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A Hydrographic Survey of Loe Pool

By Tomas Joseph

September 2015

Submitted by Tomas Joseph to the University of Exeter as a dissertation towards the degree of Master of Science by advanced study in Surveying, Land/Environmental Management

I certify that al the material in this dissertation which is not my own work has been identified and that no material I included for which a degree has previously been conferred to me

Chapter 1 Abstract

The Loe Pool Forum identified a need to produce an up to date and high resolution bathymetric data of Loe Pool to assess the current condition of Loe Pool and to use a benchmark for future monitoring and investigations. Alongside the need for bathymetric data, an accurate image of the objects and features within the pool was also identified as a needed

To produce the bathymetric data 5 days of bathymetric surveying using a single beam sonar system was undertaken, the data was then post processed and converted into WSG84 coordinates (depths were also converted into WGS84 elevations). From this data set contour maps and 3d surfaces were created to analyses the current condition of the lake.

A single day of new sidescan sonar investigation was undertaken, and this imagery alongside a larger data set recorded in previous years was also reviewed and significant objects were identified and recorded as coordinates and snapshots.

A single day of magnetic surveying was carried out, from this data two features were identified for future investigations, and a feature identified in the sidescan imagery was shown to be of nonmagnetic material. This section of the survey can be used as a reference for future and larger magnetic investigations of the lake.

The project recorded an accurate bathymetric data set which has been made available online for interested parties, specifically the member institutions of the Loe Pool Forum, to monitor and investigate the current and future conditions of Loe Pool. The bathymetric investigation identified three areas that can be seen as at risk

The sidescan investigation identified a number of large feature such as sunken trees, these objects can now be monitored and the number of objects within the lake can be monitored as there is now a record to refer to.

The magnetic data identified areas for future investigation, and determined a methodology for using terrestrial magnetometer systems for shallow water magnetic surveys.

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Chapter 2 Introduction

Aims

This project has a primary set of aims; to assess and measure the current bathymetry of the lake floor to serve as a baseline for future monitoring and investigation and make the data files for the bathymetry available to interested parties, to show the different methods this data can be presented and the types of information that can be extracted from it, and to show that this data can be combined with local terrain data of the surrounding area in the form of a DTM from the TELLUS south west project to enable the viewer to see how the landform of the area fits together. Combining shallow water bathymetry and DTM data has become an area of focus over the last decade as different organisations have realised that having combined data sets makes modelling and investigating areas much simpler than having to use different data sources solely because one area of interest is underwater (Gesch and Wilson 2002).

The reason for this project is the need for current data from the lake to allow, the organisations that make up, the Loe Pool Forum to monitor and manage the lake. A need for up to date bathymetry has been identified (Clitherow, J. 2014) as the current bathymetry (Figure 1) in use was produced in 2000 and is of a poor standard as it lacks contour labels or a depth scale. Specifically the Environment Agency will be able to use the bathymetric data

The secondary set of aims are as follows; conduct sidescan sonar surveys to identify any objects within the lake that could potential cause problems in the future, conduct a magnetic survey to identify potential ferrous objects such as plane wrecks, UXO (unexploded ordinance), or other sources of magnetic material. This area of the project is aimed at identifying possible areas for future investigation.

The Site

Loe Pool is the largest freshwater lake within Cornwall, it is an SSSI (Site of Special Scientific Interest) due to the presence of the Strapwort or Corrigoiola litoralis plant, the moth subspecies Leechi and the rare woodlouse Porcellio dilatatus (Loe Pool Forum 2015a). Along with the sand bar at the southern end of the lake known as Loe Bar, the site is classified as an AON (Area of Outstanding Natural Beauty) (Loe Pool Forum 2015b).

Historically the lake has been used for fishing and boating, but since being entrusted the National Trust activities on the lake have been limited, as one of the conditions stated by the former owner was that the pool should be a place of 'great beauty for people to enjoy without distraction' and as such boating swimming and fishing are not allowed and special permission had to be acquired for this project to be undertaken.

As discussed at great lengths in O'Sullivan (1982) and Hayes (2013) the lake sediments contain high levels of tin and other heavy metals due to the legacy of mine waste being washed downstream via the River Cober. Alongside this the lake has in the past had large volumes of phosphorus washed into it from both farmland runoff and from RNAS Culdrose the nearby naval base which deposits its waste into the lake, hwoever in recent years a great deal of effort has been made by the Loe Pool Forum (An association of parties with an interest in the Loe, consisting of The University of Exeter, The Environment Agency, Royal Navy, Natural England and the National Trust) to lower the levels of phosphates and prevent algae blooms of cyanobacteria or blue green algae (The upgrades to RNAS Culdrose waste system had an enormous impact on lowering phosphate levels). And there has not been a bloom since 2006 (Loe Pool Forum 2015a).

Previous Investigations

There have been several previous investigations into the Pool, however the bathymetric data produced so far has not been of very high resolution, with figure 1-1 being the most up to date and highest resolution bathymetric data available, and figure 4-1 shows bathymetry included in Hayes (2013) and O'Sullivan et al (1982). This shows that previous investigations have focused on the sediment and environmental aspects of Loe Pool, this has left analysis of the landform of Loe Pool in a neglected state.

Potential Issues

There is the potential for the site to contain UXO (unexploded ordinance), as the site was previously used as a testing range for the Royal Aircraft Establishment during World War 2, and there is the potential for unexploded torpedoes to remain in the lake. In the past ordinance in the form of 3" rockets have been recovered by divers (Royal Navy 1976a), and there are records of a both an armed plane crashing into the lake, a plane ditching its armament into the lake, and a post war training aircraft crashing into the lake. As such the site should be investigated cautiously and surveyors and stakeholders should refer to guidance when dealing with potential UXO threats (CIRIA 2015).

Also at least one of the potential Aircraft that crashed into the lake still may possibly still contain the remains of the pilot (Veterans Affairs Canada 2015) as the body was not recovered and burial is described as N/A. As such care should be taken that if the wreck is discovered interested parties (The Royal Navy whom the pilot flew for) should be contacted and made aware of the discovery.

Blue green algae or cyanobacteria is present in the lake, albeit in small volumes, however this should be avoided as it is contains a variety of toxins and has been linked to a variety of health risks (Rieuwerts 2008).

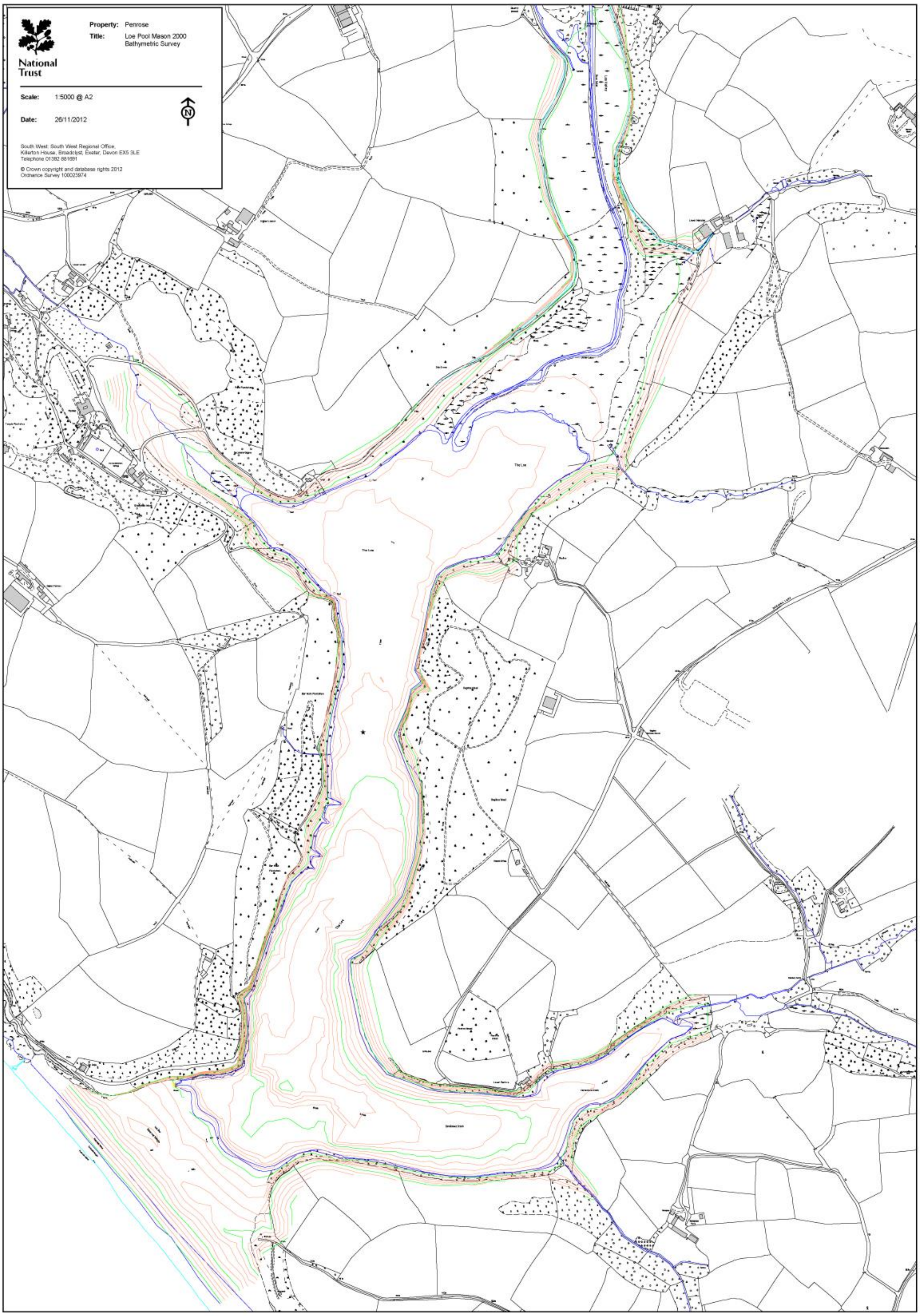


Figure 2-1: Bathymetry from 2000 (Mason 2000).

Chapter 3 Methods

This section will discuss the methods used during the survey, the principles of the techniques and why a certain technique has been chosen for this project and the potential errors. There are vast amounts of literature on all 4 of the techniques discussed in this section, as such these descriptions will be brief and focused on how the technique will be used in the survey, not an exhaustive analyses of each technique, the history of the technique will also be avoided as it is not pertinent to this project.

Sonar

As stated before there is a great deal of literature explaining the principles and theory behind sonar Gifford (2014) has a particularly detailed explanation of the principles of sonar. This section will briefly describe the principles of sonar.

Sonar stands for Sound Navigation and Ranging, but has now become a word on its own, whilst there are active and passive sonar systems this project only uses active systems so only those will be discussed. Active sonar systems operate by emitting sound waves from a transducer (the SonarMite is the transducer or echosounder in this project) which then records the time it takes for the sound wave to reflect back to the transducer and the intensity of the return signal in % or decibel (dB) (Blondel 2009).

For bathymetry the important equation is as follows; $D= v/2t$ (D= distance, V= the speed of sound, and t = time it take signal to reflect back to the transducer). The t value is halved because the initial t value is a measurement of how long it took the pulse to reach the target and back to the transducer, as we are interested in the distance between the target and the transducer we divide t by 2 to give us the time the signal took to reach the target.

Aside the from the distance to the target sonar can also be used to measure the reflectivity of the target, known as target strength (TS), this is a measure of the energy from the original pulse that reaches the transducer after being reflected from the target. This is calculated using the following equation; $SE = SL+TS-2TL-NI+DI+PG-DT-PL>0$ (Blondel 2009). The SE value must be a positive number for the target to reflect enough signal to be detected (Gifford 2014).

Single beam sonar

A single beam sonar survey will provide the data for the bathymetric mapping, multi-beam sonar would have provided a higher resolution data set but is wildly expensive and not available to the author so a single beam sonar unit –specifically the SonarMite v3 echo sounder- was employed instead.

Singlebeam sonar transducers transmit and then record sound signals (often referred to as pings) (Hogfrefe 2008), this signal is then analysed and using the previously mentioned equations calculates the distance from the transducer to the target and then records this value -while some singlebeam systems can record the intensity of the signal return the SonarMite v3 used in this project cannot.

The signal emitted from a singlebeam sonar is a fan shaped acoustic beam the angle of which varies between each model and manufacturer. However the SonarMaite v3 uses a beam spread of between 8 and 10 degrees (Ohmex 2015); the smaller the angle of the beam spread the higher the resolution of the data in that it will be recording the distance to a smaller point (The Hydrographic Society of America 2013). Singlebeam sonar is being used in this survey for its basic and most commonly used function, it will be measuring the distance between the transducer and the target, which in this case is the floor of Loe Pool.

Sidescan sonar

Sidescan sonar units are used to produce imagery of the sea/lake/river floors, in this case the Tritech Starfish 990f was used. The units are can be used to survey large swathes of an area. Sidescan sonar operates by producing a fan shaped series of pulses in a wide angle spread, usually sidescan sonar units are towfish units which are towed behind a vessel. The strength of sidescan sonar is that it can be used to produce high resolution images of the sea floor as the technique records the returning signal strength which can then be displayed in grayscale images (coloured filters can be applied to sidescan sonar, but unless a multi frequency system is being used (2 or 3 frequencies units are now in use)), the image can only display intensity of the returning signal in one frequency which limits the image to a black and white image. The technique can produce very high resolution images, with modern systems being able to show objects down to the mm scale (Blondel 2009), a weakness of the system is that it requires much more post processing to acquire depths, and while objects can be measured and heights calculated using the geometry of the object's shadow it is not a highly accurate way of measuring objects. In a very simplified analogy sidescan sonar is like taking a picture, whilst single beam sonar is akin to using a tape measure, for this reason it is sometimes referred to as side imaging sonar (Blondel 2009).

Sonar Errors

Errors can be caused in sonar surveys by a variety of issues.

1. Wave action can affect the survey massively, as the rise and fall of the boat due to wave can be interpreted as deeper and shallower measurements, and while the SonarMite v3 does have sensors to detect and correct for heave pitch yaw and roll, it can still impact the data if the movements are large enough. The survey will be conducted on an inland lake in low winds so there will be very little wave action, what little movement there is will be corrected by the internal sensors (Morang et al 1997).
2. An incorrect velocity of sound in water can have a large effect on the accuracy of recordings, this is especially true when dealing with deep water or where the velocity of sound changes depending on depth. However this will not be an issue in this survey as the water is not deep enough for it to have an impact, and it is doubtful that in such a shallow body of water there are significant changes in the velocity of sound in water ((Swedish Cartographic Society 2015)(Jakobsen 1997)).
3. Error can also occur where the sonar unit records a double signal (double surface reflection), this is where the signal reflects from the floor to the bottom of the boat and then back to the sensor, these are usually easy to identify as they present as being double the expected measurement (Blondel 2009), none were detected in during the survey.
4. Equipment accuracy, even the most sensitive sonar equipment is much less accurate than equipment used to measure topography in terrestrial settings (Total stations), for example to SonarMite v3 used in this survey is only accurate to 0.25m and that accuracy is limited to 70m in depth much shorter than the distances and accuracies achievable with land based measurement systems. However for this survey the accuracy is more than accurate enough, especially as the actual surface is subjective in some areas, being made of a very soft material using sound waves probably achieves a more accurate measurement of when the surface becomes solid than could be achieved by using a survey staff in material of the same consistency.
5. Ambient noise level can impact the sonar units, this can come from wildlife, geological processes and manmade sources. However in Loe Pool the ambient noise level is unlikely to affect the results as there are no known manmade sources of ambient noise

in the lake, and there is limited wildlife in the lake (fish, birds, and otters). That could produce sound in the right frequencies (400 kHz) and loud enough to impact the survey.

Magnetic survey

GPS

Coordinate data for the survey will be provided by GPS (Global Positioning System), this system calculates the location of the unit by measuring the distance from the GPS unit to the satellite, by taking measurements from several satellites the positon of the unit can be solved (Uren and Price 2010). The signal itself is an electromagnetic signal in the L-band (Uren et al 20010), this signal is used to produce a measurement through carrier phase measurements and cod ranging measurements. All of the GPS units used (except the LEICA 1200) use what is called code ranging rather than carrier phase (Trimble 2008). Code ranging works by the satellite broadcasting the time and position of the satellite, the receiver unit then calculates distance from the time taken for the signal to travel from the satellite to the receiver. Because the GPS clock will be far less accurate than the satellite clock errors can occur, these are resolved by receiver connecting with multiple satellites, where through a series of equations which combine to create $R= p+c\ (dt-dT)$; where R is the range between satellite to receiver, p is the pseudorange measured with clock error, dt is the satellite clock offset from GPS time, and dT is the receiver clock offset from GPS time ((Uren and Price 2010) (Gifford 2014)). Which essentially mean that a connection to four satellites is required to overcome clock error when using code ranging.

The final mapping produced in this report will be using the WGS84 (specifically WGS1984 EPSG 4326)coordinate system, this is because all of the GPS units except the LEICA 1200 use this reference ellipsoid, and it will provide less room for errors to emerge (errors produced from copying and converting data rather than error inherent in the surveying process) if the single point recorded by the LEICA is converted from OSGB36 (vN2)to WGS84, than converting the 1300000 plus points recorded in WGS84 into OSGB36. WGS84 is a standard coordinate system based on a standard reference ellipsoid or survey datum (Uren and Price 2010), while there is no substantial issue in using WGS4 it is not an ellipsoid designed specifically for use in the British Isles, unlike OSGB36; the lack of specificity towards British use (WGS84 was designed so that the coordinate origin of WGS84 is the centre of the earth's gravity, as opposed to OSGB36 which was designed so that the surface of the ellipsoid was as close to the true surface of the earth within the UK as possible (Uren and Price)) is obvious when you compare elevation data. Whereas the OSGB36 MAOD height for the reference object is 3.3596MAOD (the metres above ordnance datum in OSGB36 refers to height above sea level in Newlyn) while in WGS84 the same point is 56.246 MAOD.

The LEICA 1200 uses both code ranging and carrier phase measurements, carrier phase measurements calculate positional data by measuring the distance using different wavelengths, distance is calculated by measuring the difference in phase between the satellite and receiver signals; This can produce mm accurate position (Uren and Price 2008).

The higher the number satellites a unit can connect to the more accurate the location data produced will be, but number of satellites is not the only issue affecting the accuracy geometry of the satellite constellation can also have a dramatic impact upon the accuracy (the main issues come from when the majority of satellites in a constellation lay close to the horizon (Ordnance Survey 2015)), essentially the ideal satellite constellation would have a large number of satellites spread of the entirety of the visible sky (Srilatha et al 2009).

Figure 3-1

Figure 3-2 Trimble TPS and LEICA 1200 GPS unit.

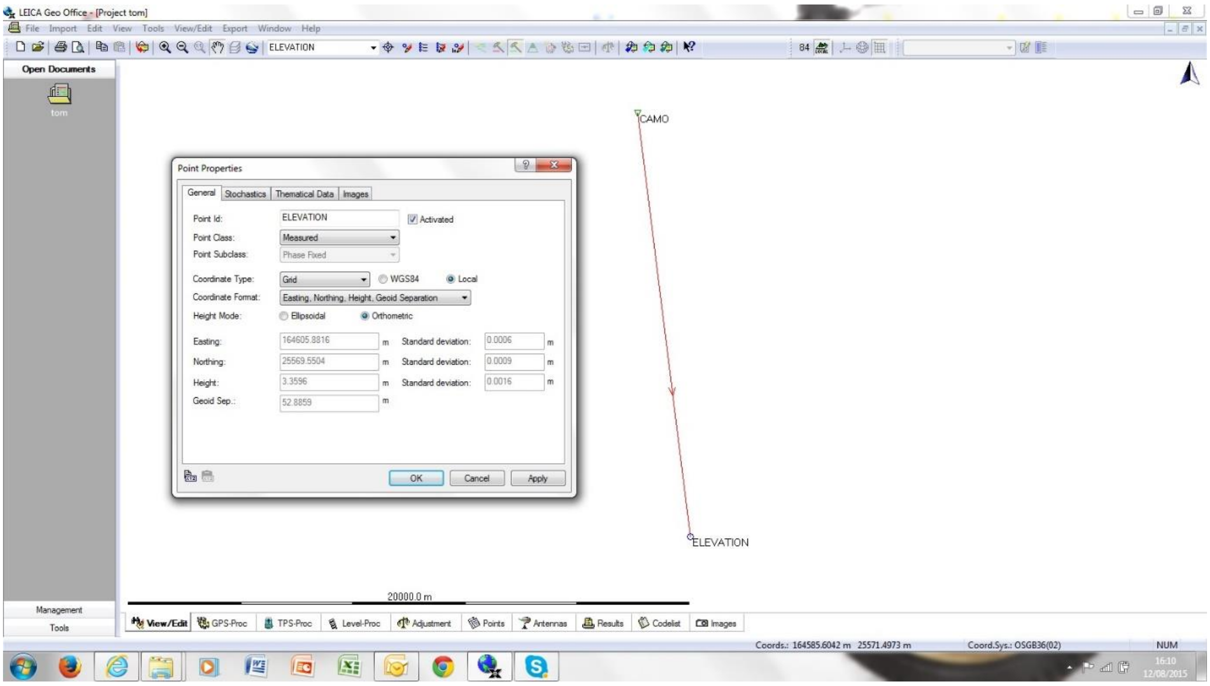


Figure 3-3 The GPS data has RINEX corrections applied to it.

4 different GPS units will be used during the survey, the JUNO SB is a handheld computer that has an inbuilt GPS unit that uses the WGS84 ellipsoid (like the vast majority of GPS systems) and

Longitude/Latitude coordinate system. It has an accuracy of +/- 2m. This is the unit that will be used to log the bathymetric data, and it combines its GPS coordinates with an elevation/depth recording taken from the SonarMite echo sounder (Ohmex 2015).

The Tritech Starfish 990f uses a Tritech Starfish USB GPS that connects with the laptop running the Starfish Scanline software, this unit has a stated accuracy of +/- 2m (Tritech 2012). The GEM GSM-19 has an inbuilt GPS that attaches to the units antenna, it has a stated accuracy of +/-1 m (GEM Systems 2008). A LEICA 1200 unit will be used to acquire elevation data and it has much higher accuracy due to its specification and the fact that to acquire a good recording the device will be left to run for 3 hours (Leica 2008), and the accuracy for the recorded point was +/- 0.0016m.

Apart from the elevation data from the LEICA 1200 none of the GPS data went through post processing, this is because the at the 1m plus accuracy levels there is little point in correcting the data. All of the GPS recorded points were within the boundaries of Loe Pool and all fell within the believed path of the boat, as such it is believed all of the GPS units achieved at a minimum the accuracies stated by the manufacturers, and possibly greater. All of the surveys were taken in clear weather with relatively cloud free skies, as the survey was conducted over a large lake there was no blocking of satellite signals from buildings or trees, and despite being in a relatively deep valley the valley sides were not steep or high enough to cause a canyon effect. All of the surveys maintained a lock on at least 5 satellites, and the GDOP value was maintained at between 2 and 5 meaning the measurements were considered between good and excellent (Srilatha et al 2009).

The as the survey will be combining the bathymetry with a DTM the depth recordings from the echo sounder need to be converted in to MAOD. To do this the following steps were taken;

1. A stable reference point which could be measured from to the water level was identified (figure 2-2), in this case a survey station from 1826. Subsequently measurements were taken at the beginning and end of every survey from a specific discrete point on the reference object (in this case the south eastern corner of the survey station.
2. On a day with fair weather and thin cloud cover a LEICA 1200 GPS unit was brought to the site and set up with a clear line of site to the survey station. The unit was then set to record its location for 3 hours.
3. Once the 3 hours were over the elevation data was recorded.
4. The GPS unit was removed from the tribrach and a Trimble TPS unit was placed in the tribrach and setup using the elevation data from the GPS (a local grid was created as the coordinate itself was not required).

5. The Trimble TPS was used to measure the elevation of the reference point on the survey station.
6. This data was then recorded.
7. The original GPS data was then exported to a computer where RINEX corrections could be applied to it, the change in elevation after the RINEX corrections were applied was then applied to the elevation of the survey station (in this case there was a correction of +0.0034m was necessary).
8. This elevation was converted from OSGB36 which is the system used by the LEICA 1200 GPS into a WGS84 MAOD elevation.
9. This point can now be used to convert the bathymetric depth measurements into MAOD elevations.

Software

The specific pieces of software to produce this report (ignoring the use of word 2013 as the word processor in which this dissertation was written).

Global Mapper is a GIS software package produced by the Blue Marble GEO, and its mains strengths for this project are its ability to open most GIS file types and convert the coordinate systems of the files, and its ability to export in an equally large variety of file types. It was used in this project to produce heat maps, LIDAR point clouds, and to convert file types.

Surfer 12 is the specific version of Surfer that was used for this project, it is a gridding program produced by Golden Software. It is designed to as a contouring and surface modelling package for terrain and bathymetric modelling, analysis, volumetric and many other features. One of the key features is the lightweight nature of the software in that it can handle large numbers of data entries (such as the 130000 plus bathymetric points recorded) without slowing down (once a grid file has been produced) where the same file size causes slowdowns in programs like AutoCAD, essentially its key feature is turning massive point cloud data into smaller grid files.

Leica Geo office is a software suite produced by Leica, it was used in this case to apply RINEX corrections to a single elevation data point.

StarFish Scanline V2.1 was used to log and then playback the sidescan sonar data, it is a freeware program and has some limitations (it cannot export georeferenced image for example), but for this project it was adequate.

Chapter 4 Local Terrain DTM

The TELLUS South West project is a survey project to map the rocks and soils of the south west of England, and was conducted the remote sensing from aircraft. While the project produced

Data from the TELLUS project will be used to merge and overlay with the lake bathymetry, so combined 3d surfaces and contour mapping can be produced of the area. The data to do this is freely available from the TELLUS project website as a DTM (digital terrain model) or DSM (digital surface model) in 5km by 5km squares. For this project the DTM data was chosen as it shows the underlying topography of an area while the DSM show buildings and other objects. The DTM was produced using Lidar surveying, and the accuracy of the TELLUS Lidar data is stated as being +/- 0.25m in elevation and an RMSE (root mean squared error) error of 0.95m in coordinate, these errors were calculated by comparing the Lidar data with ground control stations (Environment Agency 2014).

The process of editing the data for use are fairly simply and are as follows;

1. Data is downloaded from the TELLUS project website.
2. The DTM files (Loe Pool sits at the corners of 4 of the TELLUS project 5 by 5km squares) are opened in Global Mapper
3. The file is then converted from OSGB36 NTv2 British Grid into WGS84 ETRS89 and exported as a vector/LIDAR format dxf file. During this process the boundary of the exported data can be set, in this case 1.3km by 2.1km. This boundary was set as the total size of the Lidar data for the Loe was 10km by 10km, which is too large to display while still being able to view the bathymetry of Loe Pool.
4. The exported dxf file is then converted in Surfer into a grid file where an outline of Loe Pool Is used to blank the data in the location of the lake.
5. The final grid file can then be merged with bathymetry of the lake.

Essentially the process takes the large Lidar data (figure 3-1) and turns it into a smaller grid file (figure 3-2).

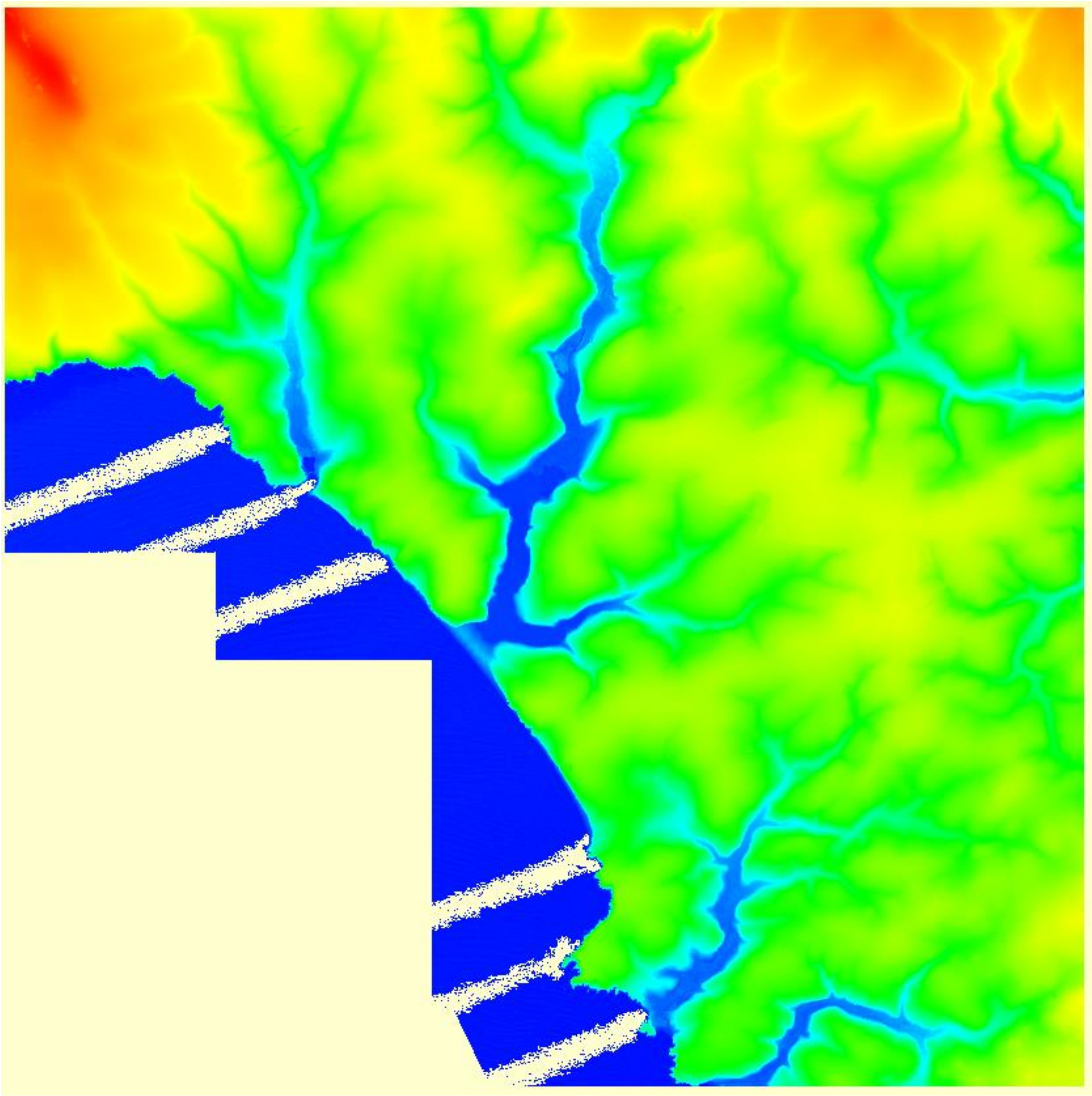
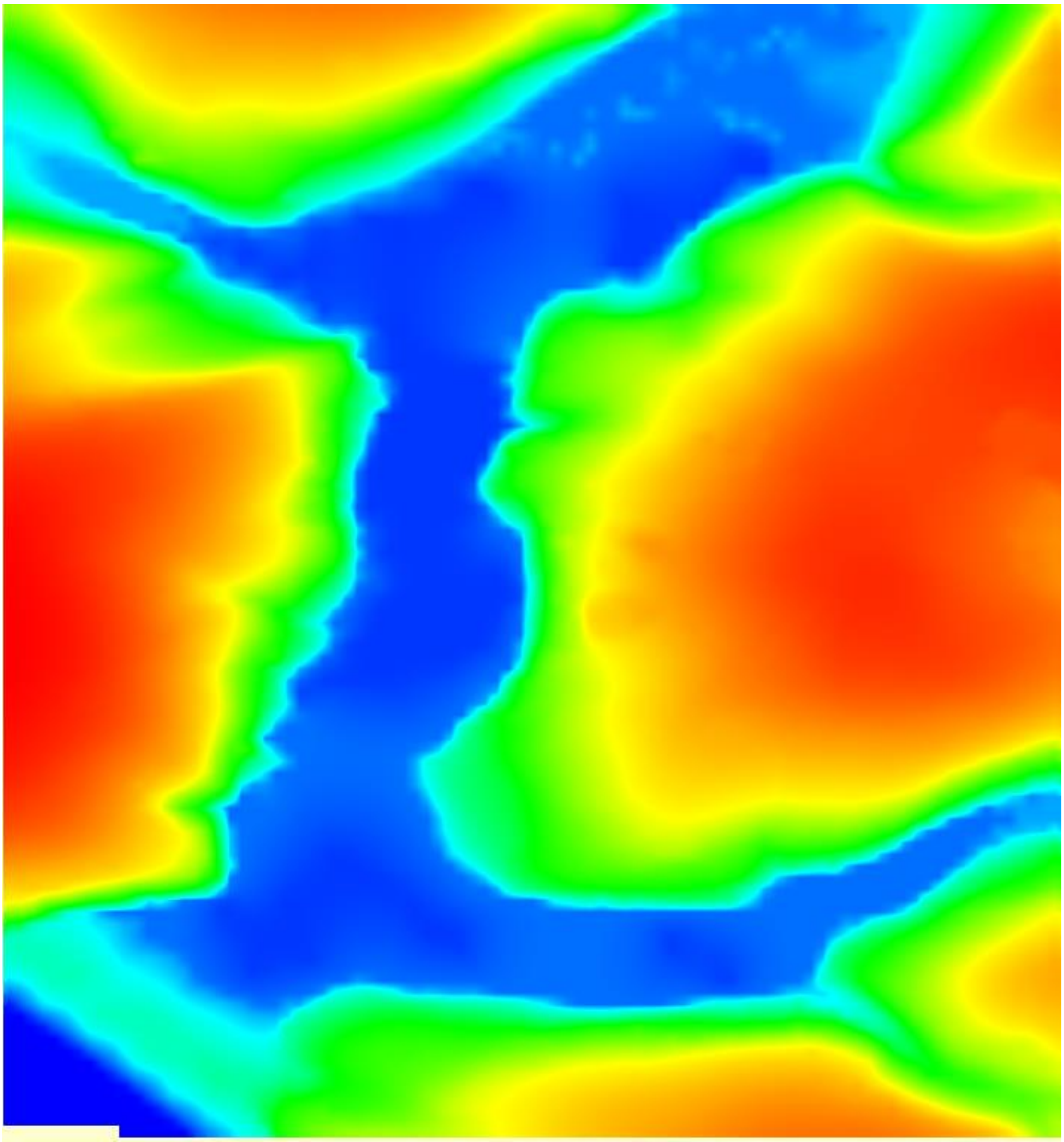


Table 4-1 The complete TELLUS Lidar data for the grids contain Loe Pool.



TablTable 4-2 The Lidar data after it has been reduced in size to the area immediately surrounding Loe Pool.

Chapter 5 The Survey

This section will describe the specific equipment used for each survey, the process of data collection and the data processing. The results will be discussed and presented in the subsequent section.

In all cases when referring to depth, the author means distance between 56.246MAOD (WGS84) and the measured point. This is the height of the corner of the reference point (a concrete survey station from 1846 in figure .fdngj) from which water levels were measured. This height was also the highest water level (approximately) observed during the course of the project.

Health and Safety

As the project would involve a substantial amount of time in a boat over water of then unknown depths, the following safety procedures were followed;

1. All persons going in the boat wore buoyancy aids at all times.
2. Only people capable of swimming were allowed in the boat.
3. Non rowing persons in the boat were to keep look out to ensure that the boat did not crash into the shoreline or catch and rip on submerged trees or debris.
4. When the boat was operated by a single person, the boat was rowed in reverse when near the shoreline or near areas where debris had been spotted.
5. A walkie talkie was kept in the boat at all times, and another was kept by someone on the shoreline who would be kept aware of the boats location. Also the National Trust staff were made aware of the survey team's presence and intended time of leaving the lake (during the magnetic survey a walkie talkie could not be kept in the boat as it would have affected the magnetic field in the vicinity of the magnetometer).
6. Surveying was not carried out during heavy rain or when there was a high likely hood of electrical storms (due to the survey taking place on open water and having a tall metal pole attached to the boat). Heavy wind was also avoided.

Single beam sonar

Equipment

The boat used as a survey platform was a fully inflatable Yamaha 350sti as picture in the following figure, this boat was used for the sidescan sonar and the magnetic surveys (the boat contained no ferrous material so could be used for the magnetic survey without affecting the sensitive GSM-GEM19 magnetometer).

Figure 5-1 (Author 2015).

The sonar unit used to collect bathymetry was the Ohmex SonarMite v3, this is an echo sounder designed for shallow water hydrographic surveying (Ohmex 2015). The SonarMite uses the Ohmex SonarLite transducer, which is a 235 KHz single beam transducer (Ohmex 2015). The transducer connected to the SonarMite which had an internal battery to power itself and the transducer. The SonarMite connects via blue tooth to the JUNO SB, which is a handheld windows mobile 6.1 device. The JUNO is a Trimble device and has an internal GPS unit which is accurate to 2 metres (Trimble 2008), the device connects to the SonarMite via a Bluetooth connection, and then a data logging application called SonarMite is used to control the SonarMite and log the data. The Juno SB GPS uses the WGS84 system like the majority of GPS devices, and uses the Geographic latitude/longitude coordinate system.

The transducer was mounted on the bottom of a pole so that the transducer was facing away from the pole but so the bottom of the pole was below the transducer and would be the first point of impact if the boat grounded thus protecting the transducer. The pole was then clamped to the transom, the clamp was adjusted so that the top of the transducer's mounting plate was just below the water level, and this placed the transducer 0.19m below the surface of the water. The SonarMite has internal sensors that detect and correct for the roll pitch heave and yaw of the boat, so the unit was placed at the back of the boat near the transom so that it was as close to the transducer as possible. The Juno SB was also mount on the same pole so that the GPS readings were taken from above the transducer.

To ensure that the transducer was always in the same position on the pole, once it was mounted the transducer was not removed from the pole until the last bathymetric survey had been undertaken.

Figure 5-2 (Author 2015).

Data collection

Data collection for this part of the project occurred on the following days, the 16th, 17th, 30th of July and the 1st and 3rd of August.

For the purposes of this survey and for the sidescan sonar surveys, the speed of sound in water was entered as 1500m/s. Whilst the true speed of sound in the water of Loe Pool could have been calculated, as is done when surveying bodies of water with greater depths, the shallow nature of the water in Loe Pool meant that the difference between the presumed speed of 1500m/s and the true speed would not produce a large enough error to affect the accuracy and precision of the survey. The speed of sound in water is usually tested when conducting surveys in deep water as changes in salinity and temperature will affect the speed of sound and will need to be corrected for; it is especially important when the sonar beam is passing through different layers of water with differing speeds of sound as these differences have to be corrected for or the return signal will produce a false result (Ainslie 2010).

Surveying the lack entailed rowing the lake to cover as much of the lake's area as possible, an engine was not used as the owners of the lake (The National Trust) did not want a petrol or diesel powered engine due to the noise and potential fuel leaks, and the electric motor used for the sidescan survey was not available during the period the single beam survey was conducted.

The most northern part of the lake was an issue during data collection, as due to the consistency of the lake floor in the most northern highlighted area in figure 5-1, the sonar could not achieve a high enough quality signal return to accept the sounding. This part of the lake was measured using the following steps;

1. The Juno SB SonarMite application and a stopwatch were synched so that they displayed the same time.
2. A survey pole was used to measure the depth, this was possible due to the shallow nature of this part of the lake, the measurement was taken when the pole began to feel resistance this meant that this readings were quite subjective due to the lose nature of the lake floor in this area.
3. The measurement was noted down and given a time stamp from the stopwatch.

One key issue was the pattern in which the boat travelled when conducting the survey, the pattern taken was to travel around the edge of the area being surveyed (usually following as close to the shoreline as possible). Then the boat would be rowed in a grid like pattern, to avoid the problems of figure 3-4 which could lead to the creation of false contour lines.

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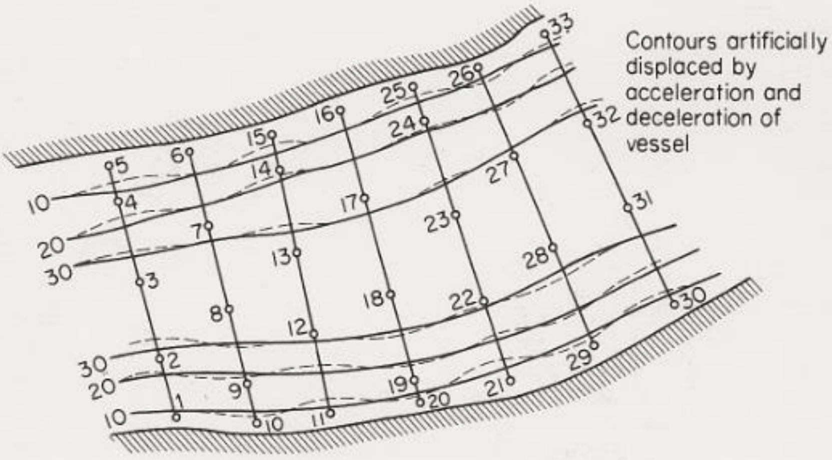


Figure 151. The dangers of transverse sounding lines in channels.

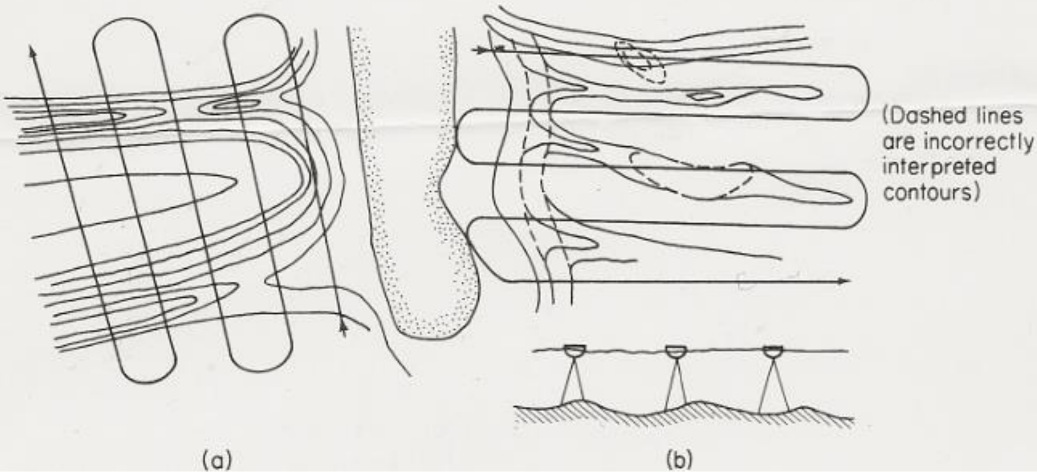


Figure 5-3(Ingham 1975)

Data processing

This section will walk the reader through how the bathymetry data was processed, the finished mapping is in the following results section.

The processing of the single beam sonar data was the most complex process out of the 4 survey techniques. The first series of steps used to process the data are as follows;

1. The data files were exported from the JUNO SB to the author's pc, using a mini-B USB cable, as SOM files.
2. The files were then opened in SonarVista software (the software is free to download from the Ohmex website, although it will persistently ask the user to register the software this message can be ignored). The files were then exported from sonar vista as CSV files.
3. The CSV files were then opened in Excel 2013. In excel the individual files were edited and incorrect coordinates were deleted. As shown in figure 3.1 most of the files had at least 1 coordinate with a latitude or longitude had been recorded as 0. If these entries are not removed then the file is almost unusable in Global Mapper, Surfer, or AutoCAD as it puts a coordinate several thousand miles away from the site and leads to large loading and (especially in the case of Surfer grids) massively distorts the data and any maps produced from the data.
4. The data was further edited by removing all entries with a low data quality value (recorded as a QA or quality analysis value), in this case all entries with a data quality below 32 were deleted, as below the only lower values were 0, 1, and 2.
5. The files were then corrected by adding 0.19 to the depth recorded, as this was the distance between the transducer and the water surface.
6. The depth readings were then further edited to represent the depth below the reference point by adding the distance between the water level of the day on which the survey was conducted, and the height of the reference object.
7. The individual files were then all combined into one CSV file and saved as TRUEDEPTHS, a copy of this file was made and the depth recording was turned into an elevation or MAOD using the WGS84 coordinate system, this was done by subtracting the recorded depth from the MAOD of the reference object. This file was then saved as TRUEMAOD.

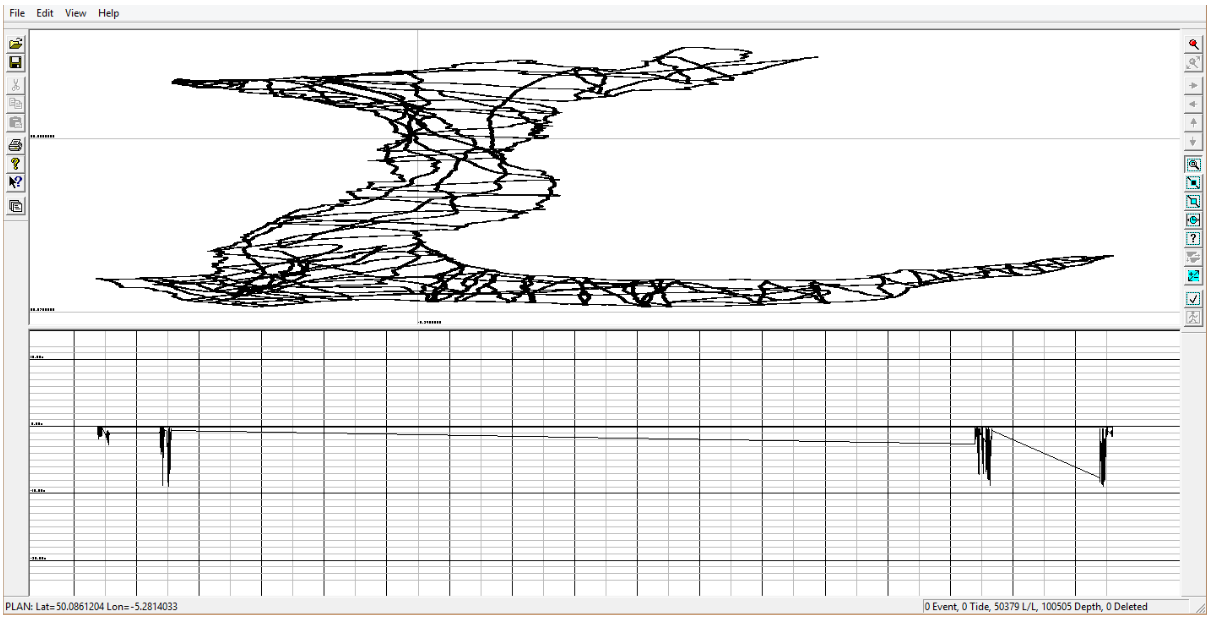


Figure 5-4 shows the combined SOM files open in SonarVista.

	A	B	C	D	E	F	G	H	I
1	Type	Date/Time	Sec	X/E	Y/N	Z/H	Tide	Depth	QA
2	D	16/07/2015 10:17	38.1	-5.29302	50.08332	0	0	0	0
3	D	16/07/2015 10:17	50.4	-5.29314	50.08331	0	0	0	0
4	D	16/07/2015 10:17	50.9	-5.29314	50.08331	0	0	0	0
5	D	16/07/2015 10:17	51.4	-5.29315	50.08331	0	0	0	0

Figure 5-5

Figure 3.4 shows the raw CSV file before editing.

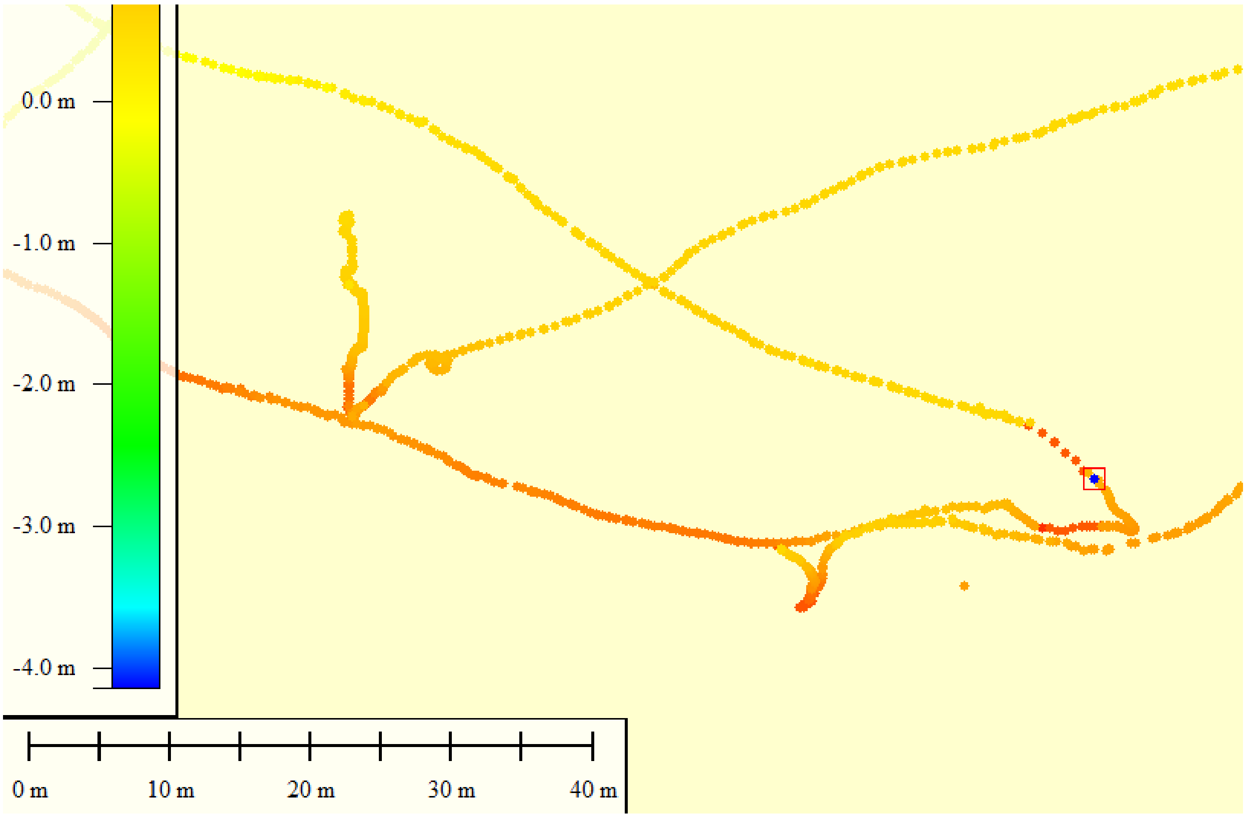
As mentioned in the previous section, one area of the lake had to be measured by hand using a survey pole, the post processing for this area was as follows;

1. The SOM file was converted into a CSV file using SonarVista.
2. The CSV file includes timestamps for each coordinate, this timestamp was matched with the timestamp for recorded depths.
3. The depths were matched to their corresponding coordinates and the file was then saved as a CSV and combined with the other files as per the previously mentioned step 7.

After completing the above steps the individual SOM files have been converted into two files, one with the elevation expressed as depth below the water level, and the other as MAOD in the WGS84 system.

The next step was to examine the data in Global Mapper to see if recorded data was in the correct place, and see if there were any obvious errors such as inordinately deep or high points. The steps are as follows;

1. The CSV files were opened in Global Mapper as Lidar Points so that each point could be selected individually, figure 3.3 shows one of the questionable points being selected to



examine.

Figure 5-6

2. Questionable points were searched for, in this case only 2 points were deemed to be questionable, both points were close to the lake's edge and both were much deeper than the surrounding area (the points will be mentioned in the results section). Figure 3-7 shows the position of these two points within the outline of the lake. These two points were removed and then the file was exported again as a CSV. This process was done for the TRUEDEPTHS file and the TRUEMAOD file.

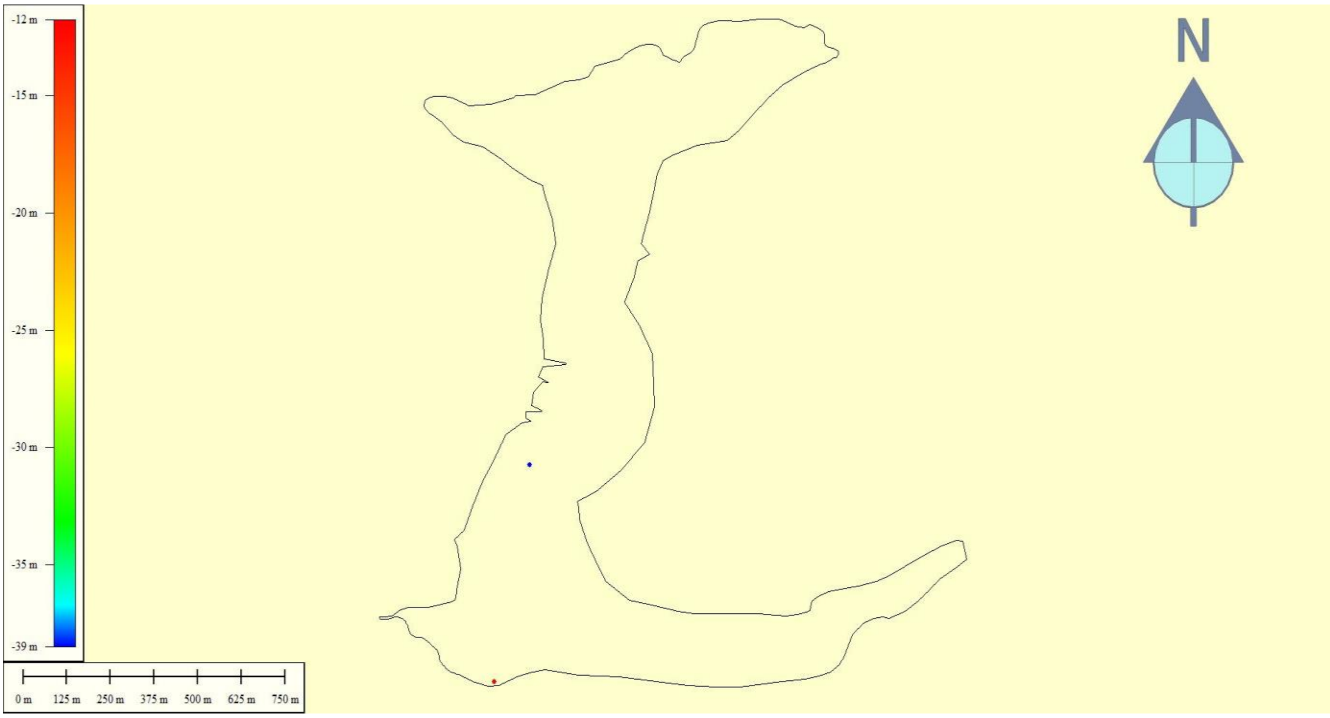


Figure 5-7 Location of the two points with questionable elevations.

3. The edited CSV file was then opened in Global Mapper again as a heat map to get a basic idea of the bathymetry of the lake floor, as shown in figure 3.5.

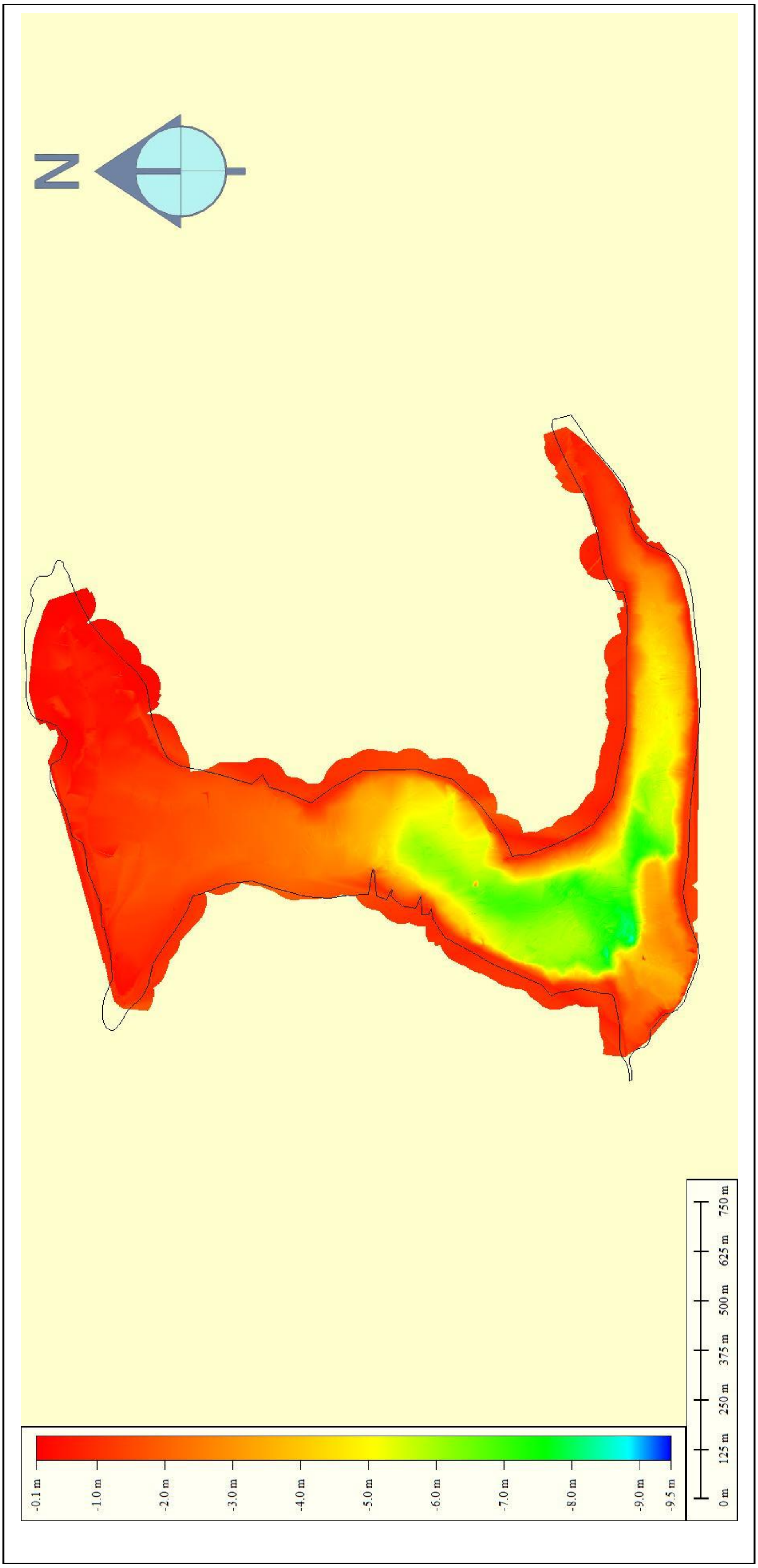


Figure 5-8 heat map of the bathymetric data

The next series of steps turned the data from a series of points into a set of contour maps and 3d surfaces, and in some of these combined the bathymetry data with the edited TELUS data and break line file as previously mentioned. This process was achieved as follows;

1. The CSV file (the steps are the same whether using the TRUEDEPTHS file or the TRUEMAOD file) was selected within surfer through the Grid data menu. This brings up the Grid menu as shown in figure 3.6.

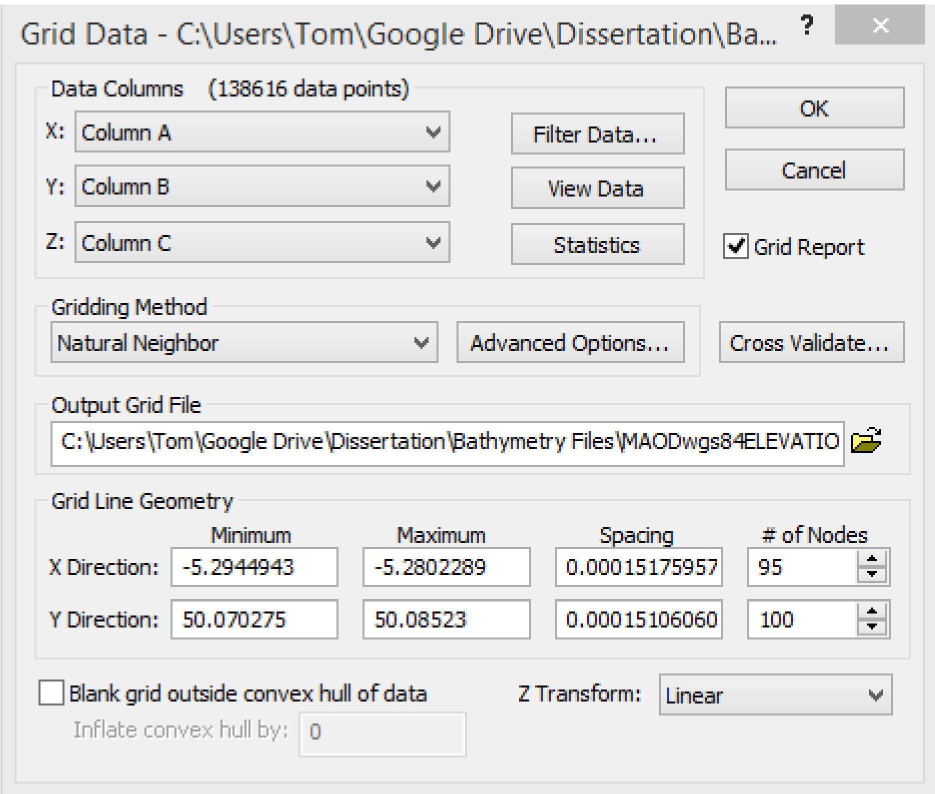


Figure 5-9 Grid menu.

2. Depending on the desired output different spacing and gridding methods could be chosen, in this case all of the grids produced using the Kriging method. This is a method of interpolation which uses a geostistical algorithm to express trends in the data (Golden Software 2015) , it was chosen as it is a very flexible method and after comparing it with other methods such as nearest neighbour and natural neighbour it did not produce false contours while the other methods did (figure 3.8). The node number can also be chosen and affects the spacing of the grid lines when the grid is produced, the higher the number the more nodes/grid lines are produced giving a higher resolution in the final contour map or 3d surface (Golden Software 2014). As shown in figure 3.7 node number and spacing can have a dramatic impact, the aforementioned figure shows one map with only 30 nodes and the other with 1000, the fewer nodes the simpler the map becomes

and vice versa with a large number; high or small numbers of nodes will distort any maps or 3d surfaces produced from the grid.

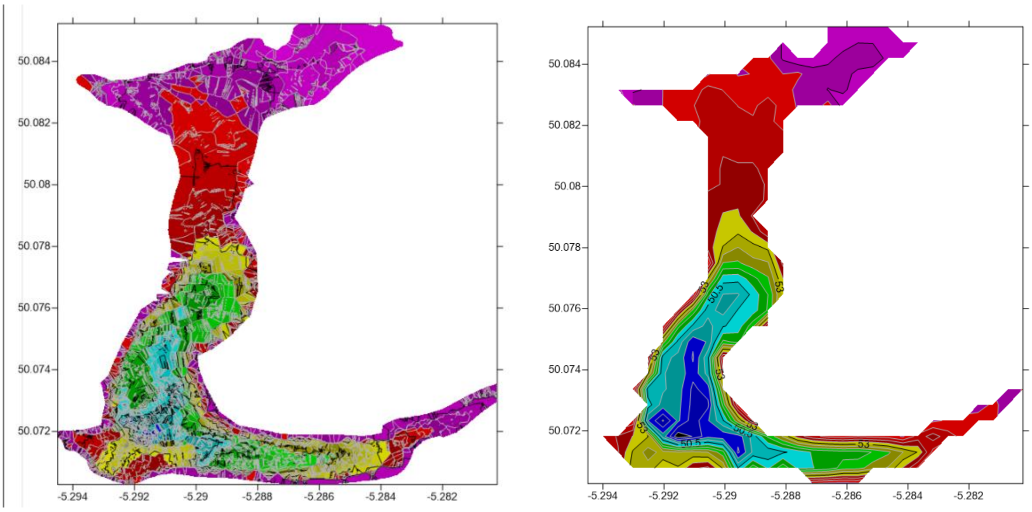


Figure 5-10 A map using 1000 nodes on the left, and one with only 30 on the left.

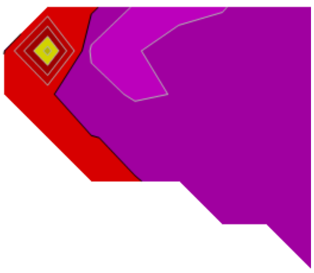


Figure 5-11 (the yellow area is a false contour generated by the Natural Neighbour method, showing a deep point which does not exist when compared with raw elevation data).

3. Once the grid file was produced it was blanked using the previously mentioned break line file, this stops the software generating data outside of the survey area, without this the data will be displayed as shown in figure 3.9.

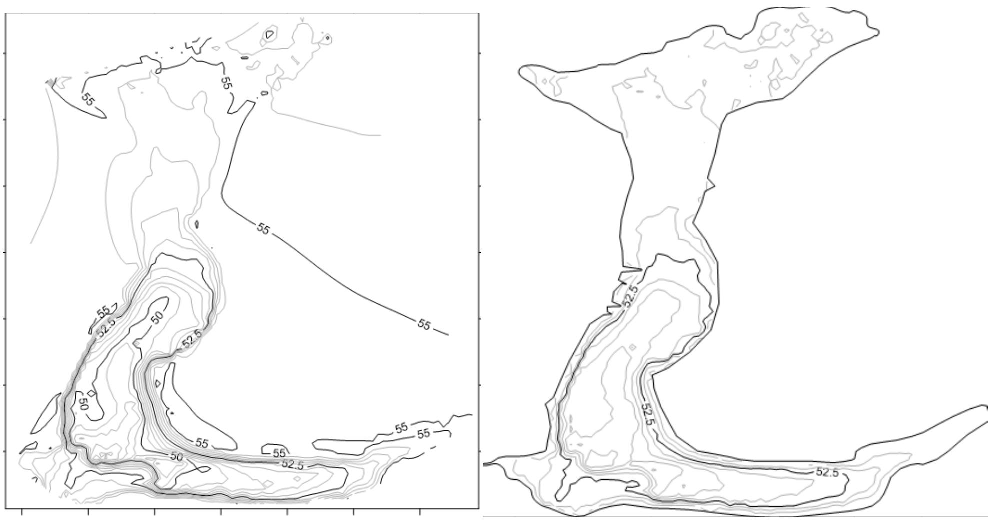


Figure 5-12shows an unblanked image on the left, and a blanked image on the right.

The final blanked grid file can then be used to produce a variety of different map types, but in this project was used to produce 3d surfaces or contour maps. At this point the processing diverges depending on whether the original file was the TRUEDEPTHS file or the TRUMAOD file. If the TRUEDEPTHS file was used, then the contour colouring and fill was selected and a colour scale applied to the image which was then exported as a dxf file to AutoCAD Civil3d where a scale bar was applied before the final map was published. With the TRUEMAOD file the grid file was combined with the previously mentioned TELUS data to show how the lake bathymetry sits within the adjacent topography.

The process of combing the data sets is relatively simple, after the bathymetric data and the TELLUS data has been gridded the user can simply overlay maps and 3d surfaces, this process is very simple and simply requires the user to create new plot file then add a new contour map or 3d surface and from the ‘new’ menu in the ‘map’ menu then select the ‘add’ from the ‘map’ menu and surfer will overlay the two data sets. Contour maps, 3d surfaces can all be overlain together as shown in figure 3-14.

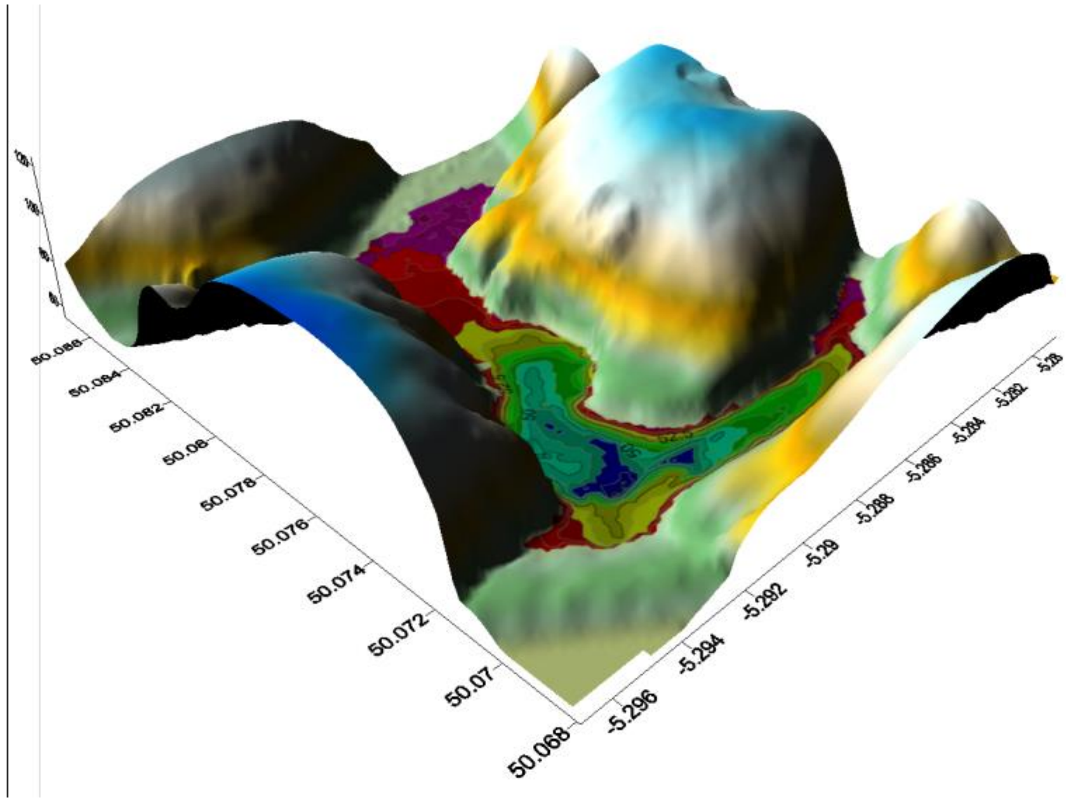


Figure 5-13shows a 3d surface of the surrounding topography with a contour map of the bathymetry.

After this has been done the maps can also be overlain with a georectified image as shown below.

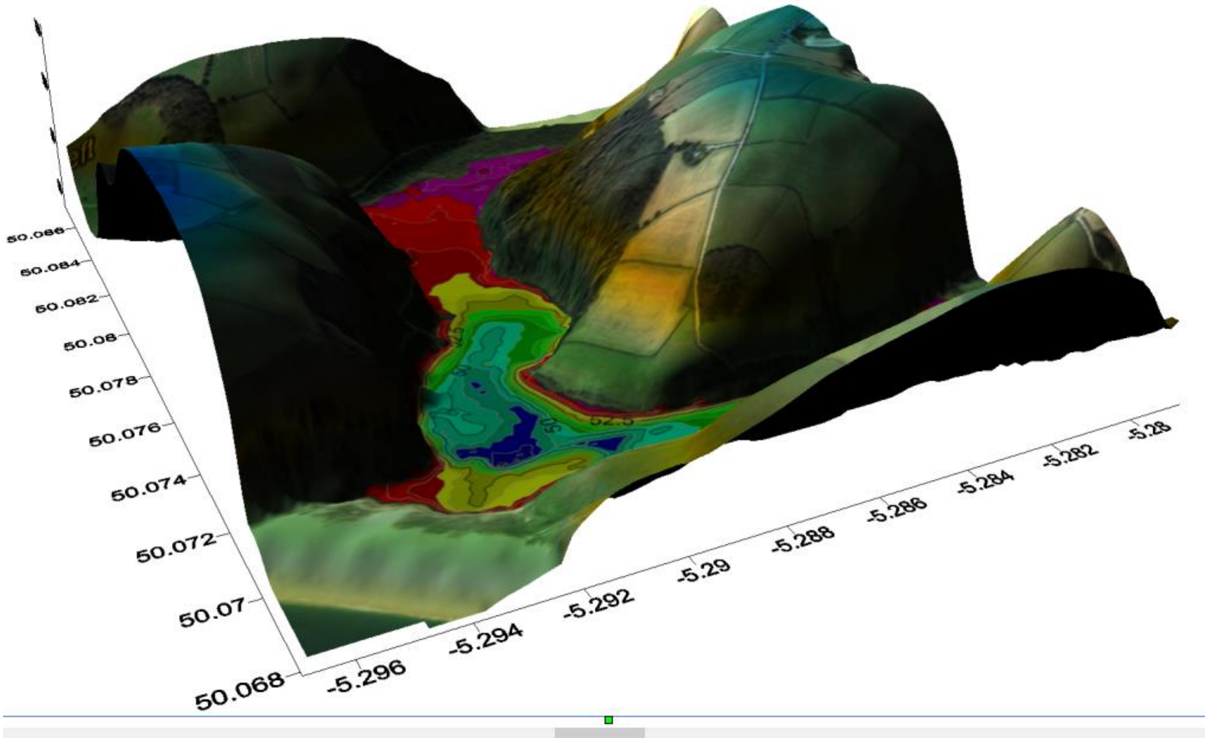
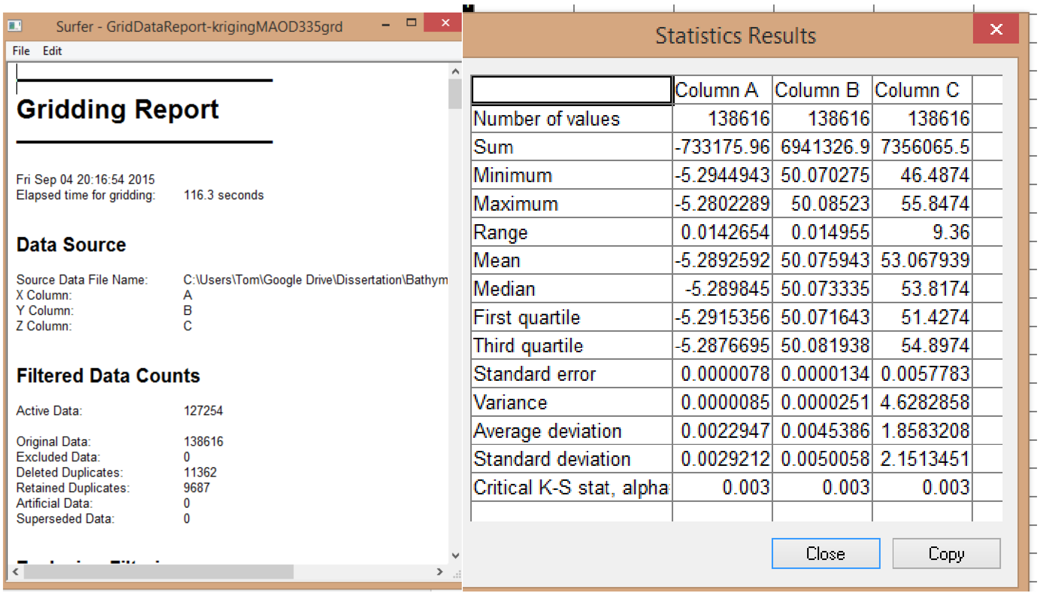


Figure 5-14 Shows a 3d surface and contour map overlain with a georectified image.

The two data sets can be combined into a single grid file by using the 'grid' menus mosaic function, but this option was not used for the final mapping for this project as higher elevation of the surrounding landscape means that the changes in height of the lake (the focus of this project) were flattened. However for future projects this feature should be looked at as it allows the user to combine multiple data sets and produce seamless contour mapping and 3d surfaces.

Surfer was also used to produce data analysis of the bathymetric data, and this will be displayed in the results section in table 1. The data for the aforementioned table was taken from the grid reports which are automatically generated whenever a grid is created and also by using the 'data' menus 'statistics' function which generates a list of statistics, for example the figure shows an example grid report and statistics report. These statistics will be discussed in the results section.



	Column A	Column B	Column C
Number of values	138616	138616	138616
Sum	-733175.96	6941326.9	7356065.5
Minimum	-5.2944943	50.070275	46.4874
Maximum	-5.2802289	50.08523	55.8474
Range	0.0142654	0.014955	9.36
Mean	-5.2892592	50.075943	53.067939
Median	-5.289845	50.073335	53.8174
First quartile	-5.2915356	50.071643	51.4274
Third quartile	-5.2876695	50.081938	54.8974
Standard error	0.0000078	0.0000134	0.0057783
Variance	0.0000085	0.0000251	4.6282858
Average deviation	0.0022947	0.0045386	1.8583208
Standard deviation	0.0029212	0.0050058	2.1513451
Critical K-S stat, alpha	0.003	0.003	0.003

Figure 5-15 shows a gridding report on the left and a statistics report on the right.

Sidescan sonar

The original plan had been to conduct a comprehensive sidescan sonar survey of the lake, but due to time constraints and consistently strong winds and heavy rains only one day of sidescan sonar surveying was accomplished. As such the majority of the sidescan imagery was taken from previous surveys conducted by my tutor Neil Wood, this data was taken between August 2012 and August 2014. There is the chance that some of the objects identified have moved in this time period, so the analysis of the imagery will focus on the type and size of the objects, locations will be given but these should not be used as anything more than very approximate locations.

Equipment

This part of the survey used the same vessel mentioned in the previous section, the unit used to conduct the sidescan sonar survey was the Tritech StarFish 990f. This is a towfish unit which uses a 1MHz CHIRP (Compressed High Intensity Radar Pulse) transmission to produce high resolution images and was specifically designed for relatively shallow water in SAR (Search and Recovery) procedures (Tritech 2012). The unit has a horizontal beam spread of 0.3º which gives the unit an operating range of 35m either side of the towfish, or 70m in total (Tritech 2012) .Alongside this the JUNO SB mentioned in the previous section was also used as a navigation tool during the single day of sidescan sonar conducted this year.

The sidescan equipment setup was as shown in the figure below, with a car battery being the power supply. Additionally a StarFish GPS receiver was connected via a USB cable to the laptop running StarFish Scanline v2.1. A small electric motor was used for the sidescan survey as the a constant speed, or at least constant movement is needed to keep the towfish moving smoothly through the water, the engine was a 55lb thrust trolling motor.

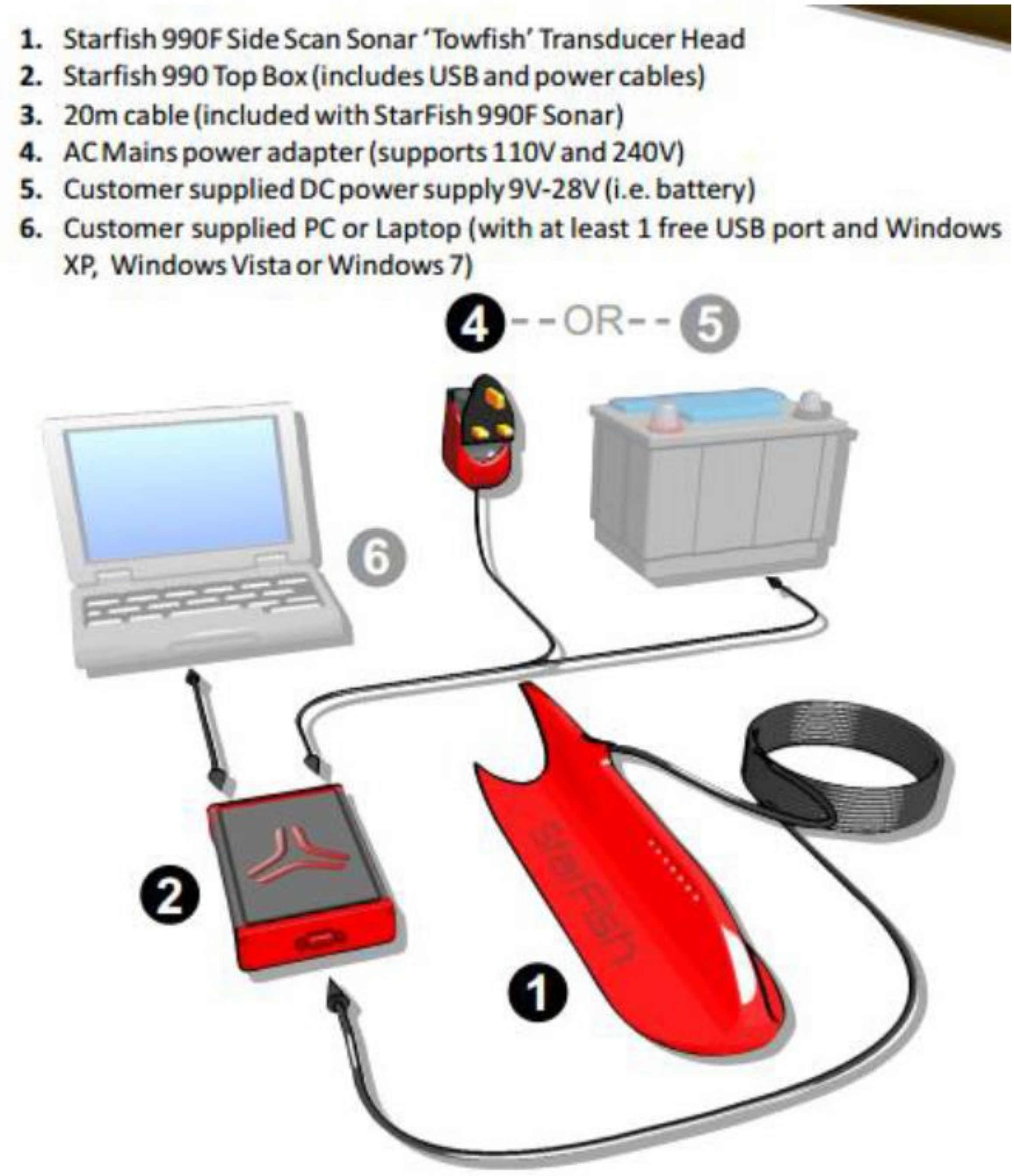


Figure 5-16 Equipment used and set up for the StarFish 990f.

Data collection

The JUNO SB was preloaded with a series of way points (Figure 3-14) which if followed would have enabled the majority of the lake to have been imaged in a single day of surveying. The way points were calculated to ensure that there was a 5m overlap between the ranges of pass of the sidescan sonar. However despite this plan three factors prevented the waypoints being followed, strong winds meant the boat was blown off course regularly, the winds also meant that the electric motor struggled and ran the battery down much faster than anticipated.

Initially the towfish cable was held so the towfish pulled along the starboard side of the boat, however the towfish did not travel true in the water and pulled on the cable as it tried to move towards the centre line of the boat, so the towfish was then moved to underneath the boat with the cable running over the centre of the bow of the boat; the towfish was much more stable in this central position, the cable length was kept short enough so that there was no danger of the towfish colliding with the electric motor. The data from previous years was taken in the same manner, except that the towfish was held over the side of the boat for the duration of the surveys.

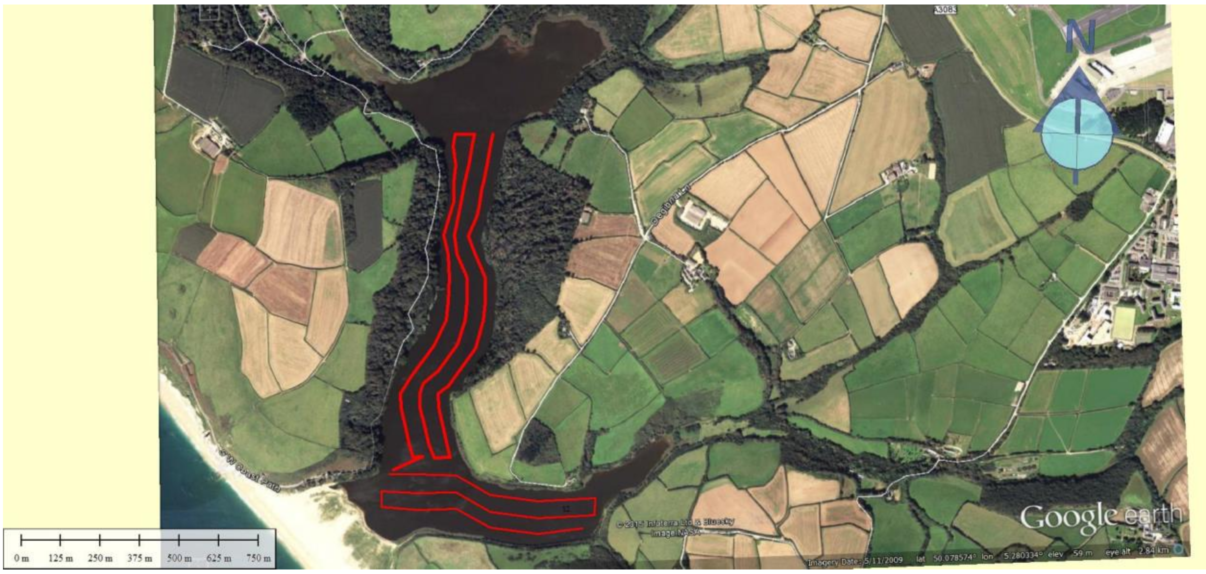


Figure 5-17 Preloaded waypoint paths that were loaded on the JUNO SB.

Data processing

The processing of the sidescan sonar data was straight forward

1. The files were exported from the starfish 990f via USB cable to the author's computer.
2. The files were reviewed using starfish scanline v2.1 (figure 3-18), when objects of interest were seen the coordinates of the object were noted down (Figure 3-19) and stored in an excel spreadsheet and a snapshot was exported of each object (Appendix B).

3. These points were opened in Global Mapper alongside an elevation grid of the lake and the depth and elevation in the vicinity of the object were also recorded in the excel spreadsheet. The map of the objects was then captured from Global Mapper and is shown in Figure 3-20.
4. The spreadsheet data was then placed into the table below (Table 3-1)

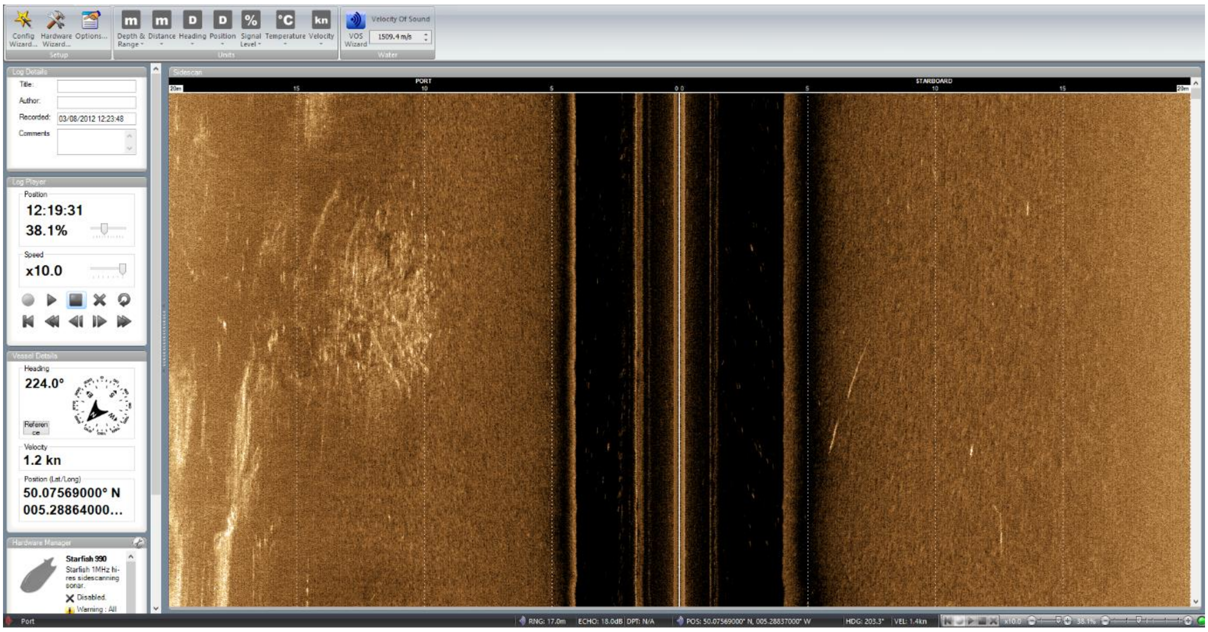


Figure 5-18 A tree is visible on the left of the image, this figure shows how data was seen when review log files.

Figure 5-19 Coordinate data is visible on the right of the image.

The imagery from previous years followed the same steps but skipped step 1.

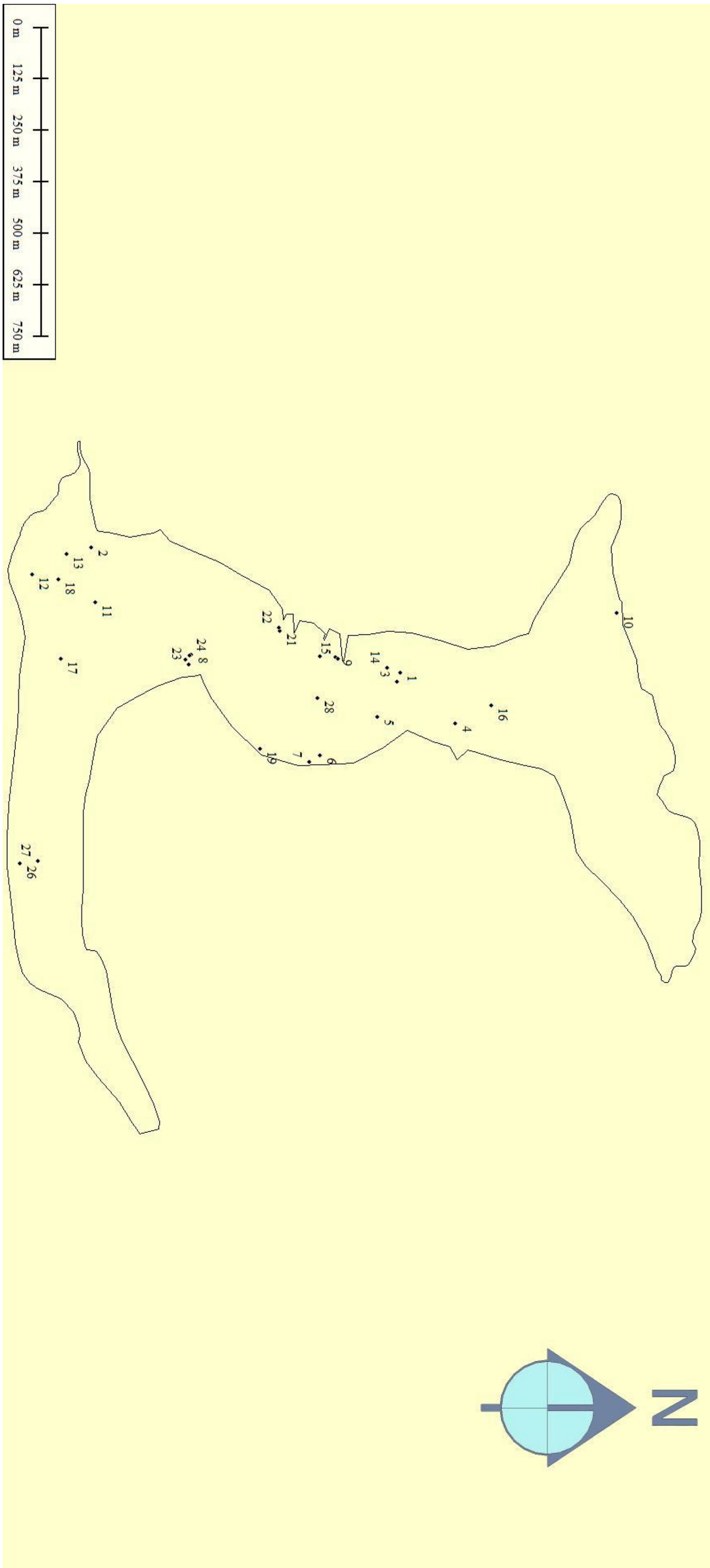


Figure 5-20

Object	Lon	Lat	Elevation (MAOD)	Depth
1	-5.290000	50.078780	53	3.246
2	-5.292720	50.072050	53	3.246
3	-5.289810	50.078710	53	3.246
4	-5.288900	50.079980	54	2.246
5	-5.289040	50.078270	53.5	2.746
6	-5.288200	50.077030	52	4.246
7	-5.288050	50.076800	53	3.246
8	-5.290400	50.074240	51.5	4.746
9	-5.290340	50.077360	53	3.246
10	-5.291300	50.083480	55	1.246
11	-5.291540	50.072140	50	6.246
12	-5.292130	50.070780	53.5	2.746
13	-5.292590	50.071530	52	4.246
14	-5.290110	50.078490	53	3.246
15	-5.290300	50.077420	54	2.246
16	-5.289290	50.080750	54.5	1.746
17	-5.290310	50.071401	52	4.246
18	-5.292030	50.071340	52.5	3.746
19	-5.288340	50.075730	54	2.246
20	-5.290347	50.077030	52	4.246
21	-5.290900	50.076160	51	5.246
22	-5.290980	50.076140	52.5	3.746
23	-5.290180	50.074180	54	2.246
24	-5.290370	50.074200	52	4.246
25	-5.290290	50.074100	53	3.246
26	-5.285840	50.070510	51	5.246
27	-5.285897	50.070895	53	3.246
28	-5.289450	50.076980	51	5.246

Table 5-1

Magnetics

Equipment

The unit of equipment used for this survey was the GEM GSM-19 (Overhauser) magnetometer, this is a high sensitivity proton magnetometer and gradiometer system. It comes with its own GPS receiver which attaches to the top of the antenna, the antennae has two sensors that attach to the antennae as shown in figure 3-21 (the sensors are the two white objects, one above the other). The use of two sensors is what allows the GSM-19 to act as a gradiometer as the magnetic gradient is measured by comparing the differences between the two sensors (GEM 2008). The total magnetic field is also measured by both sensors which allows the system to correct for errors produced by diurnal variation of the magnetic field (GEM 2008). The antennae connects to a data logger in the form of a small computer as shown in figure 3-22.

The GSM-19 was designed to be attached to a harness worn as a backpack would be, with the antenna on the back while the data logo attaches to the front of the harness (this setup can be seen in figure 3-21. However for this survey the harness was not used, instead the antenna was held in the front of the boat, the bottom of the antenna was placed using the dimple where the air intake for the bow floor is to keep the antenna and sensors in the same position throughout the survey. The data logger was placed at the bow of the boat and was covered with a towel to protect it from splashes of water.

Figure 5-21

Figure 5-22 The data logger part of the GSM-19 system (GEM 2008).

Data collection

The data collection for the magnetic survey was conducted on the 28th of August and used the equipment setup mentioned the above section, no ferrous material was aboard the boat. Due to the limited time allocated for this survey the path of the boat was an attempt to investigate three specific areas that had either known anomalies/objects or a high likelihood of containing them. The first area to be investigated was the location of objects 21 and 22 (a sunken boat and a possible pole), the second area was just to the east of Loe bar and was an area that possibly contained a submerged cave (Royal Navy 1976b). In between the second and third areas a zig zag path was taken to try and cover as much of the Loe as possible. The third area was just at northern end of the long straight part of the lake, and was just below an area searched by Royal Navy divers in the 1970's (Royal Navy 1976a) and was identified during the desktop study of Loe Pool to be a likely area for the location of one of the potential air craft wrecks in the lake. Toward the end of the survey it was decided to investigate a semi-submerged boat at the northern end of the lake, while this happened an area of high total magnetic field strength and magnetic gradient was identified and this area was then also investigated.

During the survey the display on the data logger was watched as it displayed the magnetic field strength and magnetic gradient at the current point, the reason for this was that it allowed potential objects to be identified and investigated during the survey, doing this also allowed the outline of an object to be determined. When magnetic objects 1 and 2 were identified the boat was taken over and around the area of the high magnetic readings multiple times so that the size and shape of the object would be recorded accurately, this was done by watching the data display and using it to navigate around areas of high magnetic and magnetic gradient.

Data processing

As the smallest data set the processing of the magnetic data was also the simplest, the steps were as follows;

1. The data was exported from the magnetometer as a text file.
2. The text file was then opened in excel 2013 where all data entries with a quality rating below 50 were deleted.
3. The coordinate data was exported to 2 separate excel worksheets then the total magnetic field (measured in nano teslas (nT) and magnetic gradient (measured in nano teslas per metre squared (nT/m ^{2}). These files were then exported as CSV files.
4. The CSV files were opened individually in Global Mapper as Lidar Point Cloud.
5. The Lidar Point Cloud was then examined to look for distinct areas of magnetics, these areas were then captured as images and exported and will be discussed in the following results section.

```
/Gem Systems GSM-19GW 3106186 v7.0 4 IV 2013 M ew5fl.v7o
/ID 1 file 02survey.wg  28VIII15
/00100 sensor distance cm
/UTC
/X Y elevation nT nT/m sq cor-nT sat time picket-x picket-y
line  000005
 050.0827588 -005.2905274  000001  48139.68  0009.59 59  000000.00 07 S 120843.0 00000N  0000000 N
 050.0827526 -005.2905228  000001  48135.86  0005.24 79  000000.00 07 S 120844.0 * *
 050.0827467 -005.2905170  000001  48137.42  0007.30 69  000000.00 07 S 120845.0 * *
 050.0827403 -005.2905126  000001  48141.04  0010.87 59  000000.00 07 S 120846.0 * *
 050.0827338 -005.2905098  000001  48135.82  0005.25 89  000000.00 07 S 120847.0 * *
 050.0827274 -005.2905034  000001  48134.83  0005.25 79  000000.00 07 S 120848.0 * *
```

Figure 5-23 The raw magnetic data file.

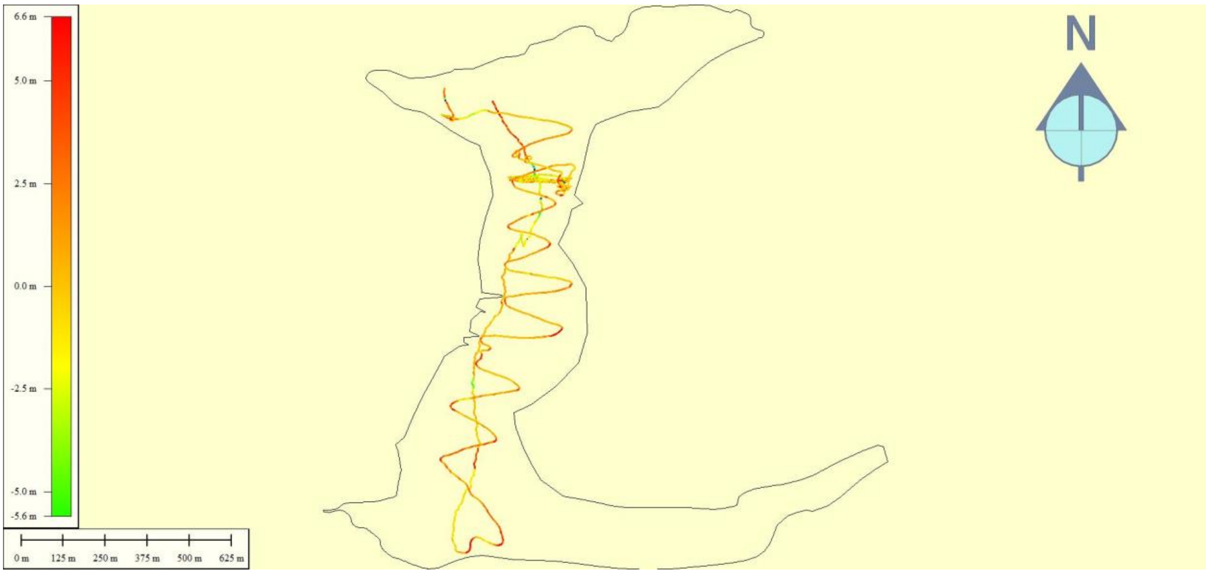


Figure 5-24 Magnetic data displayed as a Lidar Point Cloud.

Chapter 6 Bathymetric Results

	Longitude	Latitude	Depth
Number of values	138616	138616	138616
Sum	-733175.9598	6941326.909	7356065.46
Minimum	-5.2944943	50.070275	46.4874
Maximum	-5.2802289	50.08523	55.8474
Range	0.0142654	0.014955	9.36
Mean	-5.289259247	50.07594296	53.0679392
Median	-5.289845	50.073335	53.8174
First quartile	-5.2915356	50.0716433	51.4274
Third quartile	-5.2876695	50.0819383	54.8974
Standard error	7.8461E-06	1.34452E-05	0.005778344
Variance	8.53338E-06	2.5058E-05	4.628285789
Average deviation	0.002294679	0.004538579	1.858320825
Standard deviation	0.002921194	0.005005801	2.151345112

Table 6-1 Data analysis of the bathymetric data.

The above table shows a tactical analysis created by using the program surfer, this shows that the range between the deepest and shallowest areas of the lake that were surveyed was 9.36m. It also shows the large number of values, 138616 individual xyz coordinates were good points (remained after measurements with low quality (QA) values were deleted).

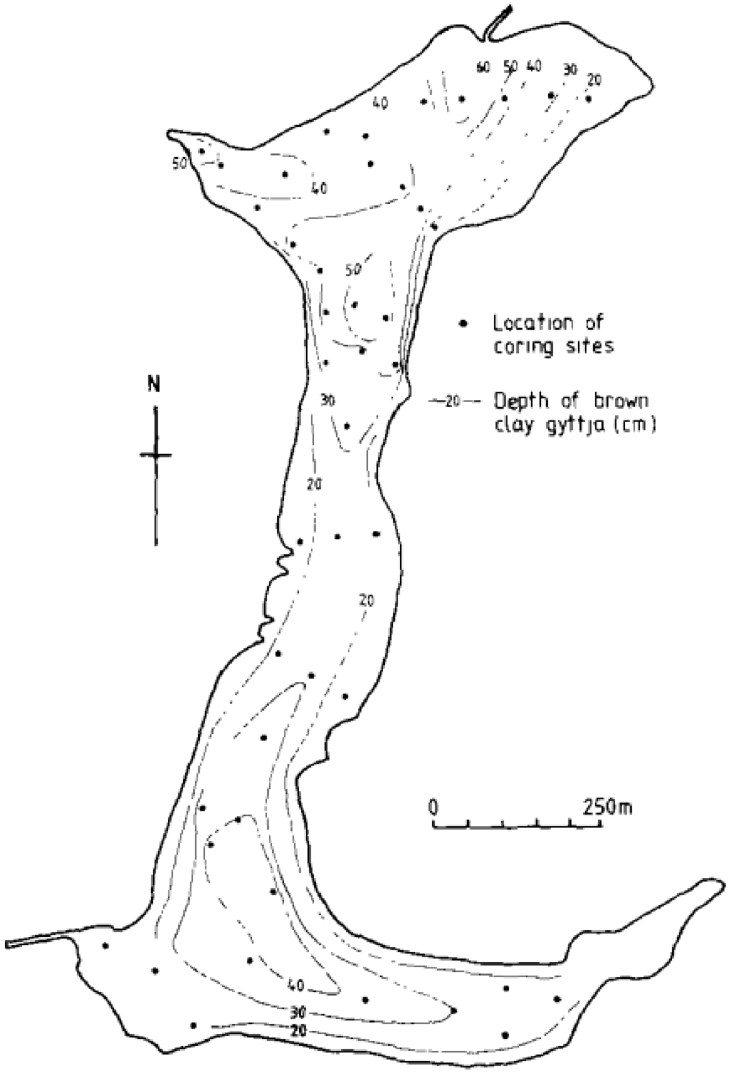


FIG.2 Loe Pool showing location of coring sites, and depth contours for brown clay-gyttja.

Figure 6-1 Location of coring sites from O'Sullivan et al (1982)

The above figure shows a map of coring sites, and one of these coring sites appears to be in the vicinity of one of the points of unusual depths marked in figure 3-7, the most northern questionable point in the figure is in the vicinity of a coring site but as the point measured only -5.86m in depth it, approximately 3 metres deeper than the surround area, is unlikely that it represents a measurement from a former coring site. The second questionable point was -11.76m in depth which makes it far too deep to have been a coring site as there were only cored to a depth of 50cm (O'Sulivan et al 1982). However the second point is in the area where a deep hole leading to an underwater cave was spotted in the past by members of a sub aqua club (Wood August 28th 2015, personal communication). No objects or anomalies can be seen in these areas on the sidescan imagery, and there is no data from the magnetic survey that could suggest anything, the two points had quality ratings of 72 and 84 so it is uncertain why they measured so much deeper than the surrounding area. No conclusion can be drawn from the available data, so it is suggested that further investigations of the two points be carried out, their locations are in table 4-2.

Longitude	Latitude	Depth
50.0703717721	-5.2920983081	-11.76m
50.075265429	-5.2912384133	-5.86m

Table 6-2 Location of the two questionably deep points.

The final outcome of the bathymetry data is the production of useable bathymetric maps, two A3 maps found in Appendix Ewerw one in MAOD and the other in Depth below 56.246 MAOD can be found, these are the highest resolution (1000 nodes by 1000 nodes) contour maps produced as any higher than this cannot be displayed properly without moving to an A2 or A1 size paper which cannot be bound in this document. An A1 map will be made available in the electronic Appendix accessible through a link in Appendix E. One issue that arrived in surfer is that the scale bar is generated from the x axis which for the files in this project was in degrees of longitude, there desired outcome however was a scale bar in metres not one in degrees of longitude. To overcome this the degrees longitude were converted into metres and then that figure was entered into the scale bar menu so that the scale bar cycle spacing was 100m but in degrees of longitude. This number is calculated by multiplying the cosine of the central latitude of the map (in this case that is 50.078) by 111.325km. This number is then divided by the desired cycle spacing (in this case 100m). So the equation for the scale bar in the A3 drawings was as follows;

$$111.325 * \cos(50.78\,°) = 71.44216801$$

$$0.1/71.44216801 = 0.00139973355$$ (GOLDEN SOFTWARE 2014)

The overall scale of the A3 drawings was chosen as 1:4000, simply because it was the largest scale using whole numbers that would fit onto an A3 sized piece of paper. All contour intervals are 0.5m as even when using the A3 paper size, smaller contour intervals did not add any information to the maps, but simply mad the map harder to interpret.

Aside from the A3 Depth map in Appendix E and figure 4-2, the following figures will (unless stated explicitly) MAOD elevation values, all scale bars are in metres. All of the following contour maps unless otherwise stated have been generated producing contours every 50cm/0.5m. The A3 maps were converted into the universal transverse Mercator coordinate system so that surfer could set the scale of the image, but in the following figures 4-2 to 4-10 the coordinate system was the geographic system that Global Mapper generates as these figures are not produced to a specific scale.

Figure 4-2 shows how the high resolution map (using the Depth file) is not effective when displayed at an A4 paper size (as the smaller differences cannot be seen at this scale), this is why the A3 size paper was chosen when publishing the higher resolution maps. The higher number of nodes in the A3 size maps allows a greater resolution of data to be displayed, and shows elevation differences between areas which are hidden when using a lower number of nodes. This can be seen by comparing the following maps which all use a 100 by 100 nodes while the A3 size maps use 400 by 400 nodes, this difference is especially noticeable when looking at the deepest area of the lake at the western end of Carminowe Creek.

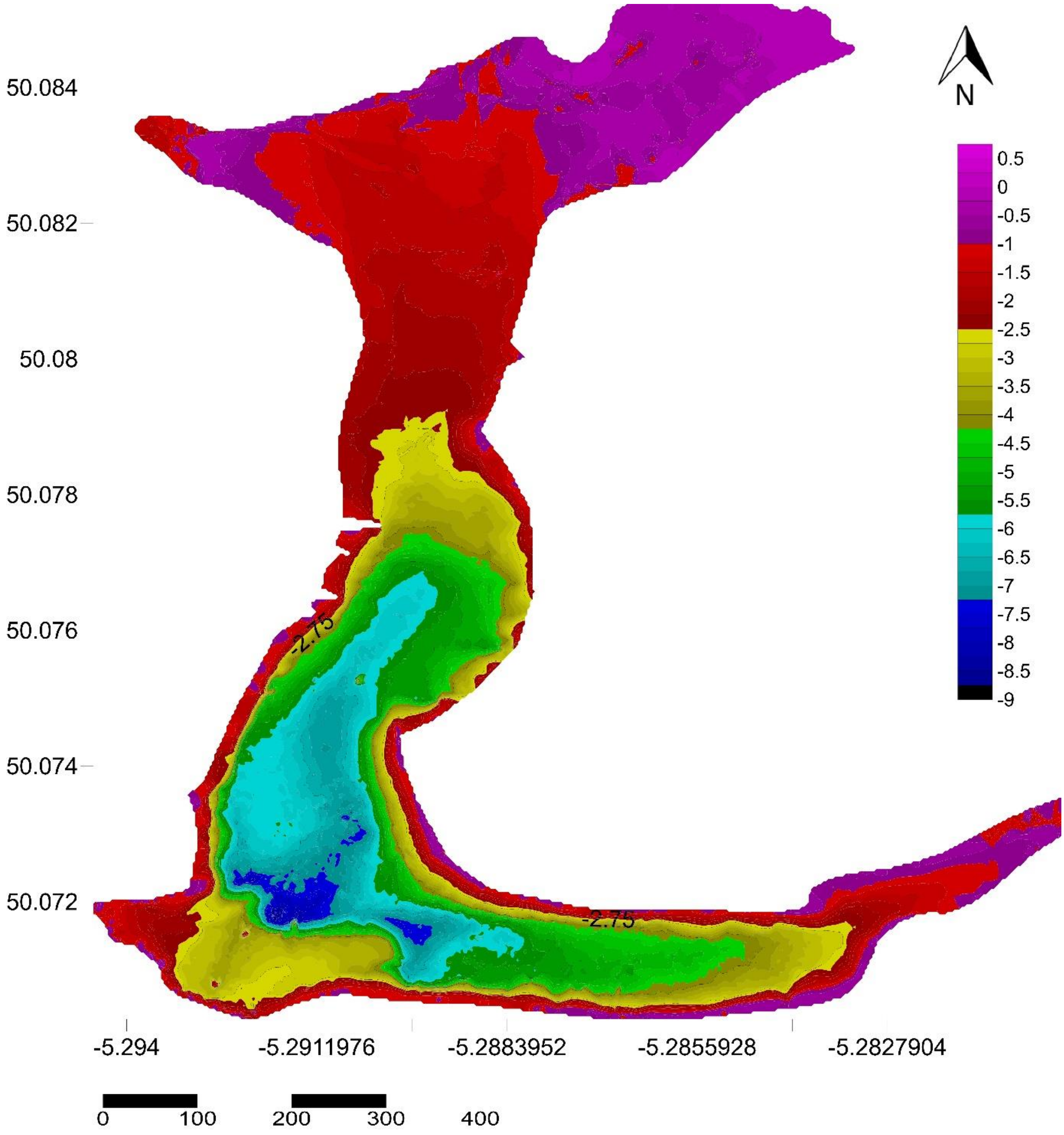


Figure 6-2 A4 scale map using 400 by 400 nodes.

Figure 4-3 shows how the bathymetry looks when displayed as a 3d surface on its own, while figure 4-4 shows how the 3d surface looks when combined with a 3d surface of the surrounded landscape. The first point to make is that by adding in the surrounding landscape surface, the elevation differences in Loe Pool seem much less significant due to the massive variances in elevation of the surrounding landscape (there is a range in elevation of 9.36m in the Loe, while the surrounding landscape has a range in elevation of 69m). This has the unfortunate effect of smoothing out the 3d surface within the Loe, so whilst it effectively shows the surrounding landscape it is not a good method of when considering the focus of this report is the bathymetry of the Loe.

This technique also shows a weakness of surfer, it cannot export 3d pdf files so while you can print or display 3d images in a flat 2d fixed position the file cannot be exported as 3dpdf that another person could move around and investigate freely, instead if someone wanted to look at the 3d surface model they would have to own Surfer ; the lack of exporting 3d pdf files is unfortunate as being able to move the 3d model freely is a very useful feature and allows the person to see how the bathymetry actually appears in the real world. Another issue that it may be possible to overcome using other software is surfer's inability to apply effective scale bars to 3d models as the scale bar has a fixed perspective that will be useless if the angle is not from a birds eye view or completely square with the model.

Figures 4-3 and 4-4 also show the weakness of trying to display 3d data, the main difficulty is that unless very flat terrain is being displayed, there will always be areas of the 3d model that are hidden from view. This means that to effectively use 3d surface images multiple angles and views must be used as shown in figures 4-5 and 4-6 which show different angles from the same surface as figure 4-3.

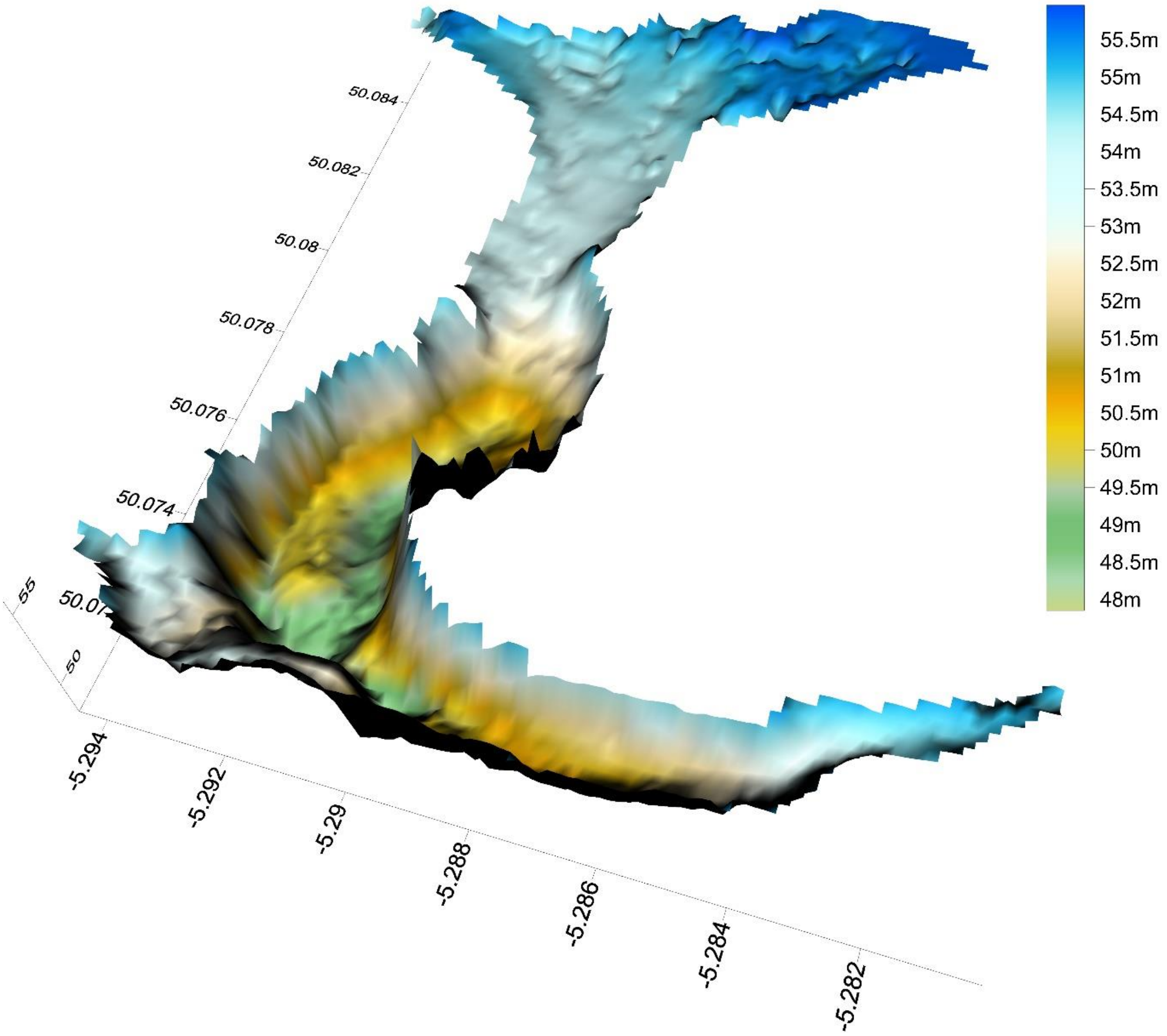


Figure 6-3 A 3d surface of the Loe.

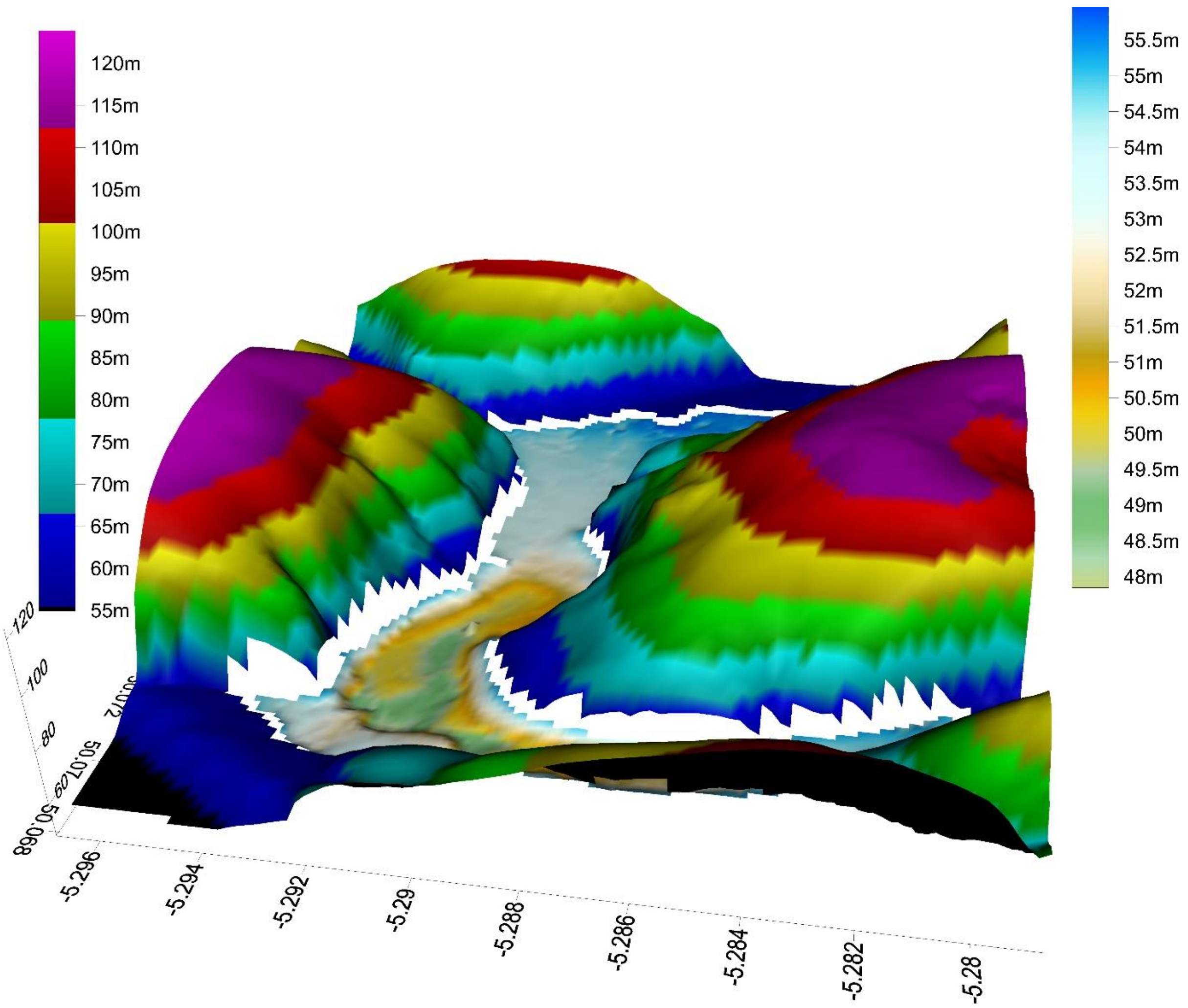


Figure 6-4 Combined 3d surface of Loe Pool and the surrounding landscape.

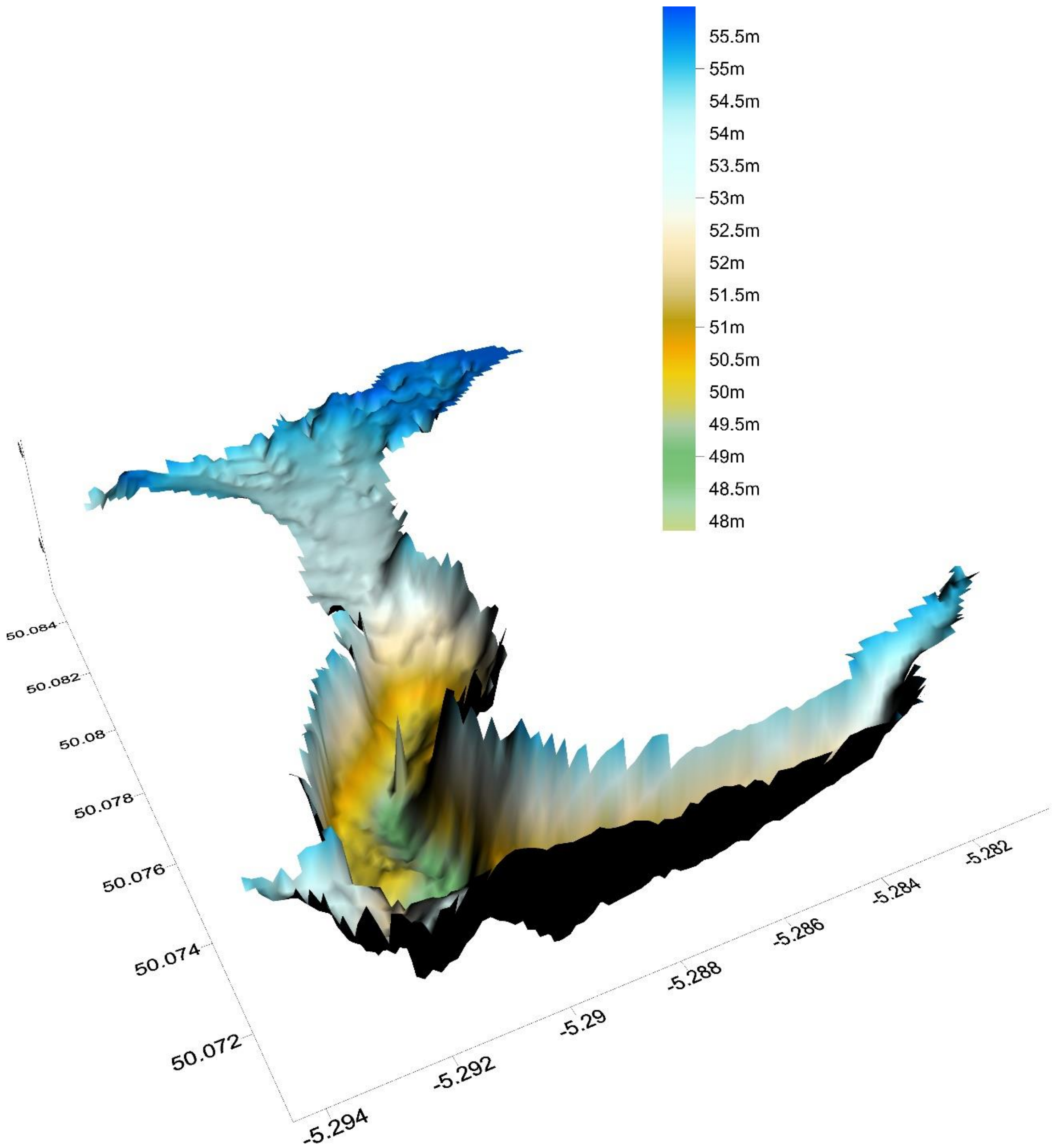


Figure 6-5 A different viewing angle, not the spike in the centre of the lake that is not visible in figure 4-3.

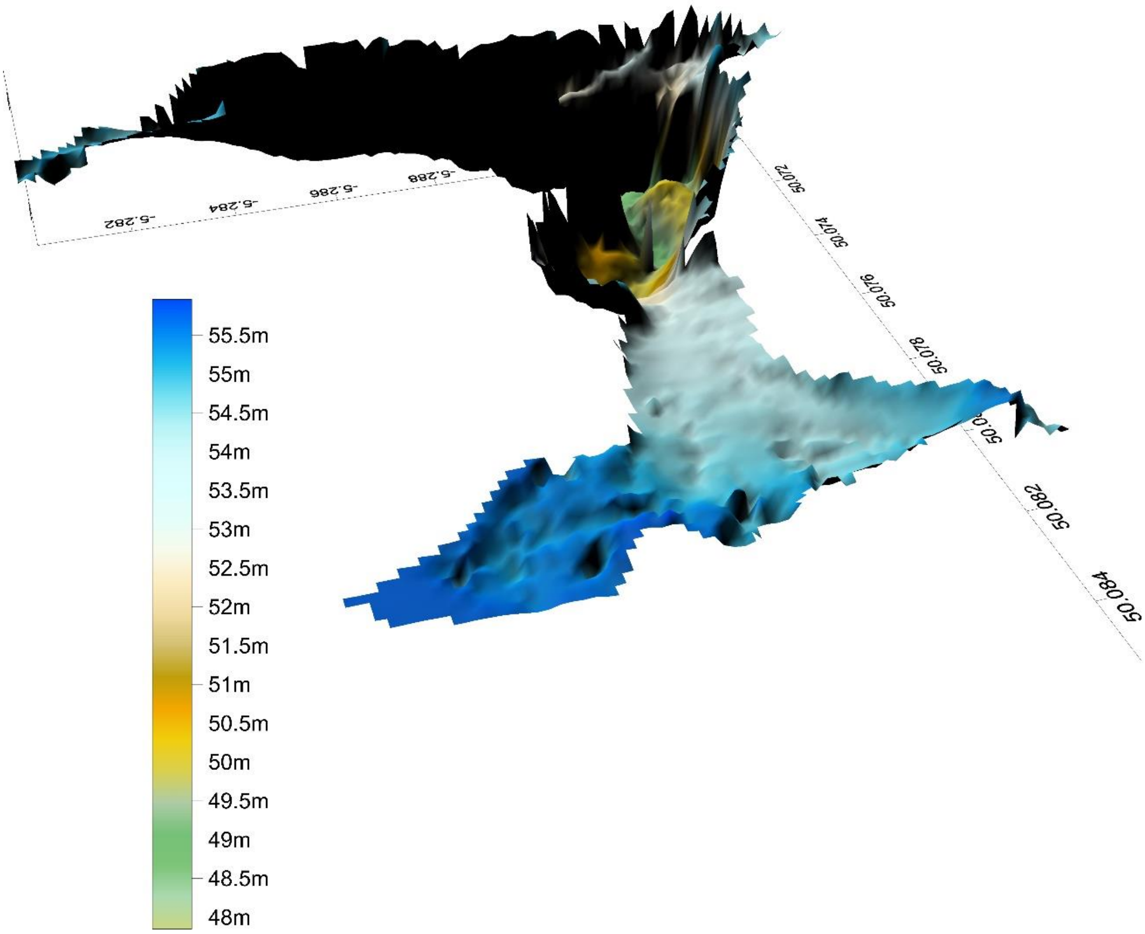


Figure 6-6 Another different viewing angle.

A more effective way of combing the 3d surface of the surrounding are with the lake bathymetry is to keep the lake bathymetry as a contour map (figure 4-7) as this allows the bathymetric data to still be interpreted faithfully without being distorted; this method still suffers from the issue of viewing angles always leaving some aspect of the bathymetry hidden from view. This combination also covers the gaps in data that can be seen as white gaps in figure 4-4.

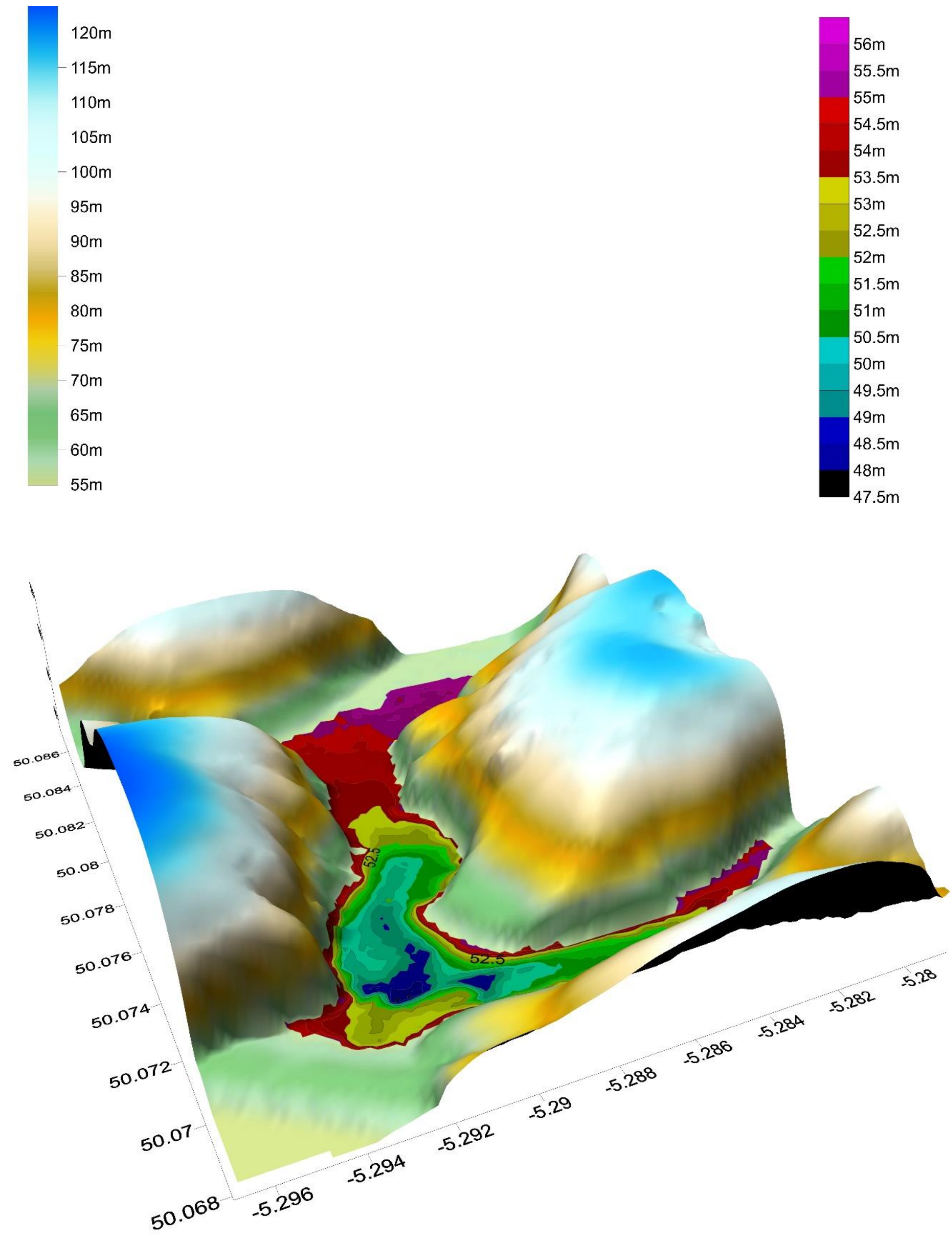


Figure 6-7 3d local terrain and a contour map of the lake bathymetry.

The next figure (4-8) shows the same 3d surfaces and contour model but this time a georectified image has been draped over the local terrain data. This allows the viewer to locate the local topography such as fields, hedges, and buildings and place them within the spatial model accurately.

The main benefit of using 3d models is that it brings spatial data to life, so rather than having to interpret contours the relationship between locations is clearly visible. The three small valleys that bring rivers into Loe Pool are clearly evident, however the use of 3d models is much more effective in an electronic format such as a 3dpdf where the user can move the model at will and examine different viewing angles at will; the technique effectively shows how Loe Pool sits within the landscape.

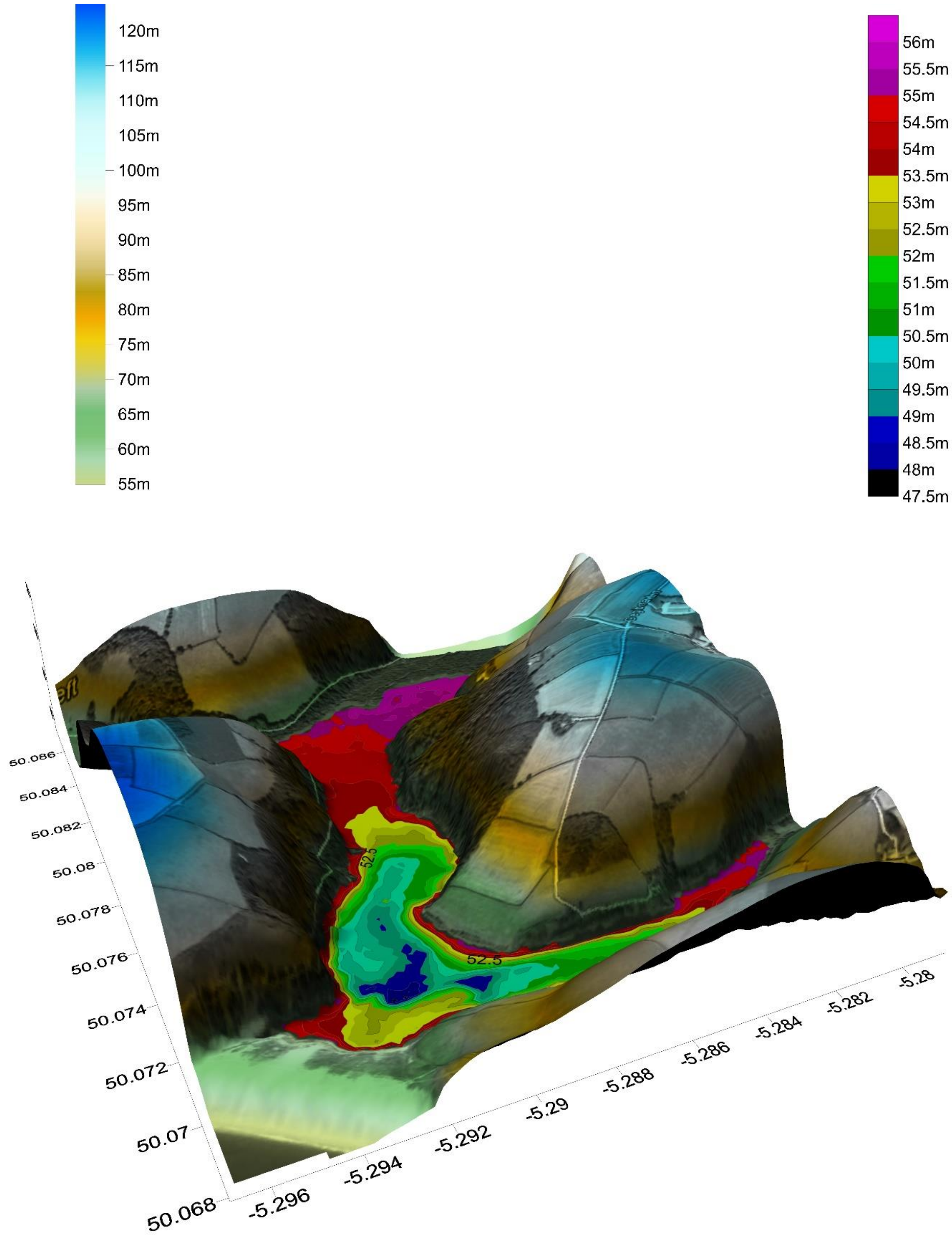


Figure 6-8 3d surfaces with georectified satellite imagery draped over the 3d surface.

Combing the bathymetry contours with contours of the local terrain can also produce effective maps, figure 4-9 shows

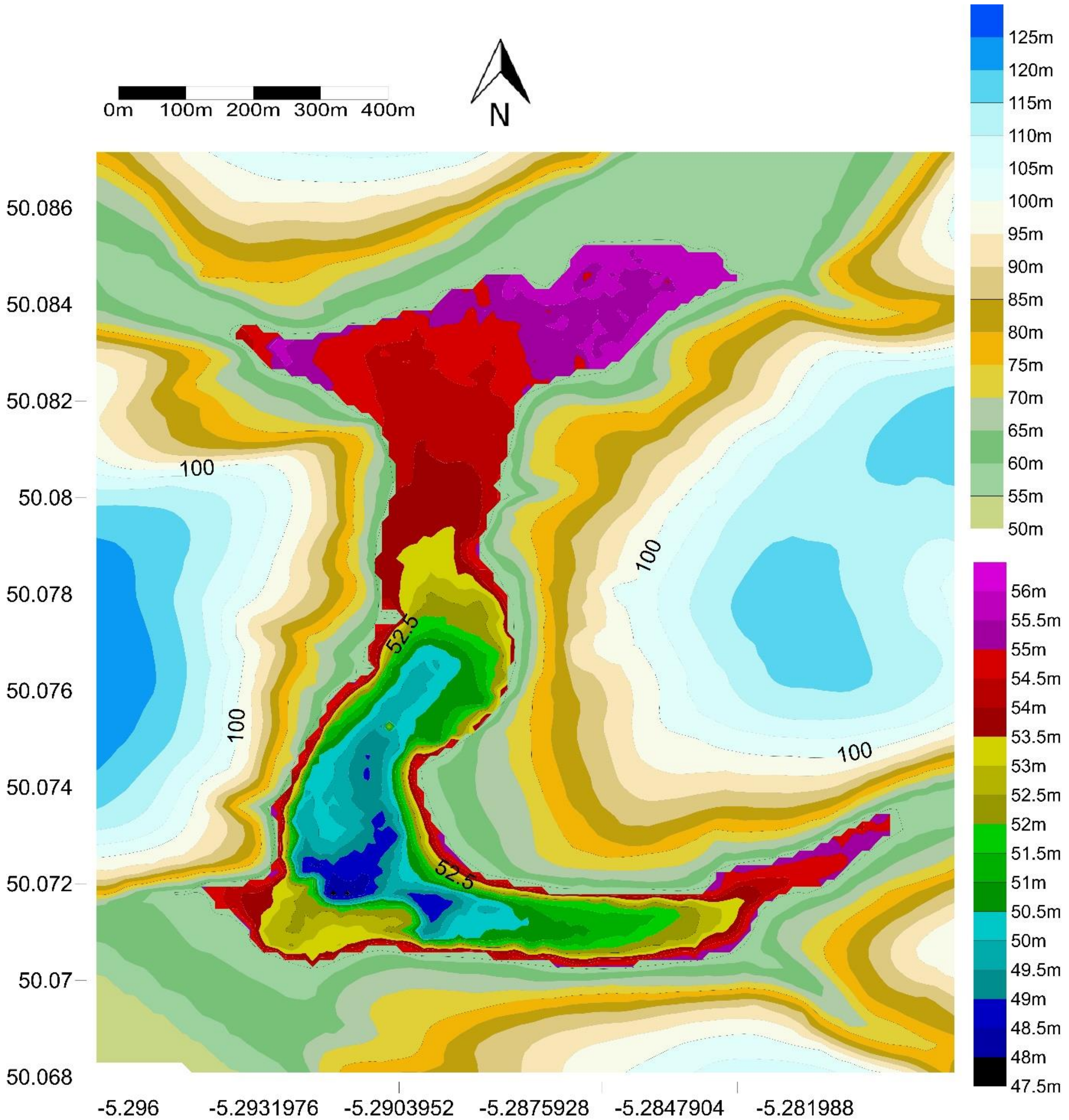


Figure 6-9 Combined bathymetry and local terrain contours.

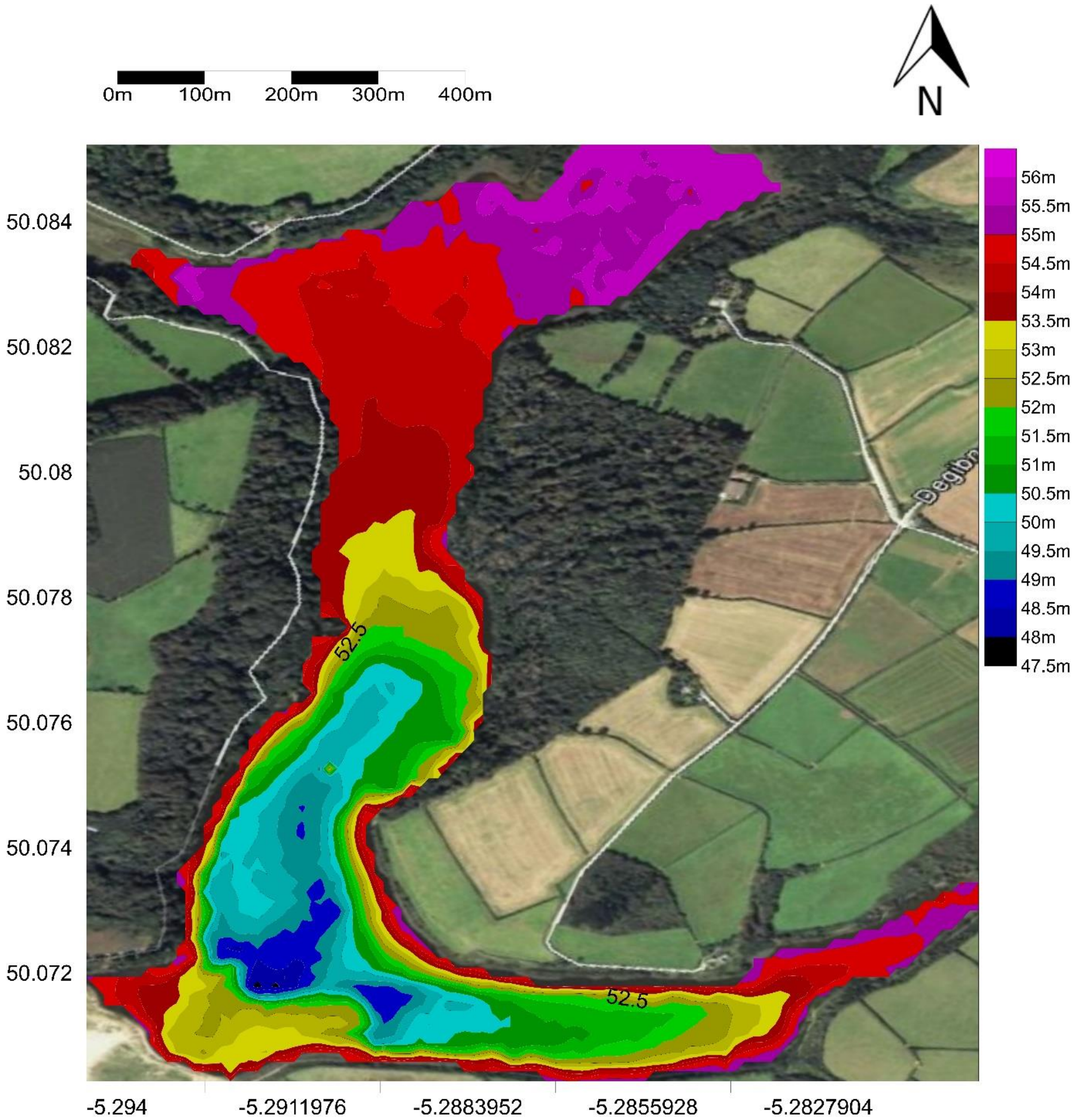


Figure 6-10 Bathymetry contours with georectified imagery.

Using surfer we can also use the bathymetry data to calculate the volume of water within Loe Pool, for this calculation the water level was set as 56.246 MAOD; the volume calculation also used a grid file using 400 by 400 nodes. Surfer produces a large number of different volume calculations, so I have chosen to only include the results from three most commonly used methods (HERBAN and ALIONESCU 2012), as this dissertation is not concerned with the volume of water but in creating a data set from which such information can be extracted in the future. Table 4-3 shows the volume of water when the upper surface or water level, is set as 56.246MAOD (the highest water level while surveying), while table 4-4 shows the volume of water when this is set as 55.284MAOD (lowest water level while surveying).

Volume	Method
1670810.0200226 cubic metres	Cut and Fill, Net Volume
1671030.4102571 cubic metres	Simpson
1670810.0200226 cubic metres	Trapezoidal Rule

Table 6-3 Volume of water when the water level is 56.246MAOD.

Volume	Method
1150924.7580359 cubic metres	Cut and Fill, Net Volume
1150958.1435034 cubic metres	Simpson
1150924.758036 cubic metres	Trapezoidal Rule

Table 6-4 Volume of water when the water level is 56.246MAOD.

Chapter 7 Sidescan Sonar and Magnetic Results

Sidescan Images and map of objects

The majority of the lake seems to be of a homogeneous nature (figure 5-1), as the majority of the material in the lake has a similar signal return strength in dB (Decibel).

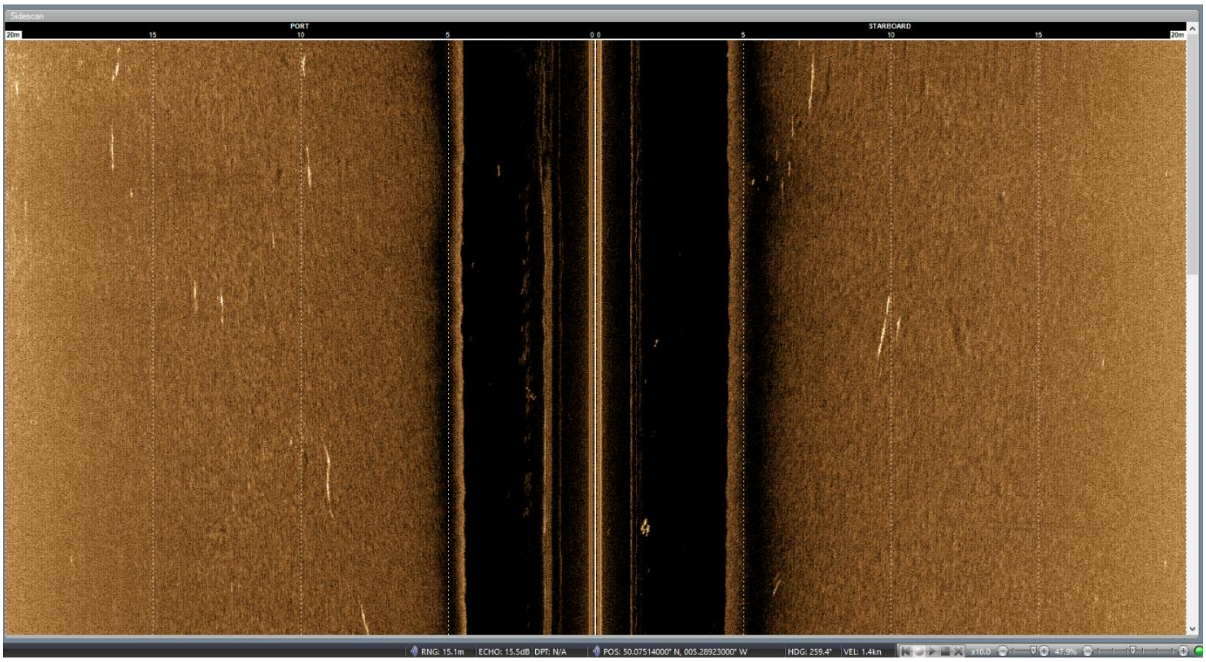


Figure 7-1

However there are large parts of the lake floor which have a stronger signal return, it is most likely that this material consists of rockier material than the homogeneous sediment (Kaeser and Litts 2013). The figures below show several white patches, these patches have a higher signal return (between 35dB and 22Db) then the surrounding area (between 7dB and 13Db). This would reflect the results of Hayes (2013) and Coard (1981) whose investigations determined the top 50cm surface of the lake floor to consist of a dark clay-gyttja. This would also match the classifications discussed in Bearndhart et al (1998) where the acoustic return of mud is described as having a “Weak, light grey to white” and sand as being “Moderate, light to dark grey” which when viewed without a colour filter as in figure 5-3 is what the lake floor resembles. This also matches descriptions given by Royal Navy divers who described the lake floor as being a top layer of easily stirred silt and then immediately underneath a distinct clay surface (Royal Navy 1976a).

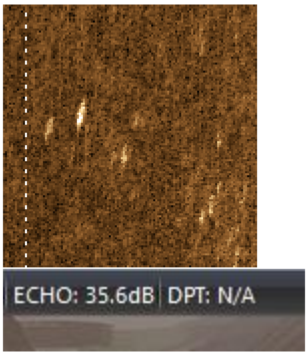


Figure 7-2

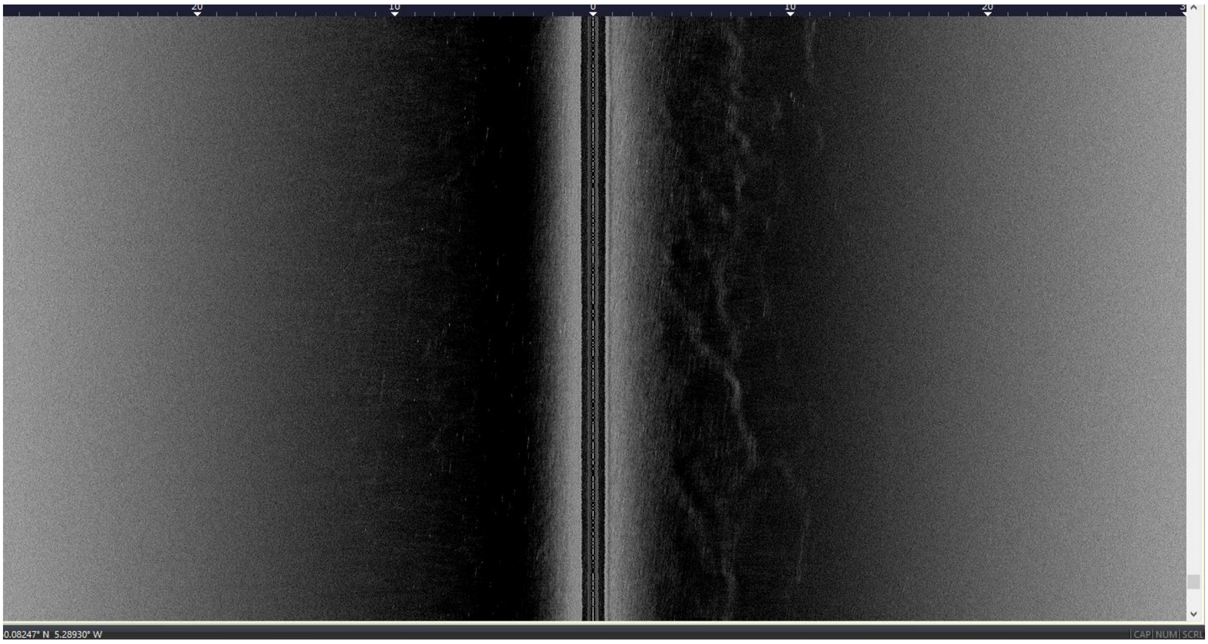


Figure 7-3

The majority of the objects record from the side scan imagery appear to be the remnants of sunken trees and branches, however there are several objects which are potentially or definitely man made. Objects 21 and 22 (Appendix C), a sunken boat and what appears to be a tall pole, are clearly not part of the lake floor. Objects 23, 24, and 25 could potentially be related to former activity in the lake such as the RAE testing during World War 2 as large wooden booms were used to suspend nets for torpedo testing, and the position of these objects would match the position of the targets marked in the map of RAE testing in figure 5-5.

What this shows us is that the lake is relatively free of large objects that could cause issues for divers, vessels using the water, or block the flow of water in our out of the lake. One issue that does arise is that the along the straight edges of the lake there is a large number of semi submerged trees which could harm vessels using the lake (these trees were one of the main safety concerns when conducting the survey as they prevented the inflatable boat from reaching certain areas, as the branches could have torn the skin of the boat and caused it to sink).

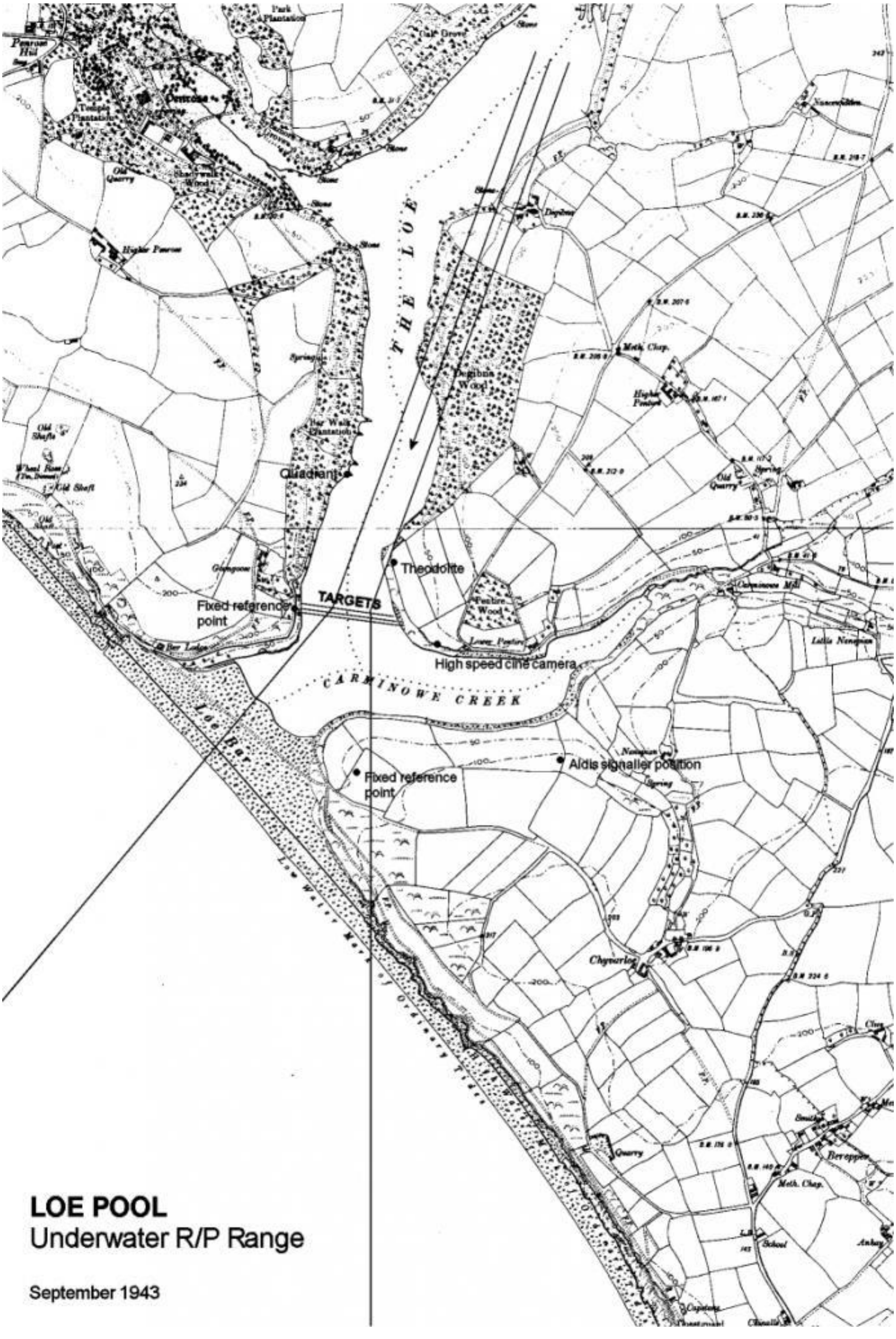


Figure 7-4 A map of the RAE torpedo range at Loe Pool (Kirk 2015)

Magnetics

The first area of investigation, sidescan sonar objects 21 and 22 (a sunken boat and tall pole like object) proved to have negative results as they did not have a noticeable total magnetic field or magnetic gradient when compared to the surrounding area. This suggests that the potential pole maybe wooden which means it may be associated with the wooden booms used to suspend torpedo practice nets (Royal Navy 1976b).

The second area of investigation, the location of a possible underwater cave also showed no noticeable difference to the surrounding area.

The magnetic survey did pass over the deep Loe Bar end of the pool, but did not detect anything. This area is one which is most likely to contain unexploded ordnance as it was down range of the torpedo net targets. Also the area is mentioned as possibly having a plane wreck "in the deep part along towards the Y with Carminowe Creek" (Royal Navy 1976b). Whilst nothing was detected a very small fraction of this area was surveyed so these results should not be taken as a definitive result as absence of evidence is not evidence of absence.

The third area did produce one point of interest and is shown in figure 5-5, this object registered a magnetic gradient of 17nT/m sq. This object has a clearly defined shape, and measures 2m by 2.5m (these measurements should not be seen as accurate measurement of the objects actual size, but merely a rough guide). The object was located in the area identified as one where there may be a plane wreck as it is close to Helston Creek (Royal Navy 1976) and the object could potentially be a part of a wrecked plane, most likely an engine. The depth of the lake floor in the area surrounding the object is 2m or 53.937 MAOD

The second object (figure 5-6) returned a much higher magnetic gradient, up to 45nT/m sq, and measures approximately 3m by 2.5m, the depth in the vicinity of the second object is 0.95m or 54.927MAOD. This object could also be related to the possible crashed aircraft, and its location in the shallow part of the lake matches the description of the lake having crashed and submerged "10 feet down in mud in Helston Creek" (Royal Navy 1976).

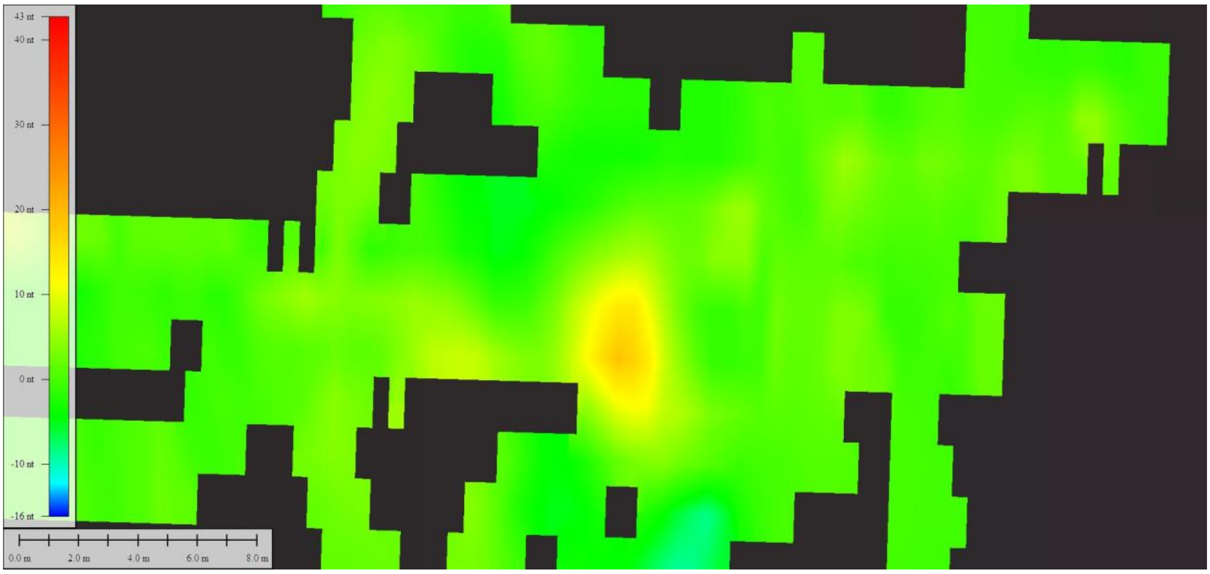


Figure 7-5 Magnetic Object 1.

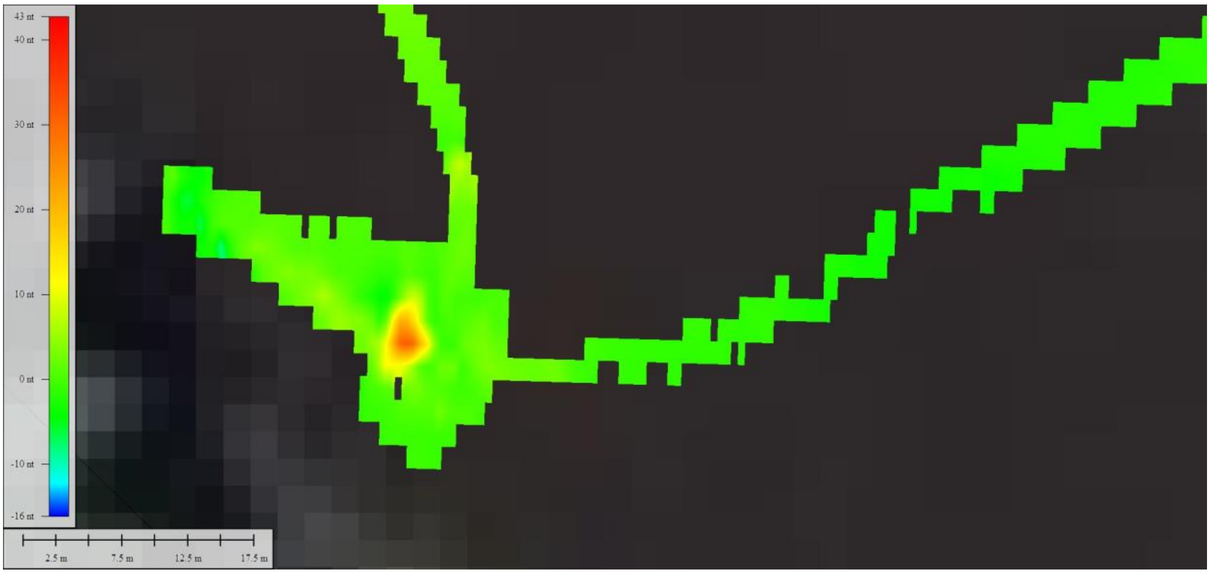


Figure 7-6 Magnetic Object 2.

Chapter 8 Conclusions

Bathymetry

The primary aim of this project was to produce a bathymetric data set that can be used a reference point for future monitoring and investigations, and this aim has been achieved. Despite the difficulties caused by low water levels the vast majority of the site has been accurately measured with only 3 small areas not being reachable at the time of the survey. However these areas have been noted and the very fact that they were above the water level at the time of the survey shows that these are the three areas that need to be monitored more intensively than the rest of the lake as they are the area's most at risk of marshland encroachment.

The second aim of the bathymetric survey was to examine methods of merging the bathymetric data with local terrain data. This also has been achieved as figures 4-7 to 4-9 demonstrate that this can be achieved in a variety of different ways using Surfer 12. The aforementioned figures demonstrated that while combining 3d surfaces does produce an eye-catching image, unless the image can be published using other software as a 3d pdf which the viewer can move around, the most effective way of conveying topography of the two combined data sets is to simply overlay the two contour maps. Overall this aim was achieved and it was shown that bathymetry and DTM data can be combined quickly and effectively. While the techniques have up until fairly recently kept separate when publishing the maps, just because the techniques used to acquire the spatial information differ drastically does not mean the data produced should be kept separate, and in the case of Loe Pool (an inland lake) it makes a great deal of sense to combine the two so that the complete topography of the area can be seen and investigated.

The third aim of the bathymetric survey was to identify areas of the lake most at risk of rising in elevation due to sediment deposition or marshland encroachment. Three areas were clearly identified as having potential issues due to having higher elevations, these are circled in red and blue in figure 7-1. While the areas at the mouths of the rivers that feed Loe Pool were already areas of concern, due to historic marshland encroachment, the bathymetry gives future monitoring and investigations a basepoint from which the rate of elevation increments can be gauged against, so in that sense the survey has been successful. Also the poor sonar signal at the northern most part of the lake indicates a high level of lose silt in the area suggesting a greater amount of sediment is being deposited in this area by the River Cober. Of particular concern is the area circled with blue in figure 7-1, if this area continues to expand and extend southwards it could create a pinch point which will trap sediment and increase the rate of at which the elevation of the lake floor in the area will increase and the rate of marshland encroachment beyond the historical rate of 1 metre per 20 years ((Sherwood et al 1970) (Loe Pool Forum 2015b)).

Sidescan and Magnetic

The main conclusions that can be drawn from the sidescan data is that the lake floor is mainly homogenous with some rocky patches, there is some debris in the pool but nothing man made of significance is identifiable without further investigation (outside of the sunken boat). A number of objects were identified and there locations marked and snapshots of the objects taken (figure 3-20 and appendix c) but a large proportion of the sidescan data was over a year old so cannot be taken as completely accurate, although it is unlikely that the larger objects have moved due to the majority of them being somewhat buried in the lake floor and the lack of strong currents in the majority of the lake.

The magnetic data shows that the GEM GSM-19 can be used to conduct magnetic surveys over shallow water and detect magnetic objects, a much larger magnetic survey is required to identify all magnetic anomalies in Loe Pool. Overall the magnetic survey was successful in identifying two objects for future investigation and proved that a terrestrial magnetometer could be used in shall water hydrographic surveys.

Chapter 9 Future Investigations and Recommendations

Environmental

The presence of blue green algae or cyanobacteria has been an issue in Loe Pool before, and whilst great steps have been taken to prevent further algae blooms and the impact of eutrophication cyanobacteria was spotted in small amounts (figure 7-2). This is already being monitored by the Loe Pool Forum (Loe Pool Forum 2014a), and the presence of cyanobacteria alongside phosphorous levels should continue to be monitored and prevented from rising.

A great deal of attention has already been paid to the sediments of the Loe ((Hayes 2013) (O'Sullivan et al 1982) (Coard 1987)), but there is still potential for projects investigating the lake sediment, especially as the last large scale coring was undertaken in 1981 (O'Sullivan 1982).

Visible Sunken Boat

A sunken boat of undeterminable size was identified and the north eastern corner of the lake and is shown in figure 7-4. This boat should be further investigated to ensure it does not pose a risk to the lake as it appears to be of substantial size and is most likely half sunk into the mud of the lake floor as it is quite shallow (approximately 1.7m deep).

Bathymetry

There are three areas of concern, they are all marked on figure 7-1. The first two areas of concern are circled in red and the third is circled in blue. These areas have sections which were far above the water level when the survey was conducted, (figure 7-3). This was unfortunate as the encroachment of the marsh into the Loe is one of the key issues affecting the site (Loe Pool 2015b), and because of the low water levels I was unable to adequately measure these areas. However the bathymetry gathered can now be used as a reference point for monitoring this encroachment, and with these 3 areas pinpointed it will require very occasional monitoring in a small area to record the encroachment of the marsh and the rising elevation of the lake floor in these areas.

Due to the low water levels during the time bathymetric data was collected, there are two areas of the lake which should be further investigate as elevation data could not be collected as the water level was either too shallow for the boat to access or the lake floor was above the water level at the time. The two main areas that require further investigation are circled in red in the following satellite image (figure 7-1).

Sidescan sonar

Unfortunately due to time constraints and poor weather a complete and current set of sidescan imagery could not be completed for this project, going into the future new sidescan imagery should be undertaken to keep an accurate record of objects in the lake, their movement (if they do indeed move), and new objects falling into the lake. It would be worthwhile to undertake sidescan sonar in the northern shallow end of the lake to investigate the areas where the two magnetic anomalies were found to see if any anomalies can be spotted on the surface of the lake.

Object heights could also be calculated in the future, as the objects were not the focus of this project the time was not spent on calculating the height of objects from their acoustic shadow. This may be awkward due to the varying bathymetry of the lake floor, but using the bathymetric data from this project should make this process easier than solely relying on the sidescan data. To accomplish this the surveyor will need to know how deep the towfish is during the survey ((TRITECH 2012) (WOOD 2015) (KAESER and LITTS 2013)) so a more refined technique than simply holding the towfish cable would need to be devised.

Magnetic

This is the area ripest for future investigation, the small magnetic survey conducted at the end of this project showed two distinct anomalies that could be linked to historical plane crashes. These two objects are in relatively shallow water and would be fairly easy to investigate via diving, grab sampling or probing. A full magnetic survey of Loe Pool could identify more anomalies, with potential UXO at in the Loe due to historical torpedo testing and the possibility of a plane dropping its armament during WW2 as it crash landed (Royal Navy 1976b).

A full magnetic survey would allow any magnetic anomalies to be plotted and investigated, this would allow anomalies to be safely investigated, further desktop study would need to be conducted to see what sort of material the torpedoes tested in ww2 were made from (to see if the material would have a detectable magnetic signature).

Contact should be made with the Royal Navy before or after the survey is conducted if a physical investigation of potential crashed aircraft is to be conducted, this is due to the fact that at least one of the possible plane wrecks in the lake still contains the unrecovered remains of the pilot (VETERANS AFFAIRS 2015).

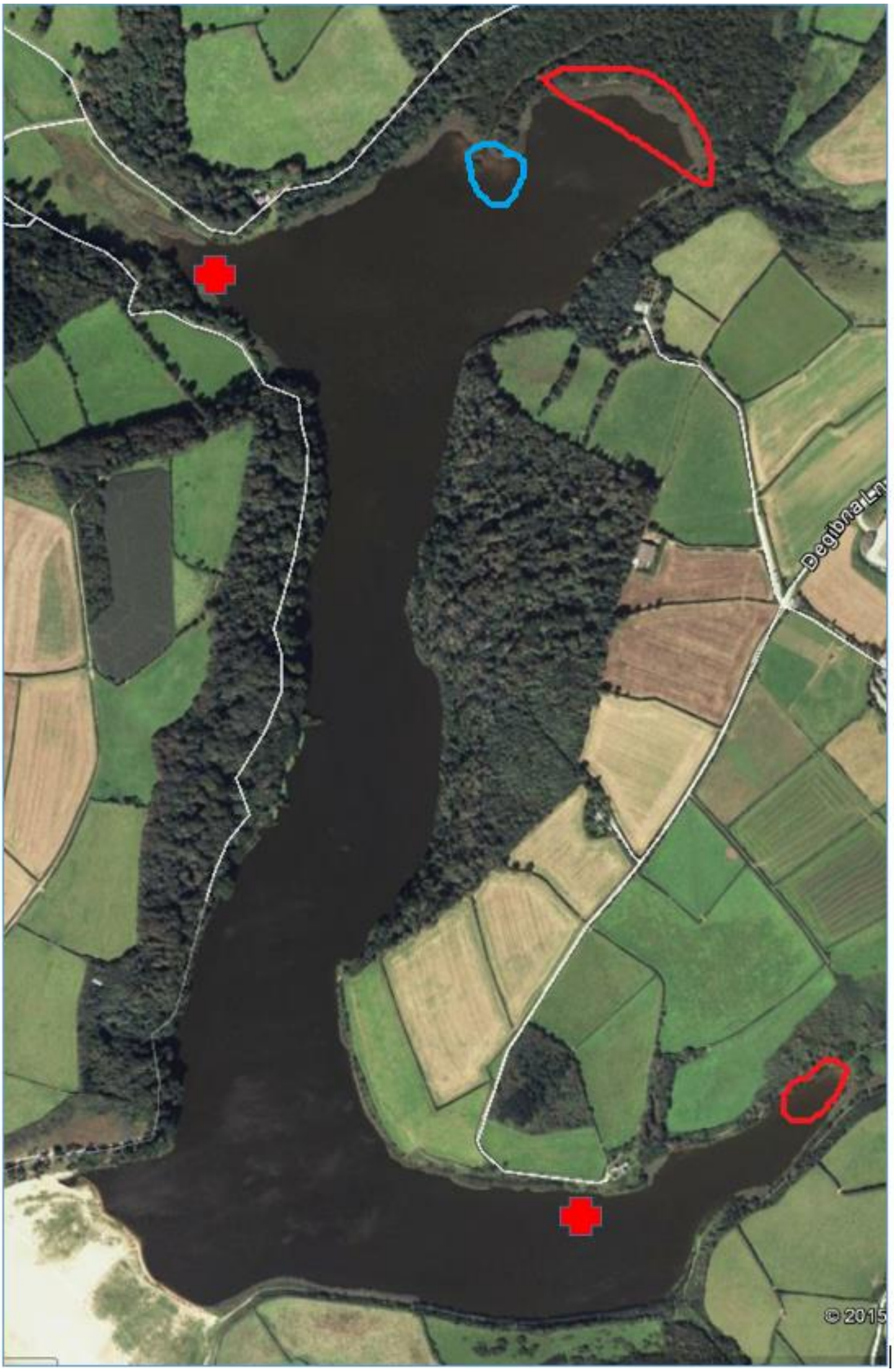


Figure 9-1 Inaccessible areas are circled in red, and areas where cyanobacteria were seen in locations marked with a red cross.

Figure 9-2 Cyanobacteria spotted in Loe Pool (Author 2015)

Figure 9-3 The area circled in blue.

Figure 9-4 Sunken Boat.

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Chapter 11 Appendices

Appendix A

Royal Navy Fleet Air Arm Press Release 03/03/1976

RN
OYAL NAVY

FLEET AIR ARM PRESS RELEASE

ROYAL NAVAL AIR STATION CULDROSE, HELSTON, CORNWALL. 31 March 1976.

NOSTALGIC RETURN TO LOE POOL BY WARTIME PILOT.

Next week, whilst on holiday in this area, Mr Gordon GREEN, DFC, AFC, and his wife - they live at Willow Springs, Old Mill Place, Pulborough, West Sussex - will visit Loe Pool, near Helston, when the RNAS Culdrose Sub Aqua Club plan to continue their search for wartime relics.

Members of the 24 strong Sub Aqua Club heard persistent rumours of aircraft having crashed in Loe Pool during, and shortly after, the war. Aircraft and parts of this era are much sought after by the Fleet Air Arm Museum at RNAS Yeovilton, Somerset, and in view of this unusual cause the National Trust and Lieutenant Commander Rogers, of Penrose, gave special permission for a search by divers to take place.

Since January teams from the Sub Aqua Club, led by Commander Steve LOWICK, Royal Navy, the Air Engineering Officer at Culdrose, have been methodically searching the Pool. There are stories that it is of unfathomable depth, thick with weed, and haunted by strange monsters. To date the divers have covered about one tenth of the Pool and have found it to be as mush as 32 feet in depth, free of weed and the bottom being of sticky clay with a six inch layer of fine silt which stirs up into a dense black cloud when disturbed. The monsters have yet to put in an appearance, however Petty Officer Ross DAVIDSON recently discovered a mysterious dark hole disappearing into the Pool bed which [redacted] will be explored at a later date.

Although no aircraft have been located a number of rockets have and the Club recently made contact with the man who fired them. Mr GREEN was a Farnborough test pilot in 1943 when the 3 inch rocket was under development and part of the trial work was carried out at Loe Pool. Operating from Predannack airfield on The Lizard, Mr GREEN fired the rockets from a Swordfish aircraft at targets on the surface of the Pool, behind which rows of nets were suspended, the holes in the nets enabling the underwater path of the rocket to be traced. A team of Porthleven fishermen were responsible for working the nets, some of whom went on to carry out a similar task at a resevoir in Wales.

Mr GREEN's work was clearly successful as the 3 inch rocket was a vital weapon in the winning of the U boat war.

Cdr. R.S.C. Lowick. 23rd February 1976.

nets,
but more often it was bad and this led to the targets being demolished, and the booms being destroyed. This led to protracted trials, but to prolonged stays in that most beautiful part of our country. Obviously the precise point of firing the rocket was of paramount importance, as was the airspeed and the altitude. The exact point was signalled by the flashing of an Aldis Lamp which one was supposed to watch for out of the right eye whilst aiming for the target with the left. It worked astonishingly well!!

All the boat work essential for these trials was carried out by a team of fishermen from Porthleven under the leadership of one Henty Matthews who was the uncrowned King of Porthleven. Regrettably he died soon after the war but there must be men there still who will remember him. I revisited Porthleven a few years ago and was recognised as 'the pilot' !! Their meeting place was an Inn down on the quay. I really do not remember the name of it, but it was on the left as one drove down to the Village from the main road. As I remember, there must have been 6 or 8 of these fellows and some of them were reasonably youthful and must be in Porthleven yet.

These experiments at Loe would have been carried out with rockets carrying heads of 25lb or 50lb, but after this we moved up to Alwen Reservoir for trials with 1500lb rockets, and the Porthleven men were brought up too, complete with their boats, in order that they could do the same job on the surface. I well remember that they were rather more interested in netting the thousands of trout which by that stage of the war infested the reservoir, than they were in tracking some metallic object making holes in other nets!! Particularly as we were up there on V.E. Day!!

I have many photographs of those days, and I enclose a few which will help you to pinpoint the exact spot where we were shooting our rockets.

There are many other things one can talk about in connection with these activities. If it would help I could spare a couple of days between March 10/12th, or perhaps better between April 5th/12th, and I think a quick stay at the Poldhu with my wife would do us both a lot of good!! We stayed there, a few months before our daughter was born, when I was operating from Predannock - as it then was - doing the trials in July 1943.

I do hope that all of this is of some interest and not just an awful bore.

Very sincerely -

Gordon Green.

Appendix B

Royal Navy Timeline of investigation into potential aircraft in Loe Pool.

AIRCRAFT IN LOE POOL

P.O.(ACM) Goodman put the concept to Cdr.(FT), but the concept was not pursued due Capt. Prices' wish not to disturb anything of interest. There is believed to be a Firefly and a Fury in the pool.

July '75	The AEO spoke to the National Trust (Michael Trinick, Saltram Plymouth), who said to speak to Cdr. Rogers (Penrose) first and get his reaction.
4 Dec '75	The AEO spoke to Cdr. Rogers who said:- a. Make approach through National Trust. b. He knows of one aircraft "10' down in mud in Helston Creek" but not of the other. c. Mr. Brown (ex-Head Keeper) might know more. He is now retired and thought to be living in Breage/Carleen area. d. Fishing interests must be safeguarded and any work done would have to be done during the closed season, ie. before May. e. During the war, Sir William Penny lived in Pentire House, and the Pool was used as an experimental range for torpedoes etc. f. Booms and cables were rigged towards the seaward end. These are now an underwater obstruction which might be cleared.
4 Dec '75	Mr. Trinick not available P.O. Goodman now on 820 NAS.
5 Dec '75	P.O. Goodman says FAA museum may have details of crashed aircraft. he does not know position but believes there to be:- Firefly Seafire Part of a Meteor Mr. Trinick contacted and would like a letter with a spare copy.
18 Dec '75	Letters sent by Captain to Mr. Trinick and Cdr. Rogers. (Pack 259/4)
2 Jan '76	Copy of Mr. Trinicks' letter to Mr. Carslake (NT Bodmin) received.
6 Jan '76	Mr. Carslakes' letter of 5 Jan received. Spoke to Mr. Carslake and arranged to visit him on 12 Jan. Spoke to Mr. Cox (FAA Museum). He has no info on aircraft crashed in Loe Pool. Spoke to Lt. Brown (MOD(N) Historic Branch). All records prior to 1955 have been destroyed, but he has a list of accidents and will extract accidents of the period and pass to Mr. Day (DNAW) asking him to forward relevant A 25 if held.
10/11 Jan '76	Walked east side of pool.

12 Jan '76 Meeting with Mr. Carslake at Bodmin. It was agreed we could start diving on receipt of a letter subject to:-

a. Sites: Loe Bar, Lower Pentire, shore NW of boathouse, seat on bar walk.
b. Key required for shore of boathouse will be provided. (Works all gates).
c. Notify Cdr. Rogers before starting first time.
d. Plot approx depths where possible.
e. Notify NT of significant finds.
f. Large objects to be removed via Loe Bar or Lower Pentire.
g. Publicity: mention special permission of NT and Cdr. Rogers in any preliminary publicity. Speak to NT if any major finds.
h. Clear away by 1 May, except one float to mark aircraft if found.
i. Mr. Carslake will ascertain if Cdr. Rogers is amenable to use of boathouse and mooring.

Mention was made of possible sources of information:-

Alfred Pascoe,	Penrose Hill, (father of present agent).
Bill Cook,	Lower Lanner Farm, (works on NT estate).
Mr. Roberts,	Lower Pentire, (was farm tenant, now retired).
Mr. Jenkins,	Nanspian Farm.
Mr. Nicholls,	Cdr. Rogers agent and NT sub-agent.

Milne spoke to Mr. Roberts (Lower Pentire) and Upper Pentire occupant. They only know of aircraft crashed in mud at Helston end of pool, in marsh. Mr Roberts confirmed that the pool was used as a range, also for seaplanes, and mentioned "Great balls of fire " being dropped into the pool.

19 Jan '76 NT letter of 24 Jan received giving permission.

20 Jan '76 Mr. Carslake rang to say Cdr. Rogers agreeable to use of boathouse if required, and could we fix doors and clear weed . I said we would have a look at these and see what could be done.

23 Jan '76(AM) Spoke to Cdr. Rogers to say we will be diving PM. He said contact Mr. Nicholls for keys to boathouse and gates. Interested to hear of any significant finds. He suggested we contact:-

a. Sir William Penny for 'Montebello' files
b. Gordon D. Green DFC AFC MHCIMA
   Willow Springs
   Old Mill Place
   Pulborough
   Sussex. Tel.2492

Cdr. Rogers also asked us to ward off any one else attempting boating while we are there.

23 Jan '76(PM) Dived at the pool for the first time, working from Lower Pentire. Laid jackstay from concrete block on bar along axis of main leg of the pool (approx 120 mtrs), with a float at each end. Jolly (Dave) and I dived with a 50 ft distance line from deep to shallow down one side of the pool and back the other. The system worked and we snagged one large tree trunk and saw several others, but would be better with a non-floating distance line. The man away from the jackstay needs a compass. Sharky, Davidson and Lonsdale dived after moving deep end of jackstay N a bit, but lost the jackstay and finished up near the outlet stream.

Dive times;-

Lowick	30 mins	8m
Jolly	30 mins	8m
Ward	15 mins	8m
Davidson	15 mins	8m
Lonsdale	15 mins	8m

25 Jan '76 Dived, working off bar, access to Lower Pentire. Two sweeps in SW corner. Snow falling some of the time. Jackstay 153 mtrs (knot 110 mtrs from blob deep end). Distance line 34 mtrs.

Sweep 1: Blob 15 mtrs from point, bears 072 degs from shore end. Shore end 54 mtrs from waters edge at bottom of bank. Depth 4 mtrs at blob.

Dive times:-

Davidson	32 mins	4m
Bart	32 mins	4m

Found line of trees just short of blob.

~~Sweep~~ 2: Shore end 55 mtrs along shore. Blob bears 072 degs

Dive times:-

Lowick	44 mins	7m
Ward	44 mins	7m
Redmond	44 mins	7m

Found trees with branches just before blob. Some before boat.

Mr. Pascoe visited during afternoon.

4 Feb '76 Ships divers covered remainder of bar end of pool. (sweeps 3 & 4). Found 2 bottles (Hamiltons).

8 Feb '76 Started working back from SE to NW in sweeps 5,6,7.

Sweep 5:

Dive times:-

Redmond	34 mins	6m	
Peach	34 mins	6m	
Gardener	34 mins	6m	(LH side).
Ward	12 mins		
Macdonald	12 mins		
Redmond	12 mins		(RH side).

Peach surfaced after 15 mins having lost the jackstay.

Sweep 6:
Dive times:-
Ward 40 mins 6m
Macdonald 40 mins 6m
Sweep 7:Jackstay badly positioned.
Dive times:-
Lowick 40 mins 8m
Rittey 40 mins 8m
Position of concrete post measured, 89 mtrs from hedge, 7 mtrs from edge of pool. Compass seems a bit suspect from plotting sweeps and bearings. Parts of 3" rocket found (tail and fin), also stoneware demijohn and Dutch gin bottle, both with broken handles.

19 Feb '76 Wrote to Mr. Green (wartime pilot who fired rockets into the pool).

22 Feb '76 **Sweep** 8: To fill in gap at each end of sweep 7.
Dive times:-
Redmond 30 mins 8m
Davidson 30 mins 8m
Peach 30 mins 8m
Sweep 9: Base 7 mtrs W of concrete post, line to Nearest point of Mr. Roberts fields into pool.
Dive times:-
Ward 30 mins 7m
Kitchen 30 mins 7m
Gardener started but surfaced with valve trouble and then cramp.
Ward found a rocket embedded deep in the mud, this was marked with an applering.
Sweep 10: Base 37 mtrs from concrete post, line to small gravel beach halfway along E shore of pool. Blob dragged under. Jackstay shortened to 110 mtrs.
Dive times:-
Lowick 36 mins 8m
Macdonald 36 mins 8m
Houghten 36 mins 8m
About a dozen bottles found, 4 good coolds(?), all at SE corner. 3" rocket warhead left in SW corner with float. Lorry driven onto bar at SW end, also cars.

29 Feb '76 Dive operated from E side of bar.
Sweep 11: Circular sweep, 44 mtr distance line.
Dive times:-
Ward 20 mins 8m
Davidson 20 mins 8m
Davidson saw "black holes" in bottom; bottom went down. Visibility reduced to nil, but he did not go into it. Position where shaded black on plan.
Sweep 12: Jackstay laid right pool, sweep done along S side of it, from W to E.
Dive times:-
Lowick 35 mins 8m
Redmond 35 mins 8m
Lonsdale 35 mins 8m

Bottle hunting at SE corner of pool yielded 2 coolds to Redmond.

7 Apr '76 Press Day!, but only the Packet reporter turned up. However Mr. Gordon Green (wartime Farnborough test pilot who fired rockets into the pool) was there, and was interested to see the rocket that

was recovered after being dug out by R. Davidson, (rocket found on sweep 9). Rocket found on 22 Feb brought out. Mr. Green said it was not one of his. The consensus was that it was a practice bomb (left in the pool). Mr. Green believed that an aircraft crashed in the pool towards the Helston end later in the war.

9 Apr '76 Spoke to Mr. Cowling who had contacted us as a result of a newspaper article. (neighbours Tel. St. Austell 2869). He was an RAF crash investigator in the war. He knows only of a Mosquito crash at Chyvarloe Farm.
Mosquito Mk. 30 ser. no. MM745 446 Sqd Predannack
Engines: Port 159037/446329
Stbd 158567/446094 Merlin Mk. 76
Aircraft burned out; armament may have been ditched in pool.

11 Apr '76 Dived in pool. Attempted to locate 'hole' found by Davidson 29 Feb, without success. Echo sounder used and 360 deg search carried out by Jolly and Peach. Then moved to N end of pool.

Sweep 13:
Dive times:-
Jelbert 27 mins 3m
Treloar 27 mins 3m

Sweep 14:
Dive times:-
Redmond 40 mins 3m
Bowles 40 mins 3m

Sweep 15:
Dive times:-
Rittey 40 mins 3m
Hatch 40 mins 3m

360 deg search
Dive times:-
Jolly 20 mins 8m
Peach 20 mins 8m

Austin assisted with boatwork and laying the jackstay. Jackstay and points of sweep 12 marked with white posts. Jackstay lifted at the end of the day.

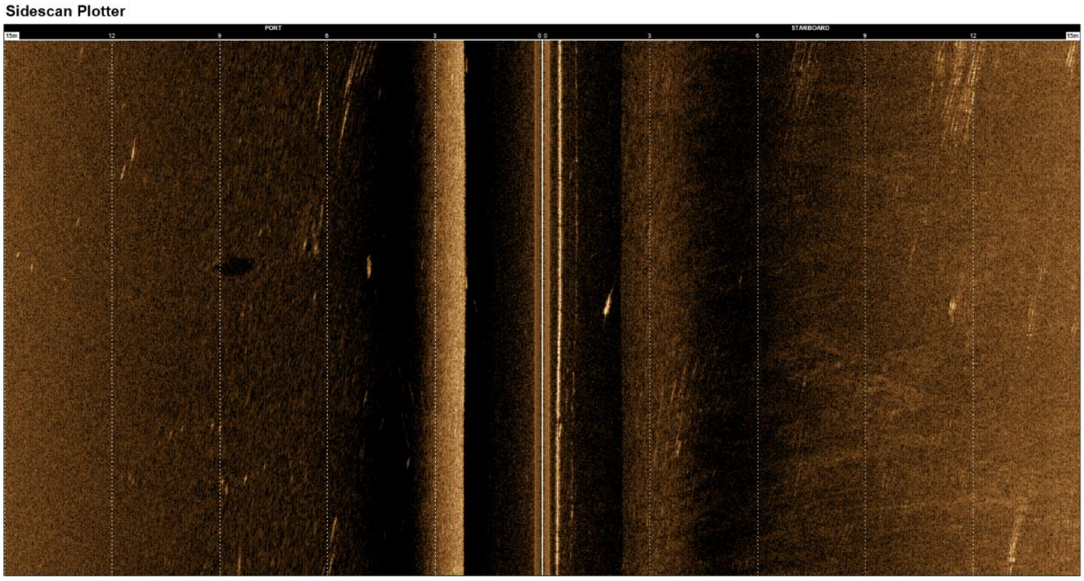
10 May '76 A. R. Hood (Devon Aircraft Recovery Group) phoned to say the man who knows the location of the aircraft is Mr. Rowe, farmer, "just past Higher Pentire Estate".

18 May '76 Anonymous letter arrived addressed to Secretary,

Sub Aqua Club, purporting to show , with primitive and ambiguous map, where the aircraft is.

12 Nov '76	Tracked down Mr. Rowe at Nansloe Farm. He was in RAF during the war and away. He thought his brother who was in the Home Guard might know something. Visited Mr. Rowe (brother) at Sunset Farm, overlooking Porthleven. He knew of Firefly in marsh, but believed there was also another plane which crashed during the war "in the deep part along towards the Y with Carminoe Creek". He did not have any more details, but thought the Home Guard superiors would know more. Canon Gotto(?), now probably dead, or Dick Hatton (or Haldon), who was H.G. captain. He lives "nearly into Prah Sands, near the Buccaneer Restaurant".
13 Dec '76	Went to Pengersick near Prah Sands and found that Dick Hatton is in a home. Mrs. Angove of Springdale, Pengersick Estate, Prah Sands, was alleged to know where the home is, but she was out. In after 1630.
13 Jan '77	Called on Mrs. Angove and established that Mr. Hatton is now c/o Mrs Martin, Cober Villas, 31 Wall Road, Gwinnear, Hayle, Tel 555. She said he has difficulty in remembering things. Canon & Mrs. Gotto are dead.

Appendix C Sidescan Images



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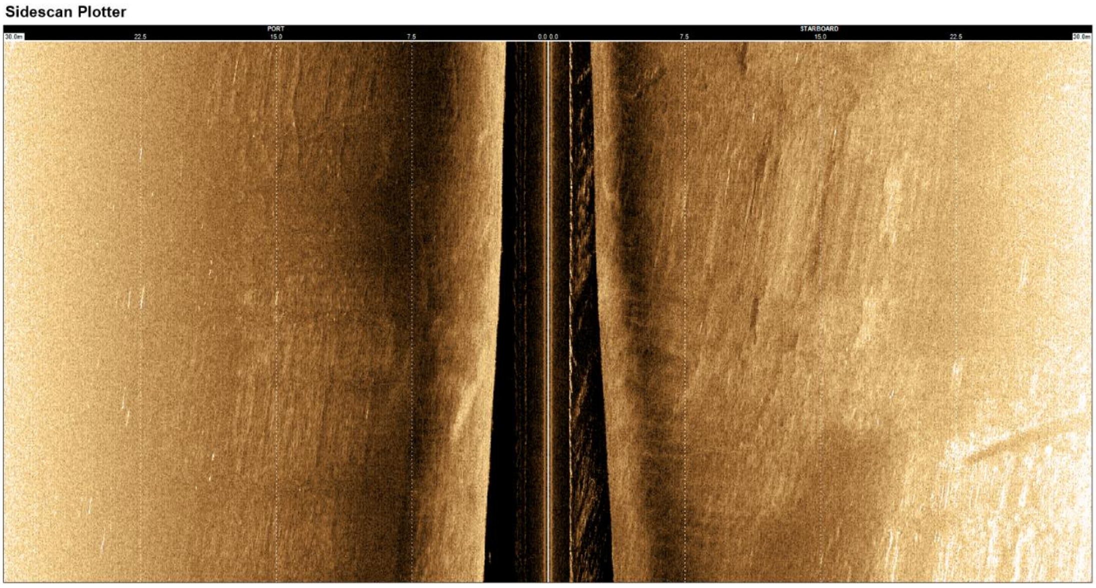


Figure 11-2 Object 2.

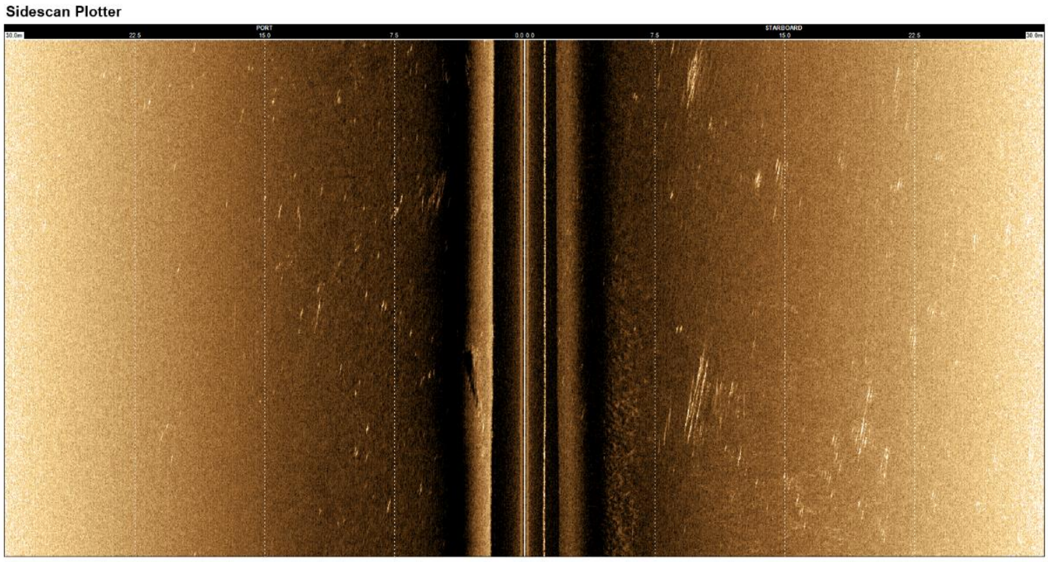


Figure 11-3 Object 3.

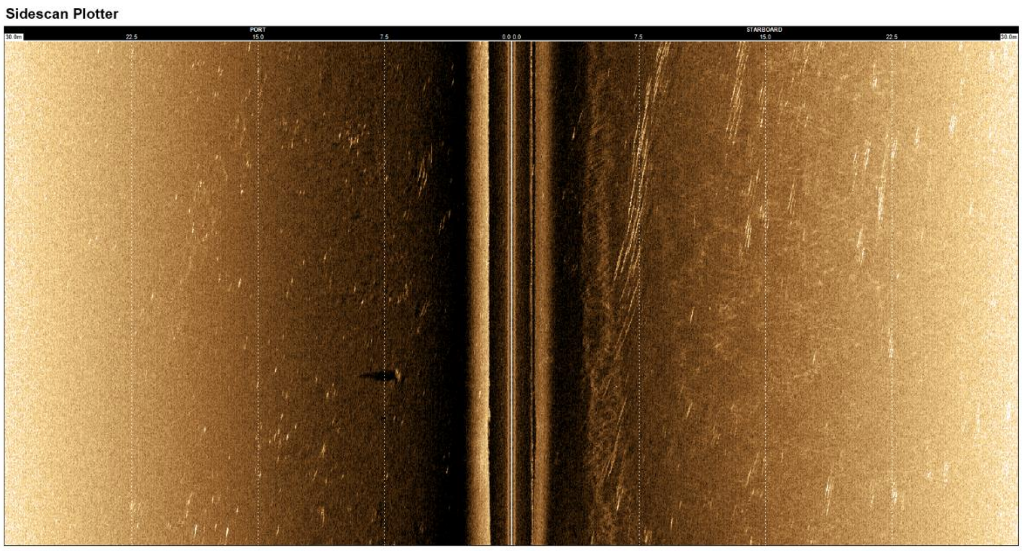


Figure 11-4 Object 4.

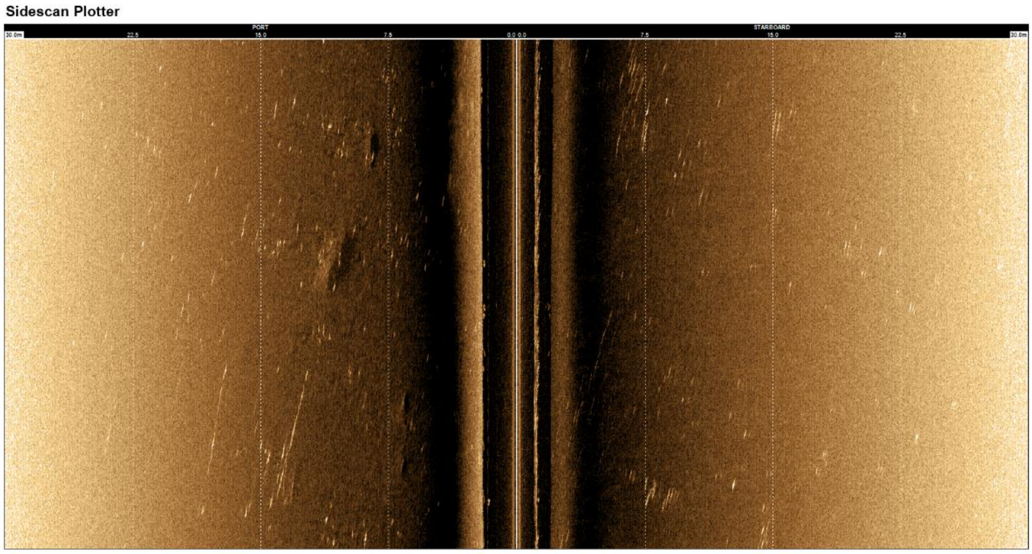


Figure 11-5 Object 5.

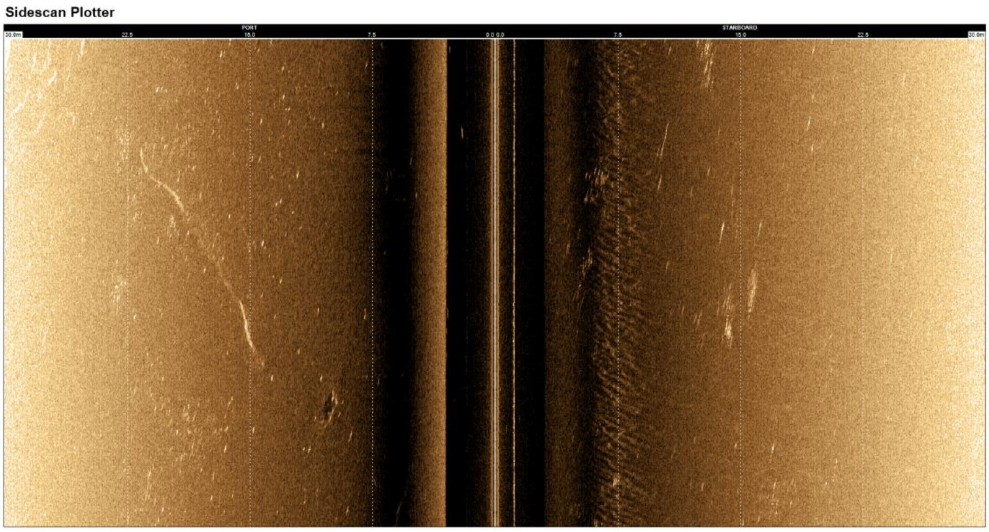


Figure 11-6 Object 6.

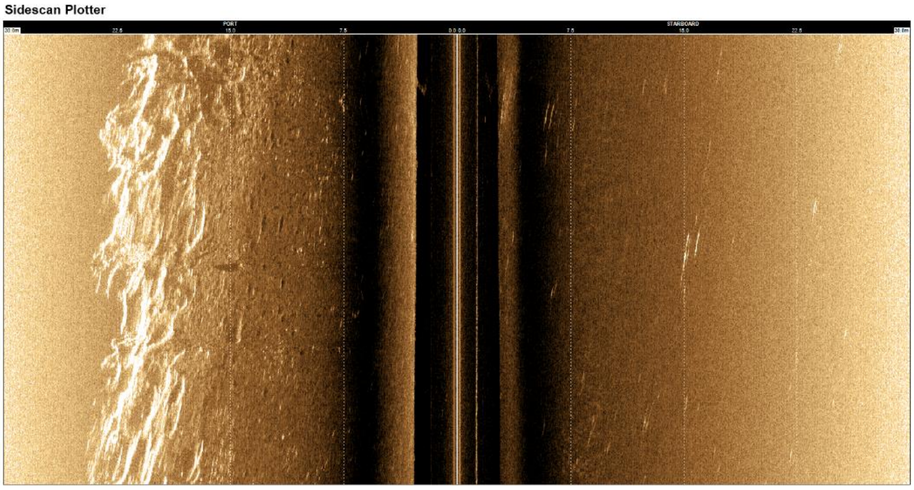


Figure 11-7 Object 7.

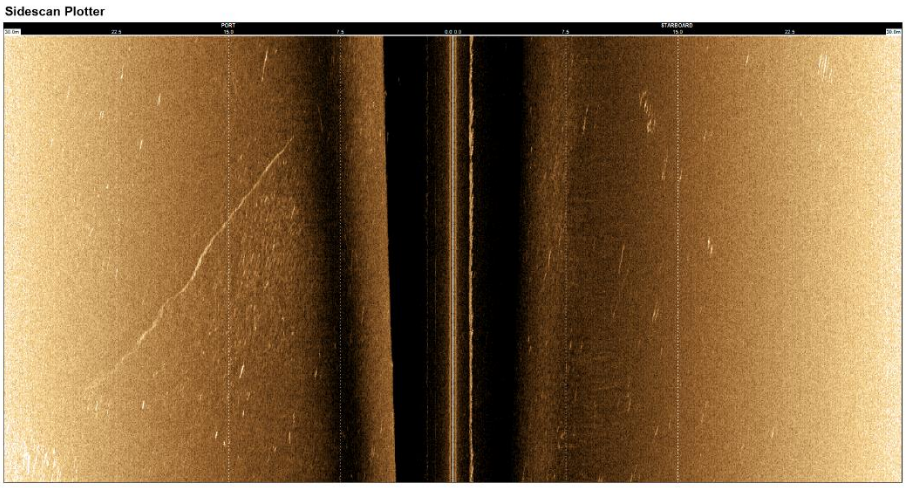


Figure 11-8 Object 8.

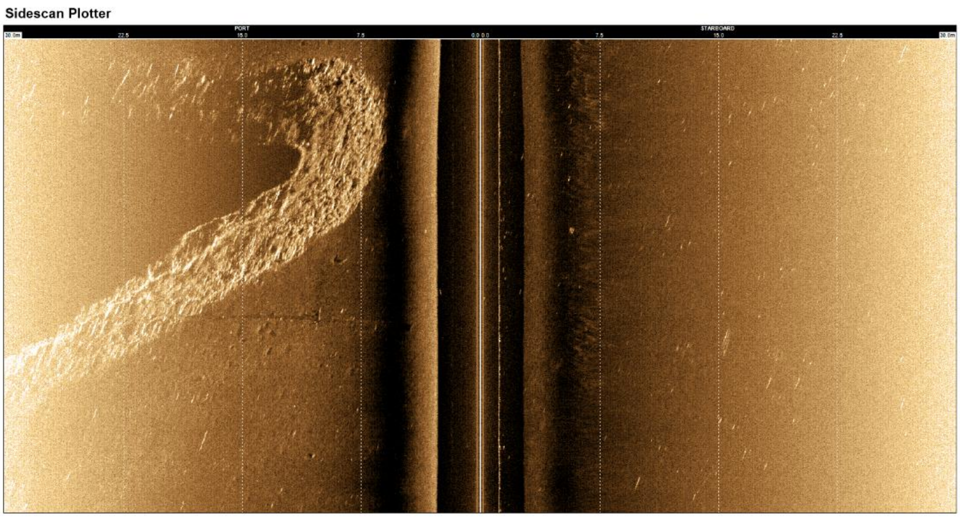


Figure 11-9 Object 9.

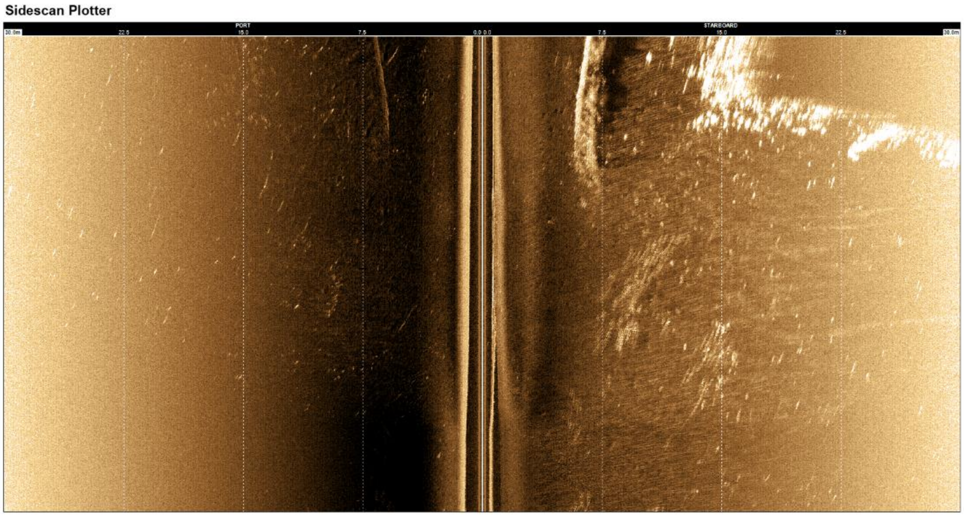


Figure 11-10 Object 10.

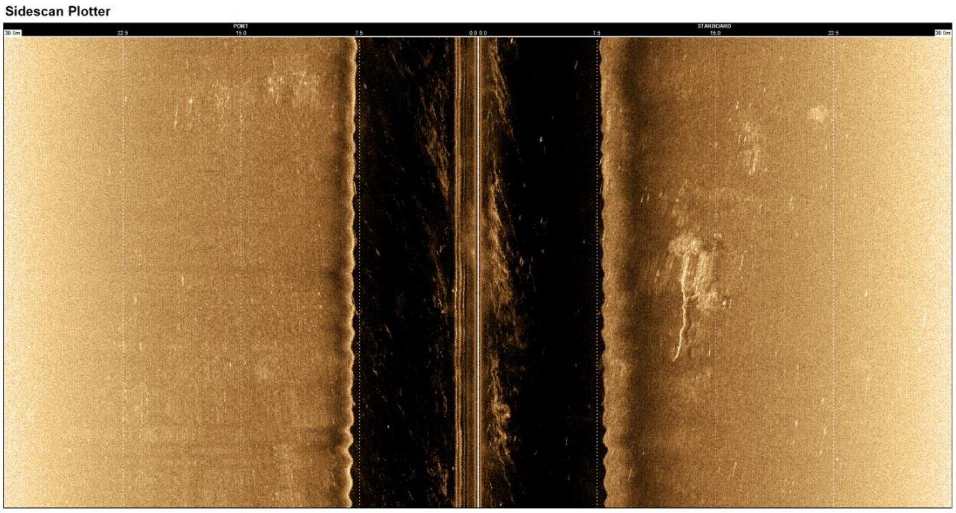


Figure 11-11 Object 11.

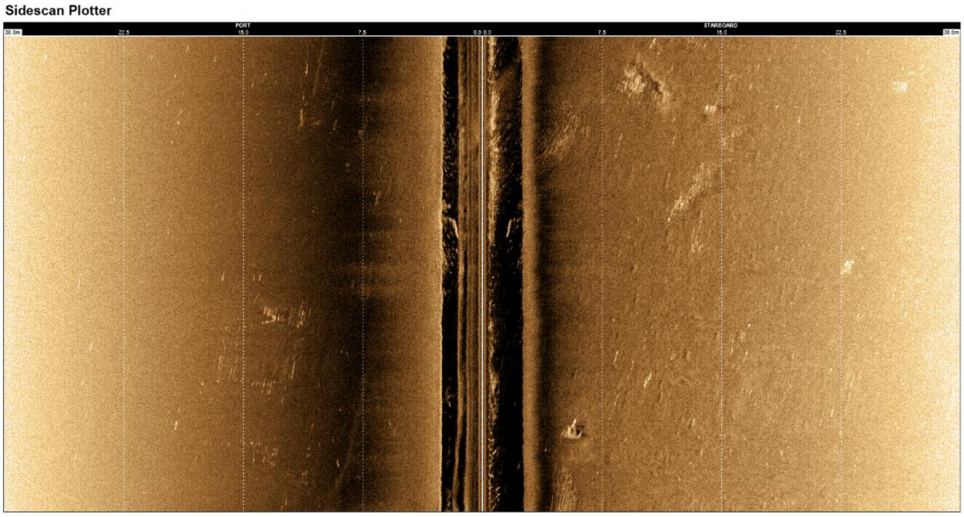


Figure 11-12 Object 12.

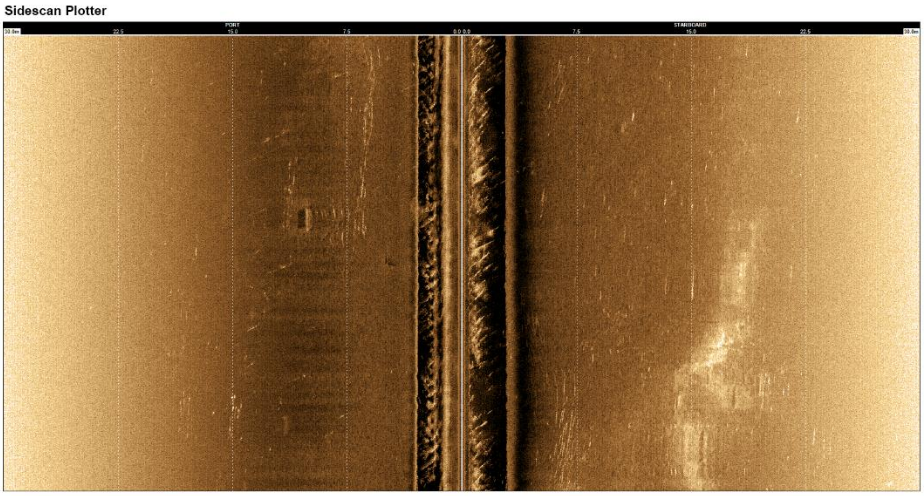


Figure 11-13 Object 13.

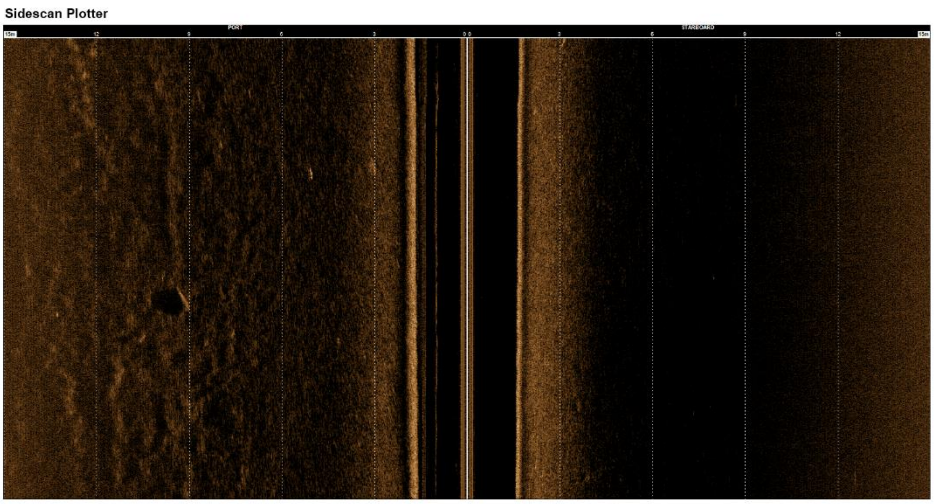


Figure 11-14 Object 14.

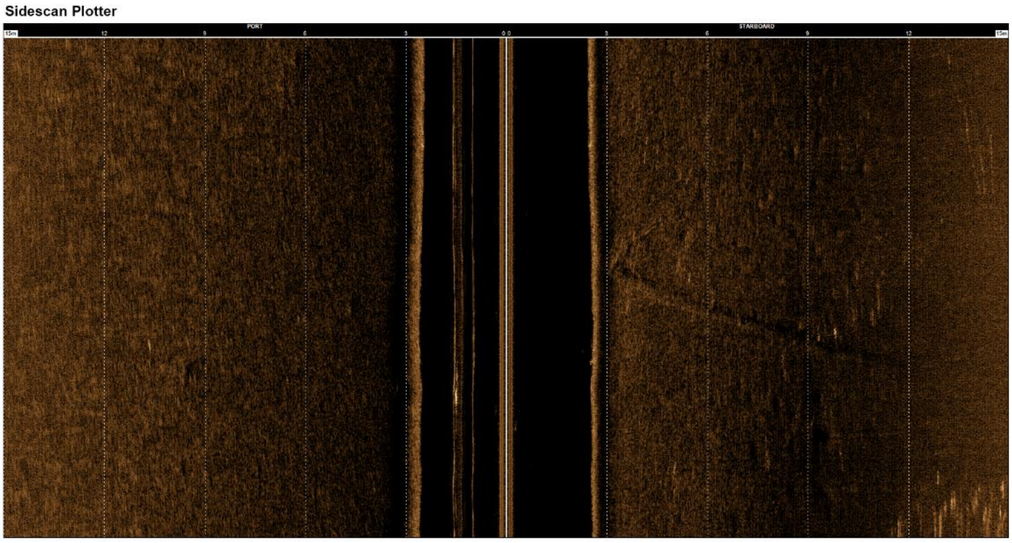


Figure 11-15 Object 15.

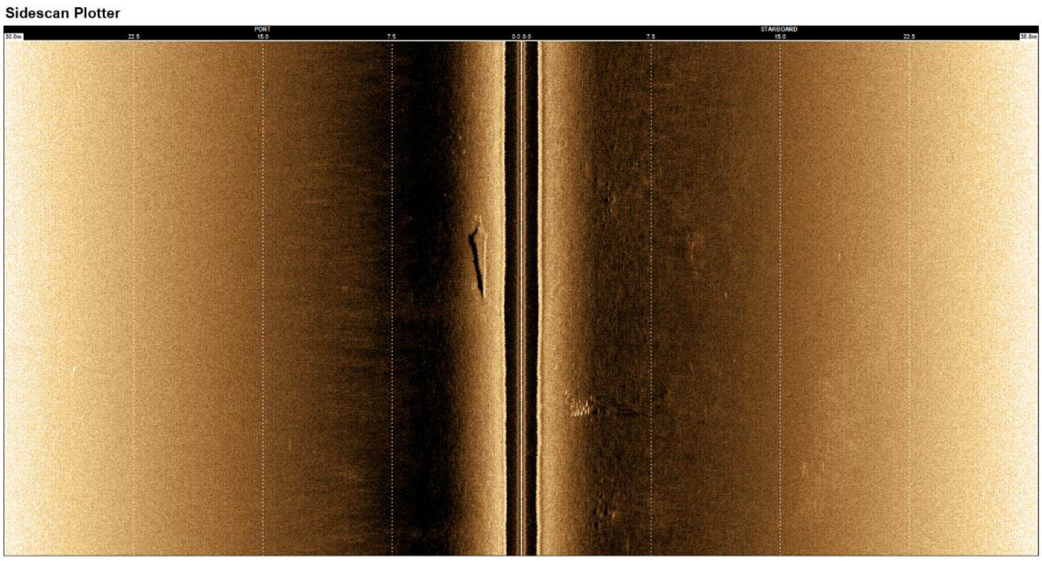


Figure 11-16 Object 16.

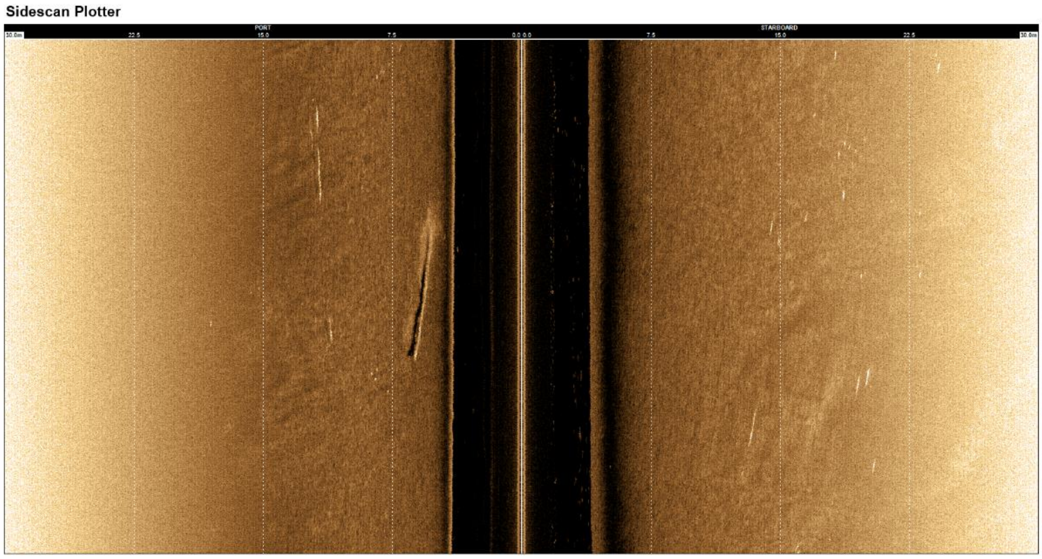


Figure 11-17 Object 17.

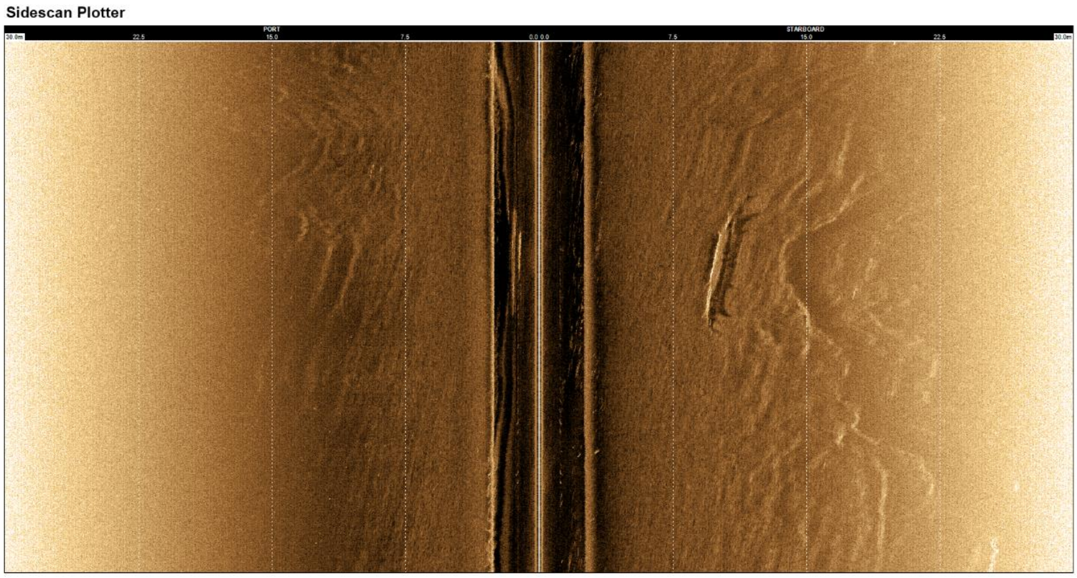


Figure 11-18 Object 18.

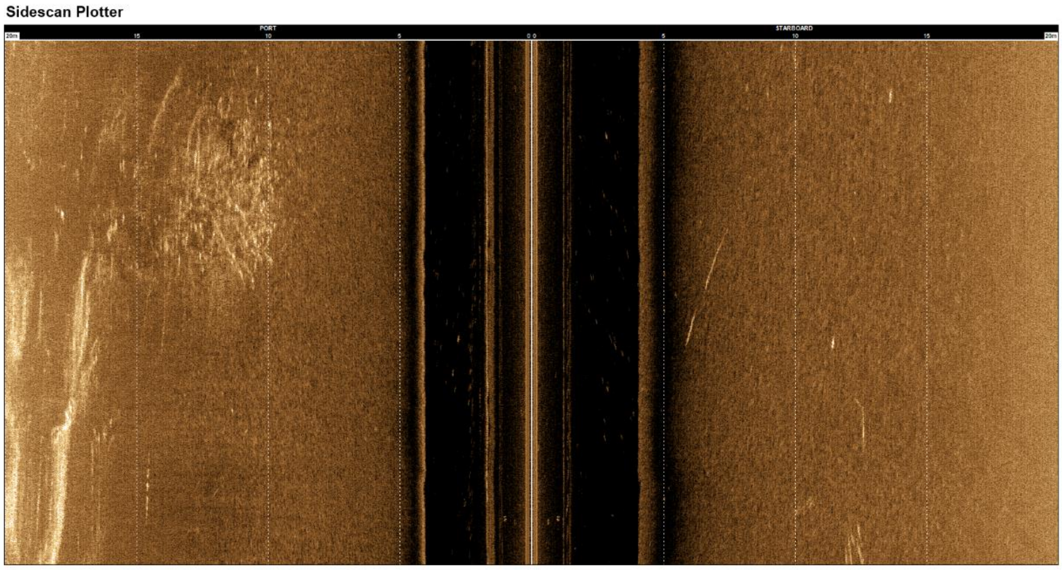


Figure 11-19 Object 19.

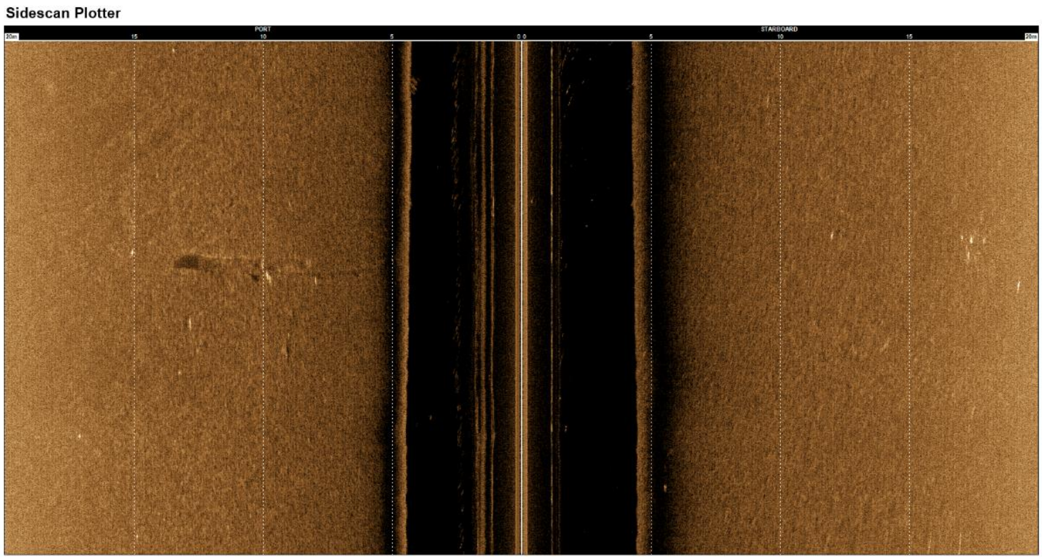


Figure 11-20 Object 20.

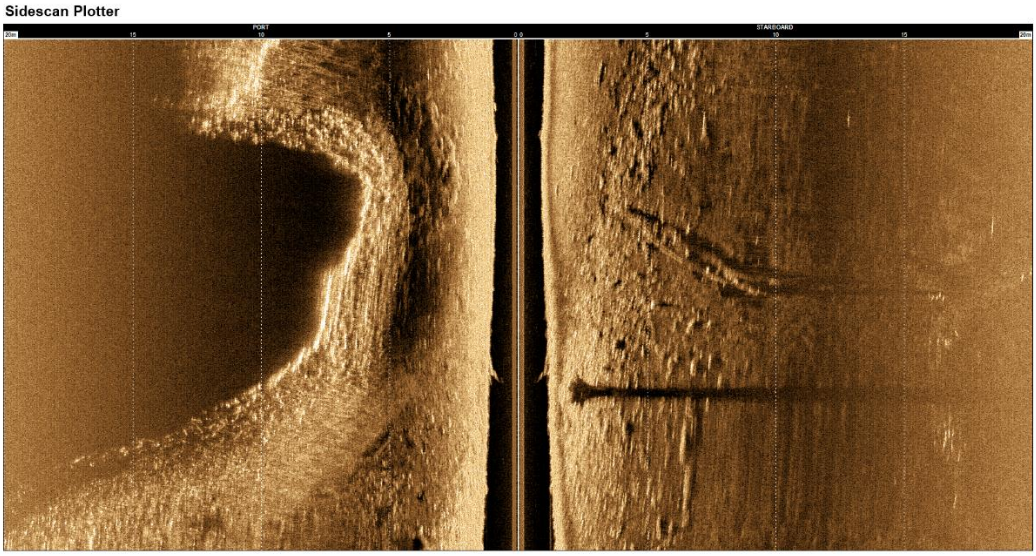


Figure 11-21 Objects 21 and 22 (from right to left).

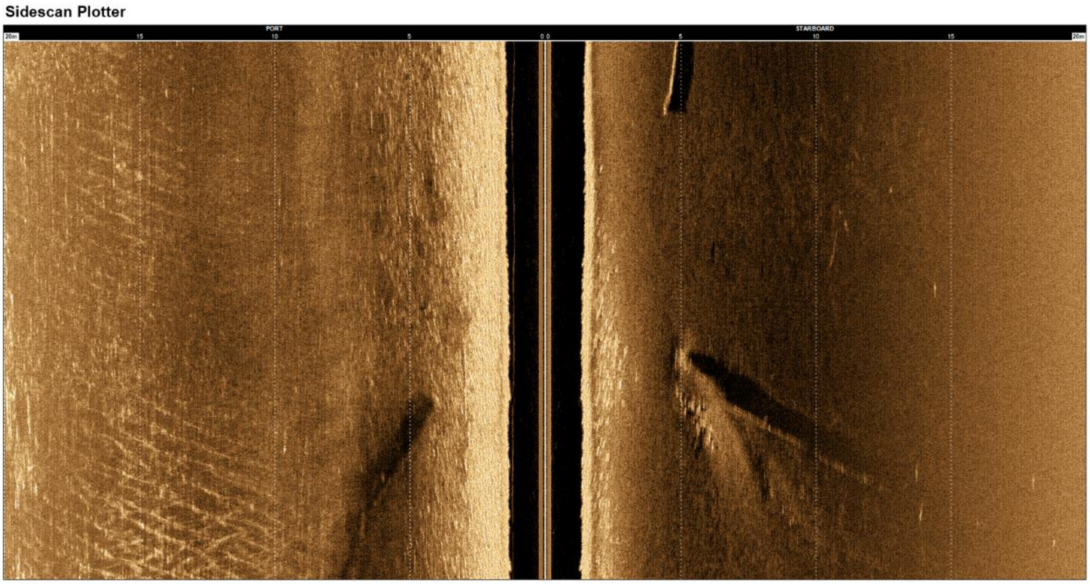


Figure 11-22 Objects 23, 24 and 25 (from left to right).

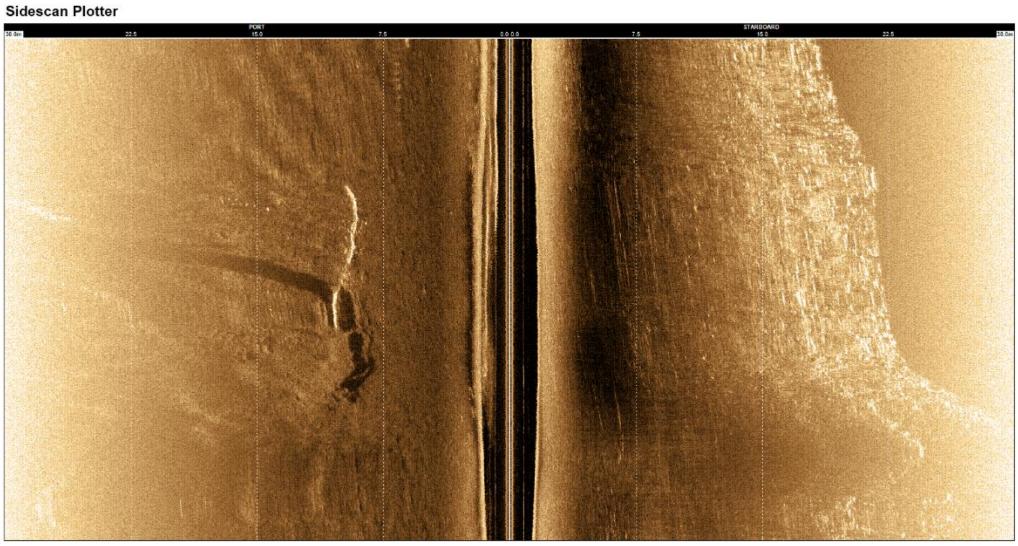


Figure 11-23 Object 27.

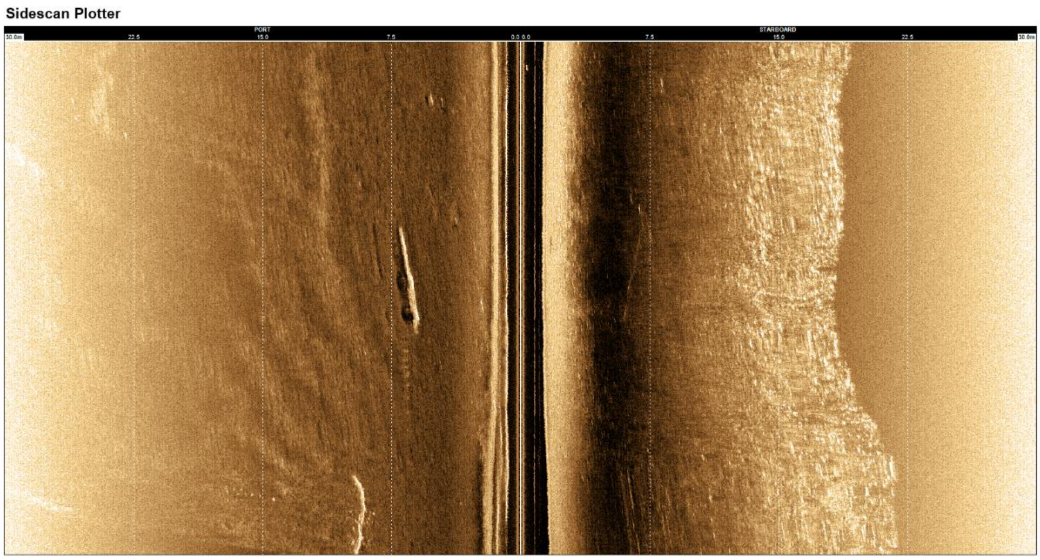


Figure 11-24 Object 28.

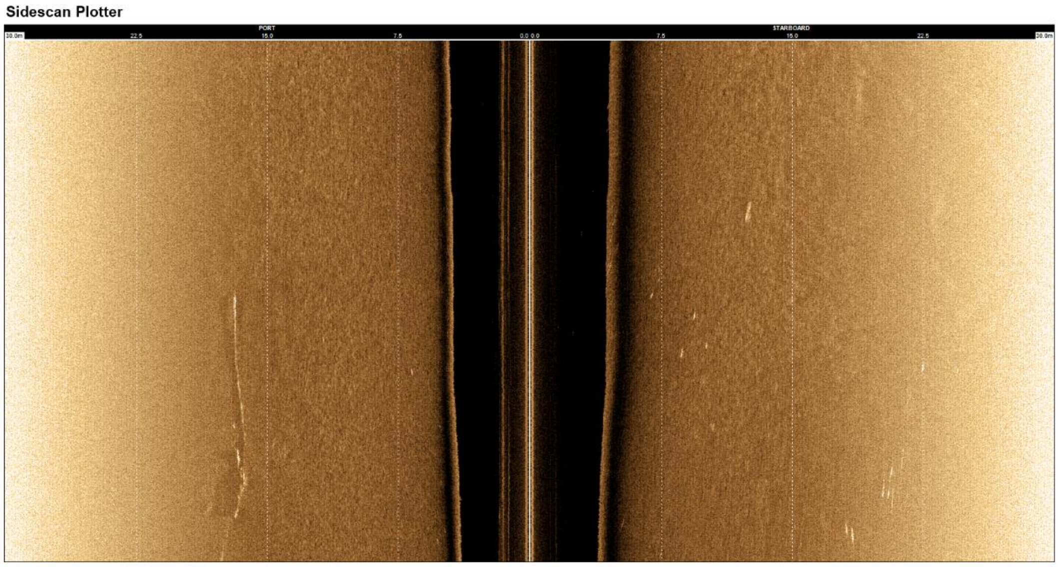
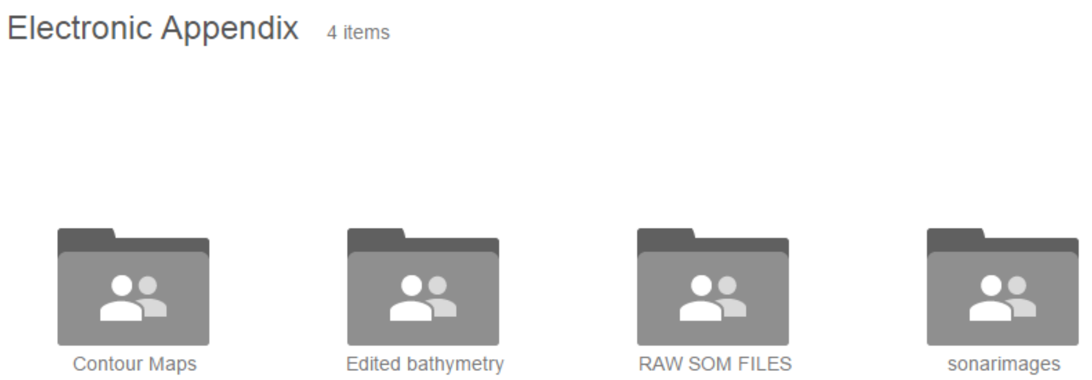


Figure 11-25 Object 29.

Appendix D Link to Online Data Files

https://drive.google.com/folderview?id=0B_tEN5tDo7S_S0NQX3l4NmJfQjA&usp=sharing



Appendix E A3 Contour Maps