important bottom features. Todd (2006) mentions that vessel movement; roll, pitch and heave are not accounted for. Roll, pitch and heave will not pose an issue for the bathymetric survey of the flooded open cast mine workings as the water surface is not affected by tide and open water swell. However, movement in the boat might affect the trim, the pole upon which the GPS antenna and transducer are mounted so they remained plumbed to one another.

2.3.3 Multi Beam

Multi beam depth sounders, (Figure 2.3), acquire bathymetric soundings across a swath of seabed using a collection of acoustic beams, as opposed to a single beam, which ensonifies only the area directly below the transducer (California Marine Habitat Task Force, 1999).

Multi beam depth sounders are much more expensive than single beam systems and require operators to have specialised skills, but with this extra cost and skill level comes much greater spatial resolution and coverage. The number of beams and arc coverage of the transducer determines the swath width across which a multi beam sounder acquires depth measurements (California Marine Habitat Task Force, 1999). Todd (2006) mentions the coverage of the seafloor may not be 100% as this depends on the depth of the water.

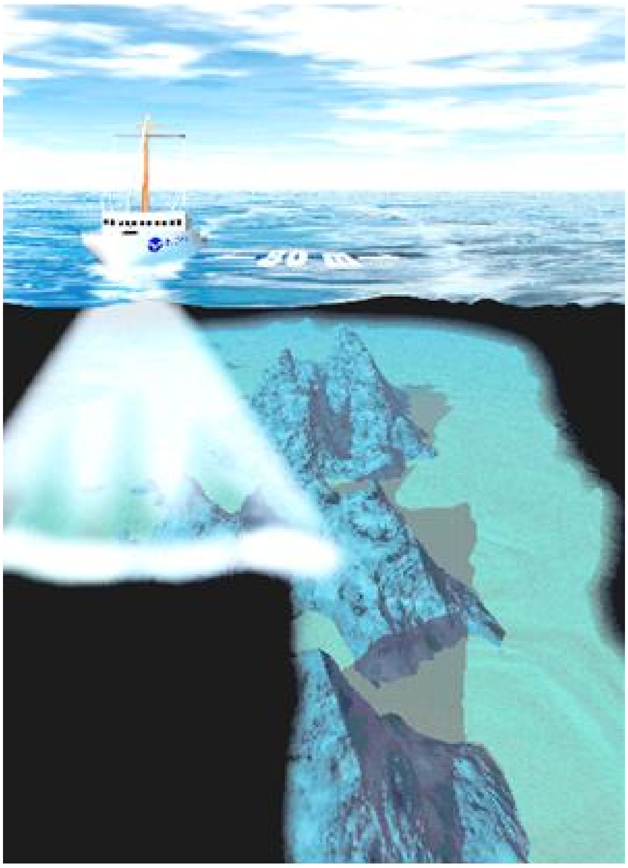

Figure 2.3 *Multi Beam Data Density*

Although acoustic methods are not theoretically limited to a given depth range (California Marine Habitat Task Force, 1999), specialized systems for beach and near-shore surveys specifically to allow access to areas that are not accessible by conventional boat-mounted survey equipment (Azimuth, 2007) can be used affectively in areas of shallow water.

2.4 Latency

Latency, with regard to RTK GPS observations, is not a new concept but needs clarification on how it will be managed during this bathymetric survey.

Latency is the delay between the time of fix and when it is available to the user (Raymond, 2005). If the GPS is in motion, the platform on which the measurements are being made will move some distance during the time when the measurement is made and the time when it is available to the user (Inglis, 2006). Latency can be separated into two components, internal latency and transmission latency, but for this project it will be treated as one.

Gibbings and O'Dempsey (2005) report that a time lag (latency) can be experienced between when a sensor record is measured and when it is recorded by the software. Similarly, latency may be experienced between when a GPS position is measured and when it is recorded. The update rate is therefore a function of the survey vessels speed. Latency of up to one or two seconds is not critical for GPS RTK positioning (Hu *et al*, 2002).

The error in the measurements of the soundings is primarily due to errors in the recorded positions (Gibbings, 2004). Without an adequate knowledge of this error, users of these systems cannot have sufficient confidence in the position solution they are obtaining (Inglis, 2006).

Latency error will be minimised if the survey vessel is motored at a slow consistent speed as Gibbings and O'Dempsey (2005) report that latency of 0.58 seconds equates to 0.7 metres when travelling at 1.2m/s in still water.

2.5 Method Selection

The methodology selection for the bathymetric survey at Satui mining operation will consider key aspects such as the remoteness of the open cast mine workings and availability of sounding equipment as this will impact on the scope and successful completion of this project operation.

GPS static surveying is the most cost effective way of establishing highly accurate primary survey control in remote areas. The accuracy of this type of survey can far exceed that of conventional survey techniques and has been adopted in establishing base station control.

A single beam, high and low frequency echo-sounder is the most reliable available equipment. The recent development of low cost depth sounders that can be linked with GPS technology has created the potential to use echo sounding as a viable method of mapping (Gibbings, 2004). Randall (2007) reports that compact digital echo sounders, rugged notebook computers and low-latency RTK GPS equipment has provided an opportunity to deploy a full single beam system in small light weight vessels. One of the limitations of using RTK GPS to establish the water level for any one sounding is that GPS positions are referenced to the ellipsoid rather than a local datum (Scarfe, 2002).

The type of positioning equipment used for bathymetric positions will impact on the scope/range of operation. The constraining nature of the inherent weakness of the radio link to maintain range with the RTK GPS will not impact on the survey as the base station will be setup close to the survey area. However, should large distances be a requirement, a Differential Global Positioning Systems (DGPS) would be a more suitable choice. From experience, RTK GPS surveys are the most cost effective way of collecting or establishing highly accurate survey positions in remote locations. Accuracies of one-centimetre horizontal and two-centimetre vertical can be achieved within seconds. This positioning technique is in real time allowing for rapid high accuracy data collection.

The transducer can be installed several different ways (Hughes & Taube, 2000). This, along with the cost of a survey vessel; purchased, leased or hired, will vary greatly and depend on size of vessel and outfitted installation; permanent or temporary. Mounting on the side of the boat is recommended for mapping (Hughes & Taube, 2000). Randall (2007) reports mounting the GPS antenna directly above the echo sounder transducer. Larger marine vessels are specifically designed and outfitted for hydrographic survey and mapping operations.

A competent bathymetric survey team, with a small survey launch outfitted with a single-beam sounder with an over the side transducer and RTK GPS will be an ideal time and cost efficient method to meeting the bathymetric requirements of bathymetric survey. A low cost digital single beam echo sounding unit coupled with RTK GPS temporary installed on a smaller boat is an ideal solution.

2.6 Conclusions: Chapter 2

All three data acquisition methods discussed lends themselves to a bathymetric survey of open cast mine workings.

Lead line observations, although accurate, aren’t in a digital format and are time consuming in the field and office. RTK GPS lends itself readily to synchronization with single beam and multi beam sounding equipment and the automation of data collection and processing.

Multi beam surveying is a much more complex and expensive undertaking relative to single beam (California Marine Habitat Task Force, 1999). Currently this technique is unattainable to low budget bathymetric surveys. However, the continuous advancement of technology in bathymetric multi beam systems, will ensure they become more affordable in the future.

Accordingly, this project utilises the low cost Ceeducer Pro single beam echo sounding system coupled with RTK GPS for positioning and navigation temporarily installed, in an over the side configuration, on a small fibreglass boat. This is discussed further in the following Chapter 3: Methodology.

CHAPTER 3

METHODOLOGY

"If you can't explain it simply, you don't understand it well enough"

- Albert Einstein (1879-1955)

3.1 Introduction

The above statement suggests that all projects, no matter how big or small, follow a procedure of varying degree and the quality of the final product is usually determined by an unambiguous methodology.

This chapter aims to clearly define a methodological process for the bathymetric survey of the flooded open cast mine workings covering such areas as planning aspects, equipment requirements, and calibration of instruments, safety issues and the final bathymetric observations.

This bathymetric survey will accurately map the topography of the underwater open cast mine workings floor. The sounding survey will follow parallel transect lines perpendicular to the longitudinal axis of the open cast mine workings at 10 metre centres. A single sounding line will be run along the length of the pit as close as possible to each of the two banks with an additional sounding line being run along the centreline of the pit to provide redundancies.

To reduce the impact of water quality and temperature variations the Ceeducer Pro digital echo sounder will be calibrated on site involving lowering a one metre by one metre metal plate to a known depth directly under the transducer. Echo soundings are recorded at the various depths. Any variation from the known distance will need to be accounted for during data reduction to obtain true distances. For example, the low frequency on average returned distances consistently longer than the known distance, a negative adjustment is necessary (see Figure 3.1).

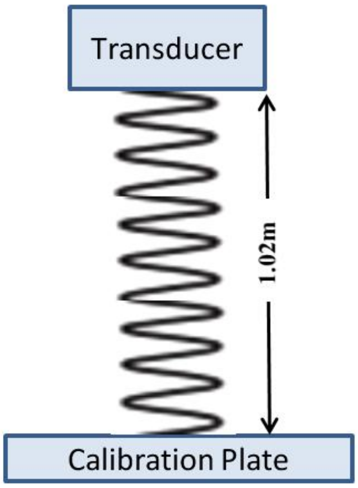

Figure 3.1 *Transducer Echo Sounding to Calibration Plate*

Once an accurate Digital Terrain Model (DTM) has been determined a volume can be calculated for the deposited material and water volume which will be represented in Chapter 4: Results and Data Analysis.

3.2 Planning

The planning phase will focus on the key critical path aspects of the bathymetric survey. Areas considered are; survey control, transect line spacing, software capabilities and mobilisation and de-mobilisation of the survey vessel, a four to five metre fibre glass boat.

3.2.1 Survey Control

All surveys, either conventional, GPS or bathymetric, must relate measurements to an established datum. The Universal Transverse Mercator (UTM) projection is widely used throughout the world as an international standard for surveying, mapping and navigation (University of Southern Queensland, 2008). Utilising a UTM a scale factor is required otherwise the deposited volumes will be incorrect. This hasn’t been taken into account as a few 100m3 here or there is considered insignificant due to the size of the machinery removing the deposited material.

An accurate survey control network exists in the area of the bathymetric survey established in the early stages of mining in zone UTM 50 South utilising the WGS84 ellipse with the locations shown in Figure 3.2. Reference ellipsoid: WGS84; Semi-major axis (metres) – a: 6378137.000; Inverse flattening – 1/Flattening: 298.257223563.

In order to reduce the impact of errors, the control stations will have a rapid topographical shot taken on them once the base station for the RTK GPS bathymetric survey has been set up on PLR 02 (see Appendix C for a complete coordinate listing). This will instil confidence by providing an immediate check on whether the control network has been disturbed. Therefore, if this control network is within allowable tolerances the survey can continue.

By conducting the bathymetric survey within the control network (see Figure 3.2) the old survey analogue of ‘working from the whole to the part’ and therefore are following good survey practice.

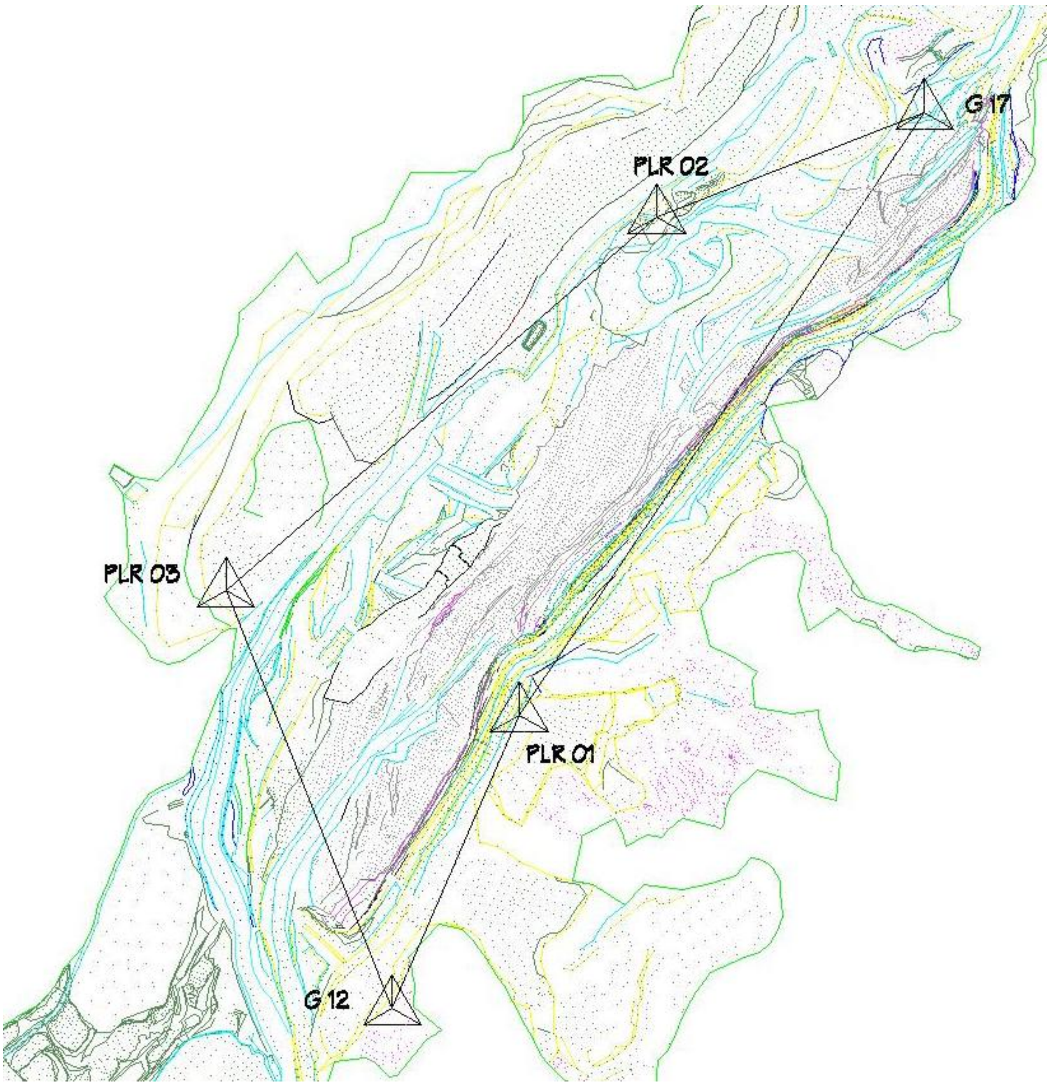

Figure 3.2 *Survey Control Network*

3.2.2 Transect Lines

The sounding survey will follow predetermined parallel transect lines perpendicular to the longitudinal axis of the open cast mine workings at 10 metre centres, Figure 3.3. The overall length is 1.5km by approximately 200metres. The transect lines will be reduced in density to 20 metre and 40 metre spacing. Sample density will also be reduced in density, from 5 metre spacing to 10 metre and 20 metre respectively.

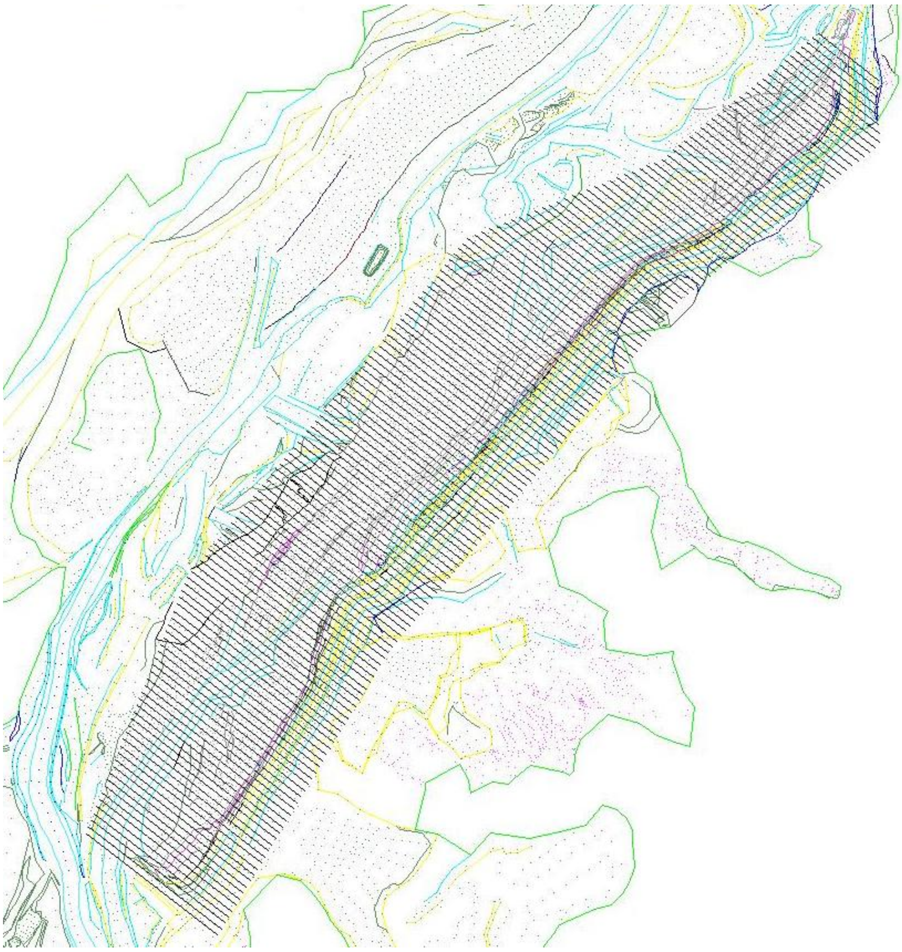

Figure 3.3 *Transect Line Spacing at 10 metre Intervals*

3.2.3 Software

Digital echo soundings are recorded directly into the Ceeducer Pro. CEEDUC2 program is used to convert the original binary files from Ceeducer Pro equipment to CEE and CPR files. CEE is the raw unprocessed data file. CPR processed data file. CEEDATA is used to download the original binary files from Ceeducer Pro equipment to notebook.

Terramodel digital elevation modelling software will be utilised for volume calculations and DTM visual displays.

3.3 Equipment

Equipment availability, reliability and compatibility are vital for this bathymetric survey of the flooded open cast mine workings due to the remoteness of the mining area. RTK GPS, digital echo sounder and survey vessel will be addressed.

3.3.1 Real Time Kinematic Global Positioning System

Positioning will be determined by a Trimble 4700 base (Figure 3.4) and RTK GPS instrument with Trimble Survey Controller 1 (TSC1) controller and ancillary equipment, which is integrated into the digital sounding system. Position data is collected at the rate of one RTK GPS corrected position fix every two seconds (depth data at the rate of six soundings per second and) and displays it in real time on a laptop computer, via priority software. The onboard computer display is also used to navigate the survey vessel along the predetermined transect lines.

Figure 3.4 *Trimble 4700 Base Station*

To mitigate latency affects, the survey vessel will be motored at a slow consistent speed in the order of 2 to 3 knots (1.03 to 1.54m/s). Latency error of up to one or two seconds is not critical for RTK GPS positioning as discovered in Chapter 2: Literature Review.

3.3.2 Digital Echo Sounder

A highly portable integrated hydrographic system with dual frequency echo sounder will be adopted and assumed that it will achieve the desired repeatability and precision. The Ceeducer Pro digital echo sounder is reliable with its single and dual frequency echo sounding capabilities (Figure 3.5).

Figure 3.5 *Ceeducer Pro Portable Echo Sounder*

The transducer technology of the Ceeducer Pro system uses low noise transducer integrated circuitry to provide fully automatic sounding from 0.32m to 99.9m (200kHz) and 0.75m to 99.9m (30kHz), (see Appendix D). The Ceeducer Pro digital echo sounder collects and logs depth and position data in digital form (depth data at the rate of six soundings per second and position data at the rate of one RTK GPS corrected position fix every two seconds) and displays it in real time on a Dell M4300 notebook portable computer, via priority software.

This project will adopt a dual frequency data observation output, being high (200Khz) and low (30Khz) respectively. The low frequency penetrates through the soft mud to the hard bottom, while the high frequency will only penetrate to the soft mud surface. The differing penetration rates of the high and low frequency into the soft mud will be reported in Chapter 4: Results and Data Analysis.

The Ceeducer Pro has an inbuilt GPS, however, this function will be disabled for the purposes of this project as the Trimble 4700 RTK GPS will be coupled with the unit. This can be seen in CEE file (Appendix E).

3.3.3 Survey Vessel

An easy to manoeuvre, small light weight survey vessel, will be used for this bathymetric survey. A locally sourced small fibre glass boat, that would become the survey vessel named the *Sapu Lidi* will be mobilised 34km from the mining project port facility to the bathymetric survey area. It is approximately four to five metres in length with a front seat steering position and outboard motor configuration.

The Ceeducer Pro digital echo sounder with sit securely on the floor with the transducer mounted on a three inch pipe attached perpendicular to the direction of travel. Cable connections, power supply and instrument configuration is shown in Figure 3.6.

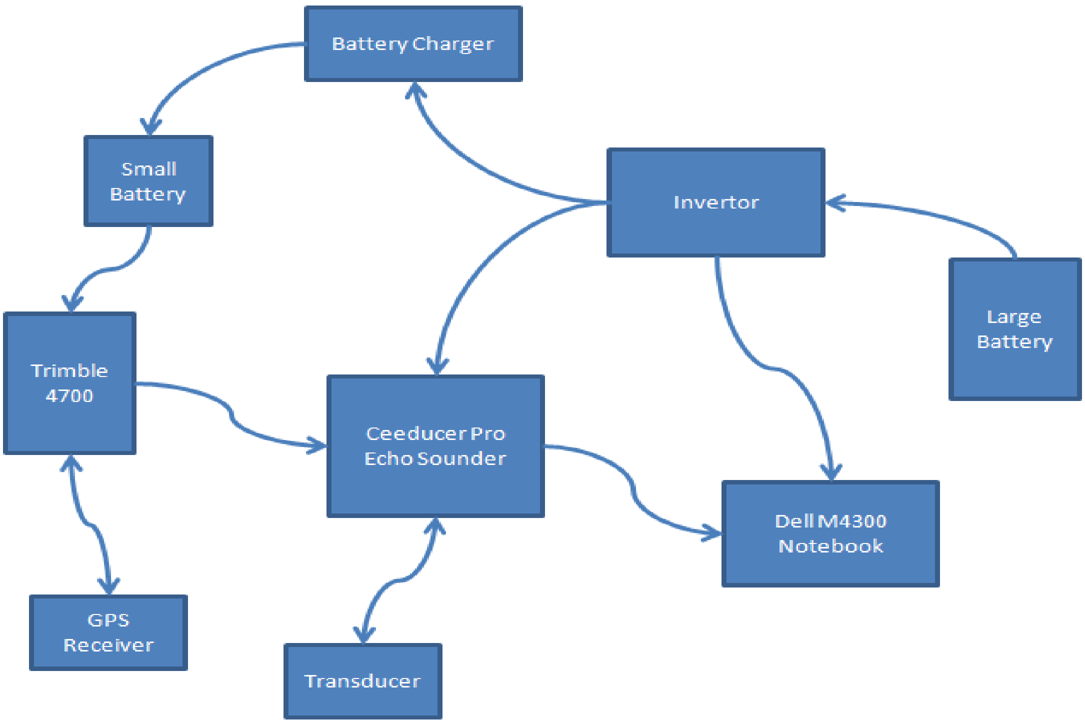

Figure 3.6 *Instrument Configurations Onboard the Survey Vessel*

A Dell M4300 notebook (laptop) will be used for navigation and backing up data. The digital echo soundings will be logged directly to the Ceeducer Pro unit with an adjustment from the surface of the transducer to the surface of the water.

3.3.4 Mobilisation and De-Mobilisation

An Iveco six tonne flat bed 4x4 truck with a 4.5m x 2.5m tray and a Palfinger pk10000, with lifting capacity of 590kg at 12.2m reach and 5700kg at 0m reach, crane attached to the tray will be used to mobilise and de-mobilise the *Sapu Lidi* from the mine project port facility to the bathymetric survey area and back again as shown below in Figure 3.7.

Figure 3.7 *Iveco Flat Bed Truck Lifting the Sapu Lidi to Waters Edge*

3.4 Field Survey and Observations

Prior to the commencement of the bathymetric survey the base station was established at PLR 02 and radio set to communicate with the dual frequency roving 4700 GPS receiver. To get initialised, RTK GPS requires a minimum of five satellites. After that it can operate with four satellites but with reduced precisions. Radio link must also be maintained at all times otherwise reduced precisions will occur or even loss of lock. Experience has proven that the expected accuracies for RTK GPS is a few centimetres in all x,y,z directions. A redundancy check and to confirm the base station is set up correctly, a second control station is checked upon to ensure correct positioning.

The RTK GPS rover will be then installed on the survey vessel in an over the side configuration. Once the survey vessel is carrying a full load, personnel, fuel and equipment measurements are made from the RTK GPS rover to the water with the mean distance entered into RTK GPS controller for antenna height. An additional distance is measured from the transducer to the water so that a transducer correction can be applied. This transducer is synchronised with the incoming data stream of RTK GPS data and once the correction is entered into the Ceeducer Pro on setup and appears in the raw data file. Once the raw data is downloaded it can be visually checked for errors. The over the side transducer configuration, which was checked for vertically prior to survey, is shown in Figure 3.8.

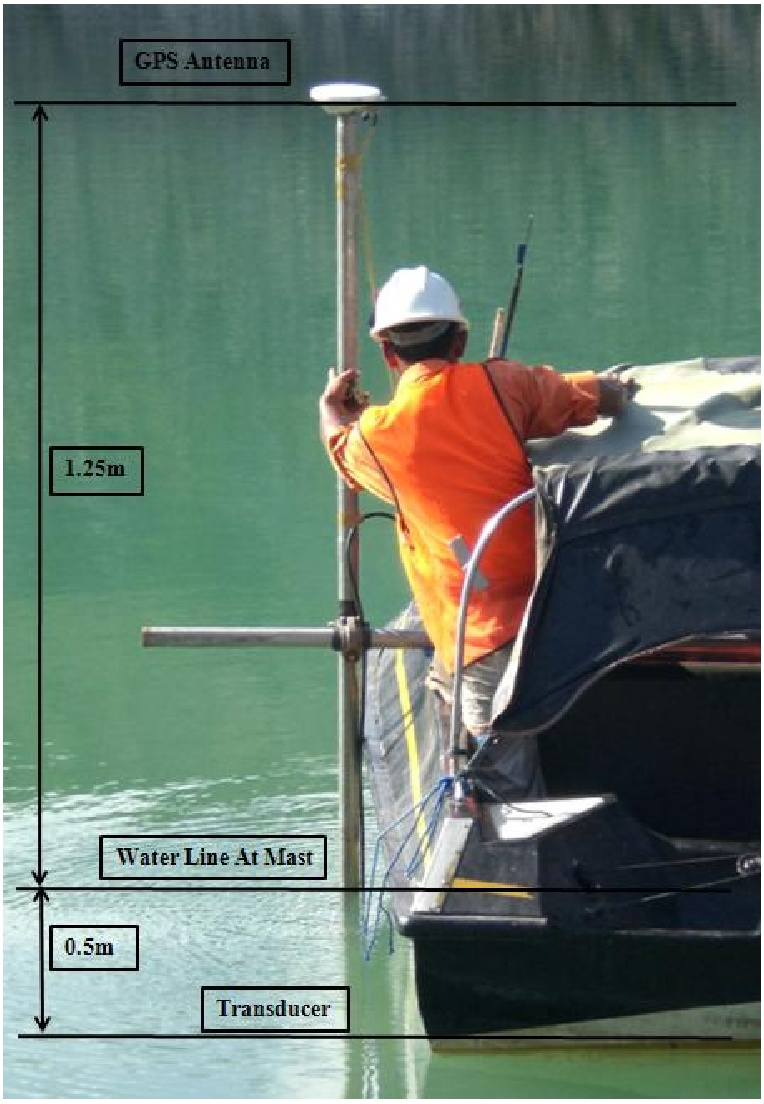

Figure 3.8 *Survey Vessel Sapu Lidi over the Side Transducer Configuration*

To check the positioning of the predetermined transect lines, uploaded previously, sighter pegs are placed on both sides of the bathymetric survey area. These are then navigated between using the notebook and Ceeduc2 software as shown in Figure 3.9. A single sounding line will be run along the length of the pit as close as possible to each of the two banks with the remaining are interpolated using pre and post floor surface. An additional sounding line will be run along the centreline of the pit to provide redundancy check on the echo soundings.

All data is recorded into the notebook with reduction conducted later by Ceeducer Pro software ready for import into Terramodel for DTM determination.

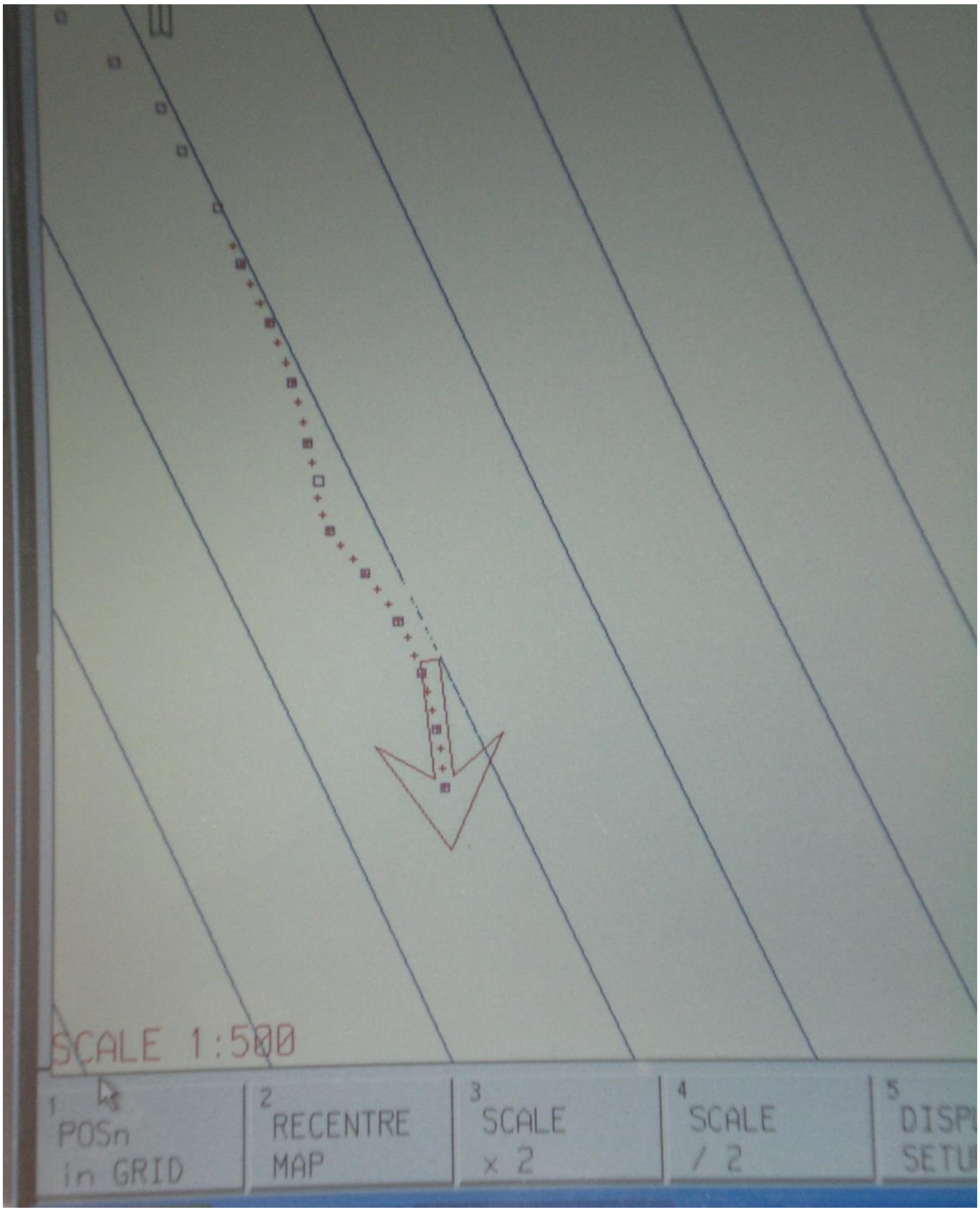

Figure 3.9 *Navigation Utilising Predetermined Transect Lines on Notebook*

3.4.1 Calibration

To reduce the impact of water quality and temperature variations the Ceeducer Pro digital echo sounder will be calibrated on site. This involves lowering a one metre by one metre metal calibration plate to known depths; 5m through to 20m directly under the transducer (Figure 3.10).

The error in the measurements of the soundings is primarily due to inadequate sounder calibration (Gibbings, 2004). If any significant or consistent errors are apparent a proportion or scale factor will be applied to high and low frequency soundings. This is done in excel and the adjusted values read into Terramodel in a csv file.

Figure 3.10 *Calibration Plate*

3.5 Conclusions: Chapter 3

The volume of deposited material and sampling point density difference on digital terrain model accuracy will be evaluated and analysed in Chapter 4: Results and Data Analysis.

The bathymetric survey will be carried out using the Ceeducer Digital Echo Sounder mounted on a small fibreglass boat four to five metres in length. All digital data will be processed using ‘Ceeducer’ bathymetric software and Terramodel digital elevation modelling software. Once the digital elevation model has been formed and edited, contours at any interval can be extracted and plotted at a desired scale. Appropriate conclusions will arise from systematic evaluation of the data collected as presented in the following Chapter 4: Results and Data Analysis.

CHAPTER 4

RESULTS AND DATA ANALYSIS

"There is no such thing as failure. There are only results." - Anthony Robbins (1960-)

4.1 Introduction

The above statement suggests that whatever are the results obtained from this projects methodology, they don't indicate failure, just a learning process to those that follow.

This chapter aims to report and conduct data analysis on the bathymetric survey data observed as outlined in Chapter 3: Methodology.

Data analysis of the calibration of the echo sounder, the high and low frequency echo soundings, the vertical accuracy of the RTK GPS, the digital terrain models and costs for removal of the deposited material will be reported upon within this chapter with further discussion in Chapter 5: Discussion and Recommendations.

4.2 Calibration

A standard 12mm nylon rope was used to lower the calibration plate to the various intervals of known depth so that echo soundings could be observed. A stretch component of the rope needed to be taken into account as the steel calibration plate had significant weight as wire rope was unavailable to attach to the calibration plate with results shown in Table 4.1.

Length (m)	Neutral Rope Length (m)	Under Own Weight Tension Rope Length (m)	Stretch Distance (m)
1	1.000	1.095	0.095
2	2.000	2.210	0.115
3	3.000	3.300	0.090
4	4.000	4.400	0.100
5	5.000	5.500	0.100
		Average	0.100

Table 4.1 *Rope Stretch Calibration Results*

This was conducted using the survey vessel in the same water body prior to the bathymetric survey. Distances were recorded from a 5 metre survey staff at 1m intervals tagged on the rope with cables ties. This enabled the stretch component of the rope used in the calibration to be understood, as shown in Table 4.2.

Depth (m)	Rope Stretch 100mm/m	Adjusted Distance (m)	High Frequency (m)	Difference (m)	Low Frequency (m)	Difference (m)	Difference Between Low & High Frequency (m)
5	0.50	5.50	5.48	-0.02	5.52	0.02	0.04
6	0.60	6.60	6.63	0.03	6.67	0.07	0.04
7	0.70	7.70	7.77	0.07	7.80	0.10	0.03
8	0.80	8.80	8.80	0.00	8.88	0.08	0.08
9	0.90	9.90	9.90	0.00	9.99	0.09	0.09
10	1.00	11.00	11.00	0.00	11.08	0.08	0.08
11	1.10	12.10	12.10	0.00	12.14	0.04	0.04
12	1.20	13.20	13.20	0.00	13.26	0.06	0.06
13	1.30	14.30	14.35	0.05	14.41	0.11	0.06
14	1.40	15.40	15.45	0.05	15.50	0.10	0.05
15	1.50	16.50	16.53	0.03	16.59	0.09	0.06
16	1.60	17.60	17.61	0.01	17.77	0.17	0.16
17	1.70	18.70	18.71	0.01	18.79	0.09	0.08
18	1.80	19.80	19.84	0.04	19.90	0.10	0.06
19	1.90	20.90	20.94	0.04	20.97	0.07	0.03
20	2.00	22.00	22.04	0.04	22.06	0.06	0.02
			Average	0.0219		0.0831	0.0612

Table 4.2 *Calibration Results at Known Depth Intervals*

The calibration results in Table 4.2 indicate that a 22mm adjustment is required to be applied to the high frequency an 83mm adjustment is required to be applied to the low frequency echo soundings for this bathymetric survey.

4.3 Echo Soundings

Bathymetric echo soundings, in both high and low frequency, were observed all in one day over two data files due to the large number of soundings recorded. The large number of soundings was required as the flooded open cast mine workings was approximately 1500m by 200m with a small sample of the data shown in Appendix F.

A single echo sounding run around the perimeter was initially completed. The assumption that a low frequency echo soundings would penetrate deeper into the soft deposited material than a corresponding high frequency echo sounding is adopted when analysing this data. The large amount of data collected during the bathymetric survey warranted the data file to be separated into two parts; data file one and data file two as described below.

4.3.1 Data File One

The total number of echo soundings recorded in the first data file in both high and low frequency was 125,256. If either a high and/or a low frequency echo sounding returned a zero value it was deemed to be corrupt with a small sample of the data shown in Appendix E. High frequency corrupt echo soundings totalled 2,621 (2.1%). Low frequency corrupt echo soundings totalled 947 (0.8%).

The total number of RTK GPS positions recorded in the first data file was 5,526. If either a high and/or a low frequency echo sounding returned a zero value either side and/or at the RTK GPS recorded position it was deemed corrupt. As such, 523 (9.5%) RTK GPS recorded positions fell into this category. The remaining 5,003 RTK GPS recorded positions were then categorised into either; low frequency with greater depth, 3,159 (63.1%), or high frequency with greater depth, 1,844 (36.9%).

4.3.2 Data File Two

The total number of echo soundings recorded in the second data file in both high and low frequency was 105,522. If either a high and/or a low frequency echo sounding returned a zero value it was deemed to be corrupt. High frequency corrupt echo soundings totalled 888 (0.9%). Low frequency corrupt echo soundings totalled 749 (0.7%).

The total number of RTK GPS positions recorded in the second data file was 4,411. If either a high and/or a low frequency echo sounding returned a zero value either side and/or at the RTK GPS recorded position it was deemed corrupt. As such, 143 (3.2%) RTK GPS recorded positions fell into this category. The remaining 4,268 RTK GPS recorded positions were then categorised into either; low frequency with greater depth 2,939 (68.9%) or high frequency with greater depth 1,329 (31.1%).

4.3.3 Combined Data Files

The total combined number of echo soundings recorded in both high and low frequency was 230,778. High frequency corrupt echo soundings totalled 3,509 (1.5%). Low frequency corrupt echo soundings totalled 1,696 (0.7%).

The total combined number of RTK GPS positions recorded was 9,937. Corrupt RTK GPS recorded positions totalled 666 (6.7%). The remaining 9,271 RTK GPS recorded positions were then categorised into either; low frequency with greater depth 6,098 (65.8%) or high frequency with greater depth 3,173 (34.2%).

4.4 Real Time Kinematic Global Positioning System

RTK GPS repeatability has been proven by past researchers and scientists (Gibbings *et al.*, 2005), leaving no doubt that RTK GPS is suitable for the position fixing of the echo soundings observation data and therefore was considered an ideal choice for this bathymetric survey, but there are some sources of error that need to be understood.

4.4.1 Vertical Accuracy

Once an RTK GPS fixed position is obtained there is still the horizontal and vertical precision tolerance 'built' into the overall solution and will vary depending upon the constellation of satellites in the solution. The vertical precision will be considered here.

The water level of still water, over a small area, will remain at a constant elevation and not be affected by the curvature of the earth is assumed when considering the vertical accuracy of the RTK GPS Reduced Level (RL) for the transducer. This is significant as the water level will be adopted as a datum that all echo soundings will be adjusted from.

The average number of satellites tracked over the bathymetric observations is 8.34. Microsoft Excel software, utilising the scatter graphing function, is used to produce Figure 4.1. For a non Global Navigation Satellite System (GNSS), this is considered a high number of satellites and is more than satisfactory in order to determine a high level of vertical accuracy.

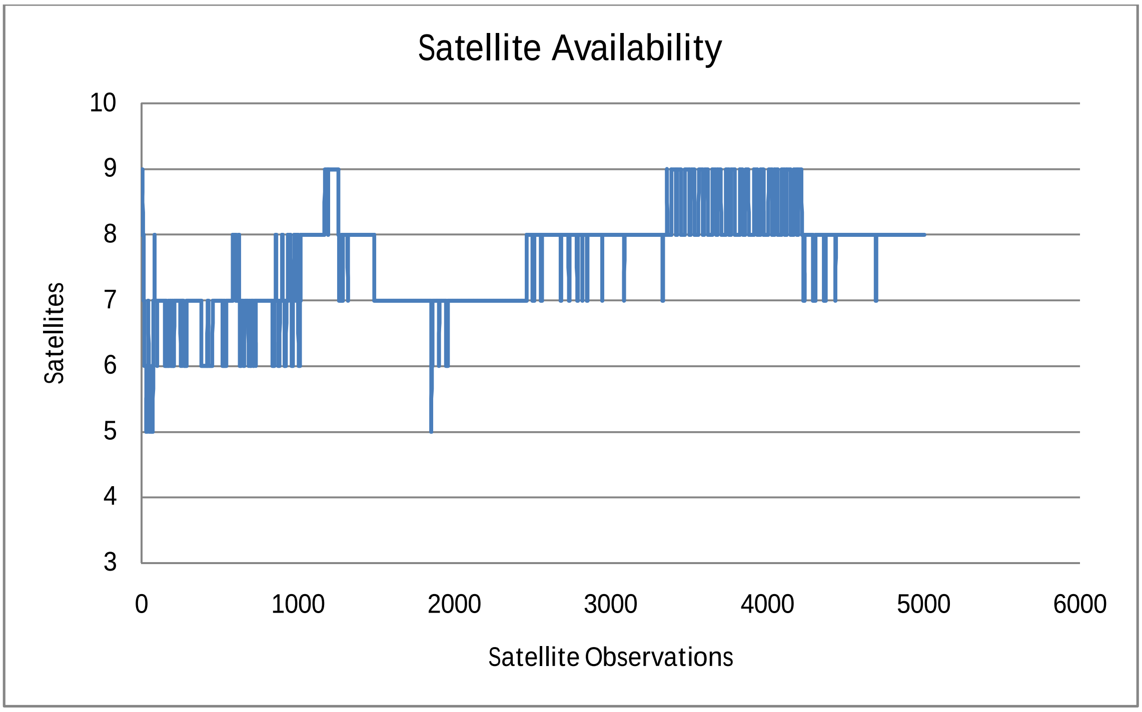

Figure 4.1 *Satellite Availability*

Considering the vertical tolerance 'built' into vertical RTK GPS position it would be expected that the RL of the water would vary slightly between recorded positions. This can be seen in the below in Appendix G.

The standard deviation of the vertical accuracy of measured water level against actual known water level of 10.65 metres can now be calculated for the data files with the average of both files shown in Table 4.3.

DATA FILE ONE		DATA FILE TWO	
GPS Average (m)	10.688	GPS Average (m)	10.691
Standard Deviation (m)	0.03103	Standard Deviation (m)	0.15648
Known Water Level (m)	10.650	Known Water Level (m)	10.650
Difference (m)	0.038	Difference (m)	0.041
		Average Difference (m)	0.0395

Table 4.3 *Water Level Comparison against RTK GPS (unit measurement is metres)*

In Figure 4.2 the RTK GPS vertical position is seen to plot above and below the known RL, water level. Microsoft Excel software, utilising the scatter graphing function, is used to produce these figures. With this in mind all high and low frequency depth measurements will be adjusted to adopt the known water level of 10.65. Possible further research is commented on in Chapter 5: Discussion and Recommendations.

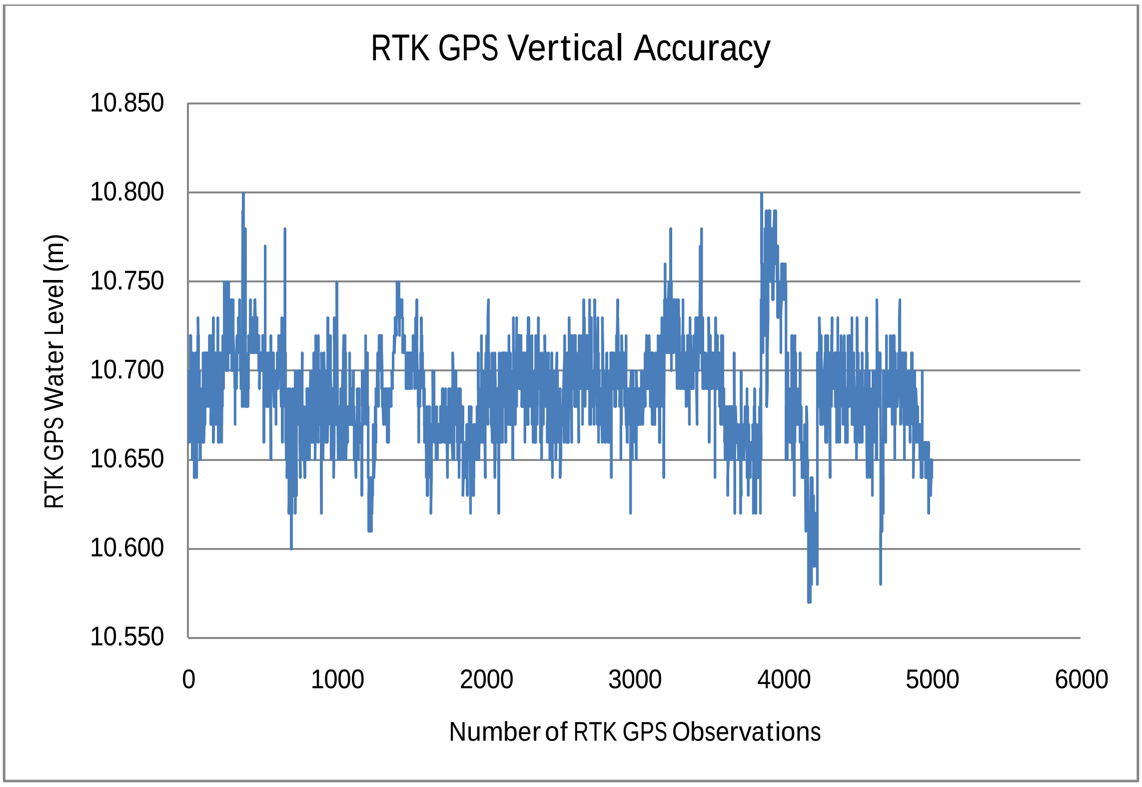

Figure 4.2 *RTK GPS Vertical Accuracy (unit measurement in metres)*

4.4.2 Latency

Latency needed to be minimised by the speed of the survey vessel kept at a slow consistent rate through the bathymetric survey. The average speed in knots is shown in Table 4.4.

DATA FILE ONE		DATA FILE TWO	
Average Speed (Knots)	4.148	Average Speed (Knots)	3.762
Standard Deviation	0.58512	Standard Deviation	0.81968
		Average Speed Over Both Data Files(Knots)	3.9552

Table 4.4 *Average Speed in Knots*

In Figure 4.3 the survey vessels speed in knots is represented in graphical form. Microsoft Excel software, utilising the scatter graphing function, is used to produce these figures.

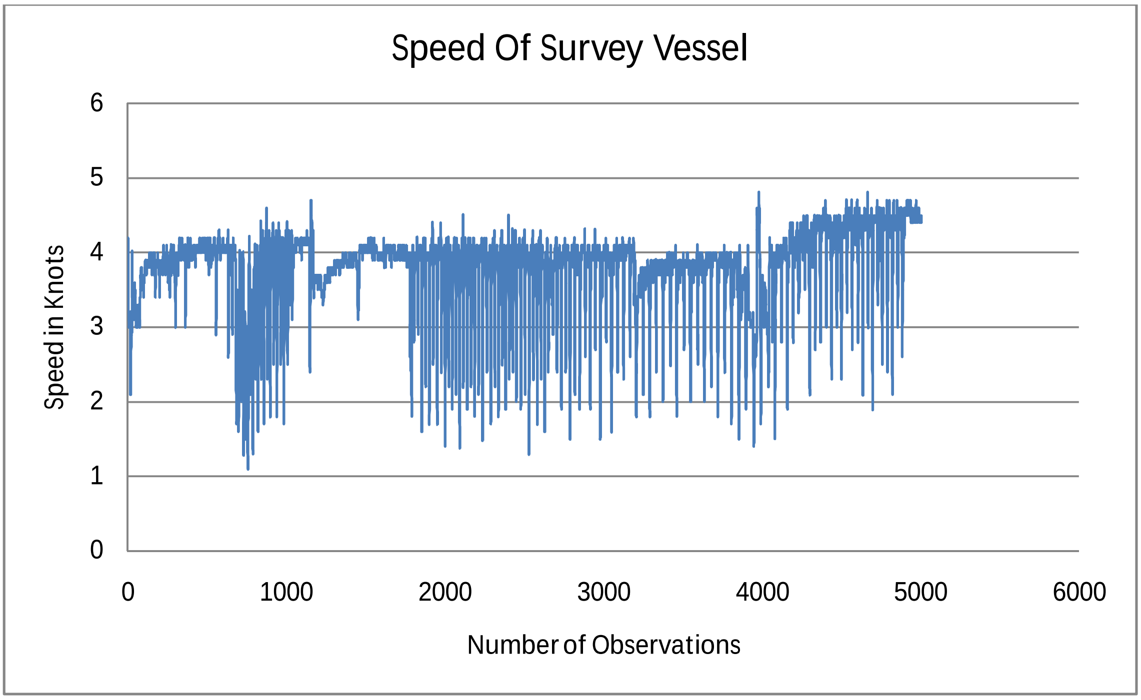

Figure 4.3 *Speed of Survey Vessel*

A conversion from knots to metres per seconds is necessary so a comparison can be made between previous researches into the acceptable range of latency.

The metrication of a survey vessels speed in knots to metres per second is illustrated in Table 4.5. Utilising this conversion table the average speed in metres per second over data file one and data file two can be calculated as 2.035 metres per second.

Speed (knots)	Metres/Second
1	0.51444
2	1.02889
3	1.54333
4	2.05778
5	2.57222
6	3.08666
7	3.60111
8	4.11555
9	4.63000
10	5.14444

Table 4.5 *Knots to Metres per Second Conversion Table*

In Chapter 2: Literature Review it was discovered that latency of up to one or two seconds is not critical for RTK GPS positioning and that latency of 0.58 seconds equates to 0.7 metres when travelling at 1.2m/s in still water. Since latency is not an aim or objective of this project, it merely needs to be understood. Therefore, it can be deduced that the latency for this survey is approximately 1 second and is not a critical source of error for the RTK GPS positioning of the echo soundings.

4.4.3 Echo Soundings

To ensure echo sounding data integrity, spikes and erroneous points were removed. An example of this is shown in a cross section as illustrated in Figure 5.1 in Chapter 5: Discussion and Recommendations. High frequency erroneous points totalled 54 and low frequency erroneous points totalled 35.

From section 3.2.2 Transect Lines it was suggested that the transect lines of 10 metre, 20 metre and 40 metre spacing with a filtered down point spacing of 5 metre, 10 metre and 20 metre would be adopted. The average speed for the bathymetric survey was 2.035 metres per second which will return an echo sounding point density of approximately 4 metres. Therefore, point spacing will be filtered down from 4 metres to 8 metres by deleting every second point in the data set and then 16 metre spacing by repeating the process. This process is repeated for 10, 20 and 40 metre transect lines. Once completed individual DTMs are generated for volumetric calculations to help determine what effect different transect and point spacing have on the accuracy of the deposited material volumes.

Figure 4.4 displays parallel transects of 10 metres with 4 metres point spacing and redundant echo sounding lines perpendicular to transect lines and some zig-zag lines.

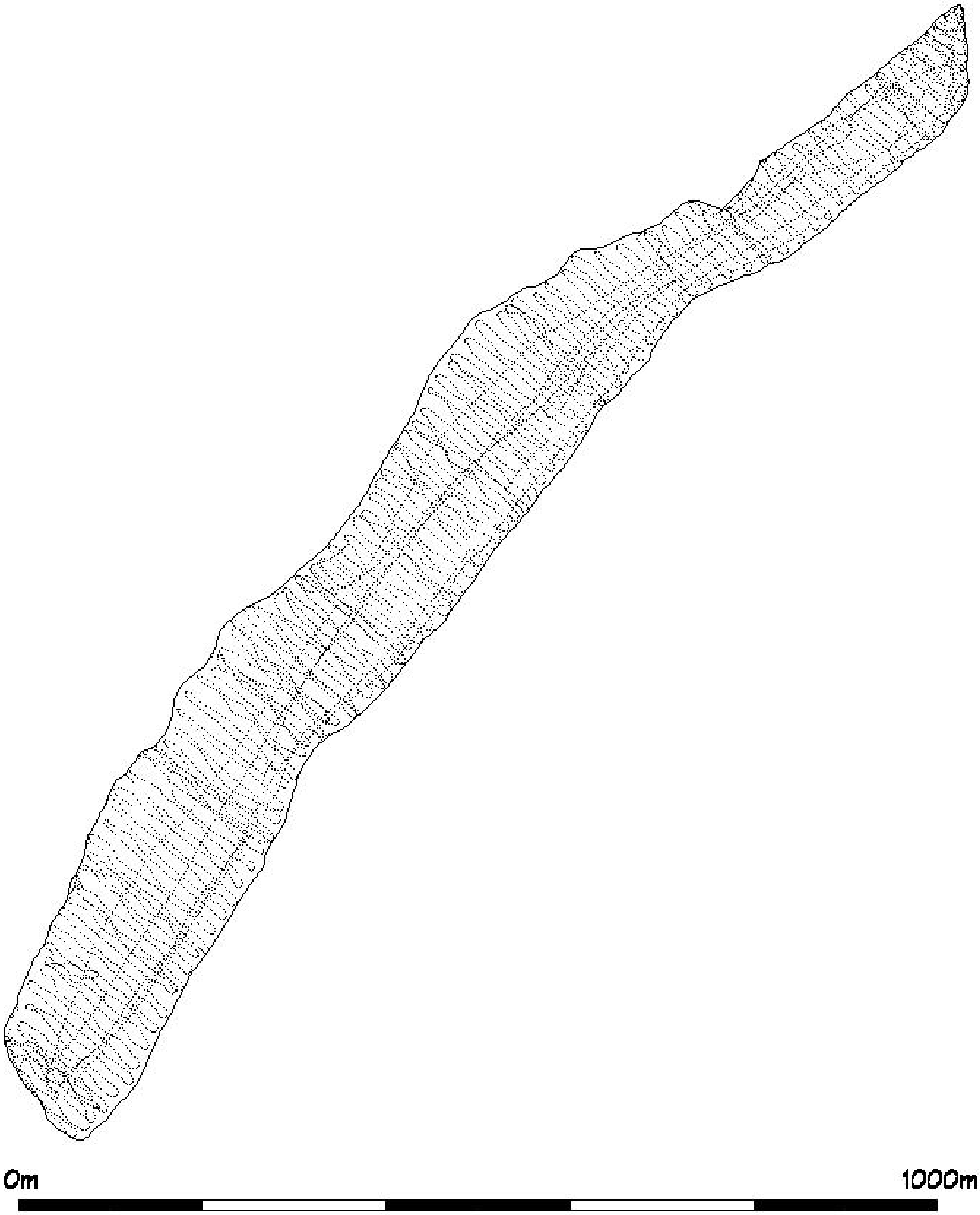

Figure 4.4 *Parallel Transect Lines 10m x 4m with Zig Zag Echo Soundings (units in metres).*

The redundant echo sounding lines perpendicular to the transect lines and the zig-zag lines are filtered out leaving 10 metre transect lines and 4 metre echo sounding spacing and is shown in Figure 4.5.

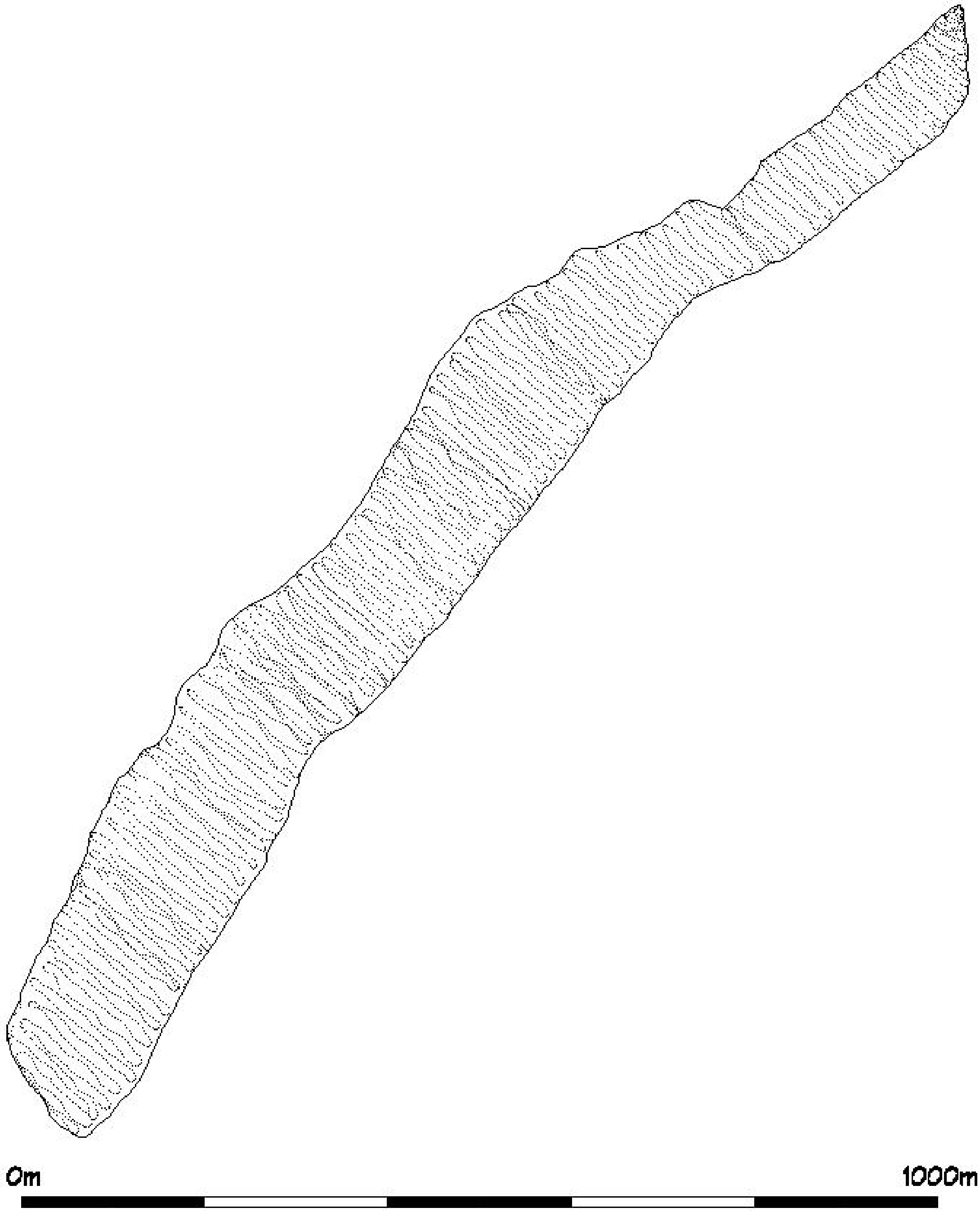

Figure 4.5 *Parallel Transect Lines 10m x 4m without Zig Zag Echo Soundings (units in metres).*

In Figure 4.6, 20 metre transect lines with a 4 metre echo sounding spacing is shown.

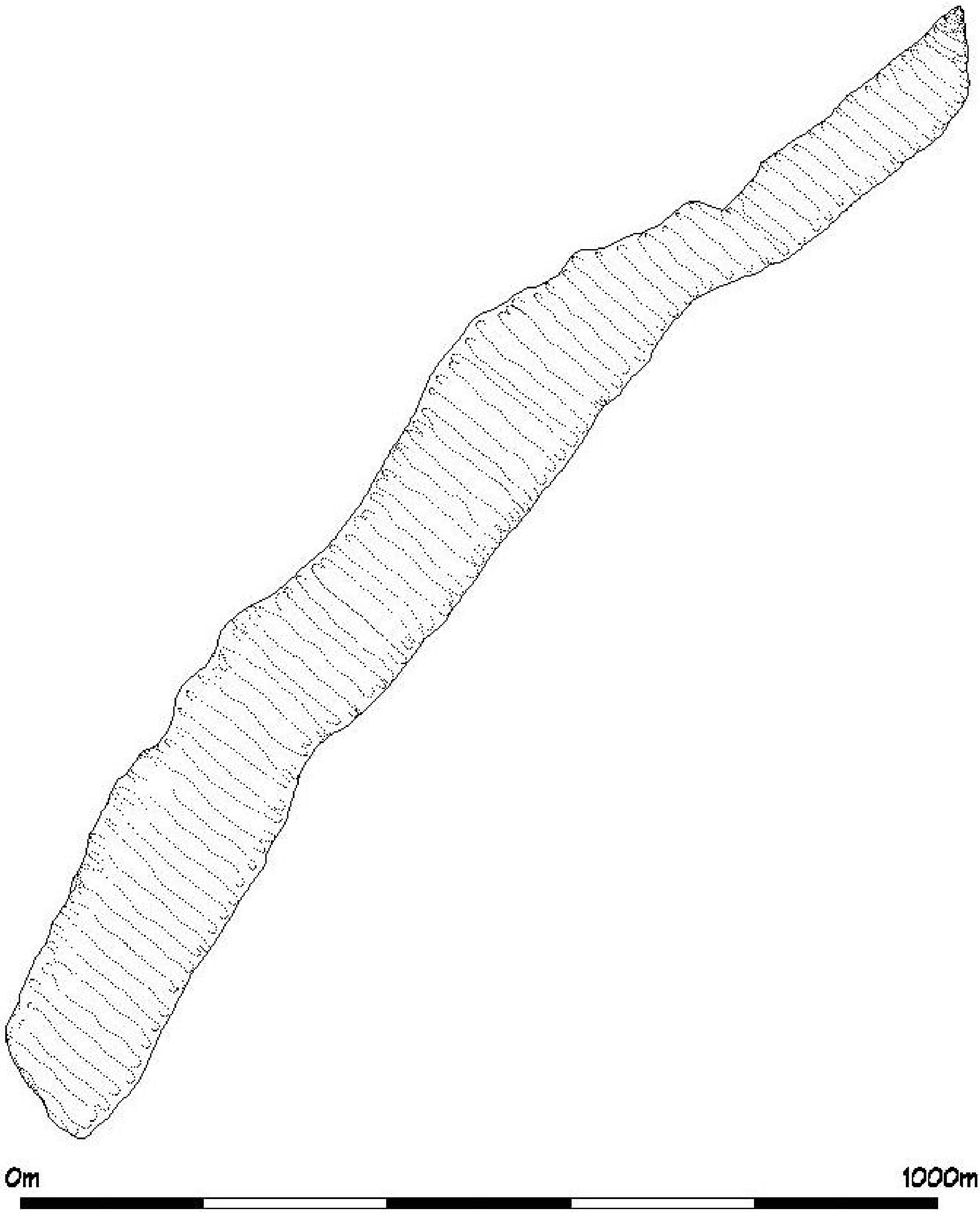

Figure 4.6 *Parallel Transect Lines 20m x 4m Echo Soundings (units in metres).*

Further to this, in Figure 4.7, 40 metre transect lines with a 4 metre echo sounding spacing is shown.

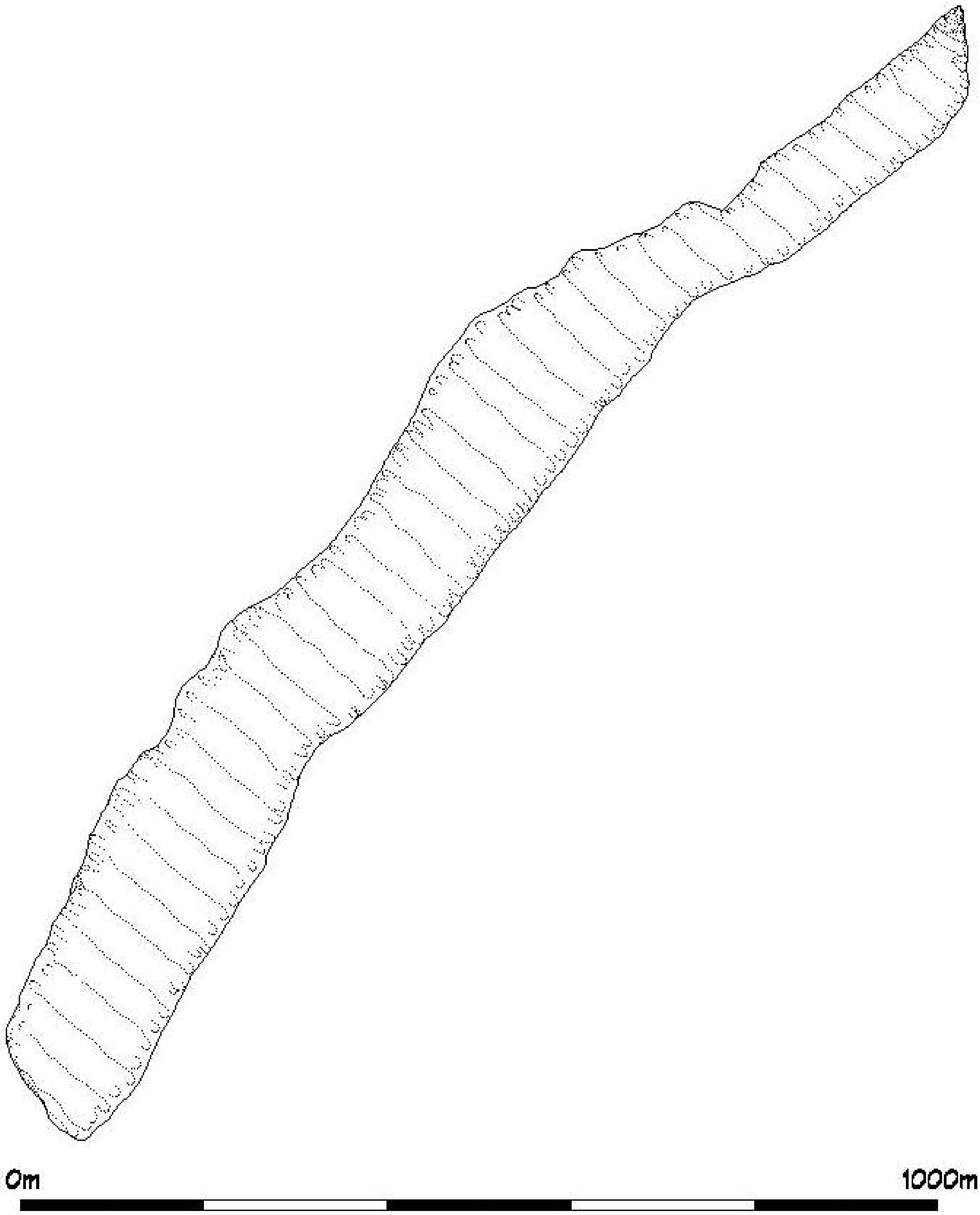

Figure 4.7 *Parallel Transect Lines 40m x 4m Echo Soundings (units in metres).*

Once the echo sounding data has been cleaned up the penetration rates of the high and low frequency into the mud can be analysed by generating a pair of DTM, one for the high frequency echo soundings and one for the low frequency echo soundings, for each transect spacing and differing point spacing.

4.5 Digital Terrain Models

A DTM is an ideal way to display and represent a three dimensional surface. Terramodel software has been utilised for all DTM generation (Figure 4.8), representation and volume calculations.

A surface is a DTM. The first and the second surface are defined by the following statements: ‘Where the second surface is above the first surface the volume is reported as fill’ and ‘Where the second surface is below the first surface the volume is reported as excavation’. The ‘Original Void’ is the surface, or DTM, that was left behind prior to the open cast mining area filling up with water. The ‘Low Frequency’ is the surface generated from the low frequency echo soundings. For example, the ‘Low Frequency 8 x 20’, is a surface generated from a point spacing of 8 metres and a transect line spacing of 20 metres. This also applies to the ‘High Frequency’ surface generated from the high frequency echo soundings.

Analysis of the transect line and point spacing, it is determined that eighteen DTMs are generated as shown in Table 4.6.

		Point Spacing (m)			
		4	8	16	
Transect Spacing (m)	10	2	2	2	DTMs Generated
	20	2	2	2	
	40	2	2	2	
			Sum	18	

Table 4.6 *DTM Generation Matrix*

In additional to this, two DTMs from the original data with the redundant perpendicular and zig-zag echo soundings will be utilised totalling twenty DTMs. These were adopted as the standard against which all the others were compared. The open cast mine workings floor, prior to filling up with water, was surveyed by conventional and was adopted as the base for all volumetric calculations.

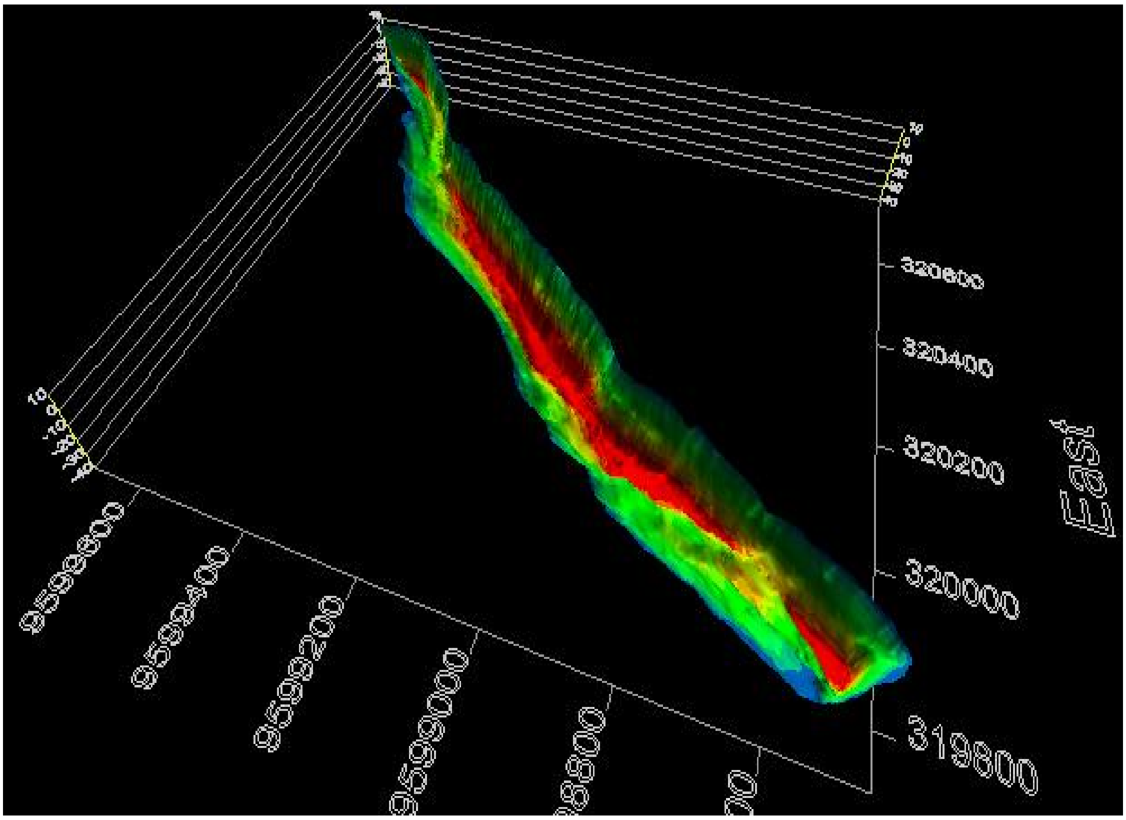

Figure 4.8 *Digital Terrain Model of the Flooded Open Cast Mine Floor (units in metres).*

4.5.1 Deposited Material Volume

The volume of deposited material is taken to be the average between the high and low frequency zig-zag echo sounding surveys at 690,769 m3.

The volume calculation is performed utilising the surface to surface earth work function in Terramodel. This process is repeated for each individual DTM. For example, where the first surface (the bottom surface) is the lower than the second surface (the top surface or deposited material layer), zero excavation will be reported. If they cross one another then excavation is reported.

The final calculated volumes of deposited material between the original void to the bathymetric surveyed surfaced, high and low frequency, with associated percentage differences is shown in Appendix H. See Appendix K for an example of the Terramodel DTM earth works report.

Decreasing the point sampling density and increasing transect line spacing considerably reduced the accuracy of the deposited material volume in both the high and the low frequency echo soundings.

A decrease in accuracy was expected, but Terramodel fitted planar surfaces between the measured points which are a source of error on its own as the open cast mining void is none linear surface. An under estimation of the volumes is typically what occurs. The low frequency results are shown in Table 4.7 and high frequency results shown in Table 4.8. No independent checks, such as lead line drops, were conducted.

First Surface	Second Surface	Fill (m3)	Area (m2)	Difference (%)	Difference (m2)
Original Void	Low Frequency	684,311	20	0.00%	0
Original Void	Low Frequency 4 x 10	680,995	40	0.49%	-3,316
Original Void	Low Frequency 4 x 20	684,950	80	-0.09%	639
Original Void	Low Frequency 4 x 40	746,397	160	-8.32%	62,085
Original Void	Low Frequency 8 x 10	689,924	80	-0.81%	5,613
Original Void	Low Frequency 8 x 20	689,593	160	-0.77%	5,282
Original Void	Low Frequency 8 x 40	753,281	320	-9.16%	68,970
Original Void	Low Frequency 16 x 10	708,925	160	-3.47%	24,614
Original Void	Low Frequency 16 x 20	712,935	320	-4.01%	28,624
Original Void	Low Frequency 16 x 40	761,545	640	-10.14%	77,233

Table 4.7 *Low Frequency Point Density Area Error*

The low frequency echo soundings from Table 4.7 represent the area between points and the percentage difference. This is seen to increase as the area increases. These errors are a direct function of the point sample density and transect line spacing. The scattering of the results are shown in Figure 4.9. The grid area of <100 m2 achieved the most accuracy of < 1%.

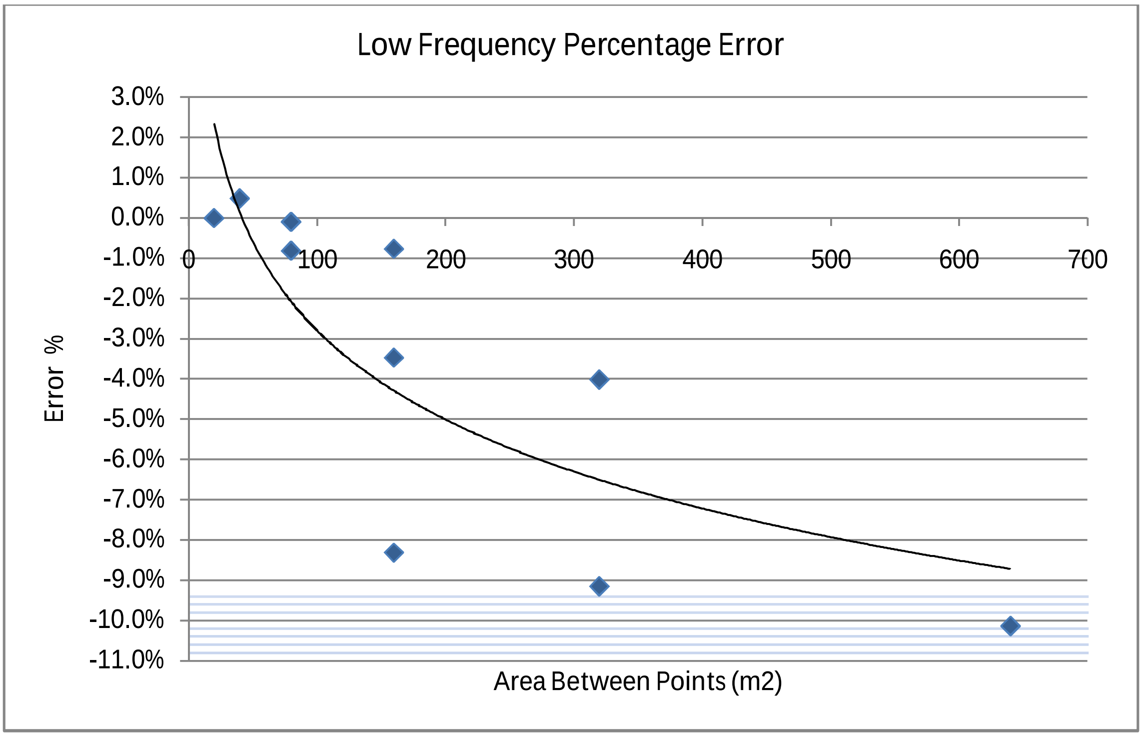

Figure 4.9 *Low Frequency Area Error Percentage (units in metres).*

Similar scattering occurs when the difference in the deposited material volume is compared against the grid area between points. The grid area of <100 m2 achieved the most accuracy of < 10,000 m3 and is shown in Figure 4.10.

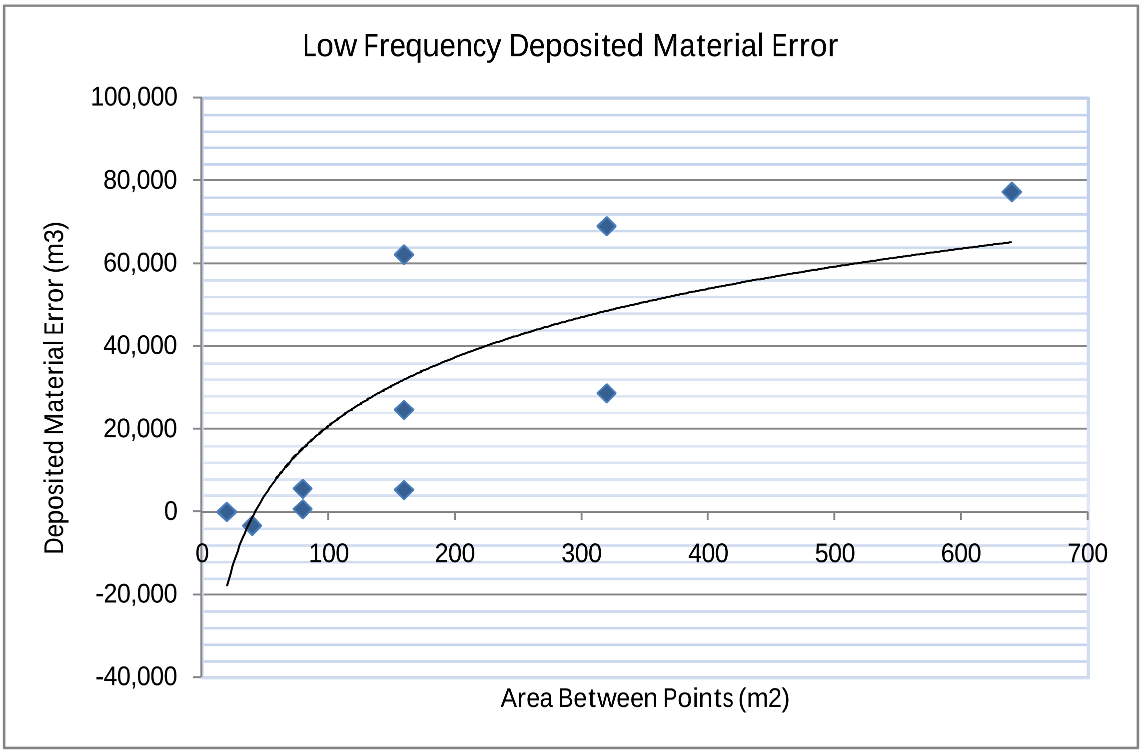

Figure 4.10 *Low Frequency Deposited Material Area Error (units in metres).*

The high frequency echo soundings returned very similar results to the low frequency echo soundings as shown in Table 4.8, Figure 4.11 and Figure 4.12.

First Surface	Second Surface	Fill (m3)	Area (m2)	Difference (%)	Difference (m3)
Original Void	High Frequency	697,226	20	0.00%	0
Original Void	High Frequency 4 x 10	688,996	40	1.19%	-8,230
Original Void	High Frequency 4 x 20	697,638	80	-0.06%	411
Original Void	High Frequency 4 x 40	748,169	160	-6.81%	50,943
Original Void	High Frequency 8 x 10	694,853	80	0.34%	-2,373
Original Void	High Frequency 8 x 20	700,074	160	-0.41%	2,847
Original Void	High Frequency 8 x 40	740,783	320	-5.88%	43,556
Original Void	High Frequency 16 x 10	715,429	160	-2.54%	18,203
Original Void	High Frequency 16 x 20	720,645	320	-3.25%	23,418
Original Void	High Frequency 16 x 40	746,207	640	-6.56%	48,981

Table 4.8 *High Frequency Point Density Area Error*

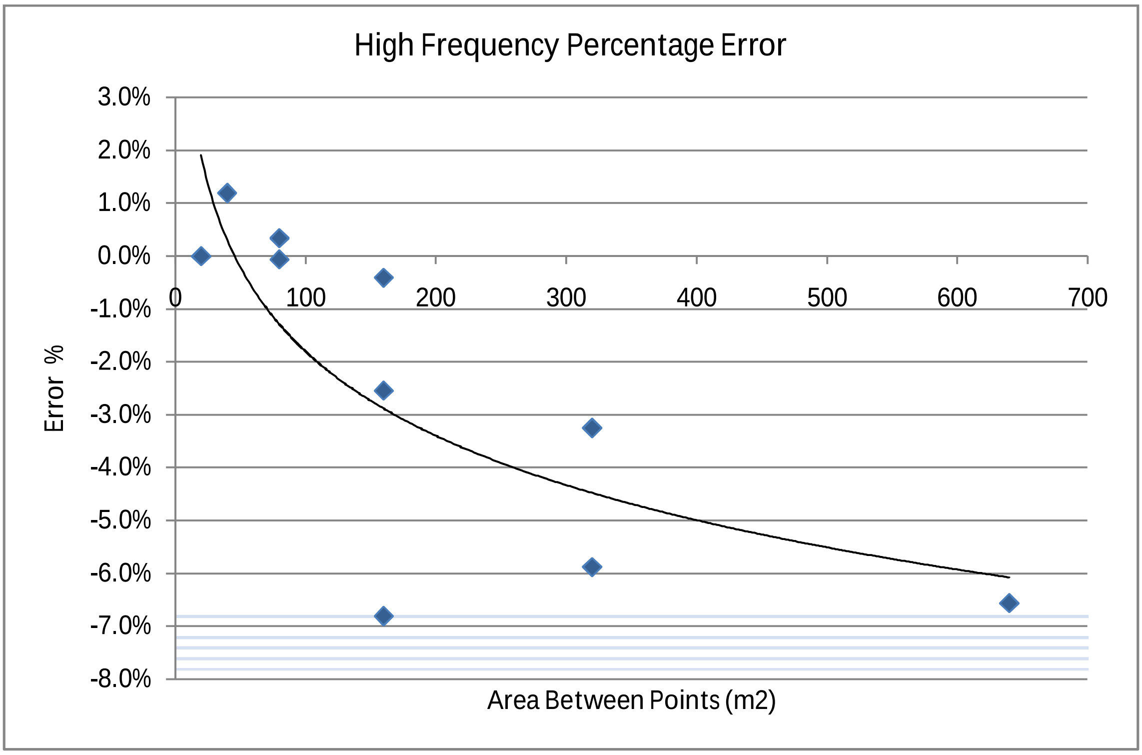

Figure 4.11 *High Frequency Area Error Percentage (units in metres).*

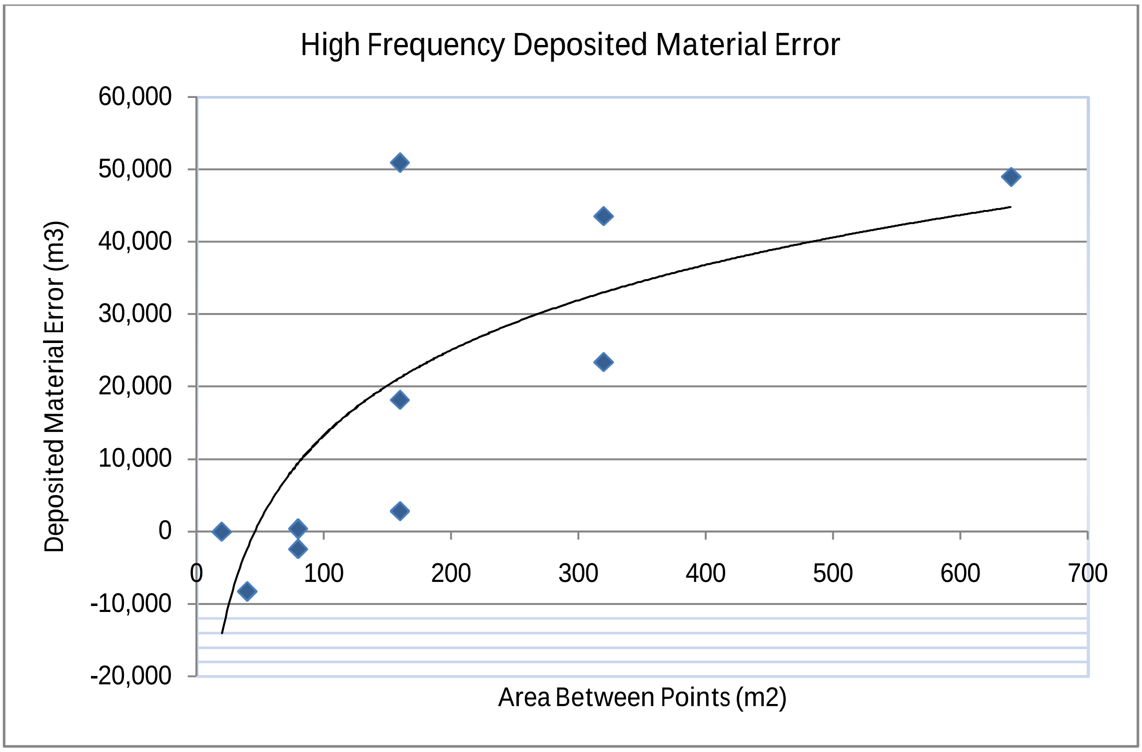

Figure 4.12 *High Frequency Deposited Material Area Error (units in metres).*

To take this process one step further the associated costs for deposited material removal, (assumed only 2/3 of deposited material requires removal at 0.34 cents to load material and 0.50 cents to haul the material an average distances of 1200 metres), is shown in Appendix I.

4.5.2 Digital Terrain Model Surface to Surface Variance

The low frequency echo soundings are assumed to penetrate deeper into the deposited material floor than the high frequency echo soundings due to the nature of there corresponding wave lengths.

Therefore it is fair to say that the low frequency digital terrain surface would be lower than the high frequency digital terrain surface. The variance between the high and low frequency digital terrain surfaces are shown in Table 4.9.

First Surface	Second Surface	Area (m2)	Excavation (m3)	Fill (m3)	Low Freq Lower than High Freq
Low Frequency	High Frequency	20	45,039	60,817	57.5%
Low Frequency 4 x 10	High Frequency 4 x 10	40	49,200	60,080	55.0%
Low Frequency 4 x 20	High Frequency 4 x 20	80	49,469	65,188	56.9%
Low Frequency 4 x 40	High Frequency 4 x 40	160	72,345	75,433	51.0%
Low Frequency 8 x 10	High Frequency 8 x 10	80	54,297	60,747	52.8%
Low Frequency 8 x 20	High Frequency 8 x 20	160	52,686	64,765	55.1%
Low Frequency 8 x 40	High Frequency 8 x 40	320	80,933	69,602	46.2%
Low Frequency 16 x 10	High Frequency 16 x 10	160	69,866	103,656	59.7%
Low Frequency 16 x 20	High Frequency 16 x 20	320	65,971	76,789	53.8%
Low Frequency 16 x 40	High Frequency 16 x 40	640	93,462	80,881	46.4%
	Average	198	63,327	71,796	53.4%

Table 4.9 *High and Low Frequency Surface to Surface Variance*

Table 4.9 indicates that an average crossing rate between the low and high frequency echo sounding surfaces is 53.4%. This was not expected as the low frequency wavelength is longer and would in theory penetrate further into the deposited material. See Figure 4.13 for a graphical representation. This leads on to the differences in penetration rates of the low and high frequencies and possible further research commented on in Chapter 5: Discussion and Recommendations.

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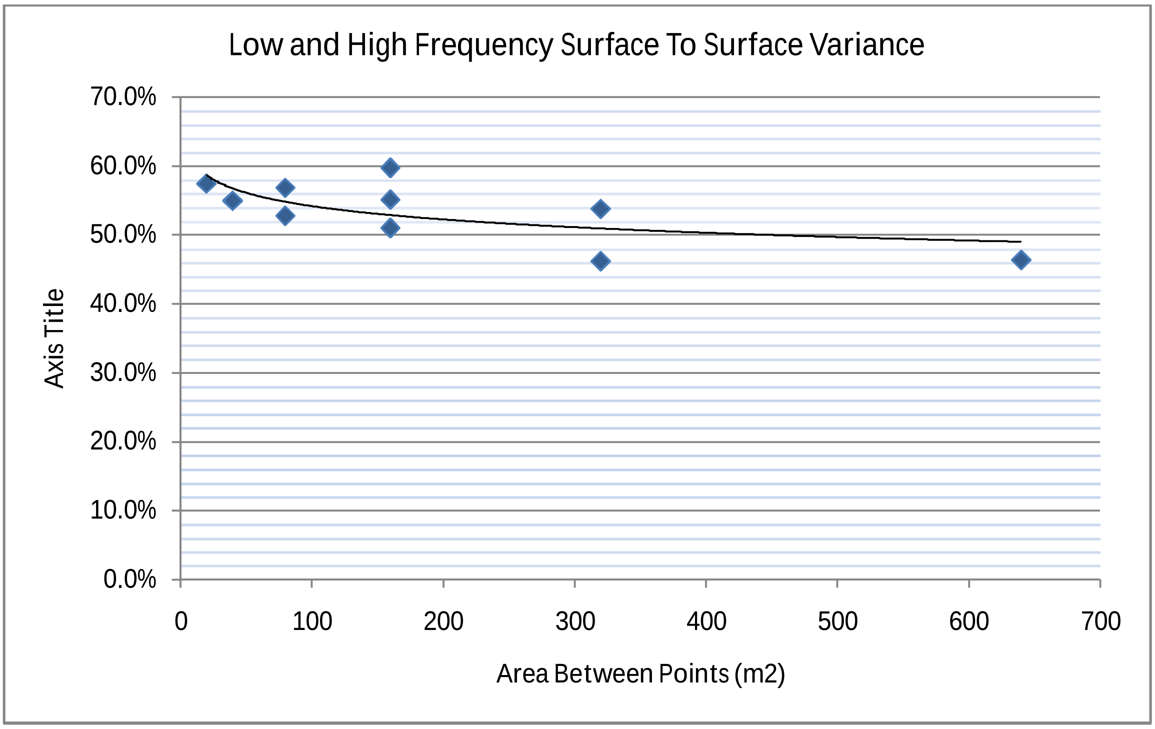

Figure 4.13 *High and Low Frequency Surface To Surface Area Variance (units in metres).*

4.5.3 Water Volume

Before the deposited material can be exposed ready for removal, the existing water body is required to be pumped out. The water volumes from each surface to the RL, which is the water level, are shown in the Table 4.10.

First Surface	Second Surface (RL)	Water Vol (m3)	Difference
Low Frequency	10.65	4,397,673	0.00%
Low Frequency 4 x 10	10.65	4,400,724	-0.07%
Low Frequency 4 x 20	10.65	4,396,885	0.02%
Low Frequency 4 x 40	10.65	4,333,525	1.48%
Low Frequency 8 x 10	10.65	4,390,764	0.16%
Low Frequency 8 x 20	10.65	4,391,165	0.15%
Low Frequency 8 x 40	10.65	4,326,552	1.64%
Low Frequency 16 x 10	10.65	4,371,674	0.59%
Low Frequency 16 x 20	10.65	4,369,355	0.65%
Low Frequency 16 x 40	10.65	4,319,386	1.81%
High Frequency	10.65	4,381,865	0.36%
High Frequency 4 x 10	10.65	4,389,815	0.18%
High Frequency 4 x 20	10.65	4,381,137	0.38%
High Frequency 4 x 40	10.65	4,330,408	1.55%
High Frequency 8 x 10	10.65	4,384,285	0.31%
High Frequency 8 x 20	10.65	4,379,058	0.43%
High Frequency 8 x 40	10.65	4,337,855	1.38%
High Frequency 16 x 10	10.65	4,364,209	0.77%
High Frequency 16 x 20	10.65	4,358,507	0.90%
High Frequency 16 x 40	10.65	4,331,937	1.52%
	Average	4,366,839	0.71%

Table 4.10 *Water Volume Utilising Each DTM (units in cubic metres)*

Utilising three Sykes HH200i 8 inch CAT3406 diesel engine pumps on pontoons with a flow rate of 6000m3 each per day at 1400 Revolutions Per Minute (RPM); 242.6 days is required to pump this flooded open cast mine workings dry. This assumes no further inflow of rain water runoff or flooding from neighbouring rivers. At $235.91 per day the total cost would be $171,695.30.

4.6 Conclusions: Chapter 4

The results of the calibration of the echo sounder, the high and low frequency echo soundings, the vertical accuracy of the RTK GPS, the digital terrain models and costs for removal of the deposited material have been analysed in detail within this chapter.

The results have been varied, from the expected to the unexpected. These results will be elaborated on further in Chapter 5: Discussion and Recommendations.

CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

"The creative process involves getting input, making a recommendation, getting critical review, getting more input, thus improving the recommendation." - Anonymous

5.1 Introduction

The above statement suggests that without thorough data input and critical review, sound recommendations will not eventuate.

This chapter aims to discuss and make recommendations from the results evaluated and analysed in Chapter 4: Results and Data Analysis.

Erroneous echo soundings, vertical accuracy of RTK GPS and point density area errors will be discussed and recommendations will be made along with comments on possible avenues for further research.

5.2 Discussion

The determination of what effect different transect and point spacing have on the accuracy of the deposited material volumes has been proven utilising inexpensive bathymetric equipment to achieve a high level of repeatable accuracy.

5.2.1 Erroneous Echo Soundings

Not all echo soundings plotted at the correct height and erroneous points appeared as a ‘spike’ in the DTM inconsistent with the surroundings undulations of the bathymetric surveyed floor. These erroneous echo soundings were edited out by manually interpreting the data by eye and utilising the quick profile and contour function in Terramodel. Erroneous echo soundings are shown Appendix J.

A cross section along a transect line with an erroneous echo sounding is shown is Figure 5.1.

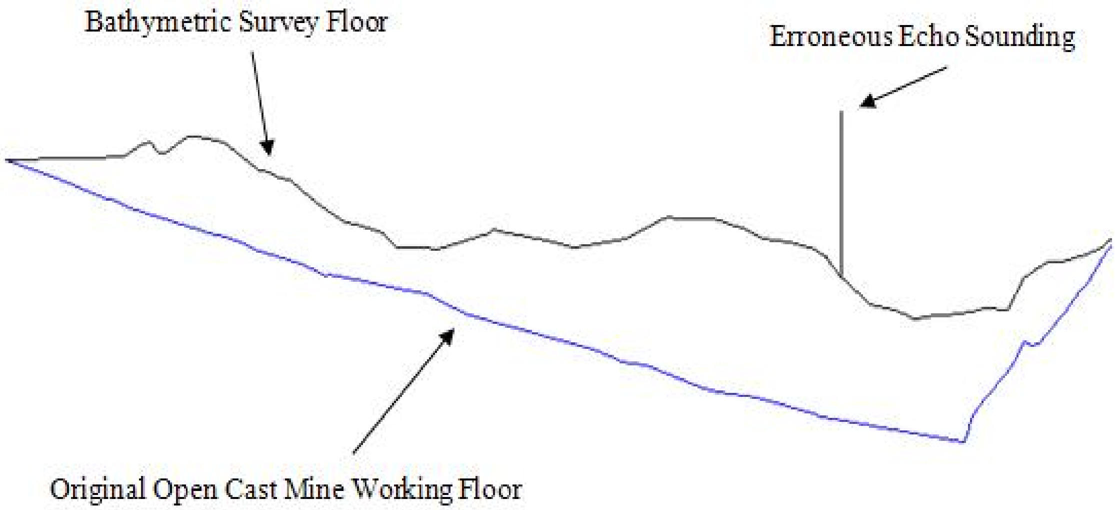

Figure 5.1 *Cross Section of an Echo Sounding Erroneous Point*

The high frequency echo soundings had more erroneous data points than the low frequency echo soundings. High frequency corrupt echo soundings totalled 3,509 and the low frequency corrupt echo soundings totalled 1,696. These numbers appear to be large but when compared against the total combined number of echo soundings recorded in both high and low frequency of 230,778, a 1.5% and 0.7% difference, brings the data points back into an acceptable range of error.

There are no floating submerged objects like fallen trees or fish as there were no streams or rivers that flow into the void and the soluble minerals suspended in the water appear to be out of the range to support substantial marine life.

The repeatability of the echo soundings accuracy can then be categorised for this bathymetric survey as 98.5% for the high frequency and 99.3% for the low frequency, which can be considered high precision and repeatability.

5.2.2 Vertical Accuracy of GPS

In Section 4.4.1 the vertical accuracy of the GPS observations was seen ‘jumping’ around the known water level of 10.65, see Figure 4.2.

In Figure 5.2 the speed of survey vessel is plotted against the measured vertical height of the RTK GPS to understand whether speed has an affect on its vertical accuracy.

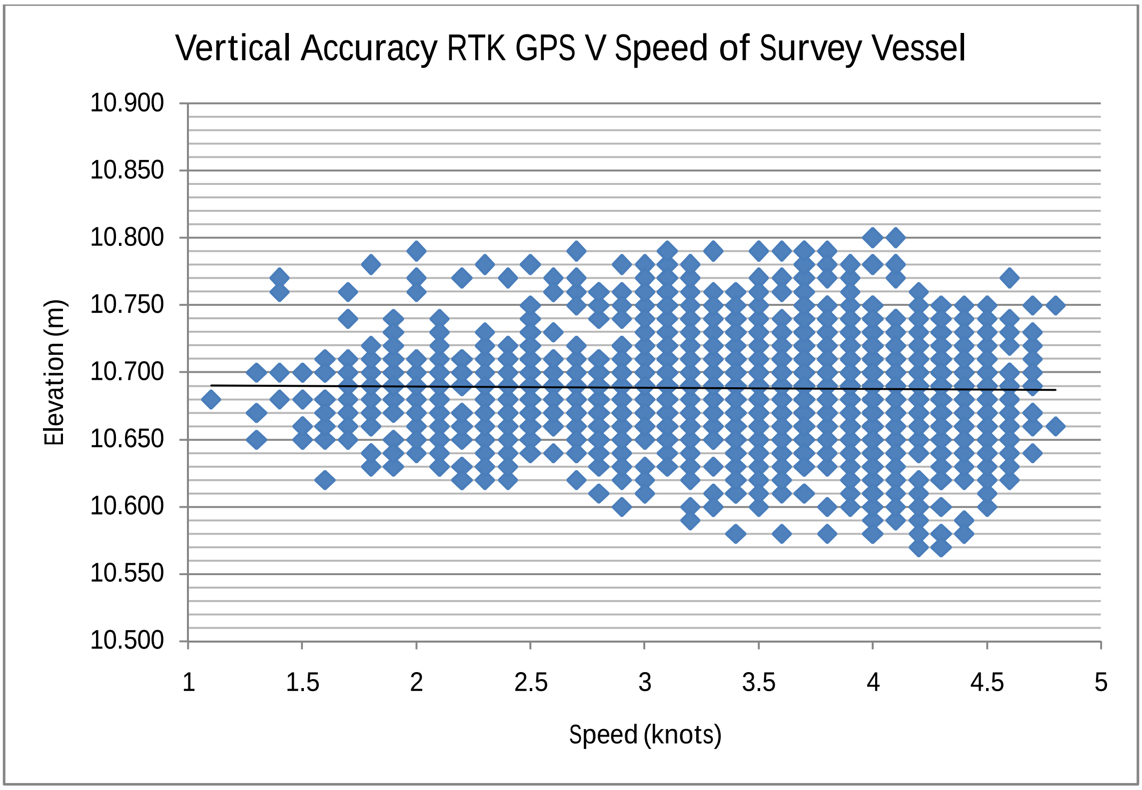

Figure 5.2 *Vertical Accuracy RTK GPS V Speed of Survey Vessel*

The degree of scatter of the elevation readings lends itself to other propagating errors such as multi-pathing from highwall when in close proximity say <10 metres or where the satellite constellation isn't conducive to high dilution of precisions.

This figure indicates that it has +-100mm effect up to the speeds recorded in this survey of approximately maximum of 5 knots. This confirms the discovery process in the literature review in section 2.4 has merit. However, a reduction of the survey vessel's speed to around 2 to 3 knots (or 1 to 1.5 metres per second) could possibly smooth out the vertical scatter.

5.2.3 Point Density Area Error

Precisions were found to decrease in both high and low frequencies with an increase in the transect line and point spacing. This increase in the area between points and the associated errors are a direct function of the point sample density and transect line spacing. Figure 5.3 plots the low frequency, previously illustrated by Figure 4.10, and high frequency, previously illustrated by Figure 4.12, together directly for a visual comparison.

Both frequencies indicate that the grid area of <100 m2 achieved the most accuracy of <10,000 m3. This leads to the differentiating penetrations rates of each frequency as a source of error which is commented on later in section 5.4.2.

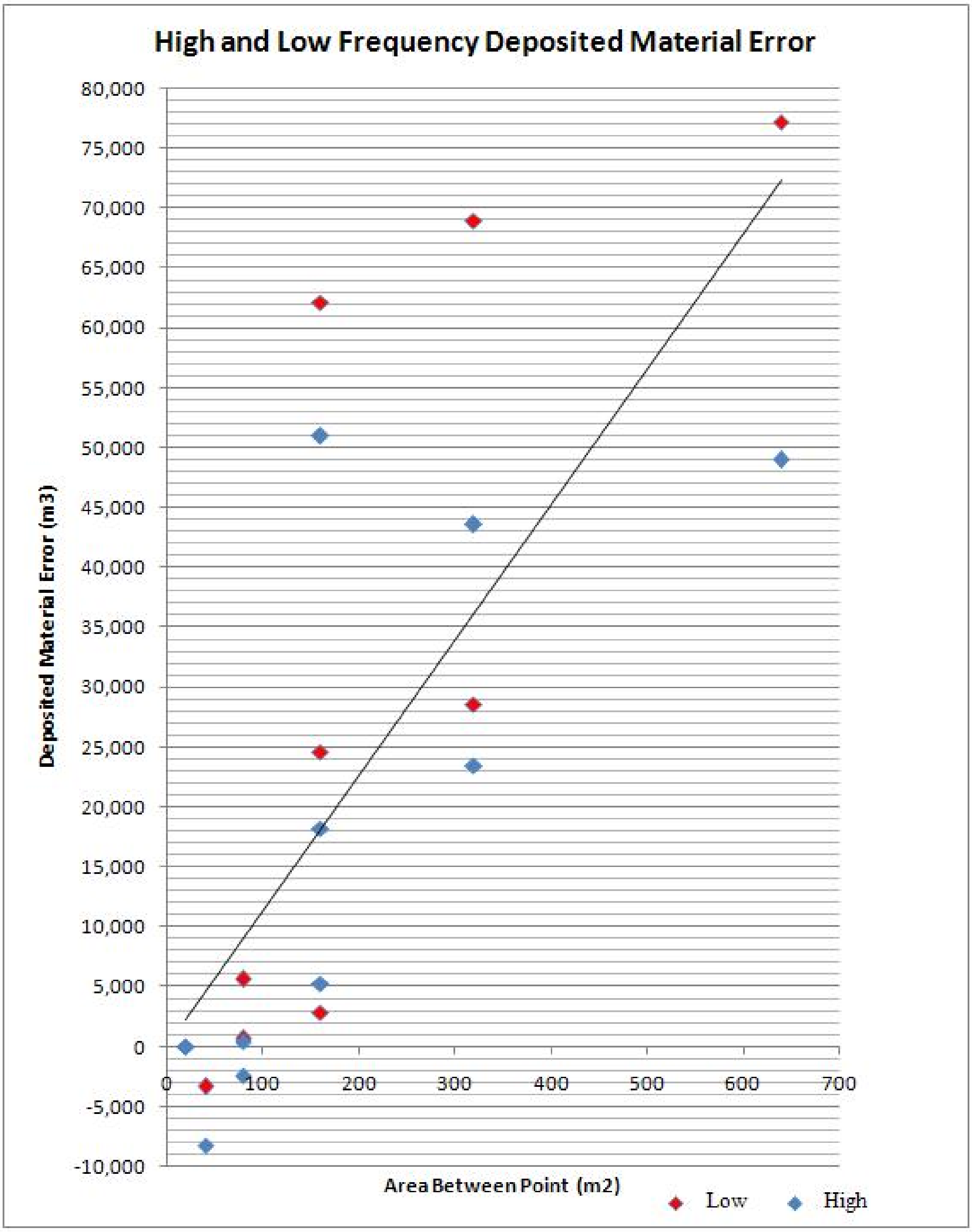

Figure 5.3 *High and Low Frequency Deposited Material Error*

The increase in error was expected but some of these errors would average out across the whole bathymetric survey due to the algorithms in the Terramodel software fitting planar surfaces between measured points across the irregular flooded mine working floor. With this in mind, the increased transect and point spacing or a point density area increase, give the impression that there are sufficient points. In reality the bottom features aren't defined properly due to the planar nature of the algorithms utilised in Terramodel, but for this project and the desired outcome is achieved.

An ideal point density area would be as many points as close together as possible. This is unachievable utilising single beam echo soundings techniques. Tables 4.9 and 4.10 in Section 4.5.1 illustrate accuracies.

5.3 Recommendations

This section summarises the recommendations with respect to the suitability of this method and its ability to achieve desired accuracy and precision is the original agreed aim for this project.

The suitability of the selected single beam echo sounding transducer, RTK GPS utilisation and survey vessel configuration has produced the desired results. But with all methods, the more times the method is repeated and upon reflection, refinements are made as our knowledge base has increased.

The average speed of the survey vessel was 3.955 knots (2.035 metres per second). Whilst this is still considered acceptable, a reduction of the speed survey vessel to around 2 to 3 knots (1 to 1.5 metres per second) would increase the point density, reduce the effects of latency (currently at approximately 1 second) and smooth out the vertical scatter of the RTK GPS water level measurements. However, a latency correction could be applied and the survey vessels speed increased for greater efficiency.

The random zig-zaging of the bathymetric echo soundings across the survey area increased the point density and overall accuracies compared to the 4 metre point density and 10 metre transect spacing. However, to increase to accuracies even more, it is recommended that a more uniform zig-zag pattern is adopted.

Given the nature of the mining industry and the environment that the bathymetric survey has been undertaken, an appreciation of the machinery removing the deposited material is required. Accuracy to a finite volume is not necessary. If we put it into context; 2500 and 3600 tonnes excavators will load material onto 80 plus tonnes haul trucks, a few cubic metres here and there isn't going to be noticed.

The techniques and equipment used for the study have been adequate and have met the required standard.

5.4 Summary

The discovery process of Chapter 2: Literature Review ensured informed decisions were made on; bathymetric equipment and systems used; data acquisition techniques required such as lead line, single beam and multi beam, and the effects of latency.

Chapter 3: Methodology followed the literature review, it considers aspects such as survey control, transect lines spacing, software, type of survey vessel and how the subsequent field observations would be conducted.

As discussed in Section 3.3.1, the RTK GPS was set up to measure one position every two seconds. Results that are recorded are shown in Appendix F. However, by increasing the measuring frequency to one second would have increased the position point density. As such, in future bathymetric surveys for greater position density, it is recommended that RTK GPS position measuring to one second not two seconds.

As discussed in Section 3.3.2 the bathymetric survey was conducted using the Ceeducer Pro digital dual frequency single beam echo sounder (measuring six soundings per second) as it is robust, reliable, accurate, portable and inexpensive.

The results and data analysis of the echo sounder calibration shown in Section 4.3, indicated a negative adjustment of 22mm in the high frequency and a negative adjustment of 83mm in the low frequency were required, however, further research in the water column effects, this may be reduced.

Section 2.4 of the literature review stated that latency of up to one or two seconds is not critical for GPS RTK positioning. The average latency observed in this bathymetric survey was 0.9836 seconds, Section 4.4.2, as such is not considered critical. Section

5.2.2 discussed a recommendation to reduce the survey vessel's speed to around 2 to 3 knots (or 1 to 1.5 metres per second), aligned with the one second GPS position recordings to increase the vertical accuracy of the GPS water level measurements.

Section 4.3 discussed erroneous echo soundings occurred when either the transducer returned a zero value or a z position inconsistent with the surrounding undulations of the bathymetric surveyed floor. These were easily identified and were managed by manual editing prior to DTM generation.

The sample point density and the transect line spacing had an effect on the accuracy of the deposited material volume; this was discussed in Section 5.2.3. Both frequencies indicate that the grid area of <100 m2 achieved the most accuracy of <10,000 m3. An optimum grid area of 40m2 was achieved by a random zig-zag pattern. However, this may be increased by utilising a more uniform zig-zag pattern across the survey area.

5.5 Conclusions: Chapter 5

Chapter 5 discusses the erroneous echo soundings; vertical accuracy of RTK GPS versa speed of survey vessel, point density area errors compared against deposited material volume for both high and low frequencies.

Recommendations on further research like the potential of differing water column density and temperature, and penetration rates of high and low frequencies into soft mud over a small consistent test area are some interesting outcomes within this chapter. The final chapter, Chapter 6: Conclusions will summarise all discussions and findings detailed in this project.

CHAPTER 6

CONCLUSIONS

"Reasoning draws a conclusion, but does not make the conclusion certain, unless the mind discovers it by the path of experience." - Roger Bacon (1214-1294)

6.1 Introduction

The above statement suggests that unless a discovery process of experience is undertaken, conclusive conclusions will not be drawn.

The original aim of this project was *“To design and validate the use of bathymetric surveying techniques to estimate the quantity of deposited material in flooded open cast mine workings to an accuracy that will allow decisions to be made about the viability of re-mining”*. This chapter validates this aim and will conclude this project by summarising what has been established, achieved, discussed and recommended during the proceeding five chapters.

6.2 Conclusions: Chapter 6

RTK GPS coupled with inexpensive over the side single beam digital bathymetric multi frequency technology has proven to be a viable solution in determining deposited material volume in flooded open cast mine workings at Satui mining operation, as Section 5.2.1 shows that the repeatability of the echo soundings for this bathymetric survey is 98.5 % for the high frequency and 99.3% for the low frequency. This can be considered as achieving a high level of repeatability and precision.

Results have proven that decreasing the point density and increasing the transect line spacing drastically reduces the accuracy of the final DTM solutions, thus the volume of the deposited material requiring removal.

The deposited material is predominantly up against the highwall. Assuming that only 2/3 of the deposited material requires removal (approximately 450,000m3), the approximate cost for removal equates to $387,000 (plus survey costs of $6,000) or 30 days at a productivity rate of 15,000 BCM per 24 hour period. The operational productivity rates will increase as a concise mining sequence can be developed with confidence. This will cater for the varying thickness of this deposited material instead of starting blind.

The suitability of this method for future work has been justified through the preceding literature review, methodology, results and data analysis and discussion and recommendations opening the door to a possible synergy between the mining industries in general and bathymetric surveying.

6.3 Further Research

Three areas of further research have been identified within this project being water column analysis and penetrations rates of high and low frequencies into soft mud.

6.3.1 Water Column

Calibration is a time consuming process and should a mining project have multiple flooded open cast mine workings spread over a larger area the water quality, acidity, suspended solids/particles and the mineralization of minerals from the differencing strata configuration; water column analysis may be useful as it would reduce the time necessary to complete a bathymetric survey at each new water body or under similar types of conditions. Further research on the water quality and how it affects the behaviour of the digital high and low frequency echo sounding may be interesting and will provide a good bench mark for future reference.

6.3.2 Penetration Rates of High and Low Frequency

Penetration rates of the high and low frequency echo soundings. The surface to surface variance between the digital terrain models, when compared to one another, it was found that an almost 50% crossing rate existed, which is not what I would have expected.

To get consistent repeatable results a small test area would need to be selected, say five 10 metre transect lines wide at 4 metre point density spacing, by the width of the mining void. This area will need to be surveyed three or more times utilising the same echo soundings and survey vessel parameters, then compare this results.

6.3.3 Latency

Latency has been understood within this project, with the magnitude of latency interpolated from others' results. This is not necessarily valid, but has highlighted the fact that it is an error that needs to be considered.

Further research applying a thorough methodology into measuring a 'transect' in tow directions under varying conditions would capture a true understanding of the affects of latency.

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APPENDICES

A

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Mark Stephen James Surtees** 0050084528

TOPIC: Bathymetric Survey of Flooded Open Cut Mine Workings

SUPERVISOR: Peter Gibbings

PROJECT AIM: To design and validate the use of bathymetric surveying techniques to estimate the quantity of deposited material in flooded open cut mine workings to an accuracy that will allow decisions to be made about the viability of re-mining.

PROGRAMME:

1. Conduct a comprehensive literature review to determine whether RTK GPS technology coupled with bathymetric equipment may be utilised effectively.
2. Determine if inexpensive bathymetric equipment can achieve a high level of repeatable accuracy.
3. Determine what effect different transect and point spacings have on the accuracy of the deposited material volumes.
4. Make recommendations with respect to the suitability of this method and its ability to achieve desired accuracy and precision.
5. Prepare a dissertation to suitable standard.

AGREED:

Mark Stephen James Surtees

____

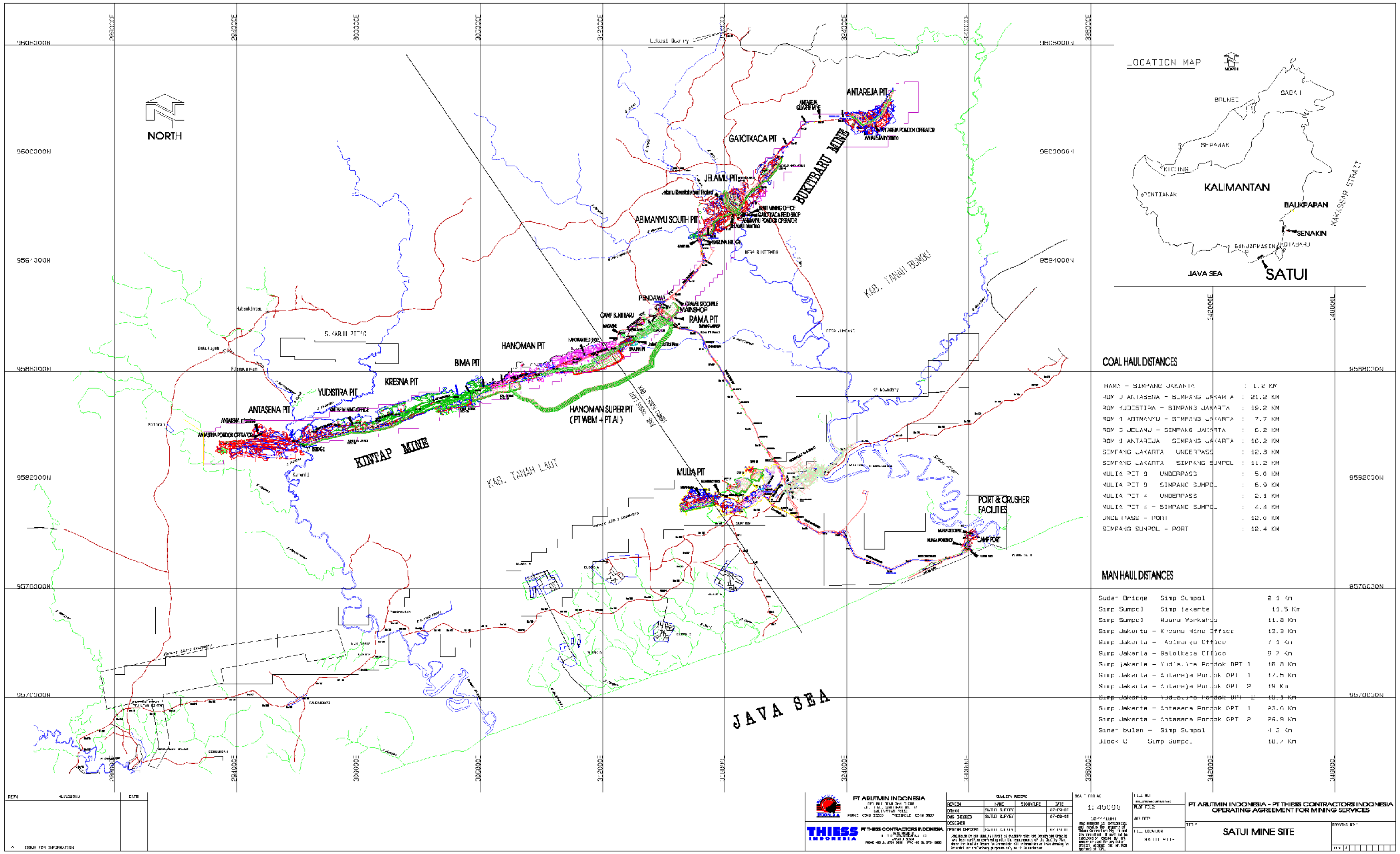
Date: 16 / 02 / 2009

Peter Gibbings

____

Date: 16 / 2 / 2009

B


NORTH
LOCATION MAP
KALIMANTAN
BALIKPAPAN
SENAKIN
JAVA SEA
SATUI
ANTAREJA PIT
GATOTKACA PIT
JELAMU PIT
ABIMANYU SOUTH PIT
BUKITBARU MINE
PENDAWA
RAMA PIT
HANOMAN PIT
BIMA PIT
KRESNA PIT
YUDISTIRA PIT
ANTASENA PIT
KINTAP MINE
HANOMAN SUPER PIT
(PT WBM + PT AI)
KAB. TANAH LAUT
KAB. TANAH BUMBU
MULIA PIT
PORT & CRUSHER FACILITIES
JAVA SEA
COAL HAUL DISTANCES
MAN HAUL DISTANCES
PT ARUTMIN INDONESIA
THIESS INDONESIA
PT ARUTMIN INDONESIA - PT THIESS CONTRACTORS INDONESIA OPERATING AGREEMENT FOR MINING SERVICES
SATUI MINE SITE

C

Survey Control Station Coordinates

Point Number	Coordinate			Bearing			Distance (m)
	Easting	Northing	Elevation	Degrees	Minutes	Seconds	
PLR 03	319637.610	9599007.740	63.620				
				49	04	53	852.800
PLR 02	320282.022	9599566.311	50.656				
				68	33	45	430.416
G 17	320682.660	9599723.622	36.023				
				213	55	17	1086.680
PLR 01	320076.234	9598821.890	37.746				
				203	24	30	478.186
G12	319886.260	9598383.060	44.390				
				338	17	43	672.348
PLR 03	319637.610	9599007.740	63.620				

D

Ceeducer Pro Specifications

GENERAL SPECIFICATIONS

Physical

Dimensions	- 27cm x 24cm x 12cm
Display	- 320 x 240 Backlit Graphic LCD with Contrast
Weight	- 3.7 Kg
Colour	- Pelican Yellow, (Black available on request)
Connectors	- LEMO 0B,1B & 2B series, Industrial RJ45, TNC

Environmental

Temperature	- 0°C to 50°C
Humidity	- 95 % non condensing
Ingress Protection Rating	- IP67

GPS options

Ashtech A12 (Std)	- ± 1.0 m (95 % DGPS)
Ashtech DG14	- ± 0.5 m (95 % DGPS)
Hemisphere Crescent	- ± 0.6 m (95 % DGPS)

IALA Beacon Receiver

Hemisphere SBX-4(Std)	- 2 channel parallel tracking - Freq range 283.5 to 325. 0 kHz - Channel spacing 500 kHz

External Data Interfaces

GPS Input	- NMEA 0183
Baud rate	- 4800 - 115200
Data bits/parity/stop bits	- 8/N/1
GPS message	- GGA + VTG
Heave Input	- TSS
Baud rate	- 4800 - 115200
Data bits/parity/stop bits	- 8/N/1
Heave message	- TSS 33

User Controls

Date/Time	- Set Date & Time
Output Formats	- Ceestar basic, Odom dual, Deso, GPS + Depth
Sound Velocity	- Auto (Salt/Brackish/ Fresh) or Manual User input
Echo sounder Draft	- Independent draft settings per frequency
Echo sounder Gate	- Set Min & Max depth for bar check
Geodetic Setup	- User defined Geodetic shift
Ext Heave Input	- Select or disable, Baud rate,
Ext GPS / Tide input	- Select or disable, Baud rate
Ext echo sounder	- Select or disable, Baud rate
Diff Options	- Select SBAS, Beacon or Local RTCM

Echo sounder

Depth Range	- 200 kHz 0.3 to 99.9 m - 30 kHz 0.75 to 99.9 m
Maximum ping rate	- 6 Hertz
Accuracy	- 0.02% of depth or 1cm whichever is greater
Resolution	- 1 cm

Transducer Options

Standard 200kHz (Std)	- 200 kHz, 8 degree beam width @-3dB
Narrow Beam 200kHz	- 200 kHz, 2.7 degree beam width @-3dB
Dual 200/30kHz	- 200/30 kHz , 8/19 degree beam width @-3dB

Power

Power Consumption	- 6 watts
Internal Battery	- Rechargeable SLA battery 2.3 amps
External Power Supply Voltage	- nominal 12VDC

E

CEE File

```
;PROCESSED FILE :    000013.CPR CREATED: 15 Jul 2009 : ALL DATA
;SETUP E/S A DRAFT:   50cm                E/S B Draft:   50cm            Veloc: (auto) FRESH
;PROJ PARAM A :       6378137.000 1/F :       298.257224
;PROJ PARAM Fe:        500000.000 Fn:     10000000.000
;PROJ PARAM LAT O:         0.00000 LON O:         117.00000    CM     Scale:         0.9996000
;PROJ PARAM Dx:           0.00000    Dy :           0.00000    Dz :           0.00000
;PROJ PARAM Rx:           0.00000    Ry :           0.00000    Rz :           0.00000   Scal  :         1.000000
;PROJ PARAM Latency:      0.00
;FMT 5 RE-PROCESSED DATA
FIX GROUP< 01A 15 May 2009 23:26:31.00     1   320111.290 E  9599104.584 N LAT   3 37 31.8833 S LON 115 22 49.3710 E HDG 221.0 SPD   3.1 DIF (4) HGT  -19.87 DPT
10.54   11.30 PDP  0.0 HDP 1.0 SVS 9
DPT  10.54 11.30
DPT  10.54 11.30
DPT  10.49 11.27
DPT  10.49 11.59
DPT  10.33 11.59
DPT  10.33 11.59
DPT  10.45 11.59
DPT  10.45 12.24
DPT  10.45 12.24
DPT  10.24 12.24
DPT  10.24 12.24
FIX GROUP< 01A 15 May 2009 23:26:33.00     2   320109.011 E  9599102.393 N LAT   3 37 31.9545 S LON 115 22 49.2970 E HDG 226.0 SPD   3.0 DIF (4) HGT  -19.87 DPT
10.24   12.24 PDP  0.0 HDP 1.0 SVS 9
DPT  10.24 11.71
DPT  10.21 11.71
DPT  10.20 11.71
DPT  10.21 11.71
DPT  10.29 11.71
```

F

Echo Sounding Output Data File

DPT	HIGH	LOW	POINT NO	EASTING	NORTHING	SPEED	WL ELEVATION	H DEPTH	L DEPTH	SATELITES
FIX	GROUP<	01A 15 May 2009 23:26:31.00	1	320111.29	9599104.584	3.1	10.670	10.54	11.3	9
DPT	10.54	11.3								
DPT	10.54	11.3								
DPT	10.49	11.27								
DPT	10.49	11.59								
DPT	10.33	11.59								
DPT	10.33	11.59								
DPT	10.45	11.59								
DPT	10.45	12.24								
DPT	10.45	12.24								
DPT	10.24	12.24								
DPT	10.24	12.24								
FIX	GROUP<	01A 15 May 2009 23:26:33.00	2	320109.011	9599102.393	3	10.670	10.24	12.24	9
DPT	10.24	11.71								
DPT	10.21	11.71								
DPT	10.2	11.71								
DPT	10.21	11.71								
DPT	10.29	11.71								
DPT	10.28	11.71								
DPT	10.4	11.45								
DPT	10.4	11.45								
DPT	10.1	11.45								
DPT	10.09	10.75								
DPT	10.09	10.75								
FIX	GROUP<	01A 15 May 2009 23:26:35.00	3	320106.839	9599100.227	3	10.700	10	10.75	9
DPT	10.18	10.75								
DPT	10.18	10.42								

DPT	10.18		10.42								
DPT	10.15		10.42								
DPT	10.15		10.42								
DPT	10.15		10.42								
DPT	10		10.42								
DPT	10		10.42								
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DPT	9.74		10.27								
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DPT	9.84		10.27								
DPT	9.84		10.27								
DPT	9.85		9.98								
DPT	9.85		9.95								
DPT	9.77		9.95								

G

Vertical Accuracy of RTK GPS Water Level (unit measurements in metres)

PT No	EASTING	NORTHING	WATER LEVEL	H DPT	L DPT	SATS
1	320107.411	9599109.494	10.67	10.54	11.30	9
2	320105.118	9599107.318	10.67	10.24	12.24	9
3	320102.932	9599105.166	10.70	10.00	10.75	9
4	320100.793	9599102.916	10.72	9.79	10.27	9
5	320098.560	9599100.594	10.71	10.95	10.49	9
6	320096.159	9599098.639	10.71	10.31	9.39	9
7	320093.649	9599097.013	10.72	9.42	10.16	9
8	320091.123	9599095.498	10.72	8.73	8.78	9
9	320088.525	9599093.999	10.71	9.12	8.90	9
10	320085.832	9599092.519	10.71	8.67	7.86	9
11	320083.009	9599091.266	10.71	7.03	7.29	9
12	320080.153	9599090.299	10.69	6.84	6.97	9
13	320077.354	9599089.597	10.70	6.21	6.31	9
14	320074.585	9599088.820	10.69	5.44	5.64	9
15	320071.980	9599088.074	10.69	4.72	4.85	9
16	320069.825	9599087.272	10.69	4.58	4.86	9
17	320068.249	9599086.063	10.70	4.97	4.99	9
18	320067.328	9599084.495	10.71	4.93	5.17	9
19	320067.104	9599082.727	10.70	6.29	6.98	9
20	320067.419	9599080.916	10.71	7.17	7.26	9

H

High and Low Frequency Direct Volumetric Comparison

First Surface	Second Surface	Excavation (m3)	Fill (m3)	Difference
Original Void	Low Frequency	25,607	684,311	3.7%
Original Void	High Frequency	22,738	697,226	3.3%
		Difference	12,915	1.9%
Original Void	Low Frequency 4 x 10	25,342	680,995	3.7%
Original Void	High Frequency 4 x 10	22,457	688,996	3.3%
		Difference	8,001	1.2%
Original Void	Low Frequency 4 x 20	25,458	684,950	3.7%
Original Void	High Frequency 4 x 20	22,411	697,638	3.2%
		Difference	12,687	1.8%
Original Void	Low Frequency 4 x 40	23,544	746,397	3.2%
Original Void	High Frequency 4 x 40	22,223	748,169	3.0%
		Difference	1,772	0.2%
Original Void	Low Frequency 8 x 10	24,312	689,924	3.5%
Original Void	High Frequency 8 x 10	22,785	694,853	3.3%
		Difference	4,929	0.7%
Original Void	Low Frequency 8 x 20	24,381	689,593	3.5%
Original Void	High Frequency 8 x 20	22,777	700,074	3.3%
		Difference	10,481	1.5%
Original Void	Low Frequency 8 x 40	23,457	753,281	3.1%
Original Void	High Frequency 8 x 40	22,283	740,783	3.0%
		Difference	-12,499	-1.7%
Original Void	Low Frequency 16 x 10	24,222	708,925	3.4%
Original Void	High Frequency 16 x 10	23,284	715,429	3.3%

		Difference	6,504	0.9%
Original Void	Low Frequency 16 x 20	25,913	712,935	3.6%
Original Void	High Frequency 16 x 20	22,798	720,645	3.2%
		Difference	7,709	1.1%
Original Void	Low Frequency 16 x 40	24,553	761,545	3.2%
Original Void	High Frequency 16 x 40	21,791	746,207	2.9%
		Difference	-15,337	-2.1%

I

Costs for Deposited Material Removal

First Surface	Second Surface	Excavation (m3)	Fill (m3)	Difference	Cost
Original Void	Low Frequency	25,607	684,311	3.7%	$ 383,214.34
Original Void	High Frequency	22,738	697,226	3.3%	$ 390,446.66
Original Void	Low Frequency 4 x 10	25,342	680,995	3.7%	$ 381,357.15
Original Void	Low Frequency 4 x 20	25,458	684,950	3.7%	$ 383,572.09
Original Void	Low Frequency 4 x 40	23,544	746,397	3.2%	$ 417,982.19
Original Void	Low Frequency 8 x 10	24,312	689,924	3.5%	$ 386,357.64
Original Void	Low Frequency 8 x 20	24,381	689,593	3.5%	$ 386,172.07
Original Void	Low Frequency 8 x 40	23,457	753,281	3.1%	$ 421,837.43
Original Void	Low Frequency 16 x 10	24,222	708,925	3.4%	$ 396,998.07
Original Void	Low Frequency 16 x 20	25,913	712,935	3.6%	$ 399,243.67
Original Void	Low Frequency 16 x 40	24,553	761,545	3.2%	$ 426,465.05
Original Void	High Frequency 4 x 10	22,457	688,996	3.3%	$ 385,837.84
Original Void	High Frequency 4 x 20	22,411	697,638	3.2%	$ 390,677.02
Original Void	High Frequency 4 x 40	22,223	748,169	3.0%	$ 418,974.57
Original Void	High Frequency 8 x 10	22,785	694,853	3.3%	$ 389,117.89
Original Void	High Frequency 8 x 20	22,777	700,074	3.3%	$ 392,041.21
Original Void	High Frequency 8 x 40	22,283	740,783	3.0%	$ 414,838.25
Original Void	High Frequency 16 x 10	23,284	715,429	3.3%	$ 400,640.08
Original Void	High Frequency 16 x 20	22,798	720,645	3.2%	$ 403,560.94
Original Void	High Frequency 16 x 40	21,791	746,207	2.9%	$ 417,876.08
	Average	23,617	713,144	3.3%	$ 399,360.51

J

Echo Sounding Output Data File Showing Zero Values

DPT	HIGH	LOW	POINT NO	EASTING	NORTHING	SPEED	WL ELEVATION	H DEPTH	L DEPTH	SATELITES
DPT	3.26	3.42								
DPT	3.26	3.42								
FIX	GROUP<	01A 15 May 2009 05:15:26.00	9	320734.102	9599663.75	3.1	10.680	3.31	3.44	9
DPT	3.31	3.44								
DPT	3.31	3.46								
DPT	3.31	3.41								
DPT	3.29	3.41								
DPT	3.29	3.36								
DPT	3.25	3.25								
DPT	3.44	3.25								
DPT	3.44	3.25								
DPT	3.44	3.3								
DPT	3.44	3.3								
DPT	3.44	3.3								
FIX	GROUP<	01A 15 May 2009 05:15:28.00	10	320736.336	9599665.993	3		0	3.11	9
DPT	0	3.11								
DPT	0	3.11								
DPT	0	3.11								
DPT	0	3.3								
DPT	0	3.3								
DPT	0	3.3								
DPT	0	3.3								
DPT	3.12	3.3								
DPT	2.95	3.3								
DPT	2.95	3.3								
DPT	2.95	2.98								
FIX	GROUP<	01A 15 May 2009 05:15:31.00	11	320739.505	9599669.531	3.1	10.680	0	2.83	7

DPT	2.87	2.83								
DPT	2.87	2.85								
DPT	2.87	2.85								
DPT	2.8	2.65								
DPT	2.8	2.65								
DPT	2.95	2.65								
DPT	2.95	2.65								
DPT	2.95	2.65								
DPT	2.95	2.64								
DPT	0	2.64								
DPT	0	2.64								
FIX	GROUP<	01A 15 May 2009 05:15:33.00	12	320741.618	9599671.971	3.2		0	2.64	7
DPT	0	2.64								
DPT	0	2.64								
DPT	0	2.64								
DPT	0	2.64								
DPT	2.32	2.47								
DPT	2.31	2.47								
DPT	2.31	2.47								
DPT	2.27	2.47								
DPT	2.26	2.46								
DPT	2.26	2.46								
DPT	2.39	2.46								
FIX	GROUP<	01A 15 May 2009 05:15:35.00	13	320743.82	9599674.22	3	10.700	2.38	2.62	8
DPT	2.38	2.62								
DPT	2.38	2.62								

K

Surface To Surface Volume Report

Project: C:\DISSERTATION\DISSERTATION.pro
Report Generated: Thursday, 9 July 2009 1:11:13 PM

Where the second surface is above the first the volume is reported as fill.

Where the second surface is below the first the volume is reported as excavation.

Shrinkage/swell factors: Excavation 1.0000 Fill 1.0000

First Surface	Number	Second Surface	Number
Original Void	35,376	Low Frequency	9,081

Volume limited to that within the constraining boundary - Object 697360
Area within boundary: 217,799.62 m2 (21.78 Ha)
Total triangulated area: 217,799.62 m2 (21.78 Ha)

Excavation Volume (m3)	Fill Volume (m3)
25,607.00	684,311.32

Net Difference: 658,704.32 m3 Borrow