Historic Landfill Investigation, Helston Cornwall.

An Environmental Survey of the Penrose and Fairground historic landfill sites.

Submitted by Rebecca James to the University of Exeter as a dissertation towards the degree of Master of Science by advanced study in Surveying and Land Environmental Management, September, 2016.

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

Signed:…………………………………………… Date:…………………………..

Acknowledgements

I would firstly like to thank my course director and one of my project supervisors Neill Wood, who has supported and guided me not only throughout this project but also over the course of this year. Secondly, thank you to David Walker for assisting me in the field when surveying at the site and to my wonderful parents and family who continuously support me throughout all of my academic endeavours. Finally, I would like to thank all of the tutors at Camborne School of Mines and also the CSM Trust for making this year of advanced study enjoyable and so worthwhile.

Abstract

The storage of any waste materials in landfill has for many years been the most common form of waste disposal in globally. However, it is this form of waste disposal that can cause many environmental problems to the surrounding environment. These problems can include contaminated groundwater sources, landfill gas emissions, noise and dust pollution. Today in the UK, it is mandatory under EU law that all landfills are designed and operate at strict standards to ensure that the engineering in place can prevent these environmental threats as must as possible. These standards for engineering of the landfill such as high-density polyethene geomembrane liners is a very modern and recent development which is now imperative in the industry. Unfortunately, due to a gap between the knowledge and awareness of the environmental issues that are linked with landfills, the engineering standards have not always been as strict. In the early 1900's landfill was seen simply as a hole in the ground that was a cheap and convenient way to dispose of waste. Thus, indicating that there were no engineering attempts to prevent issues such as landfill leachate from forming and migrating into the surrounding environment. Consequently, historic landfill sites are now a priority to local authorities and stakeholders for monitoring and remediation purposes. This project investigates a historic landfill site located in Helston, Cornwall. The site has very little documentation to indicate how it was designed or capped at the end of it's lifecycle in the 1970's. The site is of great importance to much of the community and is a local hotspot for visitors on a daily basis. Therefore, the future management of the site is at the forefront of concerns. This project used a range of geophysical techniques to gain a better understanding of the near surface physical makeup. Interpretation of these findings provided a range of theories and notions as to what and how the makeup of the subsurface influences the surrounding environment in Helston. Many of the interpretations of the geophysical results such as the electrical resistivity and electromagnetic s indicate the potential presence of both inorganic and organic contaminants, which could pose a threat to the quality of the land in the future.

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Abbreviations

COPA- Control of Pollution Act 1974

PPC – Pollution Prevention and Control Permits

MSW - Municipal Solid Waste

GNSS – Global Navigation Satellite System

RTK – Real-Time Kinematics

ATR- Automatic Target Recognition

ERT- Electrical Resistivity Tomography

IP- Induced Polarisation

Vp – Polarised Voltage

Vo- Observed Voltage

V- Voltage

I – Current

pa- Apparent Resistivity

K – Geometric Factor

Chapter 1 – Introduction

The burial of municipal solid waste in landfill is the most common method of waste disposal in most developed countries (Kjeldsen et al., 2002). Landfill sites have been identified as a major threat to the environment and especially to groundwater resources (Mor et al., 2006). The dumped waste in landfill operations is subject to excess water from a variety of sources such as surface runoff, evapotranspiration and precipitation which in turn generates high amounts of leachate that can contain high levels of pollutants. The balance of these hydrological inputs cannot be completely prevented but can be reduced with engineering solutions such as high-density polyethene linings that prevent the migration of generated leachate into the environment. However, the understanding of the environmental impacts from waste disposal in landfill has not always been understood nor considered.

1.1 Rationale

Due to the disparity of age and engineering standards of landfill operations there are many historic sites across the United Kingdom that are a concern as they could be the cause of a polluting event. Therefore the management of documented historic sites must be a priority for landowners and operators such as the Environment Agency. The Environment Agency hold an archive for all permits for landfill operations and provide an online services that highlights all active and historic landfill sites recorded in the UK.

Two of the sites marked on the Environment Agency's interactive maps are the Penrose Amenity site and Fairground (Figure 1). The fairground site is now a public car park. The location of this historic landfill now lies within Site of Special Scientific Interest (SSSI) and is open to the public to use. Therefore, the management of the site in order for it to maintain it's classification is a priority for many local stakeholders. As mentioned the age of a site influences the amount of mitigation and engineering that it received both while in operation and post-closure. However, for this site there is very little documentation regarding it’s managements. Therefore, the way that it could possibly effect the local ecosystem is unknown.

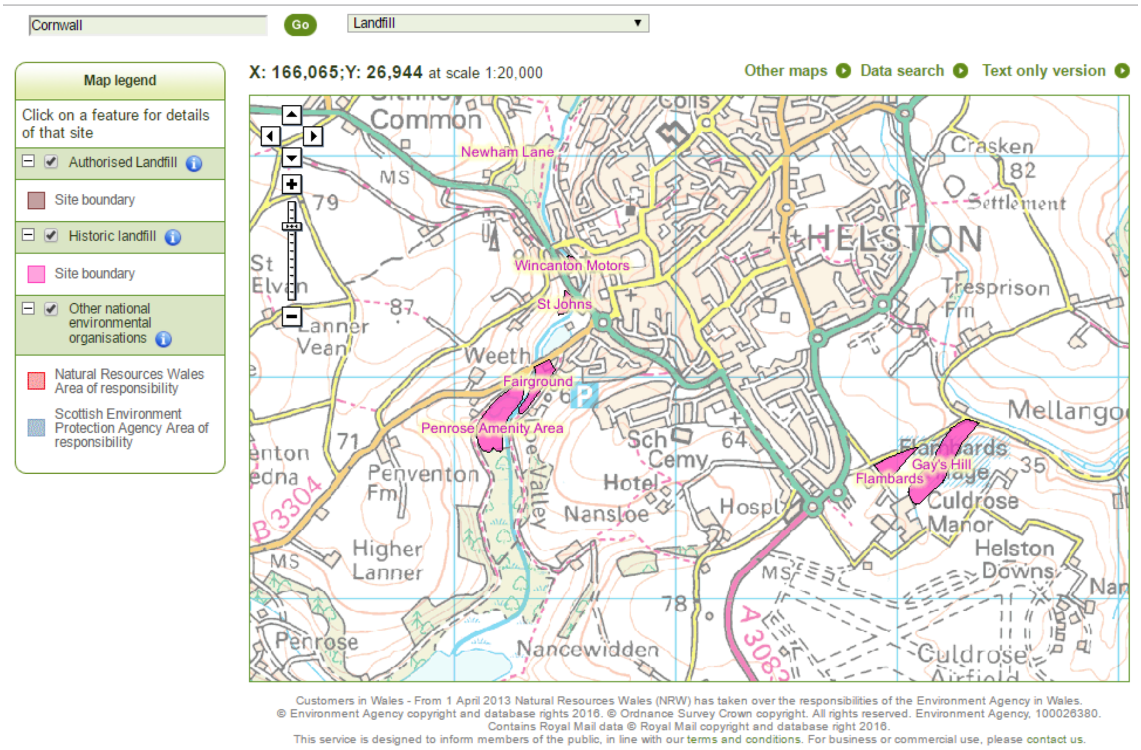


Figure 1 screen shot of the interactive maps from the Environment Agency (2016) highlighting the historic landfill in Helston, Cornwall.

From an enquiry sent into the Environment Agency, they have provided some information regarding the site. The records show that the Penrose Amenity site (HDL Reference: EAHLD07986) received a range was waste materials, predominately inert waste and also building and construction waste. It is noted on the record that it was completed in 1974. The length of operation is however not know. For the Car park site known as fairground (HDL Ref: EAHLD08122) is documented to have received inert, industrial, commercial, and household refuse and was operated by Helston Rural District Council.

1.2 Site History and Background

Helston is a busy community with a vibrant history. It has been a settlement since the 6th Century and has developed greatly through the years. Helston has always been an important market town for Cornwall's economic growth and has played an important role for many of the industries that have come and gone in the region. Figure 2 illustrates the location of Helston in Cornwall. For instance the busy market town once had great links to the sea and some argue the harbour once flowed right up the Cober catchment and onto the Penrose Estate (History Helston, 2016). Today much of Helston has changed but a lot of the infrastructure still remains. For example the Coronation Lake still remains a local recreation site and still attracts many visitors.

Due to it's busy nature the Penrose Amenity Site, once part of the Penrose Estate, has many stakeholders that are invested in it's sustainability and future. One of the main stakeholders is the Loe Pool Forum, an environmental partnership that is dedicated to improve the water quality of the River Cober Catchment and also to reduce it's flood risks (Loe Pool Forum, 2016). Another large stakeholder in the area is the National Trust who took over ownership of the land in 1974. When they took over ownership of the Penrose Estate they also acquired the Loe Pool. The Loe Pool is the largest natural lake in Cornwall and is relativity recent development to the site (Loe Pool Forum, 2016). The pool is a naturally forming lake and recent research suggests that 50% of the lakes' nutrient input is from diffuse sources upstream in the catchment. It is the Loe Pool site along with the Loe Bar that is now classed as a SSSI site and is

Figure 2 Map highlighting the location of Helston, Cornwall. Source: Digi Maps, 2016.

priority for management. Therefore, the documentation that the site adjacent from the Loe Pool, was once a landfill site does raise some questions regarding contamination leaching and other potential environmental risks. Especially as one of the main aims of the Loe Pool Forum is to improve water quality in the area.

Since the 1970's the Car Park at Helston has had many different land uses, including a public swimming pool (fig 3) for a short period of time in 1974, shortly after the landfill was closed. The pool was built by Helston Borough (Helston History, 2016). However, there were many issues due to subsidence and cracking, subsequently causing the pool to close. Since then the site has been a free public car park, managed by Cornwall Council.

Figure 3 Picture of the demolished swimming pool at the Helston site that is now the Car Park. Source: Helston History (2016).

1.3 Aims Objectives and Scope

The aim of this investigation is to carry out an environmental survey to gain a better understanding of the subsurface properties at the Penrose Amenity site and the opposite car park. These sites have been chosen based on the information provided by the Environment Agency regarding historic landfill sites. As this area has been identified as a historic landfill, the environmental implications need to be understood for future monitoring of it.

A range of different surveying methods including geophysics will be deployed to gain this understanding of the site’s near surface structure. The following aims have been highlighted as parameters for the investigation.

Aim 1: Using geophysical techniques carry out a survey to investigate the subsurface properties at both the Penrose Amenity site and Car Park.

Aim 2: Using a pXRF carry out geochemical analysis of soil sample at the site to investigate whether or not the historic landfill has an influence on contamination of the River Cober.

Aim 3: From the results for both the geophysical and geochemistry data form interpretation and subsequent recommendations for the site’s future management.

Chapter 2- Literature Review

In order to gain an understanding of the previous management of the site and how these process effect future mitigation, a comprehensive review of the current literature surrounding waste management and landfill has been completed. The evolution of the legislation that governs the operation of waste disposal is also considered.

2.1. Evolution of Waste Regulations in England and Wales

Living in a modern society there has been an increase of environmental awareness and concern in recent years, which has greatly influenced the management of waste. An increase in environmental concern has been supported by the changes in both national and European policy to mirror these concerns (Baban and Flannagan, 1998). Like all policy there are key dates that mark significant changes in policy that influence the way that waste is managed. This is not only true for the United Kingdom but also on a global platform.

Waste regulations in England and Wales have changed considerably over the last century, evolving from a society with no waste management system in place to one that is managed with a sustainable ethos. It is documented that pre-1948 there were no controls in place that monitored the tipping of waste and refuse at all. It was not until 1948 that the Planning Act was created that waste was considered in English law. Its focus was to manage controlled land use (Environment Agency, Date unknown). It's link to waste management was very loose but it was the starting point to which waste could no longer just be dumped anywhere. Even with the link to waste management in this regulation being very loose it was indeed a starting point for development in the area. The move towards management of landfill slowly grew over the next few years.

Wilson (2007) contends that recognition of environmental protection came to the forefront of waste management and policy in the 1970's. This is illustrated by the Control of Pollution Act (COPA) which was enforced in 1974. COPA was the first piece of legislation to be created that considered waste management specifically. The act required operators to consider what was being dumped at their site and how much of it was disposed. It also tentatively introduced the need for waste sites to operate with an approved license. However, these licenses did not set out any parameters for the operations to act under. COPA not only assessed the way landfill was operating but it also touched upon the consequences that could occur if it is not managed effectively. This was a positive move in waste management. The act looked at the effects that waste disposal has on water, noise and air pollution and also public health (National Archives website). Following these environmental considerations the COPA (1974) also stated that it was the statutory duty of each waste disposal authority to ensure that disposal of controlled waste was conducted in an appropriate manner. This meant that the disposal of waste would not cause any of the surrounding environment to be compromised. Unfortunately, even with the move towards considering the environmental impacts that landfill can create there still lacked a working knowledge of how to address the effects.

Following on from the Control of Pollution Act (1974), came the development of the EU Groundwater Framework Directive in 1980. This framework developed the notion that there are great environmental consequences that can occur with landfill. The framework also reassessed the favoured management method of 'Dilute and Attenuate'. The reassessment occurred because through monitoring it was concluded that the process allowed too much waste leachate to discharge into the surrounding environment, especially the groundwater sources. Following this assessment the framework published two lists of prohibited substances. This was to ensure that steps were taken to safeguard the health of the surrounding environment. List 1 named chemicals that were considered to be polluters that could cause great harm to the surrounding ground water. Such chemicals for example were, mercury, cadmium, carcinogens and hydrocarbons. The second list contained a more extensive list of more common substances that if also leached could also case significant polluting effects to the ground water. These prohibited substances included; zinc, copper, lead, selenium, arsenic and tin (Westlake, 1995). These published lists therefore led to the prohibition of both indirect and direct discharge of waste leachate that contained these chemicals from any site (Westlake, 1995). This act was a definitely a step in the right direction for environmental management within the waste sector. However, as a directive, it has been criticised that it did not provide actual strategies that could be implemented in order to protect the groundwater (Scheidleder et al., 1999). Even with no exact strategies in place the directive did influence the start of national policy to consider and accept that groundwater needs to be protected. Over time this filtered through into the waste industry and policy incorporated ways in which groundwater could be protected from the defined pollutants.

It can be seen that as the legislation and regulation that surrounds waste management develops, there is an increasing emphasis on the link that landfill as a land use has with environmental pollution. The next key piece of legislation that develops this acceptance is the Environmental Protection Act (1990). As the successor of the COPA (1974) it attempts put in place actual provisions that improve the control of pollution that is generated from industrial processes such as landfill (Country Style Recycling Ltd, 2016). The main difference of these regulations from the previous COPA (1974) is the role that regulatory authorities have in the management of waste operations. As a part of the 1990 Environmental Protection Act, it introduced the 'Duty of Care Regulations 1991' (InBrief 2016). These regulations ensured that all landfill sites were the responsibility of a local Waste Regulation Authority. It placed the responsibility on any person who imported, produced, carried, treated or disposed of waste. With this 'Duty of Care' came the requirement for the responsible person to take all reasonable and practicable measures to; prevent illegal disposal, prevent the escape of waste and finally to ensure that waste is transferred by only "authorised persons" with a written waste description (InBrief, 2016). It was the duty of these authorities to also apply for operating licences for each site. Even though it was now a necessity for each site to operate under an awarded licences there was still no set engineering standards for operators to adhere to. Following the release of this act there was subsequent 'waste management papers' that acted as a supporting document for best practise but still no governing criteria. The main issue with the enforcement of these regulations, with no set engineering regimes was that the quality of management varied from site to site in England and Wales. This was due to different Waste Regulatory Authorities operating at different levels of best practice.

Five years after the Environmental Protection Act (1990) was transposed into English Law, came the introduction of the General Development Order (1995). Under these regulations, it was required of all Waste Regulation Authorities to submit a document highlighting information of all the landfill sites that were in operation of their area from the last 30 years (Environment Agency, Date unknown). With this growing body of knowledge about the landfill operations in the UK, the management of them also developed. It was stated under this order that all Local Authorities and Waste Regulatory Authorities must consult with the Environment Agency when they receive any application to develop land that is within 250 m from a landfill site (either active or historic). This requirement was to ensure that the applicant is informed of the potential risks that are linked to landfill. For instance the applicant must be told of the risks posed to waters from contaminated leachate, the risks that come with landfill gas and also the social implications of developing near an active site (Environmental Agency, 2012). This move towards considering the environmental, geotechnical and social implications of landfill operations is a fundamental step towards sustainable waste management.

The management and control of waste disposal at landfill sites had been discussed by the EU for many years (Burnley, 2001). Finally, in 2003 the EU Landfill Directive was adopted and it directly impacted the management, operation and regulations that surround waste management. In 2001 operators of active landfill sites were required to assess the directive and prepare for changes in the engineering of the site as there would now be strict regimes that they had to comply to. The overall aim of the directive was to prevent and reduce the negative impacts that landfill creates on the environment and human health (Burnley, 2001). The directive states that it hoped to reduce the reliance that society had on landfill and thus decrease its activity as a favourable waste disposal option (Country Style Recycling Ltd, 2016). The central aspect that this legislation has that all previous did not, is the set of standards and conditions that outline the landfill’s design and operations. The directive sets out minimum standards for the location, design, construction and operation for all landfill sites across the EU (Country Style Recycling Ltd, 2016).

Alongside the implementation of the Landfill Directive (2003), the Pollution Prevention and Control Regulations (PPC) also came into force. These PPC regulations put into place a new permitting regime that applied to all active and historic landfill sites of the past 30years. From 2003 onwards all active sites were required to operate under the PPC regime. This was a noteworthy requirement for waste legislation, as it meant that the management of waste was standardised across the UK and the environmental standards of the site no longer depended on the way the local authority choose to operate. This requirement meant that all existing site had to go through a reemitting process and all regulation authorities had to review and re-permit under the new requirements. Due to the new permitting regime, it allowed all existing sites to be ranked in terms of their potential risks to the environment and thus seek to mitigate the priority sites. Under the 2003 PPC permit regime and the EU Landfill Directive (2003) the definitions of types of waste also changed to allow more efficient management of what was being disposed at each site. The new definitions of types of waste were: inert, hazardous, non-hazardous and municipal. With the newly defined waste types and the PPC permits in place, it allowed for improved documentation of what type of waste was being disposed and its quantities. Consequently, the improved documentation led to a better understanding for the management of the sites. This information allowed the PPC permits to set specific conditions that were unique to the site and also were in line with the standardised specifications set out across the UK. For instance each permit would include the operational hours of the site, the controlled volumes of leachate and gas, and the quantities and types of waste it was permitted to accept. The Landfill Directive not only changed the way sites were permitted to operate but also prohibited some substances from being disposed on land. It is in this directive that liquid, explosive and flammable waste is formally banned from being disposed in landfill sites (LARAC, 2013).

The final and most notably progressive development in the Landfill Directive in comparison to its successors is the introduction of allowances. It is documented that in this directive, that each landfill site was allocated a strict allowance for the amount of waste that can be disposed at the site each year. However, for each site that operates under a Waste Regulation Authority, any quotas not fully reached could then be traded to other authorities (LARAC, 2013). This is a remarkable step forward in making waste disposal sustainable in the UK. The financial incentives that the trading of quotas brings had an influence in the attempts to reduce the amount of waste disposed on land. It can be argued that the current landfill and waste management approach reflects the environmental costs that are of societal and political concern. The taxes and allowances placed on each site exemplifies our acceptance of these costs. In the beginning of the last century landfill was seen as a convenient and cheap way to dispose of waste and this ideology has now transformed into the opposite. Landfill is now regarded as a scar on the landscape with great environmental costs, which the introduced taxes and allowances attempt to compensate for (Morris et al., 1998).

Over the last century the understanding of the consequences that landfill and waste disposal brings to the environment has greatly improved. It has developed in such a way that landfill design and engineering is now an imperative part of the process, to safeguard surrounding environments. The current legislation no longer gives operators the ability to run their site as and how they please, the strict parameters that are set out in each PPC permit allows for more succinct and effective monitoring of each site. Consequently, given the large disparity in waste management from pre-1948 to today, the quality of environmental safeguarding of historic sites highly depends on when the site operated. By understanding the policy that was in place at different dates aid environmental investigations of landfill site such as this, as it provides some information as to how the site was operated and left once the lifecycle has ended (e.g. lined or not). A timeline of the evolution of the UK's waste management can be found in Appendix 1.

2.2. Landfill Design

As discussed, the policy behind waste management in the UK has greatly developed over the last century. However, operating under *"an economically affordable, environmentally effective and socially acceptable"* (Wilson et al., 2001: 327) waste system is yet to be established. Wilson et al., (2001) argues there is a now a gap between the engineers who manage waste and the policy makers who regulate the waste management systems. With this in mind, the varying methods of landfill engineering will now be discussed in terms of their relative merits and challenges. These techniques have developed and mirror the policy of the time, many of which are now no longer accepted practises. This again creates a great disparity in terms of the environmental quality of each individual landfill site across the UK. However, gaining an understanding of the progression of disposal methods is imperative as it aids investigations of historic sites.

Landfill sites or “dumps” have been a chosen method of waste management for a long time. It is documented that even for some of the earliest civilizations the burial of wastes has been easy (Wilson, 1976). As early as Mesopotamia, Egypt in 8000-900 BCE, dumps were established in remote areas away from the settlements (Pichtel, 2014). In the UK, waste and the management historically has been left to the individual. Which saw the disposal of domestic and human waste being on the streets during the medieval period. There is much research that has investigated these historic methods of waste disposal (See Wilson, 1976, 2007 and Pichtel, 2014). With population pressures in the urban settlements, it allowed the “street system” to develop. This was where everything from domestic waste to cinders and manure were left in the streets (Wilson, 1976). It was only in 1875 when the Public Health Act was enforced that all householders were required to store all of their waste in a “moveable receptacle” and placed the duty of disposing the waste onto the local authorities at least once a week (Wilson, 2007). During this time, public health was a small concern and landfill was simply seen as a convenient and cheap option for waste disposal.

Until the 1900’s, where landfill was no more than direct dumping waste into a hole dug in the ground (Pichtel, 2014). An example of this was the use of the marshes in Essex, which was the chosen site for the collected refuse in London. The refuse was collected in the city and shipped downstream and dumped on the marshes (Rawlinson 1958 cited in Pichtel, 2014). This option to use land with little economic value such as marshes is something that can still be seen today. However, the geotechnical issues that surround waterlogged marsh land

and its stability is now better understood and questioned. The open-pit method of waste disposal with periodic covering of soil on these unused areas was the favoured method for much of the late 19th and early 20th Century.

The late 19th Century was a transition period for landfill design and management, especially for developed countries (Westlake, 1995). With a growing technological knowledge of epidemiology, engineering and also geotechnics, there was a push to change policy and in turn the way that landfill operated. The development of new landfill sites was no longer a hole in the ground or a heap on the surface, the sites were planned and started to be lined with clay. Even with this small move forward that incorporated liners of the site, the unconsolidated waste and with industrial waste such as oil and chemical drums were not seen as a polluting risk (Tarr, 1985). The somewhat unconfined sites allowed pollution to flow into the surrounding environment. As the sites were regarded as undesirable sites these issues were not seen as an issue to the land owners or policy makers.

The “Dilute and Disperse” or “Dilute and Attenuate” principle developed in the 1970’s relied on the natural dispersion and eventual dilution of any formed leachates. This method was quickly abandoned and replaced with other methods such as containment and entombment. The abandonment of the “Dilute and Disperse” methods was a result of the increase in environmental awareness. In the 1980’s these methods along with the new legislation, there was an increased consideration for the first time of site design, engineering and management. The increased the level of control waste authorities had over hazards allowed this to happen. The principle of containment is that any leachate that is formed within the dumped waste is not able to enter the surrounding environment. Westlake (1995) describes this process as the leachate collecting within the site, gathered and treated in situ. Entombment on the other hand takes the same principle a step further. The dry-tomb approach attempts to reduce the amount of moisture in the waste to a minimum, thus preventing liquid infiltration as the waste cannot decompose (Westlake, 1995). This process occurs primarily with a composite liner and groundwater wells. These methods paved the way for a new era of waste management that considered the adverse effects that it had on the environment and also attempted to prevent negative impacts from occurring.

There still much work needed to develop the alternatives into viable methods that can support the move away from landfill as the dominate method. Until this move to a society that relies on “green alternatives” and a sustainable waste management system, landfill operation, management and design needs to continue to be a method that created as little environmental harm as possible. The ISWA (1992) state that landfill as a waste disposal technique is viewed as *an “engineered deposit of waste onto and into land in such a way that pollution and harm to the environment is prevented and through restoration, land provided may be used for another purpose”* (ISWA,1992 cited in Westlake, 1995:26). This definition is imperative while landfill is being used.

It is clear to see that both the policies that govern waste management and the social normalities of waste management are fundamental interconnecting factors that drive the use of landfill and consequently its successes or failures. In order to manage both historic and modern landfill sites all of these drivers must be understood. For it is these drivers that will unveil the way that the site was managed and subsequently how it should be managed in the future. Thus, each landfill site should be examined individually and the quality of environmental protection that was incorporated in it’s design is dependent on its age.

Chapter 3 – Background Theory

The use of geophysics has greatly increased in recent years. This is especially true for environmental investigations whereby interpretation of the subsurface layers of a site is required. As geophysics is still seen as a niche area of surveying, the theories that form the basis of each method needs to be fully understood. It is with experience and knowledge of the science that accurate interpretation can occur. Understanding these principles will indeed aid the interpretation of data collected.

3.1 Electrical Resistivity and Induced Polarisation

According to Reynolds (2011) the method of electrical resistivity was developed in the early 1900's but was only widely used in the field in the 1970's. This is due to the development of computer processing and the ability to analyse data digitally. Electrical methods have been documented as an important method of geophysical investigations and are widely connected to the monitoring of environmental problems (Borner et al., 1993). The primary use of electrical resistivity in environmental investigations is to understand the resistivity distribution and patterns in the subsurface, in order to gain a better knowledge of the soil's heterogeneity. Subsequently, the soil's resistivity can depict the soil structure, water content or fluid composition (Samouëlian, et al., 2005).

Two of the main contributors to the development of this method were Conrad Schlumberger and Wenner. Dahlin (2001) explains that the resistivity method is based on measuring the potentials between one electrode pair while transmitting a current between another electrode pair and that the depth of penetration is proportional to the separation between the electrodes. However, if the electrode separation is changed, information concerning the stratification of the ground can then be produced.

When electrical resistivity investigations are carried out, it is not the true resistivity value that is measured, but the apparent resistivity value (pa). According to Ohm's law, the ratio of the potential drop to any applied current (V/I) defines the true resistivity (*p*) (Reynolds, 2011). While apparent resistivity is “the value calculated as a product if a measured resistance (R) and a geometric factor (k) for a given electrode array” (Reynolds, 2011:292). The K factor takes into account the geometric spread of electrode and contributes a term that has the unit of length (meters). Apparent resistivity has the units of ohm-meters (Ωm).

Equation 1 Apparent resistivity where k is the geometric factor depending on the array of electrodes used.

$$pa = k\,\frac{V}{I}$$

Equation 3 Ohm's Law equation relative to resistivity

$$R = \frac{V}{I}$$

When the electrical current is injected into two of the electrodes (randomly) a difference in voltage can be measured (Loke, 1999). Using the applied current (I) and the measured voltage (V), the apparent resistivity can be calculated. However, resistivity meters measure the resistivity value expressed as R= V/I and therefore pa= kR (Reynolds, 2011). Thus, the complex relationship between true and apparent resistivity is illustrated. In order to determine the true resistivity value a process of inversion is required. This is normally a post-process stage and can be completed through specific computer software programmes.

Many modern instruments for electrical resistivity investigations are now controlled using a portable computer or tablet and also a specific computer software. This software allows the user to select what parameters they want the investigation to follow. One of these main parameters to be set is the type of array being used. The reason for defining what arrays will be used is that it effects the value of apparent resistivity that will be measured. The geometry of the electrode array is defined by the geometric factor of *k* (Reynolds, 2011). There are many different arrays that can be used for an investigation and it the output desired will influence what type of array is chosen. Some of the most common arrays include Wenner, Wenner-Schlumberger, dipole – dipole and pole – dipole (Figure **).The main difference in these array configurations has been seen to influence the resolution, sensitivity to subsurface resistivity structure and noise, and depth-penetrating capabilities of the data collected (Seaton and Burbey, 2002).

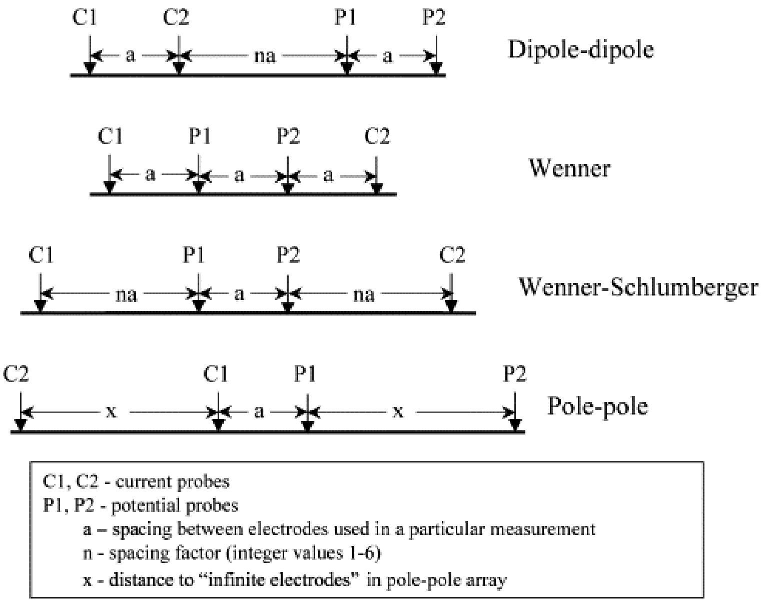


Figure 5 Summary illustration showing the different characteristics of some of the most commonly used electrode arrays. Source: Seaton and Burbey, 2002

It is becoming increasingly more favourable to collect both electrical resistivity data along with induced polarisation data (Dahlin et al., 2002). Induced Polarisation (IP) was first noted by Schlumberger in 1913 and was then used as a development during WW2 by the USA Navy to detect mines while at sea (Reynolds, 2011). From there as a method, it has been developed and more widely deployed in the mining and petroleum industry but has recently become favoured in environmental surveys. IP can be performed in one of four ways, time, frequency, phase or spectral domain (Dahlin et al., 2002). One of the most common systems of IP investigations is time-frequency where the overvoltage is utilised as a function of time whereas frequency domains measure apparent resistivity at 2 or more different frequencies (Reynolds, 2011).

Induced polarisation is an active method as the voltage generated can be applied as high as several thousand volts, which are applied to the ground in an attempt to measure the overvoltage produced. The primary principles of IP is to excite a response in the ground which is entirely dependent of the distribution and makeup of the mineralisation of the rock below (Reynolds, 2011). This method is said to be most effective when the mineral ore in the subsurface is disseminated rather than being combined.

3.2 Electromagnetic Data

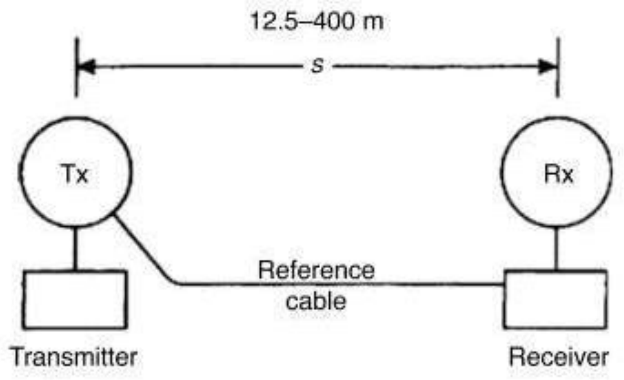
Electromagnetic methods (EM) have one of the broadest range of applications as the developments of its portability and ease of use has allowed more systems such as seaborne and airborne applications to become more widely used (Reynolds, 2011). Traditionally, electromagnetics was used for investigations such as groundwater investigations and natural resource explorations. Today electromagnetics is being applied to new projects such as hazardous-waste characterisation and geotechnical investigations (Auken, et al., 2006). One of the most common instruments are “moving source” instruments, which consist of a two-coil system.

The basic principles of EM investigations is that EM has two components that are directly measureable. These are electric and magnetic fields (Nabighian, 1991). EM can be described as a manifestation of the distribution of electrical charge and can be expressed through Coulmb’s Law (Equation 3).

Equation 4 Direct expression of Coulomb's Law

$$\nabla \cdot \varepsilon_{o} E = q$$

The main measureable difference in an area's EM field is between the free space and when in a medium such as the subsurface. When in a free space EM field can be described in terms of field intensity or flux density equally (Nabighian, 1991). However, this changes when the EM field is passed through a medium such as subsurface rock. This is due to the physical properties of the subsurface varying from one point to another.



The EM field is generated by passing an electric current though one of the coils (transmitter). It is the transmitter coil that therefore generates the primary EM field that propagates both below and above the ground. This field travelling through the subsurface media is subsequently modified to an extent relative to that which passes through the air above. The conductive medium that creates the magnetic component of the EM wave generates eddy currents. These eddy currents create a secondary EM field that is then detected by the receiver coil, along with the primary field that passes through the air (Reynolds, 2011). See figure 12.

Figure 6 Diagram illustrating the components of an EM dual-coil system. The circles represent the transmitter (Tx) and receiver (Rx). Source (Reynolds, 2011:433).

3.3 pXRF

The pXRF is a device that when in use will emit X-Ray waves in order to detect and measure the mineral composition of any given sample. The X-ray beams create a response in atoms and thus they fluoresce when under these circumstances. Some specific fluorescence can therefore be detected by the device and a quantified value of the amount of elements can be recorded. As it is the characteristics of the X-rays that cause a response in the atoms in the sample, the more X-rays that are produced within the tube in the device, the more efficient the responses. Subsequently, the more effective the responses are the more accurate the readings will be.

One of the main advantages of using the pXRF for sampling is the speed and accessibility that it provides the user. Even though the use of in-situ analysis can provide a rapid turnaround time for data analysis, Kalnicky and Singhvi (2001) argue that discrete sampling that removes the sample from the field can increase the accuracy and precision of the analysis as the sample is prepared more efficiently. However, it does mean that the sample population could potentially be lowered as it requires greater sample preparation time in comparison to in-situ analysis. Fortunately, the longer preparation time of samples will not hinder this investigation of this size.

Chapter 4 – Methodology

Both the Penrose Amenity site and the car park experience high volumes of traffic and footfall each day. Therefore, for all methods of data acquisition carried out for this investigation required planning of individual methodologies. The car park is in a prime location and is one of the only large free car parks in the area, thus receiving high volumes of traffic each day. With this in mind, the area manager for the car park at Cornwall Council was notified and granted permission to cordon off certain areas of the car park to allow both the topographical and geophysical surveys to be conducted.

4.1 Health and Safety

Health and safety considerations play an influential role in the development of a methodology for any survey (Hargrave, 2006). For this project the health and safety of both the individual carrying out the survey and all other members of the public were taken into consideration. Even though the use of geophysical techniques are not intrusive, there are some potential risks that need to be managed.

One of the methods of geophysics used will be using the FlashRes-Universal 64 to measure the grounds electrical resistivity. Which at any given time would be sending up to 350V of electrical current to two electrodes along the array. From a surveyors perspective the training provided and the understanding of the equipment meant that staying a safe distance away from the array when in operation was key. However, as this site is public land ensuring that no person came into contact with the electrodes while in use was fundamental. In order to do this the survey was operated by two people, who at all times were aware of the surroundings and could therefore intervene at any point. Also, to increase safety even further for the surveying of resistivity and IP in the car park the overflow section was cordoned off the night before surveying commenced. When deciding on the location for the electrode array, public access was always forth front in our considerations. The main worry in the amenity site was the need to keep dogs at a safe distance from the set up. Again, the vigilance of the surveyors reduces this risk.

Finally, for the health and safety of the surveyor and any others assisting them appropriate footwear and high visibility vests were worn whilst on site. These safety measures meant that the public were aware of the operators and could therefore take care when using the site and to also be visible to the public if any safety concerns were raised. Every effort was taken during the acquisition of data to ensure that the aesthetics of the site were not harmed or deteriorated in anyway and that the disruption to public users was minimal. A full risk assessment was completed and approved prior to the work carried out in the field and can be found in Appendix 2.

4.2 Site Locations

The site surveyed is located in Helston, Cornwall and as previously discussed is now used as the Penrose Amenity site and free public car park. In order to acquire all data required, it was divided into four areas. These areas have been highlighted on the map in Figure 6.

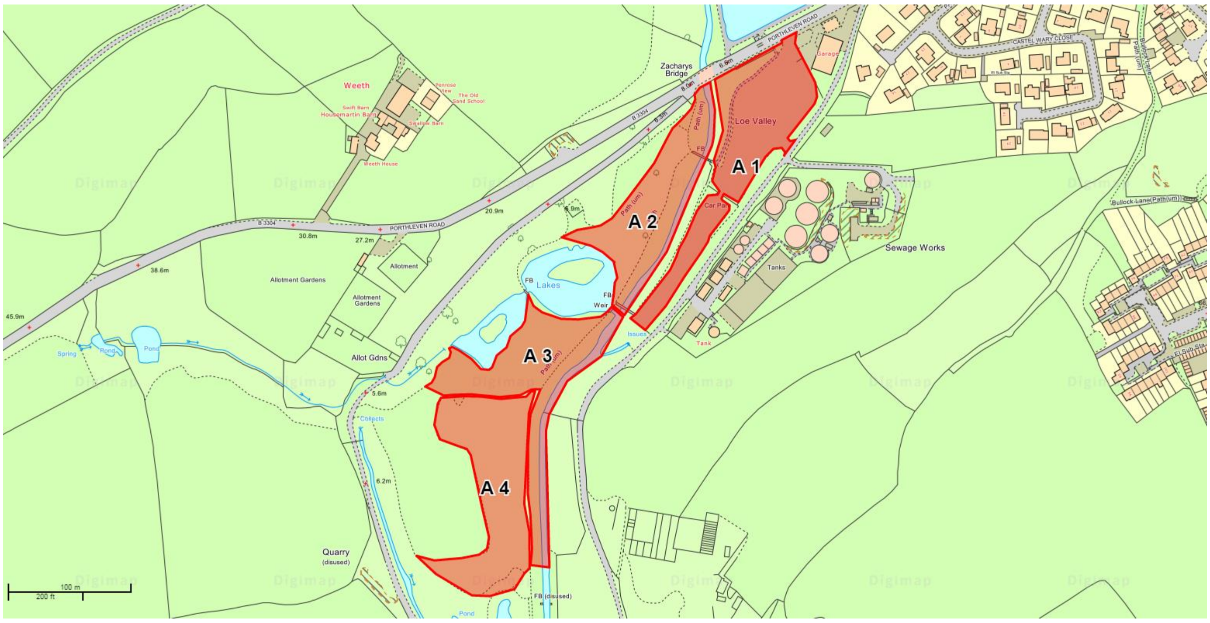


Figure 7 Ordnance Survey map of the site location in Helston. With overlaid annotations of the separated areas A1-A4. Including both the Penrose Amenity Site and the Car Park.

The area on the map marked as ‘A1’ is the public car park owned by Cornwall Council and the other areas A2-4 are part of the Penrose Amenity Site, and is part of the Cober catchment.

4.3 Primary Data

All data collected for this investigation is primary data collected between 27th June 2016 and 21st July 2016, this includes the topographical survey, geophysical survey and soil chemistry data. Each methodology is explained and discussed in this section of the chapter.

4.3.1 Topographical Survey

The first and most time intensive piece of data collection was the topographical survey of the site. As the site is relatively large the survey was carried out over multiple days. Due to the size and nature of the site, multiple control points were required in order to cover the entirety of the site. The control points were all established using the Trimble R10 GNSS system during a site reconnaissance trip (Figure 7). This Global Navigation Satellite System (GNSS) produced by Trimble, provides continuous real-time kinematic (RTK) surveying system. It creates this coverage via either satellite or internet connections depending on the location (Trimble Navigation Limited, 2016). This GNSS system was used as it provided fast and accurate coordinates for each of the chosen control points. The receiver receives and processes signals from a range of orbiting satellites, thus allowing the 3D coordinate positions from satellites to be calculated (Uren and Price, 2010). The R10 uses the WGS84 global coordinate system to reference positions on the Earth's surface. In total 8 control points were established across both the Penrose Amenity site and also in the Car Park.

Figure 8 Photo of a Trimble R10 GNSS receiver. Source: Trimble Navigations Limited (2016).

For each of the 8 control points a survey nail or wooden stake was sunk securely into the ground. For any wooden stake used, it was ensured that they were hammered securely into the ground in order to avoid causing any trip hazards. Once the nails or wooden stake was securely in the ground in the desired position, the R10 was set up over the point using a quick release tripod. Once the machine was setup and fully compensated the coordinates were recorded for each control point. A summary of each station and it's coordinated can be found in table 2. Bridge, Island and Meadow points are all located in the Amenity sites and the other five in the Car Park.

Table 1 Summary of all control points established with the Trimble R10 GNSS system.

Control Point	Eastings (mE)	Northings (mN)	Elevation (m)
Bridge	165345.451	26973.147	6.500
Island	165285.509	26850.248	4.910
Meadow	165228.810	26844.074	6.570
Blue Van	165370.790	26948.493	7.394
Far CP	165337.969	26889.322	7.839
Sewage Works	165415.558	26985.352	6.792
Middle CP	165416.662	27014.792	6.792
Roadside	165391.010	27037.375	6.789

A full equipment list for the topogrpahical survey can be found below (figure 8).

- Leica Total Station TPS 1200
- 3 tripods
- Detailing pole
- Leica 360° Prism
- Leica Circular Prism
- Box battery

Figure 9 Full equipment list used for the Topographic survey at the Penrose Amenity site and Car Park, Helston.

The method of “Known Backsight” was adopted to survey the features at the Amenity site. In order survey all of the detail required for Areas 2 and 3. The total station was firstly set up on the control point “Bridge” and a tripod with a prism was setup over the point “Island. The “Known Backsight” method allowed orientation of the total station to be possible as both coordinates for each station was known. All features that were accessible on the site were surveyed, this included the river that flows through the site. For this, the “top” and “bottom of bank” codes were chosen to indicate the height and depth where possible of the river. However, it is important to note that parts of the river in Area 4, were too deep for a surveyor or assistant to access. Once all of the features in Area 2 has been surveyed, a series of spot heights were measured.

This process was repeated for Area 3, where the total station and prism were interchanged, so the TPS was sat over “Island” and the prism was on “Bridge”. Once again the method of “Known Backsight” was used and surveying of the area was carried out. When detailing all the areas, the Leica 360° prism was used with the detailing pole (Figure 9). Using this type of prism allowed for Automatic Target Recognition (ATR) tracking to be utilised effectively. This application on the total station allowed it to track the position of the prism and increased the efficiency of recording observations.

Figure 10 Photographs of detailing the top of the river bank at Penrose, Helston. Using a detailing pole and 360 Prism. Source: Author, 2016.

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At times using the detailing pole and prism was not possible. For example the bank of the river was at times too deep to wade in with the prism and pole. In cases such as this, the total station was switched to RL mode which allowed for reflector-less observations to be recorded.

For the surveying of Area 4 there were no control points established due to it being a wooded area that would not allow the GNSS system to work to a desired accuracy. The limited coverage in the area therefore required a series of temporary stations to be setup to traverse around the site. In total, six temporary stations were setup to survey area 4 (Figure 10).

Figure 11 photographs of the temporary station traverse around Area 4 on the Penrose amenity site. Source: Author, 2016.

After, all areas in the Amenity site were completed the car park was then surveyed. The survey in the overflow car park was carried out using again a known Backsight method as it was efficient to use the control points “Blue Van” and “Far CP” as these positions both allowed to survey the full extent of this area. For the survey of the main section of the car park, it was best to use a resection methodology. In order for a resection to be carried out, the positions of at least three points need to be known. In this case “Blue van”, “Sewage

Works” and “Middle CP” were used. This method was ideal in this situation as the “middle CP” point was roughly 45° between the other points which is desired for a an accurate resection. The presence of vehicles, especially high sided ones did cause some challenges for line of sight.

4.3.2 Electrical Resistivity and Induced Polarisation

For this investigation the method of Electrical Resistivity Tomography (ERT) was adopted to gain an understanding of the sites soil resistivity. ERT is a method of mapping variations of resistivity in the near-surface or also called subsurface imaging.

The FlashRES-Universal 96 Resistivity and IP meter was the system used at acquire data for this investigation (Figure 11). Using this system, the resistivity meter, switching box and two core cables, along with 64 steel electrodes were all required. As the site is split into two different land uses and thus two different landscape characteristics, electrical resistivity data was collected on both the car park site and the Amenity site. The advantage of using these types of geophysical methods is that if needed large areas can be covered in one day with no disturbance to the site (Dalan et al., 2010). Another advantage of using this system is that it is entirely controlled using the software that runs on a laptop, which means that if needed the whole array can be established with only one surveyor. However, this investigation was operated by two people for logistical reasons.

Figure 12 Photograph of the FlashRES-Universal 96 system used for the resistivity data collection, it also shows the laptop used to run the data acquisition. Source: (N. Wood, 2016).

The electrical resistivity data collected at the car park site focused on the overflow section of the site. This allowed the area to be cordoned off easily and limited any disturbance from other users of the site and also increased safety while it was operating. As the whole data acquisition is run through the software programmed on a laptop it allowed for specific parameters to be set. Due to the length of the site it was decided that the 64 steel electrodes would be set out at 0.5 m intervals along a transect of 32 m. This therefore allowed for an exploration depth of 6.5 m. The depth of exploration is 20% of the line length. It is imperative when using electrical resistivity that the electrodes have good ground contact. This was at time a challenge here as the car park is laid with concrete and then a covering of loose gravel. Once the electrodes were laid out at the appropriate intervals and secured into the ground correctly, the core-cables were then connected. These cables were also connected to the resistivity meter. From there, all of the data collection is controlled through the software on the laptop. The appropriate parameters were selected before the session was started. These parameters included array type, length of transect, and spacing of electrodes. Three arrays were selected and they were ZZ, Wenner and Dipole-Dipole.

The process ran for approximately 45 minutes and at any given time two electrodes along the array were charged with an electrical current. Therefore, being vigilant of passers-by and also dogs off leads was important. The programme was also set to run in a stacking mode of 4. Meaning that for every point at which a reading is taken, 4 measurements is actually recorded and an average taken. As explained inversion for each measurement was required post-process to produce true resistivity values. In order to give the data set some context, the electrode array was surveyed using a Trimble M3 Total Station. This was carried out using the established control points, “Blue Van” and “Far CP”. Because of the position of the array, a resection was carried out. Meaning that the total station was roughly 45° between both control points, providing a good line of sight to survey in each electrode position (Figure 12).

Figure 13 Photographs of the resection setup to survey the positions of each electrode used for Electrical Resistivity.

The same methodology was adopted for the second day of data collection at the Amenity site. This time the electrode array was arrange across a section of Area 3. Due to the increased size of the area at the Amenity site the array configuration was changed. The 64 steel electrodes were set out at 1 m intervals. With this 64 m long transect the depth of exploration was therefore12.5 m. The same parameters were set on the laptop and the same ZZ, Wenner and Dipole-Dipole arrays were chosen with a stacking value of 4. This time the resection was carried out using the control stations “Island” and “Meadow”.

The very advantageous feature of using the FlashRes-Universal 96 is that it has the ability to also run Induced Polarisation (IP) investigations simultaneously to the resistivity. For this survey, time domain was used as it measures the decay of the supplied voltage between two of the electrodes once the current has been switched off. The resistivity meter is able once the current is switched off to measure the residual voltage or overvoltage that decreases with time. The ability to collect both sets of data in one session is ideal and increases the efficiency of data collection and also will hopefully aid the later interpretation.

Once the data had been collected for both the electrical resistivity and IP arrays, it was run through a computer software and from there displayed into relevant maps for analysis. The software used was Surfer Version 3. Unfortunately, this is not the most recent and advanced version of Surfer and therefore the tools available to manipulate the data was limited.

4.3.3 Electromagnetic data

For this investigation the GSSI EMP-400 Electromagnetic Profiler (figure 13). This is a dual-coil system that consists of two coils of wire separated by a constant distance. One coil acts as a transmitter and the other as a receiver. The advantage of using a system like the EMP-400 is that it does not require any direct contact with the ground, unlike the steel electrodes used in the resistivity survey. The dual coil system of the EMP-400 profiler allows both the in-phase and the quadrature components to be recorded. For this survey, the parameters were set to not only record both in-phase and quadrature but also at 15000 Hz and 3000 Hz frequencies.

Figure 14 Photograph of the EMP-400 Profiler in the field (Source: Author, 2016)

The actual data acquisition method was designed as a grid system. This is based on the way that the profiler is operated. For both the car park and the Amenity site a grid system was constructed of x and y 1 m intervals. For the Car Park, the x lines were spray painted onto the ground running from 1-10, across the width of the overflow car park. 40 m from the first line a second line parallel to the first was also marked up (Figure 14). Once these parallel lines were mark up, a rope with markings at every meter was laid across the first transect line at point 1. The 1 m marked points on the rope indicated were each measurement would be recorded.

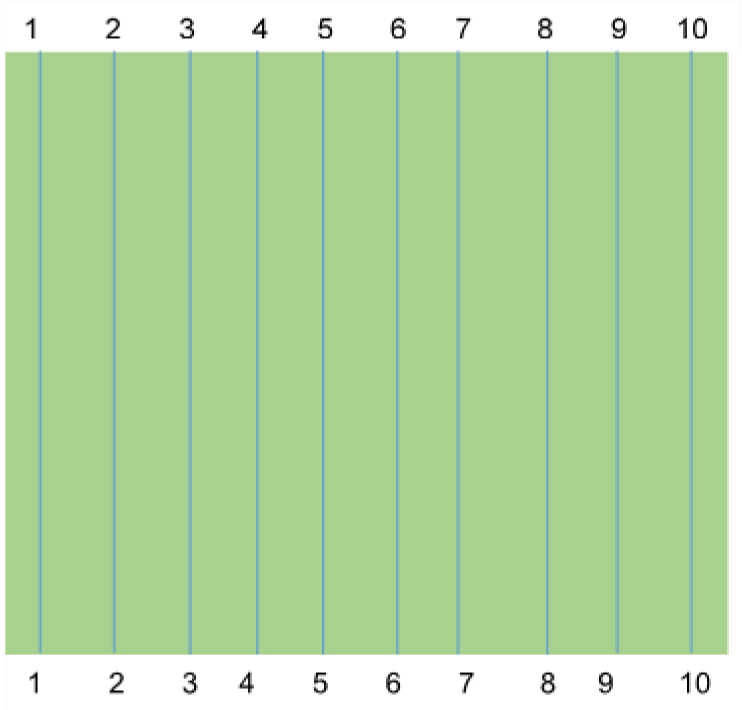

Figure 15 Schematic diagram of the grid system used for the data collection of the EM data.

Before any data could be collected the profiler had to be calibrated, firstly to the surrounding environment and secondly to the user. For the calibration to the environment the profiler was placed onto a wooden box and allowed to set to the different atmospheric conditions. Then the user held the profiler at the height they intended to carry it and was once again set to that level. It was fundamental that the user was magnetically clean in order to not create any unwanted noise when collecting data. Once all calibrations were finished, readings were taken. Starting on line 1 the first reading was taken. Once the first point was taken, the used simply walked to the next marked point 1 m away and took the next reading. This was the process for each time along the grid. The same process applied to the data collected in the Penrose Amenity site. Due to the size of the Amenity site, 2 girds were set out. The first being 12 transect lines at 42 m in length and the second being 8 transect lines at 32 m length (Figure 15.) Once all of the data had been successfully collected, each of the ends transects were surveyed in using the Trimble M3. This once again was to give the readings context in its orientation.

Figure 16 Photograph illustrating the grid system used to collect the EM data. The red stakes mark the start and end of each transect line. Source: Author, 2016

The data once processed was run through the software Surfer Version 3, like the resistivity and IP data. Unlike the resistivity data not having access to the most up-to-date version of the software did cause some issues in terms of presenting the data. For example, when the EM data was gridded correctly using the Kriging method, the whole grid was filled with the data. However, this created a false representation of the data. As not all of the grid contains data as a strict method was adopted to highlight where the data was collected from. Therefore, the filled grid was an exaggeration of the actual data set. Therefore, a post map that showed the location of each data point allowed for blanketing to occur. The limitation of this is that the selection of the gird location is not very precise and can create a distorted image. Even though every effort was taken to ensure that the gird system use was aligned correctly, the maps produced do not always follow an exact rectangular shape.

4.3.4 Portable XRF

Soil samples were taken from a section of the River Cober that runs through the Amenity site. The samples were taken using a steel auger and were taken in a systematic approach ensuring that each sample was roughly equidistant apart, to ensure that whole river was evenly represented. However, any features of specific interest were also included in the samples. Samples were taken on both sides of the river channel and for each site the corresponding GPS readings were taken. In total 23 samples were taken along the river and 4 in the field area of areas 2 and 3. Attempts to take samples further down the river were tried, however the depth of the river on the meanders did not allow it. The sample sites can be seen on the map below (Figure 16).

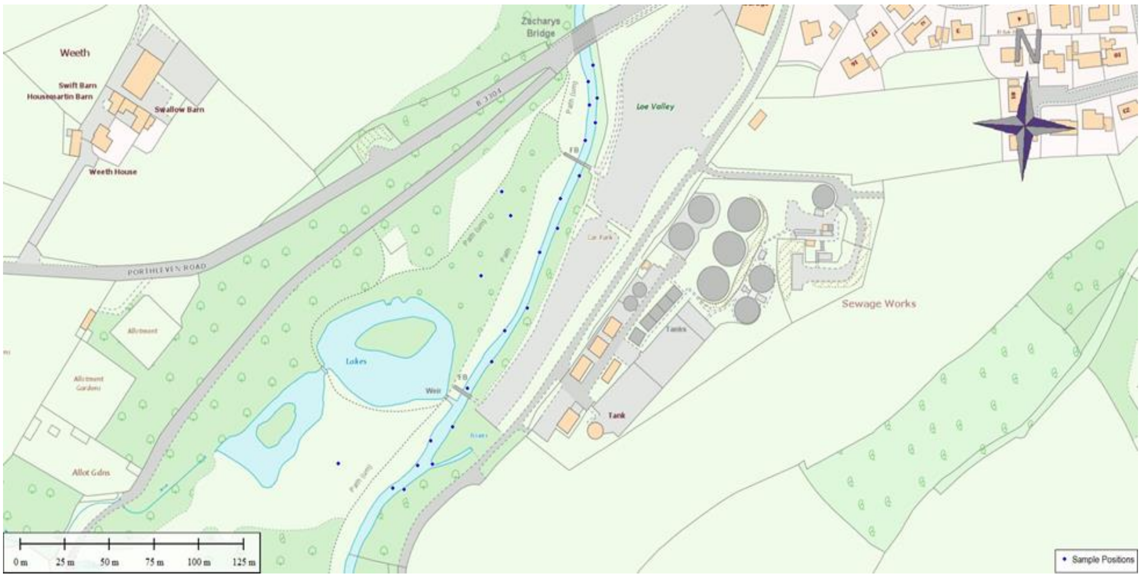

Figure 17 Map illustrating the soil sample positions taken from the river banks at of a section of the River Cober at the Penrose Amenity Site.

Training for operating the pXRF was given before it was operated and a full risk assessment was completed (see appendix 3). In many investigations the analysis of any samples taken will be carried out in the field. However, for this project all readings were recorded after the samples were taken.

It is also important to note the procedure followed when carrying out the analysis of each sample. As the device uses X-ray beams to observe element concentrations of samples, there are some health and safety precautions that need to be adhered to. For instance the operator of the device, the area within a 2 m radius of the head of the device were seen as a “controlled area”. This meant that no other persons were allowed within this area when samples were being analysed. The machine was to be held at arm’s length away from the operator when the sample was being analysed. Each sample before analysis is to be flattened and any large grains were removed. The sample was then placed onto a solid surface and the p-XRF window at the front of the device was slowly rolled onto the centre of the sample. The device was set to take a reading when triggered for 60 seconds. Once the 60 seconds finished each element recorded was saved onto the device but was also recorded on a hard copy. The sample was then turned over and a second reading was taken for an additional 60 seconds. Again these measurements were recorded to provide an average.

Chapter 5 – Results

Following the completion of all data collection, each type of data was taken individually to be processed. The following sections of this chapter illustrates the results found from the post-processed data.

5.1- Topographical Survey

Once the field work for the topographical study was carried out, all of the jobs and data files were extracted from the Total Station and all data was run through the computer software LSS. Running the data through this software allowed for any erroneous data to be highlighted and rectified if required. From here, the data was exported to AutoCAD and final editing of the data was carried out. The final completed topographical map can be found in Appendix 4.

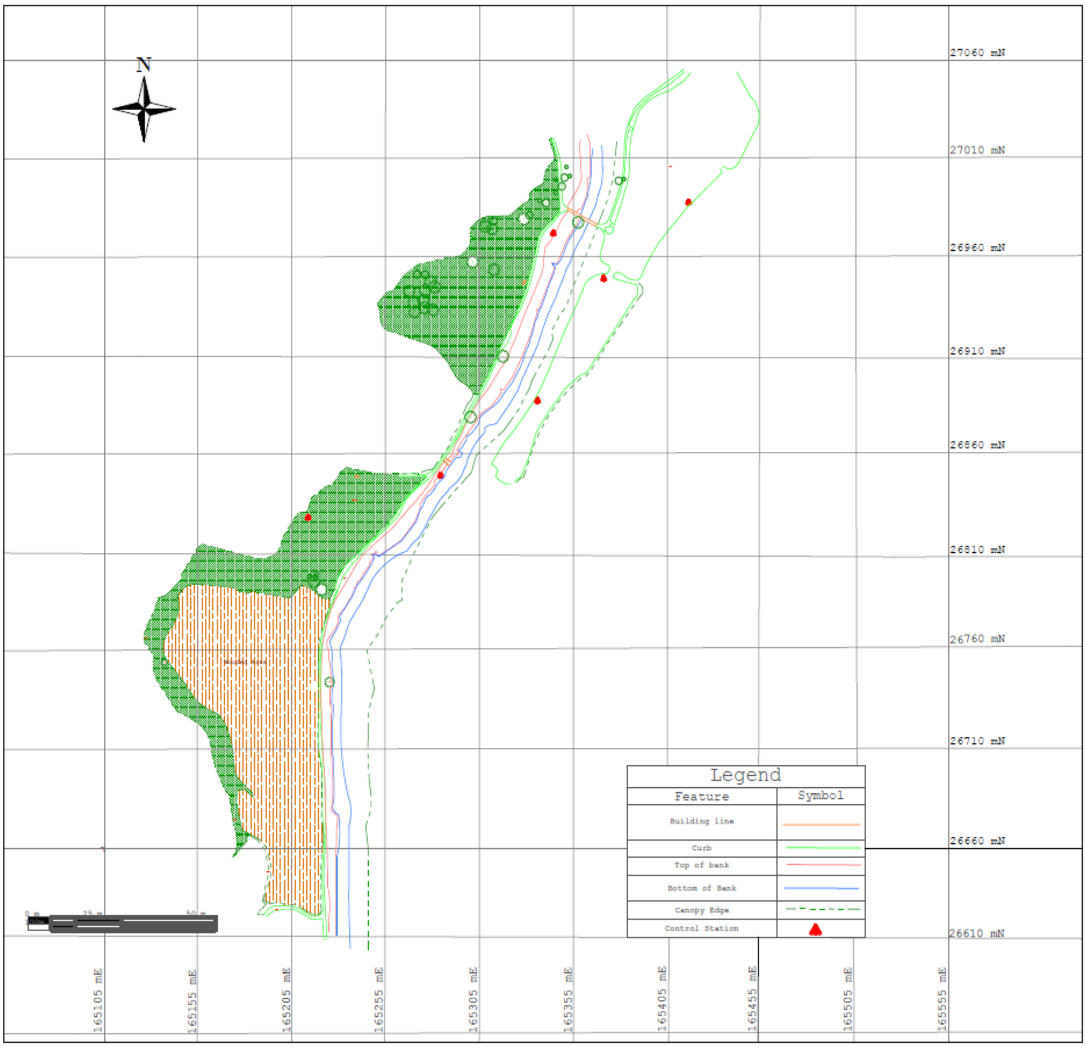

Figure 18 Screenshot of the final topographic map of both the Penrose Amenity site and Car park.

5.2 Electrical Resistivity and Induced Polarisation

5.2.1 Car Park

Figure 18 below is a map displaying the electrical resistivity data collected from the Car Park set up. It can be seen from the heat map that there are three significant anomalies that spark interest. For instance the areas highlighted between 15-30 m of the electrode array represent areas of high resistivity. Specifically, there are areas of resistivity that reach 1150 Ohms / m surrounded by areas of lower value. These high resistivity anomalies stand out against the overall resistivity trend of the array that falls within 50 – 250 Ohms/m. Thus, the extreme highs of over 750 Ohms/m are stand-alone areas and are of specific interest. These areas of high resistivity area a good indication that the ground is not completely homogenous which is indicative of a typical landfill site.

The IP data for the Car Park array (Figure 19) has been considered to be both separate and coupled with the resistivity data. In order to highlight this relationship the following maps were produced by overlaying the IP over the Resistivity data. Thus, illustrating the differences between the data and also how the two are linked. Figure 19 with the IP data overlaid onto the resistivity data, it is possible to see that there are similar patterns of highs and lows. The use of contours to illustrate the IP data indicates that there are areas again between 15 – 30 m of the electrode array whereby there are areas of high induced polarisations as well as resistivity. The potential presence of leachate contaminants is possible as high IP observations is indicative of contamination in the soil or groundwater (Buselli and Lu, 2001). Figure 20 is a heat map that illustrates the induced polarisation data of the Car Park only.

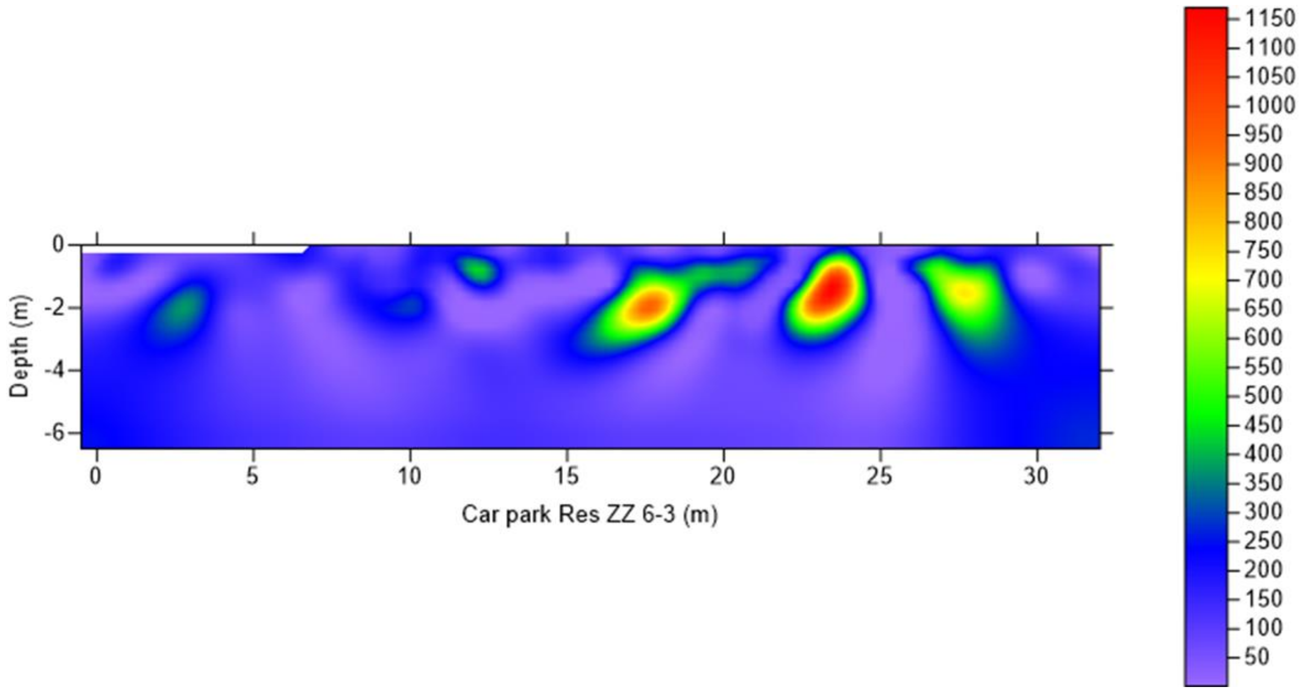

Figure 19 Heat map illustrating the resistivity results for the car park (ohms/m)

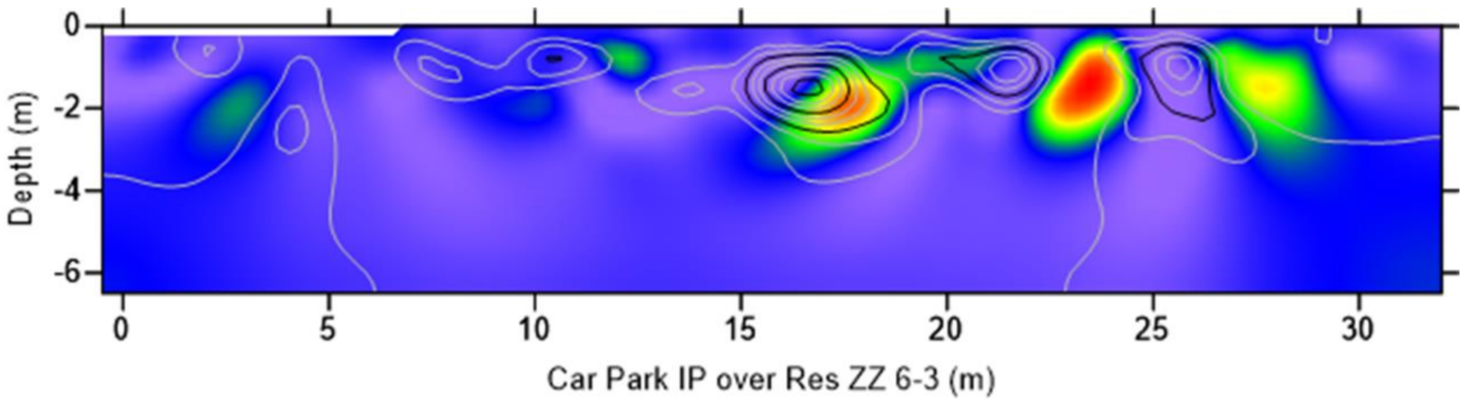

Figure 20 Heat map illustrating the Results overlaid on the Resistivity Results for the car park

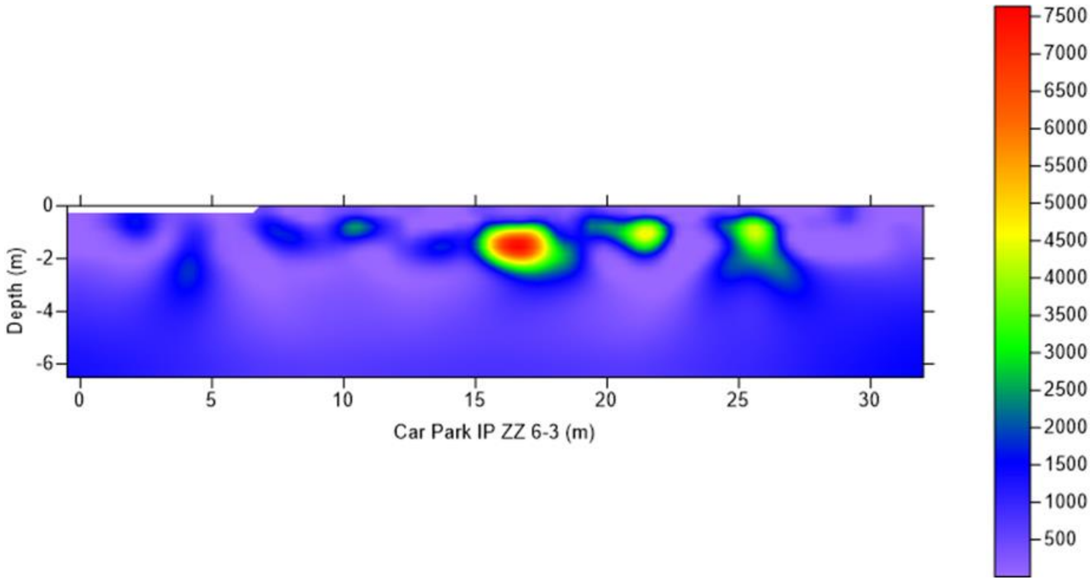

Figure 21 IP results from the Car Park survey mV/V.

5.2.2 Penrose Amenity Site

Succeeding the Car Park results, is the electrical resistivity results for the setup at in A3 of the Penrose Amenity site. Figure 21 illustrates the Amenity site's resistivity results. From the map it is again clear to see that there are areas of high resistivity, which lie between 20 and 30m of the electrode array. These highs reached 900 Ohm/ m which is lower than that observed at the Car Park but is still significantly high in terms of electrical resistivity. Again the background resistivity of the site lies between 50- 200 Ohm/m which highlights this area of considerably higher resistivity.

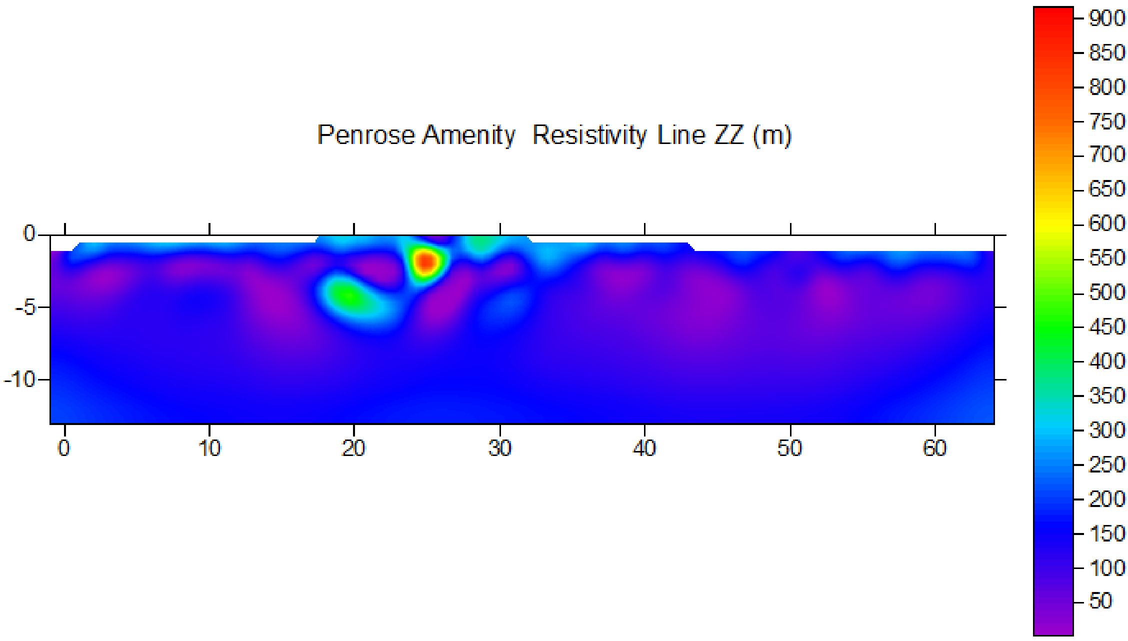

Figure 22 Heat map presenting the electrical resistivity result from the Penrose Amenity Site array.

Ohm/ m

Figure 22 illustrates the induced polarisation results of the Amenity site survey and shows that again the area of high IP are similar to that of the resistivity results. The highest values of IP were again observed between 20 -30 m along the electrode array at values of 4200 m V/V. What is noteworthy for these results is that unlike the resistivity data there are also areas of moderately high IP readings along the array. There are 7 areas highlighted as the green areas on the heat map which indicate observations of 1400-200 mV/V. These areas indicate areas of interest for the survey. The high anomalies found in both the IP and resistivity data could indicate either a plume of contamination from landfill leachate or a void in the ground.

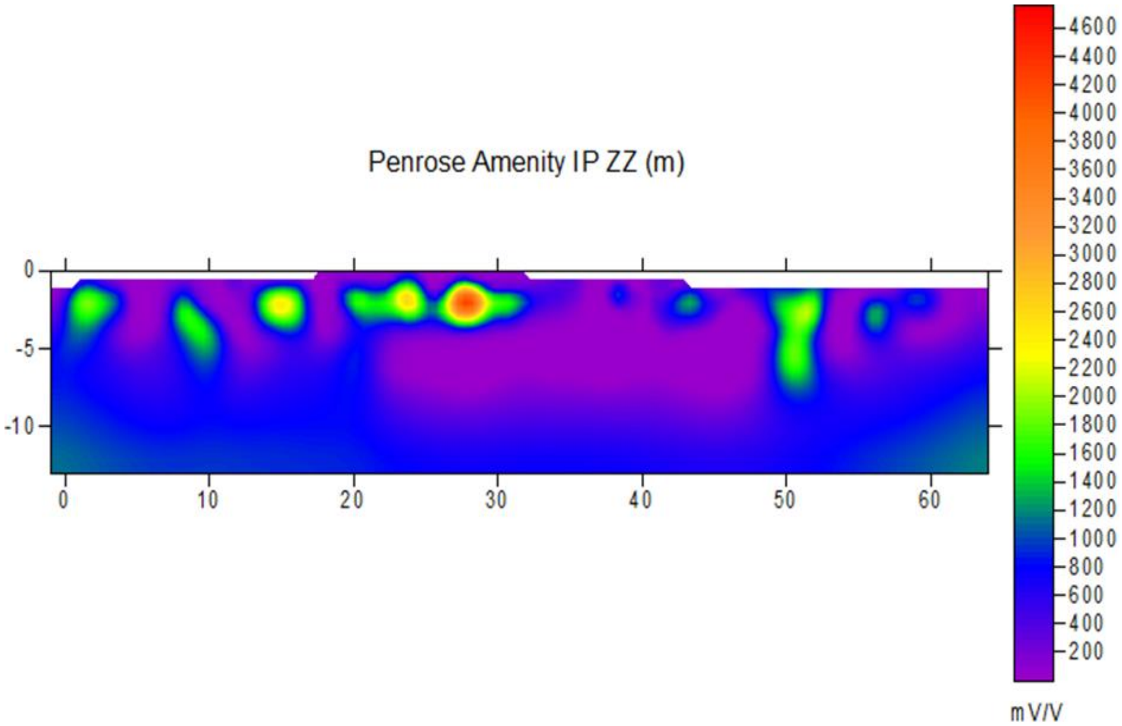

Figure 23 Map illustrating the IP results from the Penrose array (mV/V).

5.3 EMP-400 (Electric Magnetics)

EMP- 400 profiler records measurements of EM fields in two ways; as Quadrature measurements and as In-Phase. Research shows that the In-phase measurements are sensitive to low resistivity bodies and the Quadrature measurement are sensitive to variations in the earth's electrical properties (Al-Tarazi et al., 2008). Therefore, the EM data has been presented in these forms separately. It is also important to also note that the measurements were also recorded at both 15000 Hz and 3000 HZ frequencies. The different frequencies play a pivotal role in what the data is in fact showing. For instance, the data is only the true conductivity readings at the 15000 Hz and the 3000Hz readings are only supplementary to this data and should not be interpreted as the true readings alone. Therefore, for each of the setups the data has been displayed for each frequency separately.

5.3.1 Car Park

Figure 23 illustrates the Quadrature results of the Car Park at 15000 Hz. It can be seen in this map is that there is a predominate area of high conductivity in the far left corner of the Car Park Grid. This high reaches values of 5400 ppt. This is very high in comparison to the surrounding background readings that for majority reads at 2000 ppt. The In-Phase readings at 15000Hz (fig.24) have been displayed alongside the Quadrature readings. The In-phase readings highlight 5 areas of high conductivity anomalies at around 14000 ppt. Due to the nature of the in-phase mode and its sensitivities, these anomalies were not as prominent in the quadrature dataset.

Conductivity at 15000 Hz has also been measured and presented in a heat map. The conductivity is the apparent conductivity which is the inverse of resistivity. With this in mind, figure 25 illustrates the both the extreme high readings at the top left of the grid at 120 Millisiemens/m. There are also the 5 areas of high conductivity anomalies ranging at 40-75 Millisiemens/m that were highlighted in the in-phase data. The emphasis on these anomalies in the apparent conductivity indicates that these are areas of interest to the investigation and hold properties that modify the natural conductivity of the landscape above the natural levels.

All data recorded at 3000 Hz can be found in Appendix 5-7.

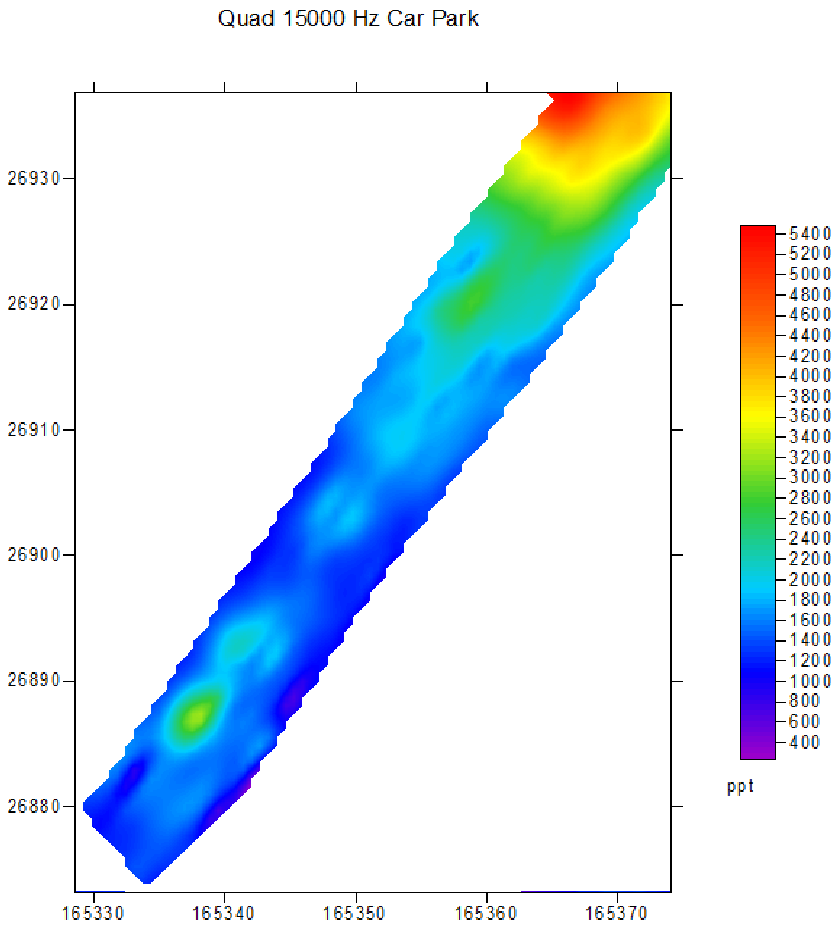

Figure 24 EM results for car park in in-phase 15000Hz

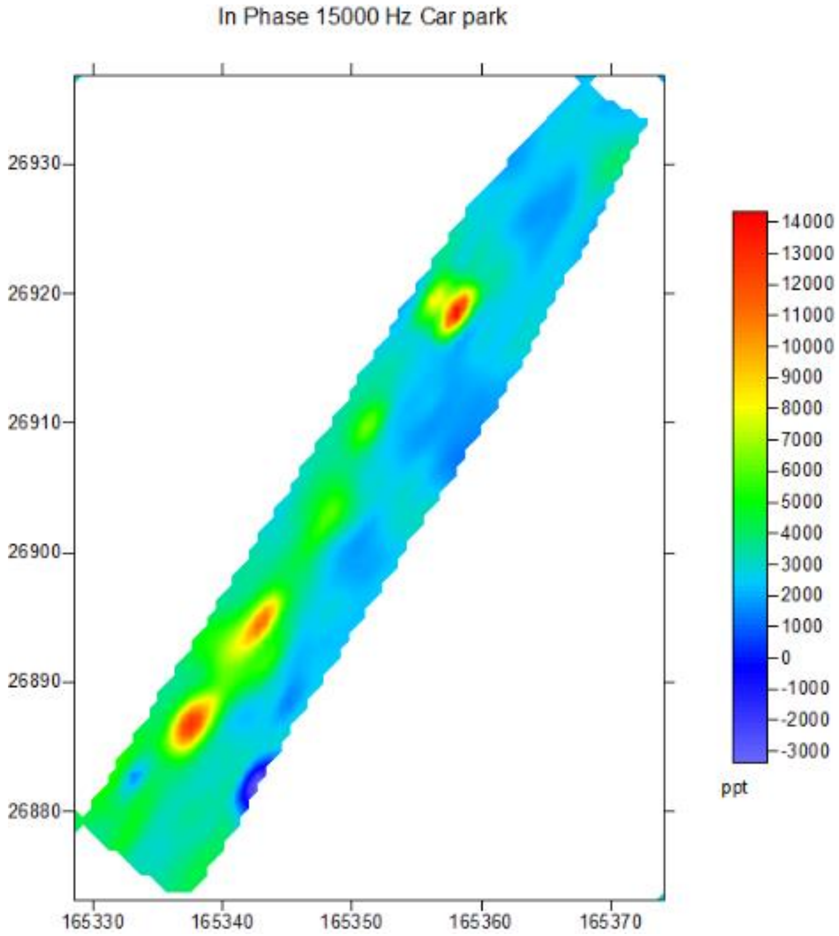

Figure 25 Heat map illustrating the EM results from the car park in the quadrature mode at 15000 Hz

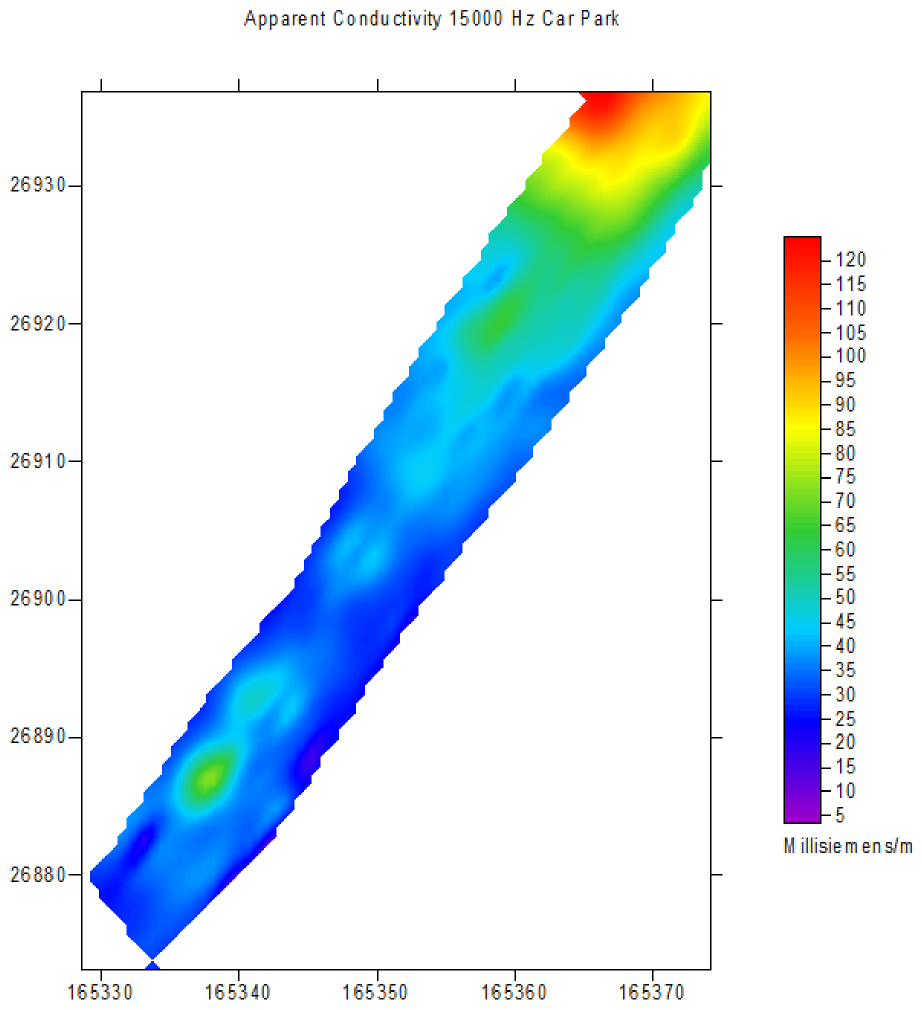

Figure 26 Heat map of the apparent conductivity from the EM results at the Car Park.

5.3.2 Penrose Amenity Site Grid 1

As explained in Chapter 3, the gird was laid out as a 12 x 42 m grid system. Figure 26 is the result of the survey in the quadrature mode at 15000 Hz. It illustrates that for the most part of the grid the readings were recorded to be at -200 – 300 ppt. This is an extreme low anomaly in the data that is an area of interest for this project. The overall background readings ranged between 100-300 ppm in the south and increase gradually to 300-700 ppt to the North. There is a predominate area of high readings to the left hand side of the grid with readings of 1700 ppt. Figure 27 illustrates the 15000 Hz frequency in the In-phase mode. The In-Phase results indicate that there are areas of high conductivity not only to the upper right region of the grid but also to the left again at values of between 3000-8000 ppt. These high conductivity anomalies could be suggestive of little magnetic susceptibility and could therefore be properties of contamination.

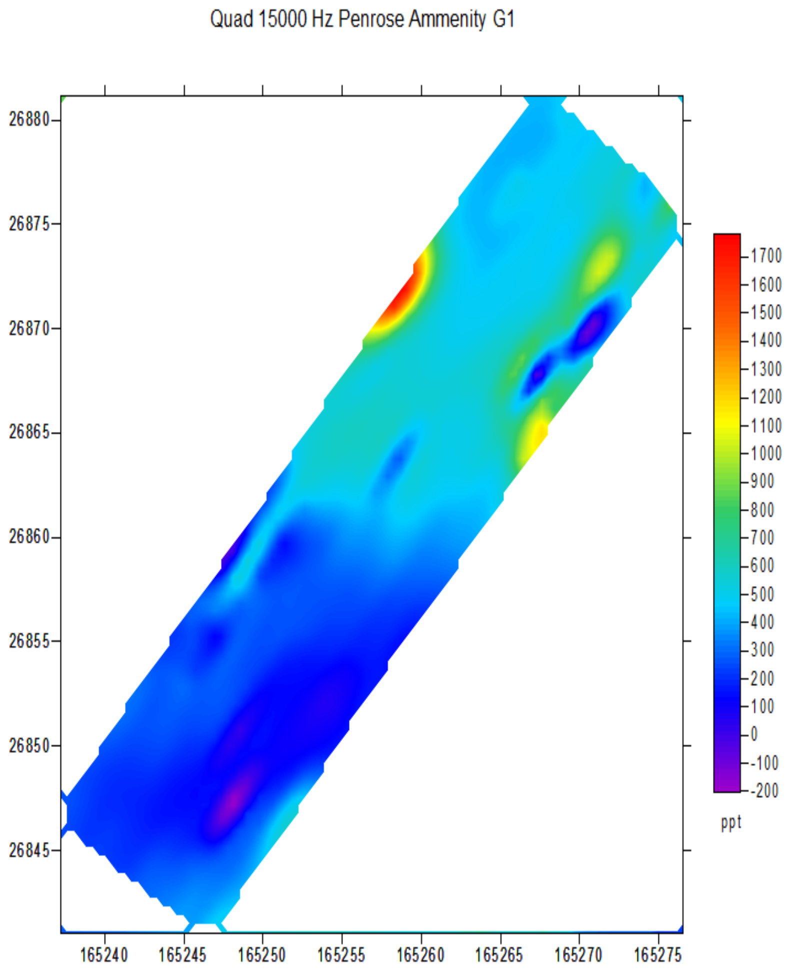

Figure 27 Heat map of the Quadrature results for the Penrose Grid 1 results at 15000 Hz.

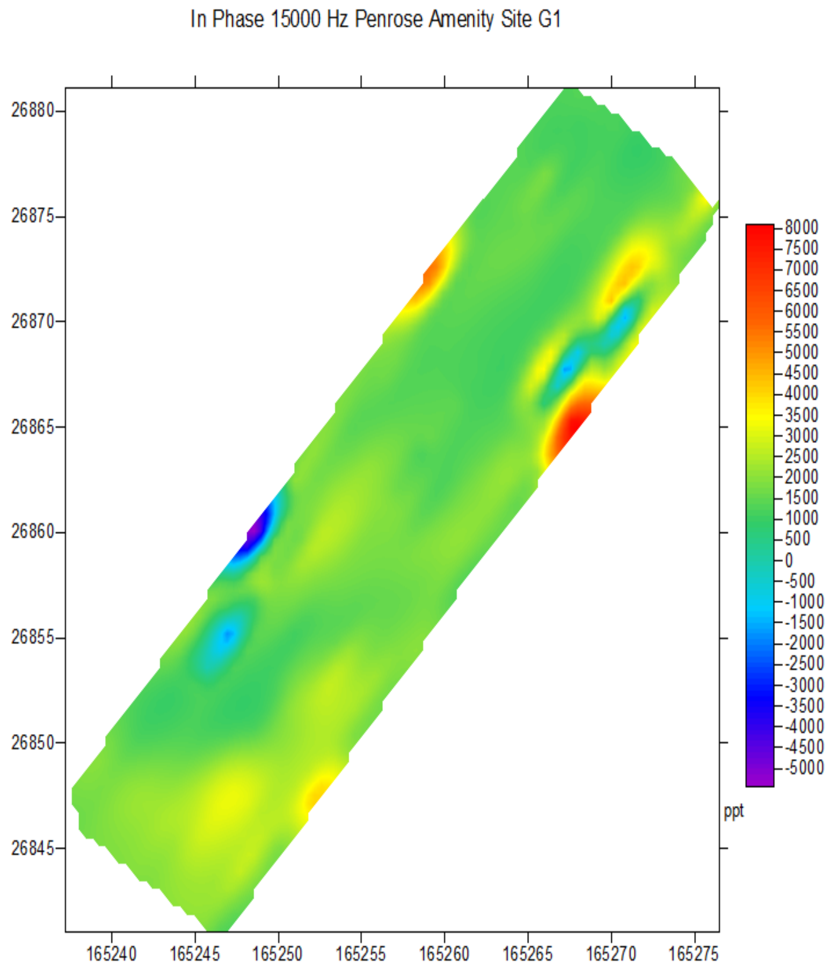

Figure 28 Heat map of the In-phase results at 15000Hz for Penrose Amenity Site Grid 2

The apparent conductivity at 15000Hz is displayed as figure 28 below. The conductivity readings for Grid 1 at the Penrose Amenity site reiterates that there is an overall apparent conductivity in that area of between 2-14 Millisiemens/m with a significant difference of 40 Millisiemens/m at the upper left area. The presence of this high is in all the apparent conductivity, quadrature and in-phase datasets, illustrating that there is a significant change in the natural resistivity and conductivity in the area in comparison to the surround background levels. Once again all results for the site at 3000 Hz are in Appendix 8-10.

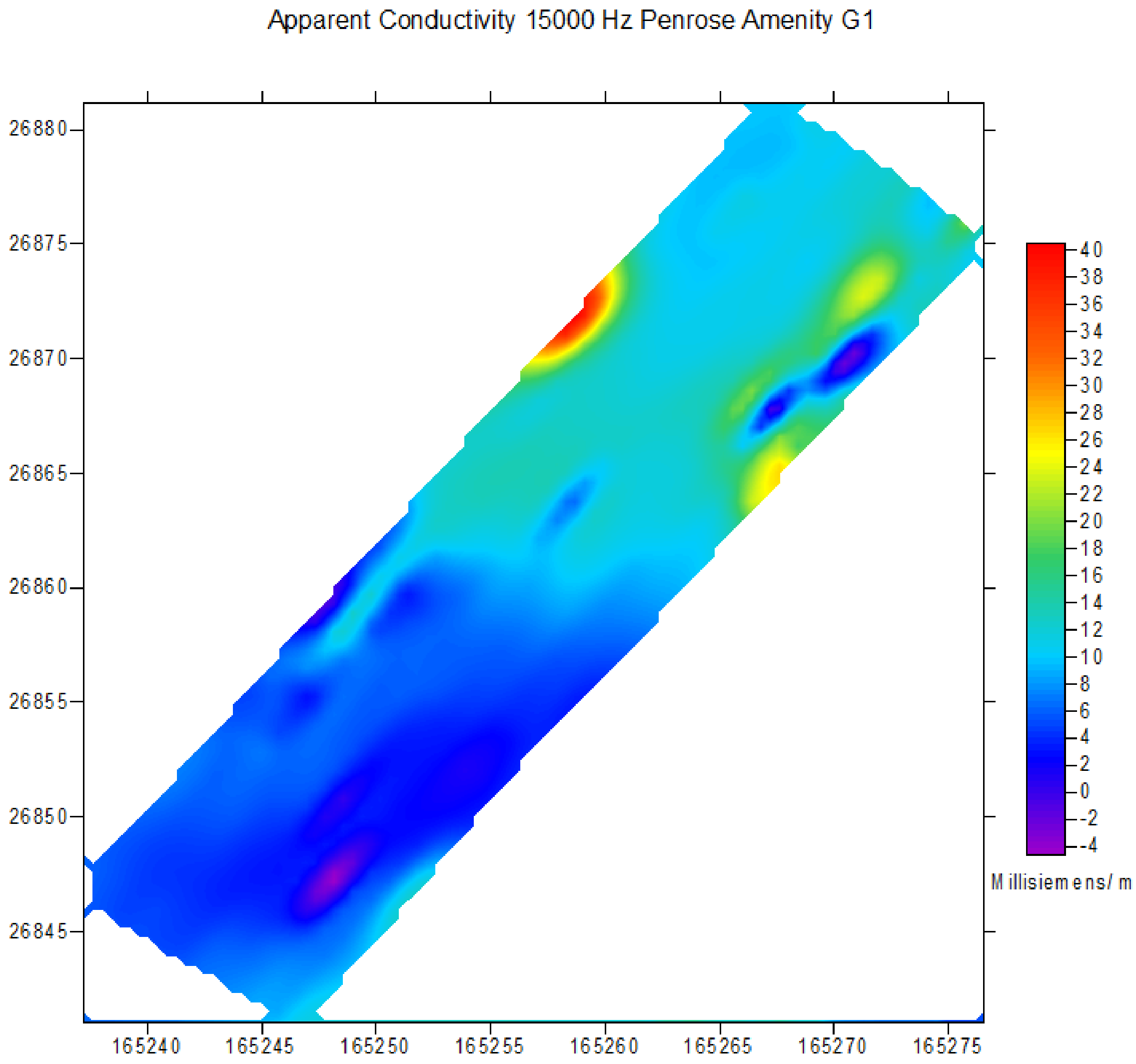

Figure 29 Heat map of the apparent conductivity at the Grid 1 in the Penrose Amenity site.

5.3.3 Penrose Amenity Site Grid 2

Figures 29-31 display the results 8 x 32m grid system. Figure 29 illustrates that the quadrature 15000 Hz has an overall high conductivity with values that fall between 200-800ppt. However, in amongst the high conductivity of the background levels in the quadrature mode, there's a distinct feature highlighted as a blue area with readings of -100 and -1000 ppt. This extreme low conductivity reading could be suggestive of a void in the ground.

In comparison to the quadrature results, the In-Phase results highlight a distinct smaller feature of lower conductivity towards to end of the grid with readings of -500ppt. Again using both the in-phase and quadrature results is very useful as it allows a full interpretation of all features picked up with the profiler. For instance the indications that the readings from both the quadrature and in-phase results provide is the possibility of a void or non-mineralised rock as there that area's physical properties are highly resistive.

Figure 31 is the apparent conductivity readings of Grid 2 at 15000Hz. The apparent conductivity readings of the gird once again highlight the two main features located in the grid. The large feature picked up by the profiler has a range of conductivity that spans from around 6 Millisiemens/m up to -22 Millisiemens/m. All of these findings form the basis of further discussion and interpretation of the makeup of the subsurface of the site and also how it influences the surface features on the surface.

Finally all of the 3000Hz data can be found in the Appendix 11-13.

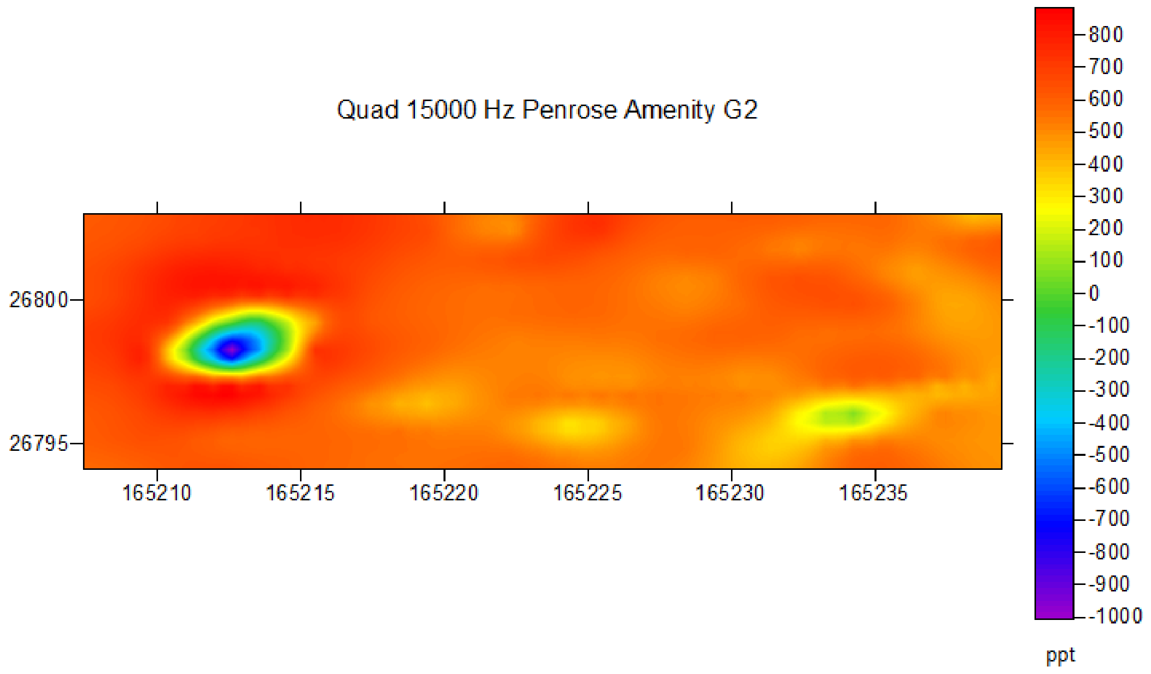

Figure 30 Heat map illustrating the final EM setup at Grid 2 at the Penrose Amenity site in the Quadrature mode at 15000 Hz.

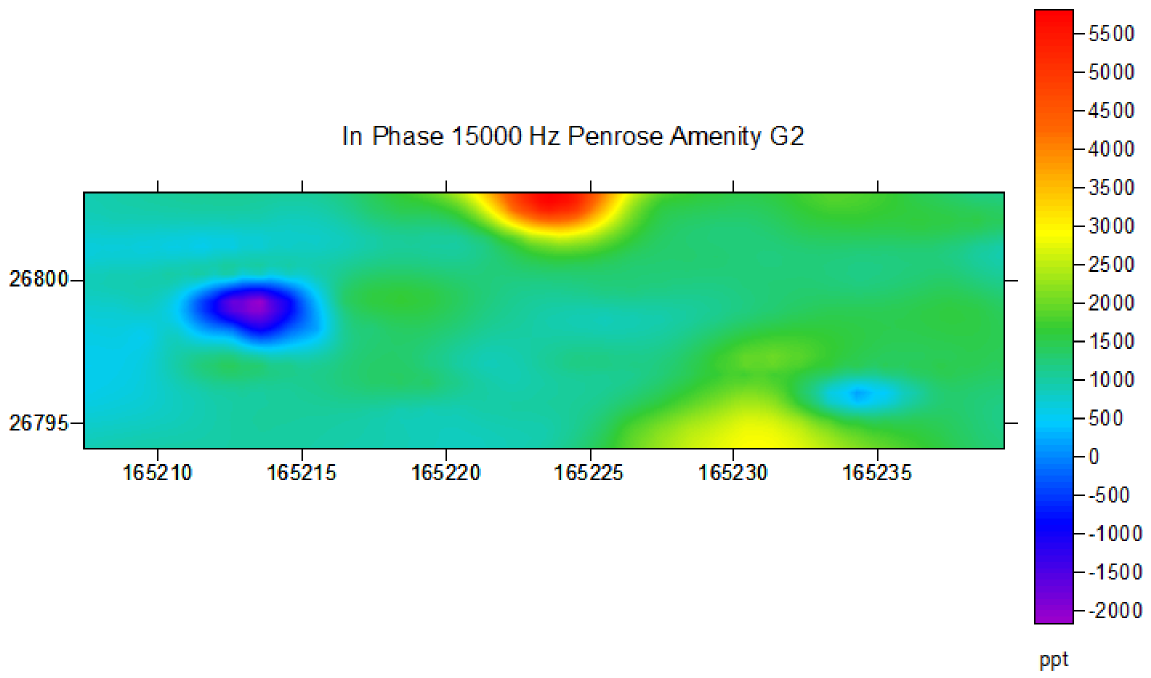

Figure 31 Heat map of the in-phase EM results at Penrose Amenity Site Grid 2

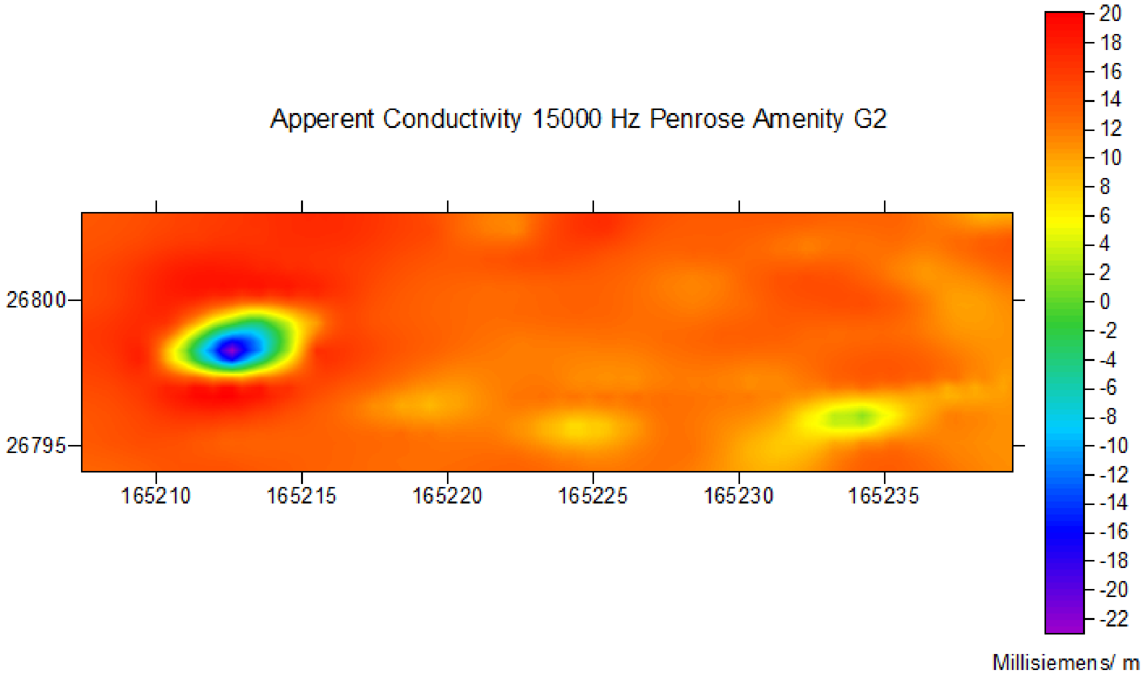

Figure 32 Heat map illustrating the final apparent conductivity results at 15000 Hz for the Grid 2

5.4 pXRF

Once all of the XRF results were recorded and averages were taken, maps illustrating each individual element were created. Understanding the levels of contaminants at the site will help future monitoring and subsequent management.

5.4.1 Iron

It can be seen that the levels of iron for the most part is observed to be in the range of 20,000 and 32, 000 ppm (fig. 32). However, there is a stretch of the river downstream that shows highs of up to 46,6000ppm. In order to understand these areas of interest within the data, additional maps were then created that looked to locate the position of the quartile ranges of the data and their position along the river. Figure 33 illustrates these quartile ranges and separate the lowest values from the highest. Thus, focusing the investigation to specific areas along the site to understand the spread of data in greater depth. It emphasises that the high values of iron can be found to the North of the river, near a water outlet that is stained orange and also to the South of the river. From anecdotal evidence from users of then site, it has been suggested on a number of occasions that building rubbish was dumped at the site. Suggesting the possibility that scrap steel could have been tipped.

Figure 33 Heat map of Fe concentrations (ppm)

Figure 34 Map illustrating the quartile ranges of Fe (ppm)

5.4.2 Zinc

Secondly, the observed Zn levels were mapped as a heat map to demonstrate the overall spread of the data (fig. 34). The map below indicates that the levels of zinc are relatively low values with the majority of readings ranging from 35-250 ppm. However, there is high reading of 350 ppm at the South of the area.

Figure 35 Heat map of the Zn concentrations across the sample area (ppm)

Therefore, in order to better understand the trends in the zinc data the levels again were separated into it's upper, lower, median and highest quartile ranges, as seen in figure 35. It emphasises that the data for the most part falls within the lower and median quartile ranges which are 35-79 ppm and 79.5-131 ppm. It seems that these value are equally spread across the river.

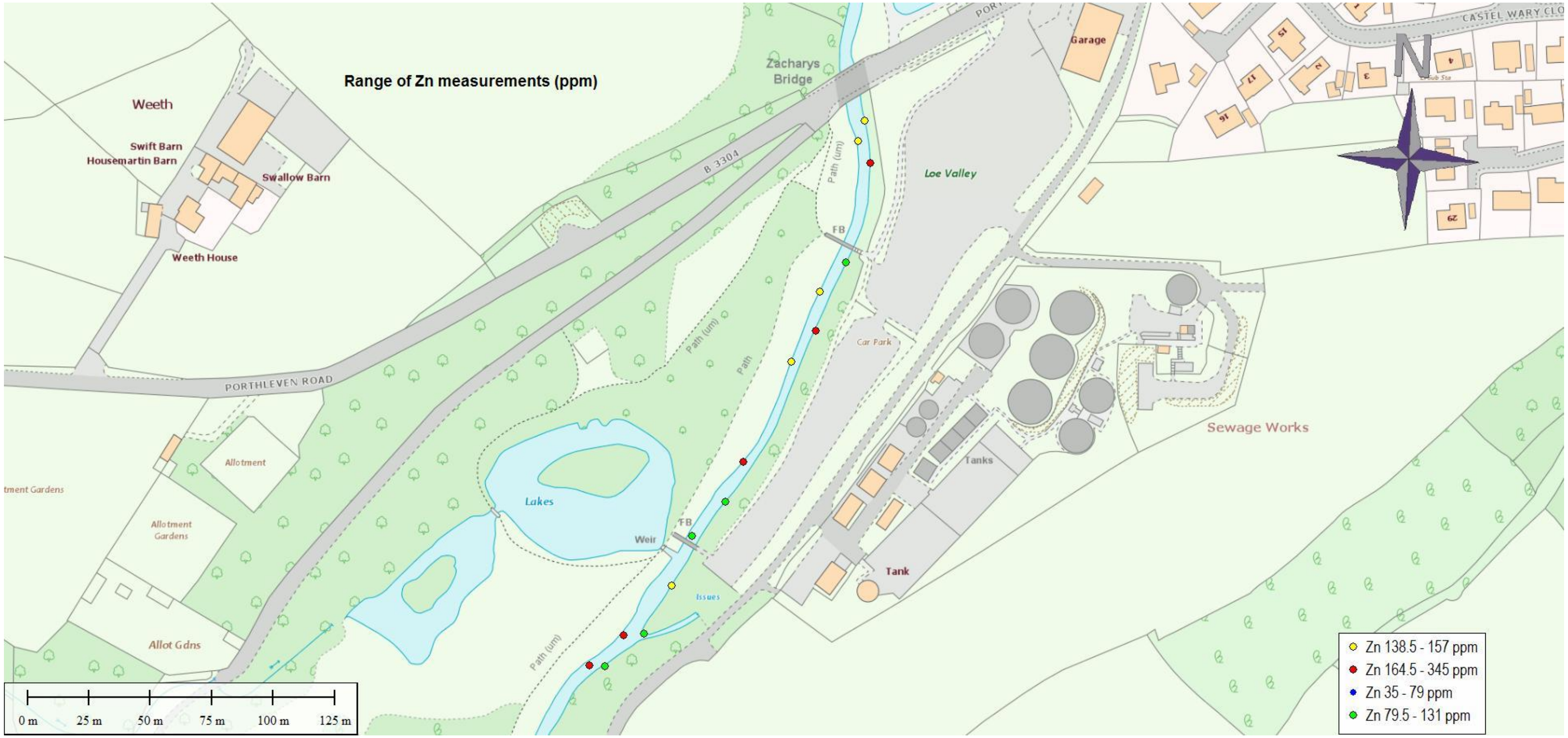

Figure 36 Map presenting the location of concentration levels of Zn across the site (ppm)

5.4.3 Arsenic

Arsenic being a well-known contaminant and it’s presence in any environmental survey is of interest for monitoring. Figure 36 again, highlights the spread of the data across the river running through the site at Penrose. It illustrates that there is some traces of arsenic at the site. Especially downstream, where there is an area of high As concentrations reaching 563 ppm.

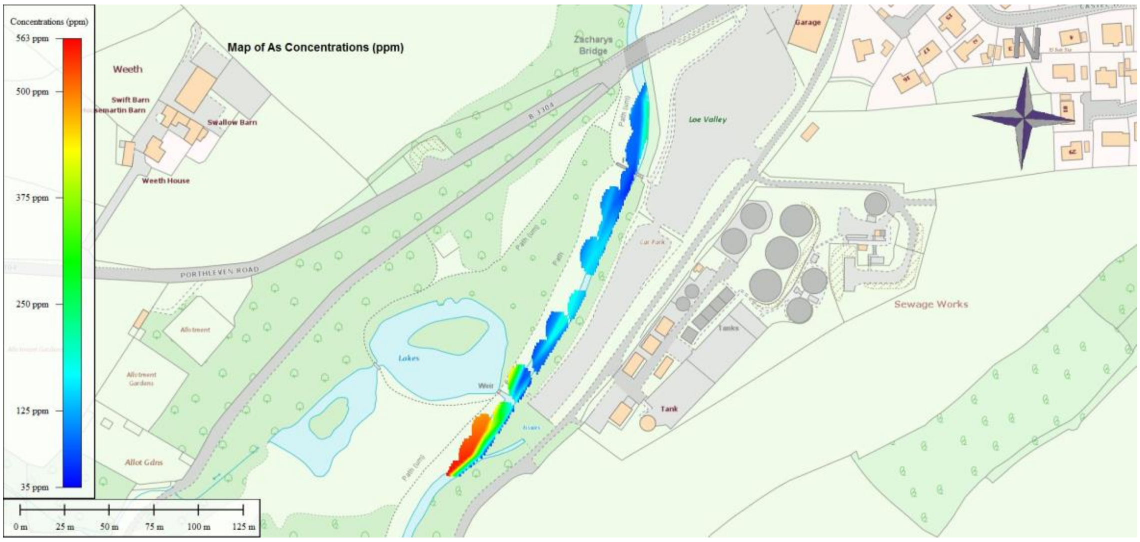

Figure 37 Heat map illustrating the spread of data across the river for As concentrations (ppm)

As there are traces of arsenic at the site, the location and quantities of such need to be understood. Figure 37 illustrates that there are areas of high arsenic values of 257.5- 562.5 ppm at both upstream to the North of the site and also to the South. There are also consistent median values of 126- 237 ppm in the mid-section of the river. These readings of arsenic need to be investigated and understood further as it needs to be evaluated in terms of environmental standards. If levels of toxic elements such as arsenic exceed accepted environmental standards mitigation will be required.

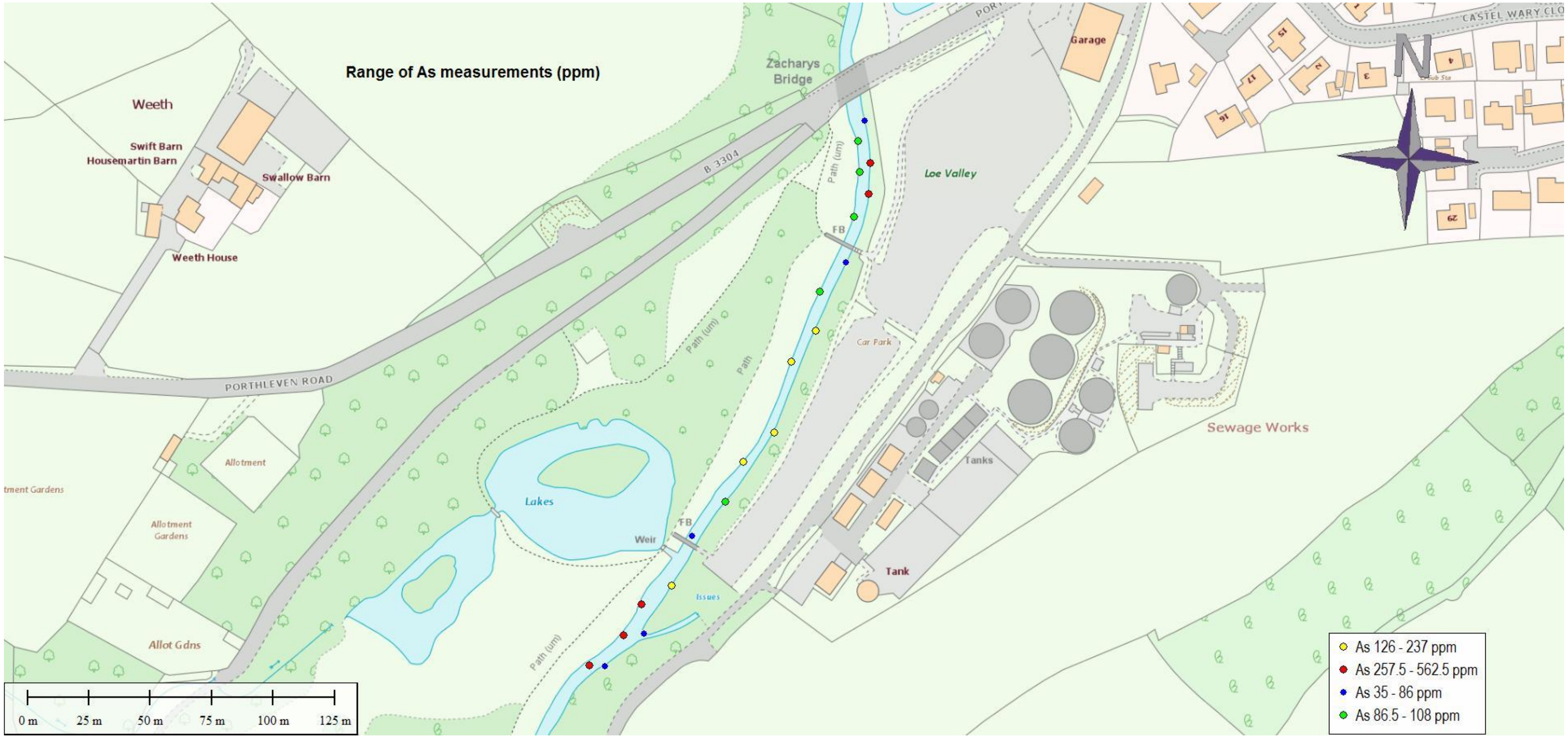

Figure 38 Map representing the quartile ranges of As levels (ppm)

5.4.4 Calcium

Figure 38 below illustrates its presence across the site and its quantity. It can be seen that there are low levels of calcium to the North of the river and gradually increases further downstream. There are spot of higher concentrations of calcium along the eastern bank of the river and finally one spot of increased concentration at the South of the site.

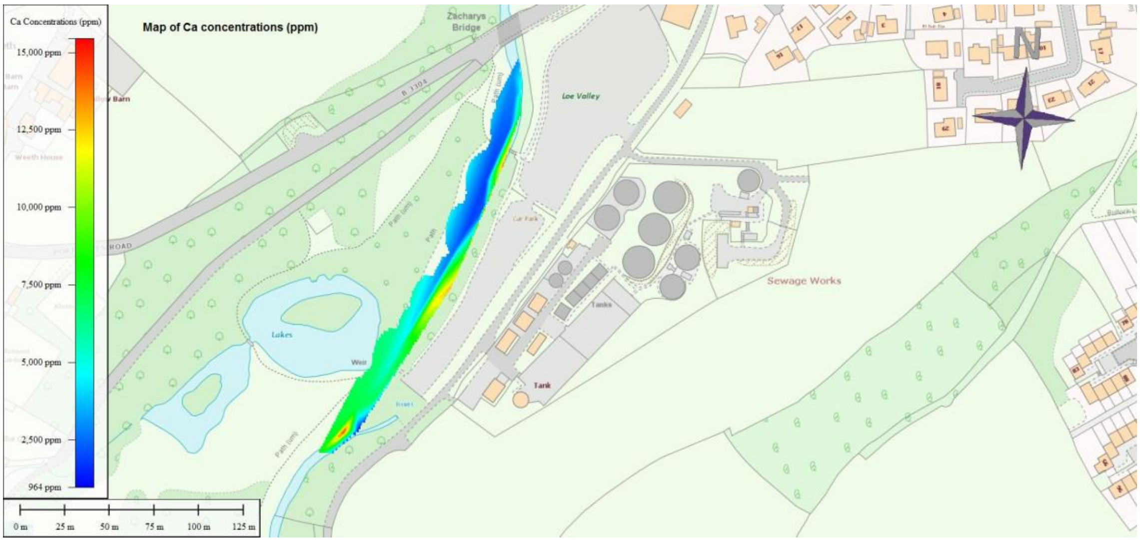

Figure 39 Heat map for the Ca concentrations observed across the river (ppm)

The upper and lower values of the site have once again been split and represented as individual quartiles in Figure 39. It can be seen that the Northern area of the river, recorded Ca quantities of 2517- 5006.5 ppm and 5238.5-7853.5 ppm. The areas of high concentrations of Ca that were highlighted in the heat map in Fig 38 above and in the below map are of values between 8612 – 15450 ppm.

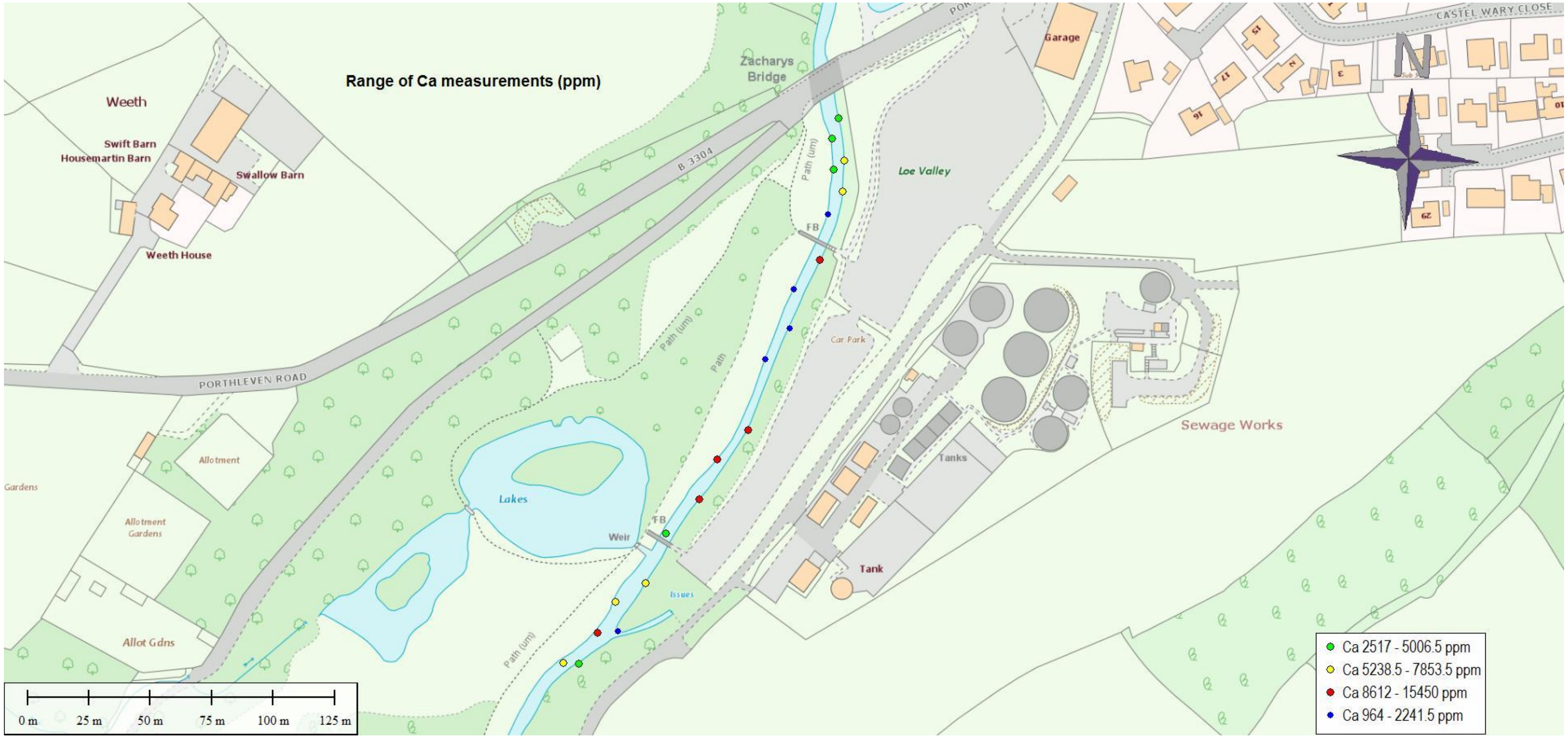

Figure 40 Map presenting the quartile ranges of Ca values at the river site (ppm)

5.4.5 Cadmium

Cadmium is a known contaminant that can cause great environmental harm to an ecosystem. Again, it's presence in this investigation needs to be considered, quantified and analysed. Figure 40 demonstrates the spread of cadmium observed across the river site. It can be seen from the map that the levels are for the majority lie between 20ppm and 45 ppm.

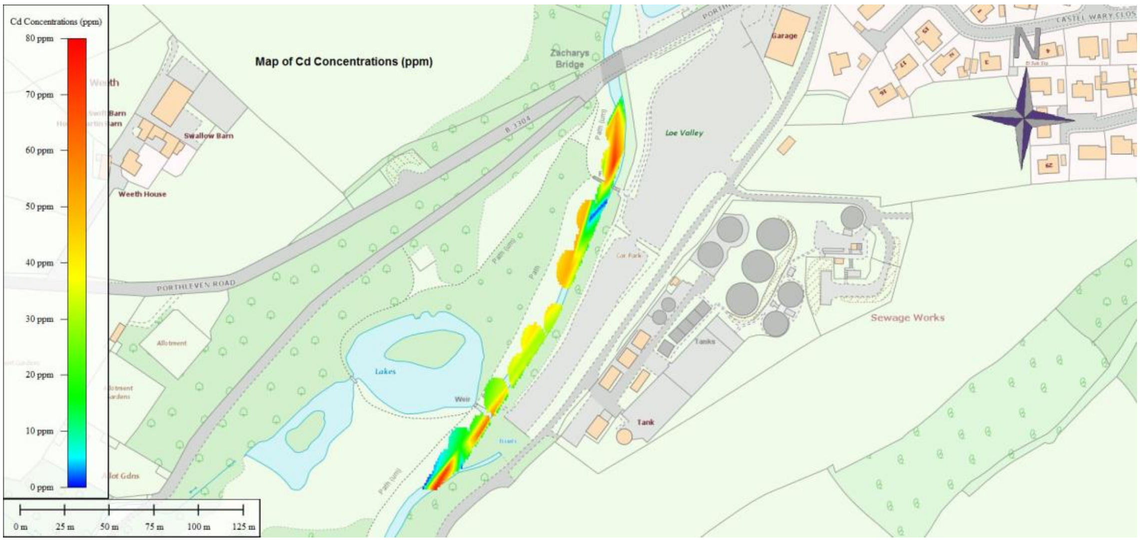

Figure 41 Heat map of the cadmium values observed at the site (ppm)

Figure 41 illustrates the exact positions of these ranges in the data and therefore can aid any further analysis. It can be seen that there are samples taken where no cadmium was observed and others that recorded levels of up to 80 ppm. Again like arsenic and other elements it's presence on the site could be cause for concern if it exceeds the prescribed environmental standards. The middle section of the river does not reach the highest values of cadmium but records values of   16-30.5 ppm and 31-51.5 ppm.

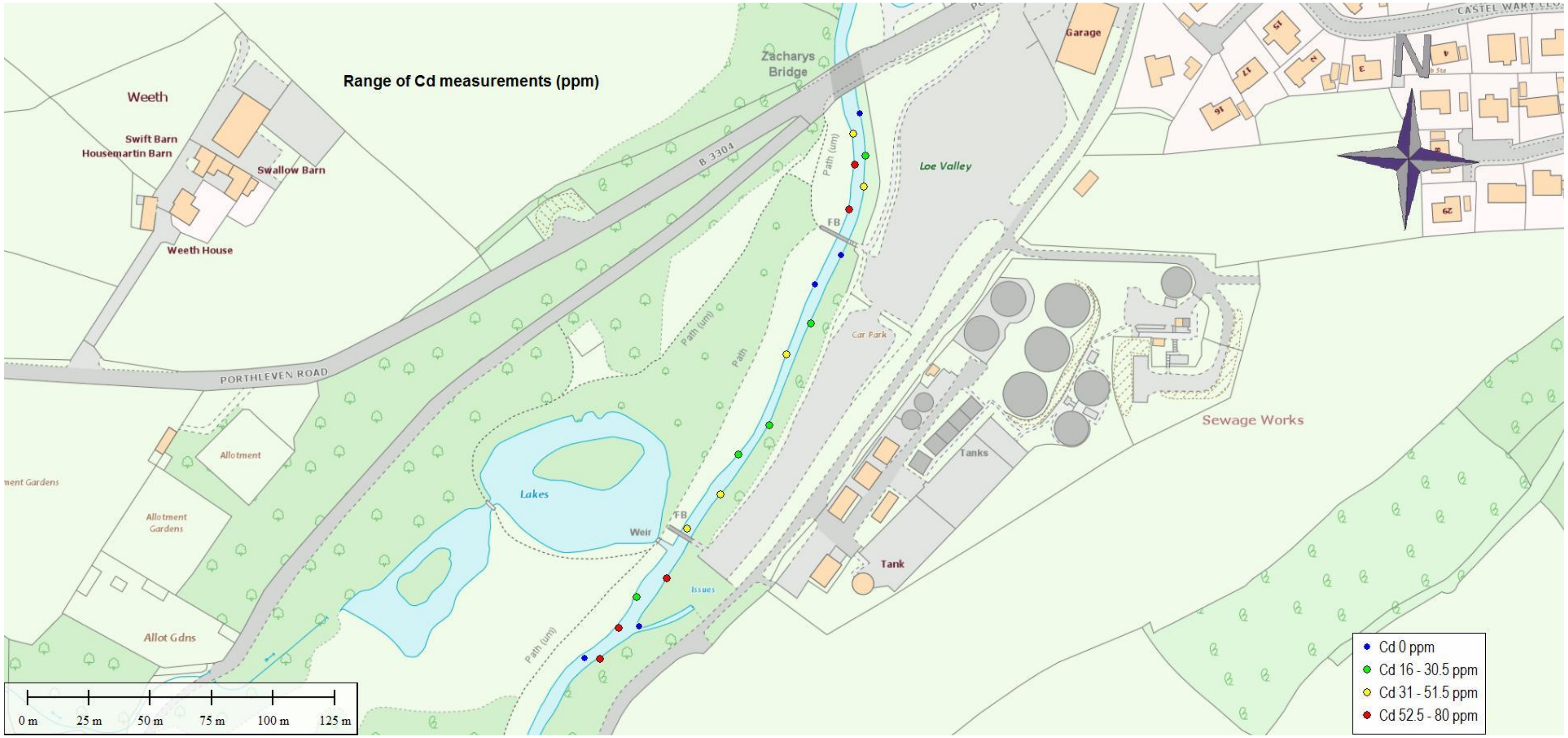

Figure 42 Quartile ranges of Cd at the river site (ppm)

5.4.6 Lead

Lead again is a common element to be abundant in the environment. However, like any element organic or inorganic if found in abundance in the environment it can cause environmental harm and degradation. Figure 42 is a heat map that illustrates its observed recordings at the site. It can be seen that the majority of observations recorded levels at the lower end of the spectrum. However, there is a small section at the Northern part of the river transect that measured some levels of higher concentrations.

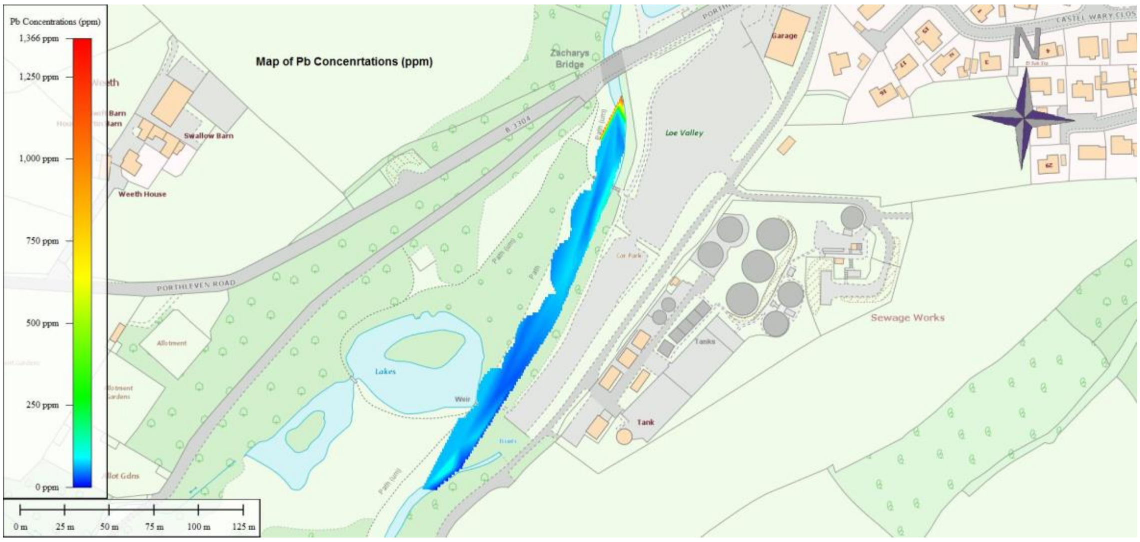

Figure 43 Heat map of the Pb concentration (ppm)

Figure 43 presents the quartile ranges of the data again split into the lower, median, upper and highest ranges within the data. It can be seen that the lowest values that span the river, represent by the blue dots, are of values between 0 and 40.5 ppm. While the highest readings were observed to be between 81- 1366.5 ppm, which are represented by the red dots on figure 43.

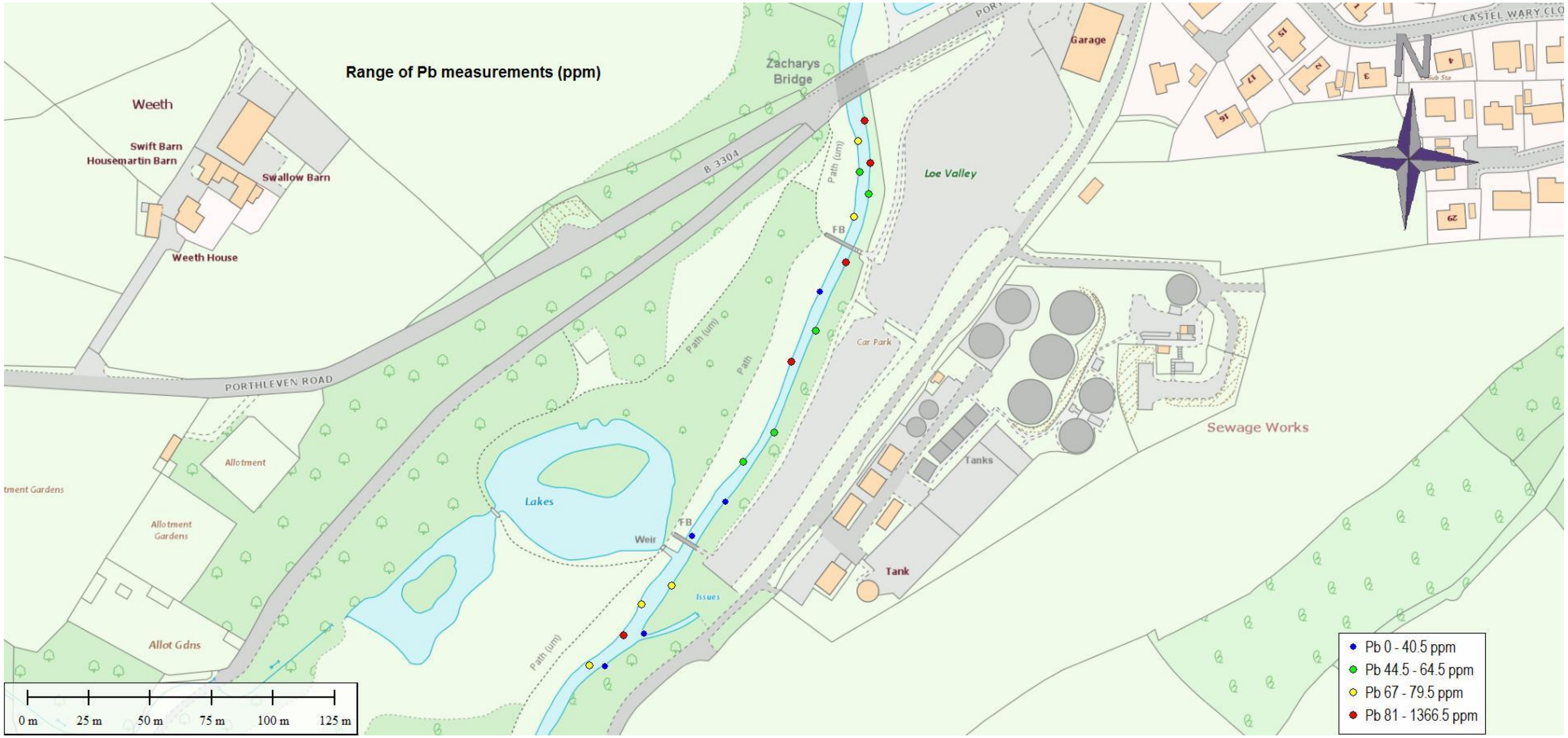

Figure 44 Quartile ranges of Pb at the river site (ppm)

5.4.7 Copper

Copper is the last element to be analysed from the soil samples taken from the river at Penrose. Figure 44 illustrates the spread of copper concentrations found at the site. Again, there is an area at the downstream on the survey area where there is a localised anomaly of high Cu concentrations at 945 ppm. The rest of the upstream areas have readings that reside around 33-250 ppm.

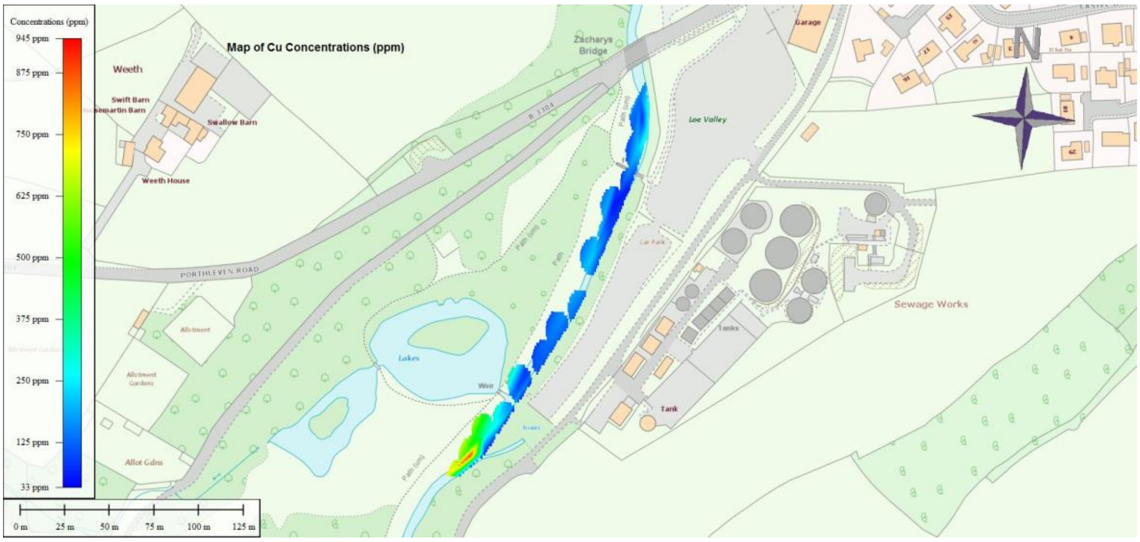

Figure 45 Map demonstrating the spread of Cu concentrations across the river site (ppm)

Figure 45 also demonstrates the location of each sample that contained traces of copper and also its quantified quartile levels. For instance, there are high levels of copper found at the top of the river to the north and then again in the south. These high levels of copper were recorded to be between 304-945 pm. The mid-section of the river recorded mid-range concentrations of copper at 96-127.5 pm (green dots) and 148.5- 218 ppm (yellow dots).

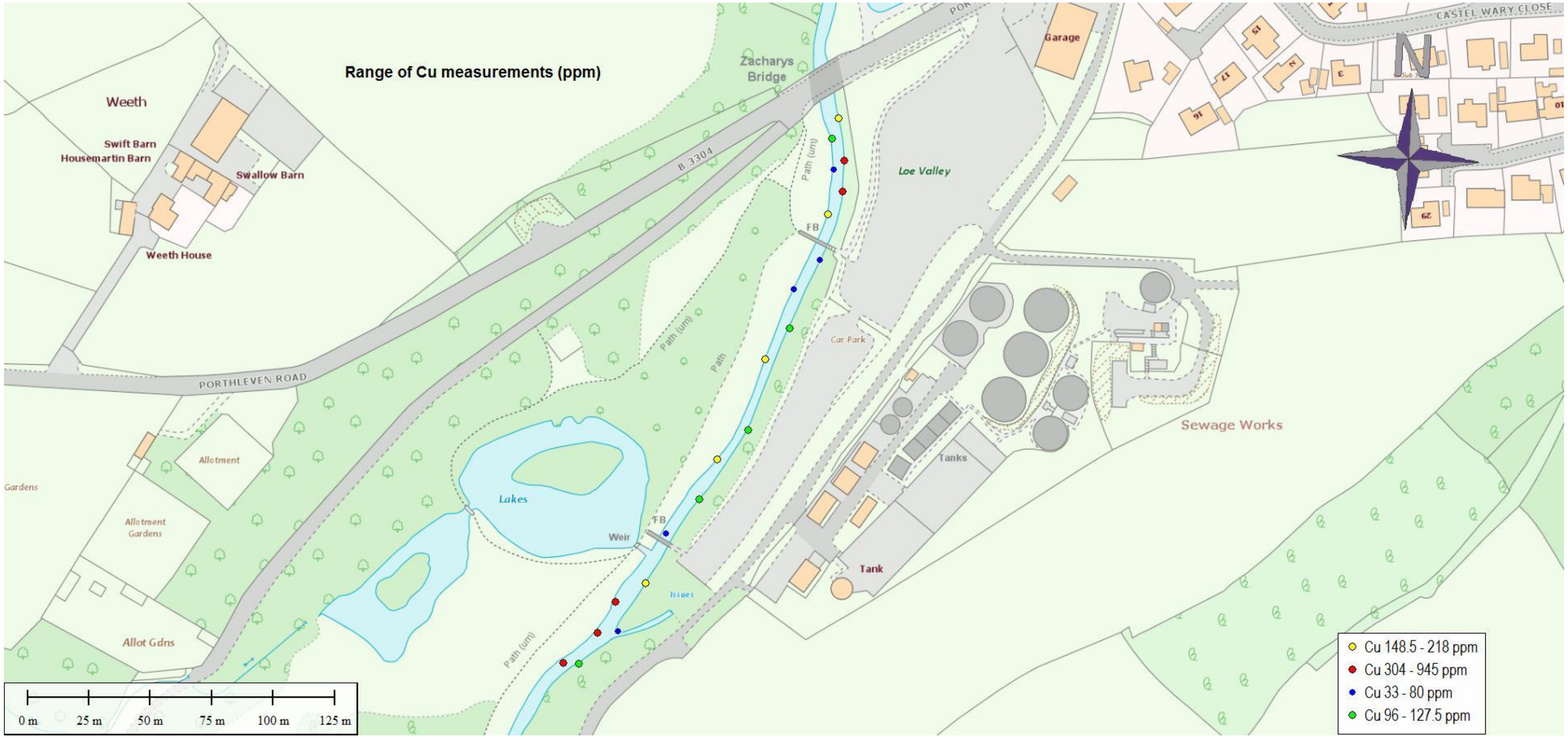

Figure 46 Map of the quartile ranges for the Cu results at the river site at Penrose (ppm)

Chapter 6 – Discussion

The aim of this project is to evaluate the physical makeup of the landscape at the Penrose Amenity site and Car par as it was once used as a landfill site. The results of the topographical survey, electrical resistivity, induced polarisation, electromagnetic and XRF data has been presented and analysed in the previous chapter. The discussion chapter aims to interpret these results in more detail and to discuss how these findings impact the future of the site and its subsequent management.

6.1 Electrical Resistivity and IP

The results from the electrical resistivity and IP survey has suggested that there are three significant localised anomalies of high resistivity, located along the resistivity line in the car park. These levels of up to 1150 Ω/ m are suggestive of areas of localised contamination from organic contaminants. This interpretation of the results is based upon the principle that the presence of organic compounds modify the resistivity of the subsurface as they act as good insulators. Thus, increasing the resistivity measured in that area. Organic compounds such as phenols, polyaromatic hydrocarbons (PAHs), acetone, benzene and toluene and chloroform are a few of the common compounds located in leachate from landfill sites (Freeze and Cherry, 1979). These compounds act as insulators as they drive the water out of the area. From both the Environment Agency documents and from local anecdotal evidence, there was a lot of building waste dumped at the site when it was active. Thus, the occurrence of dumping chemicals such as oil is a high possibility. As there are three areas of high resistivity anomalies in a relatively linear pattern, it could indicate the migration of a leachate plume that has been absorbed in either the groundwater or soil media. Typically, leachate migrates from the unsaturated zone towards the water table. From here, the leachate will mix with the groundwater to forma contamination plume that will normally flow in the direction of the groundwater (Vasanthi et al., 2008). This could be indicative of what is happening at this site.

When the resistivity and IP data was overlaid on one another it was possible to see that the areas of both high resistivity and IP overlap. The high IP readings therefore reinforce the possibility of contamination in the area. This is due to IP being effected by the electrochemical properties of the ground as well as the resistivity of the medium (Buselli and Lu, 2001). This interpretation of the electrical resistivity and IP data in the Car park is not the only interpretation of what could be found below the surface but is a strong possibility. Other interpretations could be the location of a boulder or void, as these features are also highly resistive to electrical currents.

The electrical resistivity results from the Penrose Amenity site highlight two distinct localised anomalies of high resistivity. Which could again indicate the presence of contamination. When in this state the contamination plume is traceable back to the source as it can follow a linear trend when migrating. This trend can be seen in the Penrose resistivity results as both to the left and right of the anomalous high, there is a linear feature of low resistivity of 50 Ω/ m. This feature of low resistivity follows the line of the electrode array and could indicate a potential contamination plume. As landfill sites are typically heterogeneous in terms subsurface properties due to the range of dumped waste, it is possible that the type of contamination could vary from inorganic to organic from the car park to the amenity site. The IP results of the array at the amenity site again supports the idea that there could be a plume feature there again with the extreme low values of the chargeability in the area.

6.2 Electromagnetic data

6.2.1 Car Park

For instance the Quadrature 15000Hz at the car park highlighted an area of high conductivity at the far end of the grid. The as this high anomaly is found in the quadrature phase is can indicate that there is the potential of either a substance with metallic properties as metals are good conductors of electricity or of contaminated water. Both are potential possibilities. As the sensitivity of the in-phase mode to magnetics is not just limited to ferrous properties which is very useful for investigations of landfill sites. Therefore, by analysing the in-phase results, one would assume that if the highly conductive anomaly found in the quadrature results is also highlighted in the in-phase results the likelihood of it containing metallic properties is high. However, the area to the far left of the grid in the car park was not noted as an area of high conductivity in the in-phase mode. Thus, supporting the theory that it could be an area of contaminated ground water as, typically contaminated water when measured with EM waves are distorted to show high levels of conductivity due to the increased ion contents (Reyes-Lopez et al., 2008).

What is also noteworthy for the in-phase results in the car park is that there are 5 areas in a linear pattern of high anomalies that run along the grid, this could indicate the location of metallic objects that have been dumped at the site or again an area of contamination. The apparent conductivity results also highlight the linear trend but also the anomalous high in the far left of the grid.

6.2.2 Penrose Amenity Site Grid 1

Again, for the Grid 1 EM results, there are localised anomalies that could represent certain possibilities in both the quadrature and in-phase results. As both of the results are independent of each other they could pose different possibilities. The primary reason for these results to be independent of each other due to their sensitivities when deployed. As mentioned the in-phase measurements are sensitivity to magnetic susceptibility and the quadrature measurements act as a proxy for conductivity. Therefore, any trends need to be examined both individually and with each other in mind.

The 15000Hz quadrature results have revealed a small localised anomaly of high conductivity towards the top left of the grid on the Amenity site. This localised high reading could be indicative of the presence of inorganic contaminates. However, opposite this high anomaly there seems to be an area of extreme low conductivity readings which is indicative of possible boulders, voids, or organic contamination. There is also an area towards to bottom of the grid in the figure of similar extreme low anomalies that could be indicative of a similar feature. The in-phase results have shown that this area that has been highlighted as with an extreme low reading in the quadrature results, has indeed been analysed to show that it also has high magnetic susceptibility. Having both low conductivity (high resistivity) in the quadrature and in-phase results. Thus, this evidence could suggest that it is an area of a metal container that holds organic contaminants such as oil that are gradually leaching into the surrounding area. Even though this is a possibility it cannot be ignored that there is the potential that this anomaly is not a container of contaminants leaking oil but it could also be a piece of dumped reinforced concrete, which is exhibiting high resistivity due to the presence of rebar. The apparent conductivity of these areas again reiterates that there is an area of highly conductive material to the left of the grid that supports the notion of contaminants being present. These notions cannot be confirmed until further intrusive methods are carried out for ground trothing purposes.

6.2.3 Penrose Amenity Site Grid 2

Finally the results from the second grid setup on the Penrose Amenity site was analysed and exposed an area of localised anomalies located at the start of the grid. The results for this grid have indicated an area of extreme lows that are greater than any of the other setups. The measurements observed an area of low conductivity that reached levels of up to -1000 ppt in the quadrature phase. This level of low conductivity is standalone regardless, however, it is made to stand out more so as it is surrounded by an area of relativity constant conductivity of around 800ppt. An anomaly of this extremity very much so sparks interest as to what is causing it and it could be a range of reasons. The in-phase results also have emphasised that this is an area of great interest as it again exhibits low conductivity in the in-phase results also. In fact the in-phase observations exceed the quadrature with readings reaching up to -2000 ppt. Given these observations, it was no surprise when the apparent conductivity results also revealed that the area demonstrated characteristics of low apparent conductivity of -22 Millisiemens/m. The feature that has been picked up could be one of many things. For instance an area of high resistivity in both the quadrature and in-phase results could mean that it could be an area again of contamination. Or equally it could be a large boulder or void. The notion of it being a boulder is ruled out in terms of probability as this boulder would have to display characteristics of little to no mineralisation in the rock at all. It is suggested that this is not the case in this instance as a large boulder with no mineralisation in this area of Cornwall is very unlikely and rare. Consequently, the notions of it either being an area of extremely contaminated groundwater or soil is possible as it is positioned in close proximity to the areas of high levels of contaminants found from the XRF samples. However, it cannot be ruled out that this is the location of an uncapped void. This is very plausible as the site's capping methodology has not been documented well.

6.3 pXRF

It is widely noted that the storage of waste regardless of its type in landfill sites poses the threat of potential problems (Fatta et al., 1999). These problems range from the contamination of soil, groundwater or surface water and the consequences of each could be detrimental not only to the health of the local ecosystems but also to the local aquifers and drinking sources. Therefore, the river that runs directly through the site and that separates the car park and amenity site could be direct receptor of the contamination, which in turn could be transported downstream.

Kjeldsen et al's work (2002) put forward that landfill leachate is a water-based solution that can be made up of four groups of pollutants, they are; dissolved organic matter, inorganic macro components, heavy metals and xenobiotic components. Leachate from landfill is generated from a variety of parameters that are part of the hydro-biological balance such as precipitation, surface runoff, evapotranspiration and infiltration (Fatta et al., 1999). It is because of these parameters that the process of percolation occurs, and the transfer of pollutants from the waste materials to the percolating water can occur (Kjeldsen et al., 2002). However, the physio-chemical characteristics of the leachate are dependent upon the composition of the waste that is present and the water content that is available (Mor et al., 2006).

By using the pXRF to analyse the samples taken it has been possible to look at the inorganic compounds that are associated with the leachate. For example it is documented that some of the most common inorganic compounds found at landfill sites are amongst the following, calcium ($Ca^{2}+$), magnesium ($mg^{2}+$), Sodium (Na+), Potassium (K+) and iron ($Fe^{2}+$) (Kjeldsen et al., 2002). In terms of the heavy metals that are common with landfill they are amongst, cadmium

(Cd2+), chromium (Cr3+), copper (Cu2+), lead (Pb2+), nickel (Ni2+) and zinc (Zn2+). Based on this information, it can be seen that there is a presence of a number of these pollutants found at the site in Helston. However, like any sources of contamination and pollution it is the quantity and form of the contaminants that causes an issue.

In terms of this investigation there were some elements that did pose a concern to the health of the site which could be related to the historic landfill that is present. Firstly, arsenic which is widely known as a toxic metalloid that is monitored closely in all environmental impact assessments as it can cause a great deal of harm. In the soil guideline values that are published by the Environment Agency (figure 47), the high levels of arsenic that were observed at the site (536 ppm) do exceed what is the allowable threshold for residential and allotment land uses which are set at 32 and 43 mg/kg respectively (Environment agency, 2015). Therefore, it is suggested that the As levels are monitored in the future and if these levels are continuously seen then there is some scope for mitigation to be put in place.

The second element that exceed the soil guideline values was lead. The highest readings of lead ranged between 81-1366.5 ppm and the allowable threshold values published are between 450-750 mg/kg. Therefore this does cause some concern as it is documented that the occurrence of high Pb concentrations at historic landfill sites and in the greater area is common. Mor et al., (2006) have published research that suggest that the presence of Pb in the environment surrounding a historic landfill is caused by the dumping of lead batteries, paints and pipes. These concentrations along with the knowledge that this is the type of waste that was dumped at the site it does suggest that there is some form of leachate being generated and transported into the river.

Cadmium is always a concern when carrying out any environmental investigation. In this investigation there were levels of cadmium present in the samples that did exceed the residential and allotment threshold values that are 10-1.8 mg/kg respectively (Environment agency, 2015). However, the max value recorded was 80 ppm which does not exceed the threshold value set for commercial land use but it is still a higher level than desired.

The work carried out by Mor et al., (2006) also suggests that the presence of dark brown/orange staining could be the cause of oxidisation of ferrous to ferrous iron and the formation of ferrous hydroxide. This notion is very relevant at this site not only because of the landfill but also because of influences of contamination from upstream where there is a great deal of mining history. Thus, there is the possibility that there are still some traces of iron flowing downstream and into the river at this site. This is supported by the location of an outflow pipe at the upstream area of the river near the road, which is stained orange, indicating the formation of iron hydroxide which is a common feature of historic mining sites.

Assessment of Potentially Toxic Elements

Parameter	Function of Land Use	CLEA Soil Guideline Value (SGV) mg/kg	EC Directive 86/278/EEC mg/kg
Arsenic (As)	Residential Allotment Commercial Agricultural and after sewage sludge application	32 43 640 -	- - - 50
Cadmium (Cd)	Residential Allotment Commercial Agricultural and after sewage sludge application	10 1.8 230 -	- - - 3
*Chromium (Cr)	Residential with plant uptake Residential without plant uptake Commercial and Industrial Agricultural and after sewage sludge application	130 200 5000 -	- - - 400
Mercury (Hg)	Residential Allotment Commercial Agricultural and after sewage sludge application	10 26 26 -	- - - 1
Nickel (Ni)	Residential Allotment Commercial Agricultural and after sewage sludge application Agricultural and after sewage sludge application Agricultural and after sewage sludge application Agricultural and after sewage sludge application	130 230 1800 - - - -	- - - At pH 5.0-5.4 = 50 At pH 5.5-5.9 = 60 At pH 6.0-7.0 = 75 At pH 7.1+ = 110
Selenium (Se)	Residential Allotment Commercia Agricultural and after sewage sludge application	350 120 1300 -	- - - 3
*Lead (Pb)	Residential with plant uptake Residential without plant uptake Commercial and Industrial Agricultural and after sewage sludge application	450 450 750 -	- - - 300
Copper (Cu)	CLEA Agricultural and after sewage sludge application Agricultural and after sewage sludge application Agricultural and after sewage sludge application Agricultural and after sewage sludge application	Non available at present - - - -	- At pH 5.0-5.4 = 80 At pH 5.5-5.9 = 100 At pH 6.0-7.0 = 135 At pH 7.1 + = 200
Zinc (Zn)	CLEA Agricultural and after sewage sludge application Agricultural and after sewage sludge application Agricultural and after sewage sludge application Agricultural and after sewage sludge application	Non available at present - - - -	- At pH 5.0-5.4 = 200 At pH 5.5-5.9 = 250 At pH 6.0-7.0 = 300 At pH 7.1+ = 450

Figure 47 Table showing the UK soil guideline values (SGV) for potentially toxic metals (UK Environmental Agency 2015)

6.4 Further Recommendations

From the results and interpretation of the findings from this report several notions have been put forward regarding what can be found in the subsurface of the Penrose Amenity site and Car Park in Helston. It has been mentioned previously, that these notions are just suggestions of possible interpretations of the data. It can be assumed that what lies beneath both the car park and the Amenity site is not homogenous ground, due to the sites former landuse as a landfill site. The documentation provided from the Environment Agency states that different types of waste dumped there. Therefore, supporting some of the theories that a range of contamination could be present.

As the site is now classified as a SSSI site, the presence of contamination is a great concerns. Also, as the area has a history of flash flooding with increased rainfall in the winter it is possible that these hydrological factors could increase the amount of leachate that migrates into the groundwater sources and could be transported downstream. In an attempt to monitor the levels of contamination, further soil samples could be taken over the length of a year. Thus, illustrating a temporal and seasonal fluxes in contaminant levels. Once these figures are known, additional management systems could be put in place to reduce and mitigate the leaching. The XRF results can aid this investigation by highlighting areas such as downstream of the site that exhibited extreme high measurements of several elements such as arsenic and cadmium. In addition to the soil samples taken from the river banks, samples could also be taken from the field areas at the Amenity Site.

Much like the XRF locations provide a starting point for further research, the features revealed in both the Electrical resistivity, IP and EM results provide accurate locations of areas that are of interest to the sites makeup. Some of the features analysed in all of the geophysics data did reveal the possibility that there was contamination present at the site. Therefore, if desired further intrusive methods of investigation could be deployed on site. For exampling drilling or boreholes could be carried out but instead of sampling anywhere on the site causing a great deal of disruption, the sampling could take place in the exact locations that have been highlighted in the previous chapters. This will decrease the time needed to carry out the investigation and also will limit the amount of aesthetic disruption caused to the protected site. It is also suggested that a full geophysical investigation is carried out the site to explore the possibility of other features of interest. For example, more electrical resistivity and IP array could be deployed in the main car park area and along the path ways closer to the riverbanks. Increasing the amounts of arrays and EM grids could highlight further areas of interest, which in turn will aid any intrusive investigations that are required.

An addition to the further geophysical and intrusive methods that could be carried out at the site, it is also suggested that some geotechnical research is conducted. As mentioned at the start of the project, the car park site was once used as a public swimming pool. However, it closed due to consistent issues of subsidence and cracking. Subsidence is a common characteristic of landfill sites and it can cause issues to infrastructure close by. Again, there has been anecdotal evidence that some of the local businesses located close to the site have experienced issues of subsidence in recent years. Therefore, with this evidence along with the documentation of the swimming pool history, there is a call for some geotechnical investigation at the site. Understanding, the geotechnical aspects of this site will be very beneficial for the future as there are many dwellings close by and subsidence could cause a great deal of damage to properties.

Chapter 7 – Conclusion

The Penrose Amenity site and Car Park has been an integral part of the Helston community for many years. With several different land uses the site is now a favoured recreational area. This investigation has been carried out to assess the influence that the using the area as a landfill in around 1960's has on the area today.

A range of geophysical methods have been utilised in an attempt to gain a better understanding of what is below the surface of the site and how that influences the environmental quality of the site. Due to the age of the landfill and the policies that were in place at the time, there is no guarantee that the site was lined at all and could therefore pose many environmental issues. The results from the geophysical surveys that have been carried out at the site provide several notions as to what could lie beneath the surface. A common theory from interpreting the resistivity, IP and EM data is that there is some contamination areas in both the car park and the Amenity site. Therefore, monitoring of the site for potential contamination plumes that could migrate to degrade the surround groundwater sources is imperative. It is only by understanding the subsurface properties that effective management can occur. Consequently, a further geophysics survey of the whole site is suggested as it would be beneficial to develop the theories outlined in this investigation. This along with intrusive methods could influence the future management of the site.

What this study has also shown is that there is an area along the river that is an outlet of high concentrations of the majority of all elements that were recored. This area can be seen on most of the maps produced. Thus, supporting the geophysical data of contamination on the site. Both the water and soil quality does not require

Main Body of text word count: 15059

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Appendix

Appendix 1 – Summary diagram of the evolution of waste regulations in England and Wales

Pre 1948

- No controls over waste disposal and it's management

1948

- **Planning Act (1948)**
- Controlled land use focus
- Loose mangagement over waste disposal
- Landfill seen as a convience - cheap and easy to carry out
- No thought given to pollution

1974

- **Control of Pollution Act (1974)**
- The lifecycle of landfill starts to be considered
- 1st piece of legislation regarding waste disposal and landfill
- Attempted to make changes focused on waste disposal and water, noise and atmospheric pollution
- Also considered public health for the first time
- Duty of the Waste Disposal Authority to investigate and monitor what was dumped and how much
- 'Dilute and Attenuate' management priciple widely adpoted

1980

- **EU Groundwater Framework Directive (1980)**
- Reassessed the use of 'Dilute and Attenuate' in landfill management
- Prohibited both the indirect and direct discharge of waste leechate into the surrounding environment
- Published 2 lists of substnaces that are harmful to the environment if discharged into the groundwater

1990

- **Environmetal Protection Regulations (1990)**
- Introduced waste management licences to landfill sites
- All active sites must apply for a license in order to operate
- Each site was managed by a Waste Regulation Authority
- There was no regulatory standard for the Waste Regulation Authorities to adhere to
- Thus, the quality of environmental management varied across all authorities
- Some Authorities enforced stricter regimes than others and there was no uniformity across England and Wales
- Begin to see a move from 'Dilute and Attenuate' to an engineering perspective

1995

- **General Development Order (1995)**
- Required all Waste Regulation Authorities to provide local government with information of all of the landfill sites in their area from the lst 30 years
- The information asked for was detials of what had been dumped and the quantities of each.

2003

- **EU Landfill Directive (2003)**
- When introduced it impacted the management, operation and regulations of landfill sites directly.
- In 2001 operators were told to evluate the directive as they were to now complie with the new specific engineering regulations.
- Environmental Permitting (England/Wales) took over from the Environmetnal Protection Regulations (1990)
- This included the Pollution Prevention Control Regulations introduced to all active landfill sites - all exisiting sites had to go through repermnitting with their Waste Reg Authorities under the new PPC regime.
- This process of repermitting allowed ranking of all sites to occur. The sites of priotiry in term of environmental risk was seen and approporatie management was sought.
- Between 2003-2006 , 200 plus sites were repermitted
- This new PPC permitting regime introduced three types of waste that can be disposed of in Landfill- much stricter regulations now apply; Inert, Hazardous and Non-Hazardous.
- PPC Permits set out Landfill conditions for the operator to obide by - no grey areas. They set out the operating hours, controlled volume of leechate and gas created and also the quantities of what types of waste can be disposed.

Appendix 2 – Copy of Risk Assessment

<table>
<tr><th colspan="6">Part 1: General information about the trip</th></tr>
<tr><td colspan="3">Reference / Module Number/Name
(if applicable)</td><td colspan="3">CSM M118 Dissertation and Project</td></tr>
<tr><td>Fieldworkers Name:
(Lead person if a group)</td><td colspan="2">Rebecca James</td><td>College(s):</td><td colspan="2">Camborne School of Mines (EMPS)</td></tr>
<tr><td>Assessors Name:
(if different form above)</td><td colspan="2">Neill Wood</td><td>Discipline(s):</td><td colspan="2">MSc Surveying and Land/Environmental Management</td></tr>
<tr><td>Fieldtrip Start Date:</td><td colspan="2">27/06/2016</td><td>Fieldtrip End Date:</td><td colspan="2">19/07/2016</td></tr>
<tr><td>Number of staff travelling?</td><td colspan="2">n/a</td><td>Number of students travelling?</td><td colspan="2">1</td></tr>
<tr><td colspan="3">Number of Undergraduates?</td><td colspan="3">Number of Postgraduates?</td></tr>
<tr><td colspan="3">n/a</td><td colspan="3">1</td></tr>
<tr><td>Is this a research trip?</td><td>Y</td><td></td><td>Is this a teaching trip?</td><td></td><td>N</td></tr>
<tr><td colspan="3">Exact destination location(s)?</td><td colspan="3">Fair Car Park,
Porthleven Road,
Helston,
Cornwall</td></tr>
<tr><td colspan="4">Do you have previous knowledge of this location?</td><td>Y</td><td></td></tr>
<tr><td colspan="6">Describe the purpose of the trip *(Provide as much detail as possible)*</td></tr>
<tr><td colspan="6">Independent research for final MSc dissertation. Using a topographical survey and geogphysics to locate potential historic landfill.</td></tr>
</table>

What activities / tasks being carried out on the trip? (*include both work and recreational activities*)			
Activity / Task		Activity / Task	
Select only the activities that apply			
NB: Where multiple examples are provided in the activity / task list delete as appropriate e.g. if 'Photography' only, delete the word 'Filming'			
Surveying (marine, terrestrial, coastal)	Yes	Photography / Filming	
Swimming / Snorkelling (freshwater/marine)		Lifting / Carrying / Moving Objects/Animals and/or equipment	Yes
Sailing / Boating (freshwater/marine)		Teaching	
Diving (open water and/or restricted access)		Laboratory work	
Skiing		Water sports e.g. surfing, body boarding	
Caving / Pot holing		Manufacturing / Engineering	
Climbing (hills, cliffs, rocks)		Clerical / Administration / Attending Conferences/Meetings	
Work involving Mammals		Work involving Amphibians	
Work involving Insects		Work involving Fish	
Work involving Reptiles		Work involving Birds	
Mining / Blasting / Quarrying		Tree Felling	
Drilling / Coring		Farming (Agriculture)	
Interviewing people		Driving (roads/off-road)	Yes
Hunting / shooting		Archaeological excavation	
Other: Use these columns/rows to add / insert other activities not listed in the examples provided above			

Training and Experience		
Is there any specific training and/or experience required for this trip?	Y	N
If Yes, what specific training and/or experience are required for this trip? *Provide details below*		
Drawing upon previous surveying knowledge that has been developed over the past year on the MSc course.		
Are all participants sufficiently trained and/or experienced to partake in this trip?	Y	N
If No, what arrangements are in place to protect the unqualified / inexperienced participants? *e.g. supervision etc.*		
Equipment		
Is there any equipment being taken on the trip?	Y	N
If Yes, list the equipment being taken on the trip? *Provide details below*		
Traverse kit- Total station, Tripods, Prisms, detail pole Geophysics equipment- EMP 400 and electromagnetics equipment Hand Held XRF		
Is there any equipment / items that could harm users or others being taken on the trip e.g. x-ray, laser, containing radioactive equipment etc? ***NB:*** *Care should be taken depending on the type and destination/route of travel*	Y	N
If Yes, list and describe the equipment / items being taken on the trip? *Provide details below*		
Hand Held XRF		
Is there a need for personal protective equipment (PPE)?	Y	N
If Yes, list and describe any equipment being taken on the trip? *Provide details below*		
Hi Vis vest Covered and study footwear		

Part 2: Travel and accommodation arrangements			
What modes of transport are you using to travel to your destination and at your destination?	*Select all that apply*		*Risk Rating*
	Private Vehicle	Yes	**L**
	University Vehicle		**L**
	Hired Vehicle (Driving Self)		**L**
	Hire Vehicle with Driver (Road)		**L**
	Public Transport (Road)		**M**
	Public Transport (Rail)		**M**
	Taxi		**M**
	Motorcycle		**M**
	On Foot	Yes	**M**
	Aircraft (from UK airport)		**M**
	Sailing Vessel		**M**
	Other: Insert Here		**M**
Are you being met at your destination country and/or final location destination?	*Select all that apply*		*Risk Rating*
	Traveling alone	Yes	**M**
	Meeting an unknown person		**M**
	Meeting a known person		**L**
If multiple answers given, provide a brief explanation?			

<table>
<tr><td>What are your return journey arrangements?</td><td colspan="3">Will be travelling to the site with a field assistant in a private vehicle. Once at the site all equipment will be moved on foot.</td></tr>
<tr><td colspan="2">Will you require overnight accommodation?</td><td>Y</td><td>N</td></tr>
<tr><td rowspan="4">If No, proceed to Part 3

If Yes, how is your accommodation being arranged?</td><td colspan="3">Select all that apply</td></tr>
<tr><td colspan="2">Arranged and booked yourself</td><td></td></tr>
<tr><td colspan="2">Arranged and booked by the destination host</td><td></td></tr>
<tr><td colspan="2">Arranged and booked by the University from the UK</td><td></td></tr>
</table>

PART 3: Preparation arrangements

<table>
<tr><td colspan="2">Answer all the questions in this section</td><td>Y / N</td></tr>
<tr><td colspan="2">Do you have a contact(s) at the location?</td><td>Y</td></tr>
<tr><td colspan="2">Do you need any licences, permissions or site access permits for this trip?</td><td>Y</td></tr>
<tr><td colspan="3">If yes, describe what licences (including driving), permissions or site access permits required including conservation areas and sites of special scientific interest</td></tr>
<tr><td colspan="3">I have spoken to the local council to ask for site access and they have confirmed and given me permission to use the site. Notification as to when I am on site will be required by them via email.</td></tr>
<tr><td colspan="3">NB: If you’ve answered negatively to any of the questions in Part 3 above indicating that further actions are required please transfer these to the action plan below</td></tr>
<tr><td>Remedial Action to be Taken</td><td>By Whom</td><td>By When</td></tr>
<tr><td>Insert the action to be taken and arrangements to be put in place in these rows</td><td>Insert Name</td><td>Insert Date</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Add More Rows as necessary</td></tr>
</table>

PART 4: About the work and lone working

Answer all the questions in this section

When will work be carried out?	Day:	Y	N

	Night:	Y	N
Is there a possibility that someone will be lone working?		Y	N
If Yes to lone working, what are the arrangements for maintaining contact with lone worker(s)? *Refer to the Lone Worker Standard and lone worker risk assessment for further information and guidance.*			

PART 5: Communication methods / arrangements
Detail the arrangements in place for communicating with the University and at local level whilst on the trip e.g. lone working procedures in place - buddy systems, GPS, radios, mobile devices, email, social media etc.
I will be with a field assistant when out in the field. Both of us will have mobile access and a buddy system will be put in place. My supervisor will be made aware of the days that I am out in the field. On the days that supervision is required to carry out the geophysics my tutor will be with me in the field.

PART 6: Emergency arrangements for this trip e.g. first aid, location of nearest medical centres etc.	
Answer all the questions in this section	Y / N
Do you have appropriately trained first aid participants on the fieldtrip?	N
Do you have access to professional medical assistance?	Y
Do you have contact numbers for local medical centres?	Y
Detail the emergency arrangements in place for this trip	
The nearest local medical centre for the site is Helston Minor Injuries. A fully stocked first aid kit will be carried at all times.	
NB: *If you've answered negatively to any of the questions in Parts 6 above indicating that further actions are required transfer these to the action plan below*	

Remedial Action to be Taken	By Whom	By When
Insert the action to be taken and arrangements to be put in place in these rows	*Insert Name*	*Insert Date*
To ensure that a first Aid Kit is prepared	R. James	27/06/2016
Add More Rows as necessary		

PART 7: Are there any cultural issues to be considered?

i.e. the location / people / site where the work is taking place

Select only the cultural issues that apply

Religious Customs / Spiritual Considerations	N	Limitations in Photography / Film / Media	N

If yes to any of the above, provide details of the arrangements in place to address these matters

PART 8: Are there any security issues?

Select only the security issues that apply

Crime / Assault	N	Theft	N	Arrest	N

If yes to any of the above, provide details of the arrangements in place to address these issues

PART 9: Are there likely to be any welfare and wellbeing issues?

Select only the welfare and wellbeing issues that apply

Lone Working / Isolation *(refer to part 4 for lone worker arrangements)*		Stress	Y	Relationships *(Working & Recreational)*	

Workload		Medical Needs		Fitness / Exhaustion	
Homesickness		Language Barriers		Food Intolerance	
If yes to any of the above, provide details of the arrangements in place to address these issues					
To ensure that each day in the field is planned and thought out before hand to allow the day in the field to be productive.					

PART 10: Activity and recreation arrangements		
Have all staff and students been made aware of the rules and arrangements for the trip including both work and recreation activities? e.g. *code of conduct, appropriate clothing, equipment, travel, accommodation, alcohol etc.*	Y	N
***NB:** If you've answered negatively to any of the questions in Parts 10 above indicating that further actions are required transfer these to the action plan below*		

Remedial Action to be Taken	By Whom	By When
Insert the action to be taken and arrangements to be put in place in these rows	*Insert Name*	*Insert Date*
Add More Rows as necessary		

PART 11: Insurance arrangements *e.g. travel, vehicle, equipment etc.*	
Answer all the questions in this section	Y / N
Have you notified the University Insurance Office of this trip?	N
Have you received confirmation from the Insurance Office that you have appropriate insurance(s) in place for this trip?	N
***NB:** If you've answered negatively to any of the questions in Part 11 above indicating that further actions are required transfer these to the action plan below*	

Remedial Action to be Taken	By Whom	By When
Insert the action to be taken and arrangements to be put in place in these rows	*Insert Name*	*Insert Date*

Ask supervisor how to go about this	r.james	27/06/2016
Add More Rows as necessary		

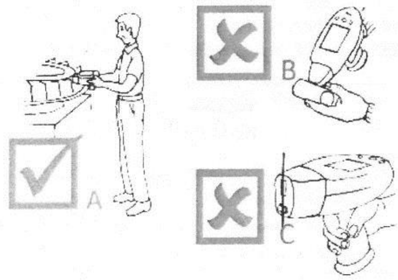
PART12: Supporting information		
Can you confirm that all the information / documentation required in the 'Supporting Information' checklist have been obtained?	Y	N

Appendix 3- Copy of XRF Training Approval and Risk Assessment

Camborne School of Mines

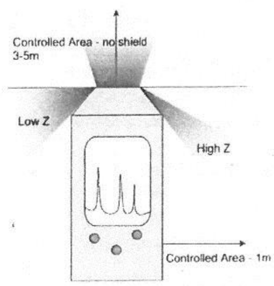
Specific local rules for governing the use of the Niton XLt Environmental Analyser (portable XRF):

1. These Local Rules are supplementary to the University Rules for Radiation Use. All users are required to refer to and follow these rules.
2. Users of this instrument are registered as designated radiation workers with the university and approved as an authorised user by the Radiation Protection Supervisor (RPS), Mike Bell (m.g.bell@exeter.ac.uk; 01329 725339), or deputy following training (Kate Moore, CSM: k.moore@exeter.ac.uk; ext5693).
3. The XRF is located in room 3085, and authorised users must sign out and return the XRF to Kate Moore, providing details of the site visit and work to be undertaken. Details of equipment performance and usage must be recorded on safe return of the machine.
4. All users of the XRF **must** read the safety information contained within the Local Rules and sign the declaration before being authorised to use the equipment.
5. During use the area within a 2 metre radius of the head is designated as "controlled". Operation is undertaken at arms length, using two hands and facing square (A), and must not be directed towards any persons.
6. While the XRF is in use (shutters open) and the external warning lights are flashing, time spent immediately adjacent to the machine must be kept at a minimum. Hands and fingers should **not** be place adjacent to the aperture during use and samples must **not** be analysed while held by hand (B). The samples must fully cover the aperture to minimize scatter of X-rays.
7. The XRF should not be left unattended and in view in the vehicle. If the vehicle has to be left unattended it must be securely locked in the boot.
8. Any adjustment operations or machine failures that are needed must **not** be attempted. They should be reported and carried out by authorised persons at Niton, who will be contacted by Kate Moore.

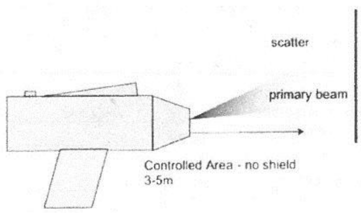


Additional safety information for governing the use of the Niton XLt Environmental Analyser (portable XRF).

The radiation profile is highest in front of the primary beam, which is mitigated by covering the entire primary beam by the sample. However, secondary scatter of the beam occurs to an angle of up to 45° from the sample on all sides (a and b). Particular attention must be paid to stand behind the area of secondary scatter of the beam and to ensure that no other person stands within the area of secondary scatter of X-rays.



a) View from above



b) View from the side

Images from the Society for Radiological Protection

1

Subject	Dose Rate or detected radiation
Annual occupational dose limits for adults	
Whole body	20 mSv
Pregnant worker	1 mSv
Selected medical requirements	
Typical chest x-ray	0.06 mSv
Typical head / neck x-ray	0.2 mSv
Typical pelvis / hip x-ray	0.65 mSv
Typical CAT scan	1.1 mSv
Internationally recognised limits set by the International Commission for Radiological Protection (ICRP) www.icrp.org 1 5 cps (counts per second) ≈ 1 μSv/h ≈ 1μGy/h	

DRAFT RISK ASSESSMENT
Camborne School of Mines
ASSESSMENT OF RISK ASSOCIATED WITH USE OF PORTABLE XRF ANALYSER

Personnel involved: Rebecca James - Student
(inc. status) Kathryn Moore - Staff Inductor

Title of Experiment/Procedure: Helston Landfill Survey
Aim: Explore if the River at Penrose Amenity Park has levels of leachate.

Substances used: ...X-ray beams....... Hazards identified: ...Radiation................

Sources of information on which this is based: Instrument manual

Is there a less hazardous alternative? Y / N
If "yes", why not use it? Lab based XRF → incurs cost and does not allow on the spot testing.

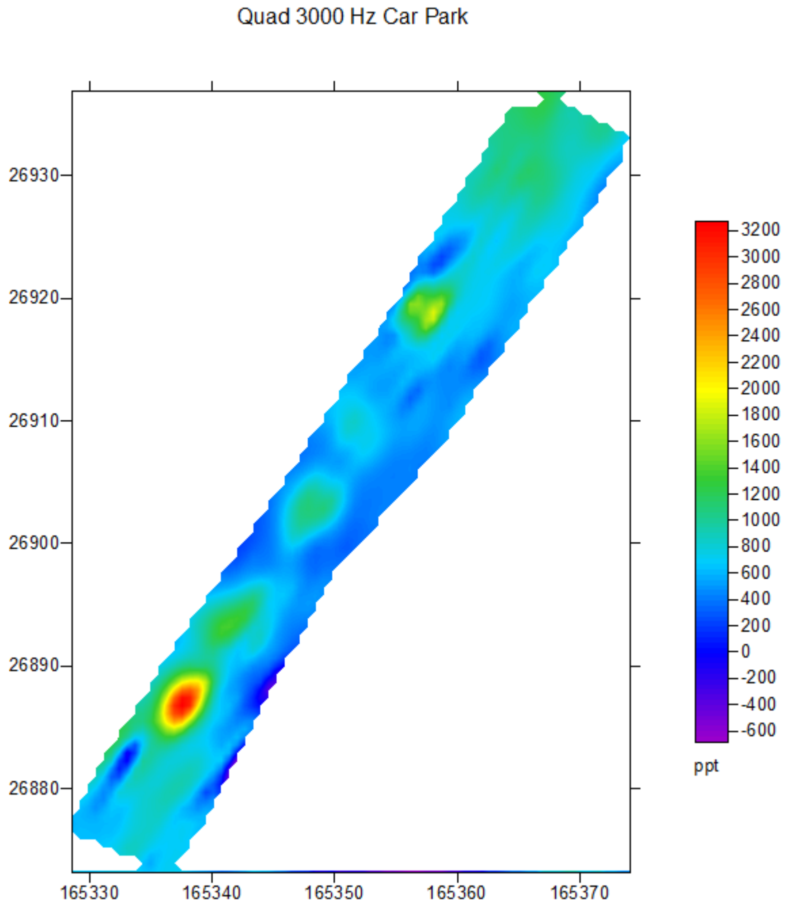
Control measures to be adopted:
Isolate personnel from backscatter at all times.
Ensure that beam is not activated unless sample completely covers window in front of X-ray tube.
If using in a laboratory, display an 'X-ray in operation' sign on door.

EMERGENCY PROCEDURES
If any of the substances or procedures identified above are likely to pose a special hazard in any Emergency or if any personnel are affected, then identify below the action to be taken:
Inform the Radiation Protection officer – Mike Bell 01329 725339 or Kate Moore for further instruction 01326 255 693

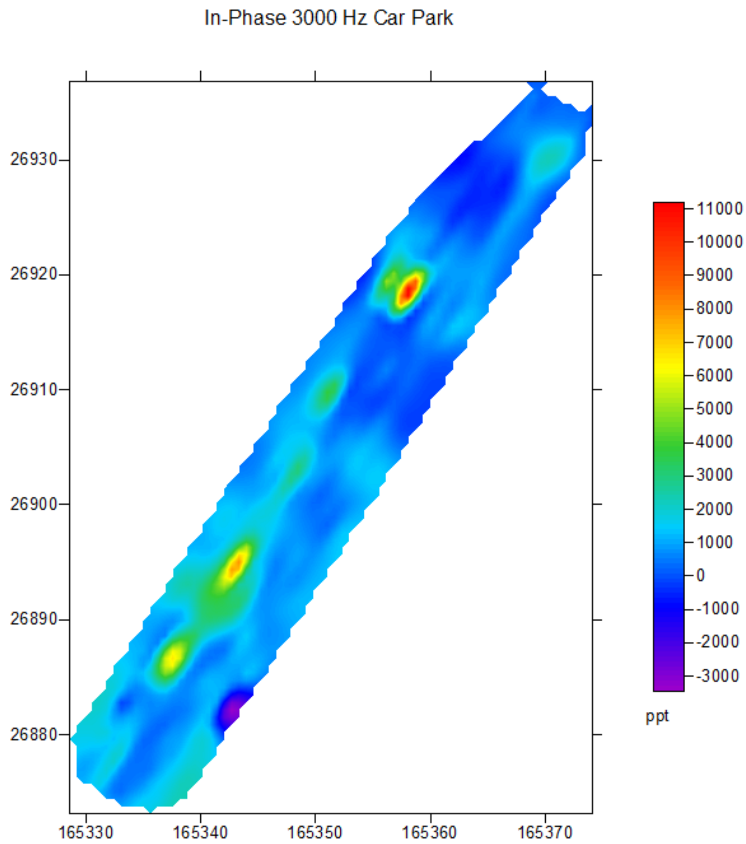
Name of Assessor: K L Moore
Status of Assessor: Lecturer Date 28/7/16 Signed K L Moore
Name of Supervisor (for students only): Date Signed
Head of School: Date Signed

Appendix 4- A3 Map of the site *(see overleaf)*

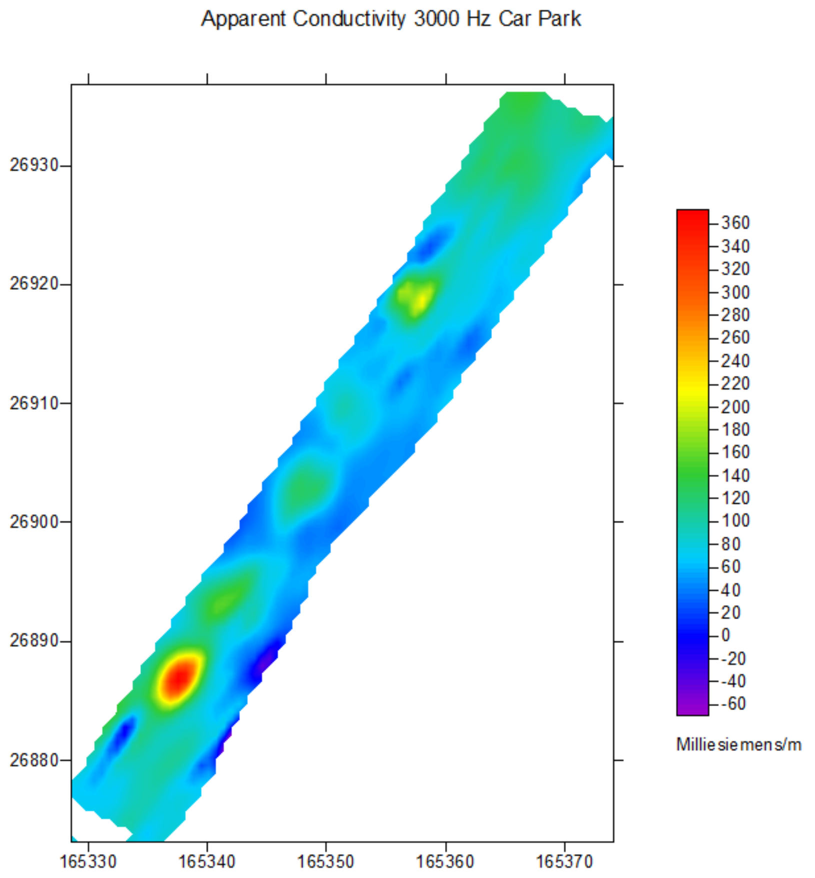
Appendix 5- Quadrature 3000Hz at car park



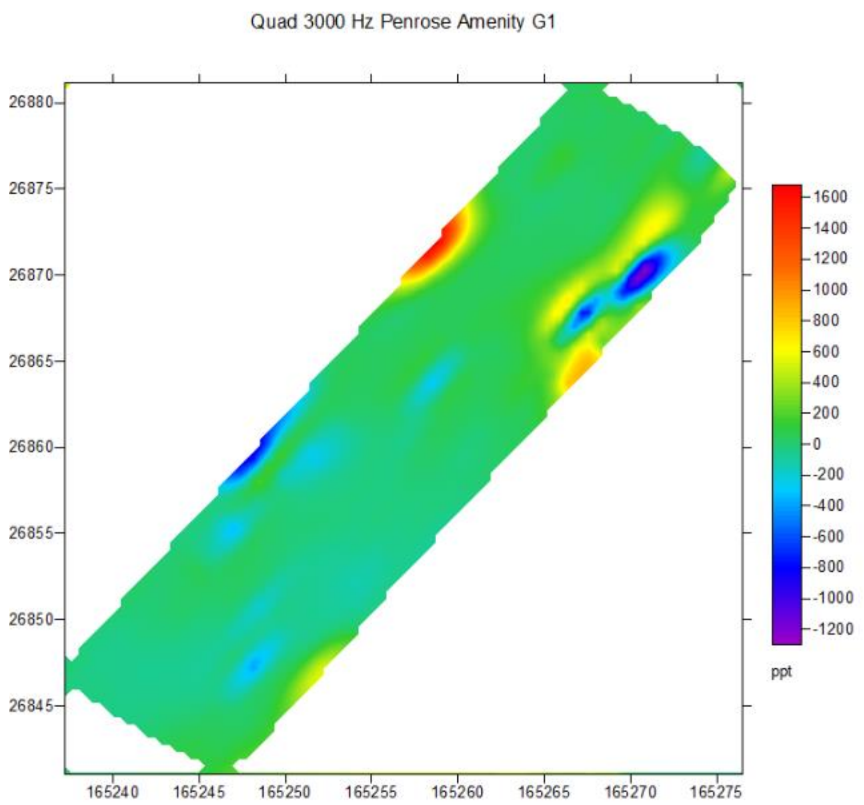
Appendix 6- In-phase 3000Hz in Car Park



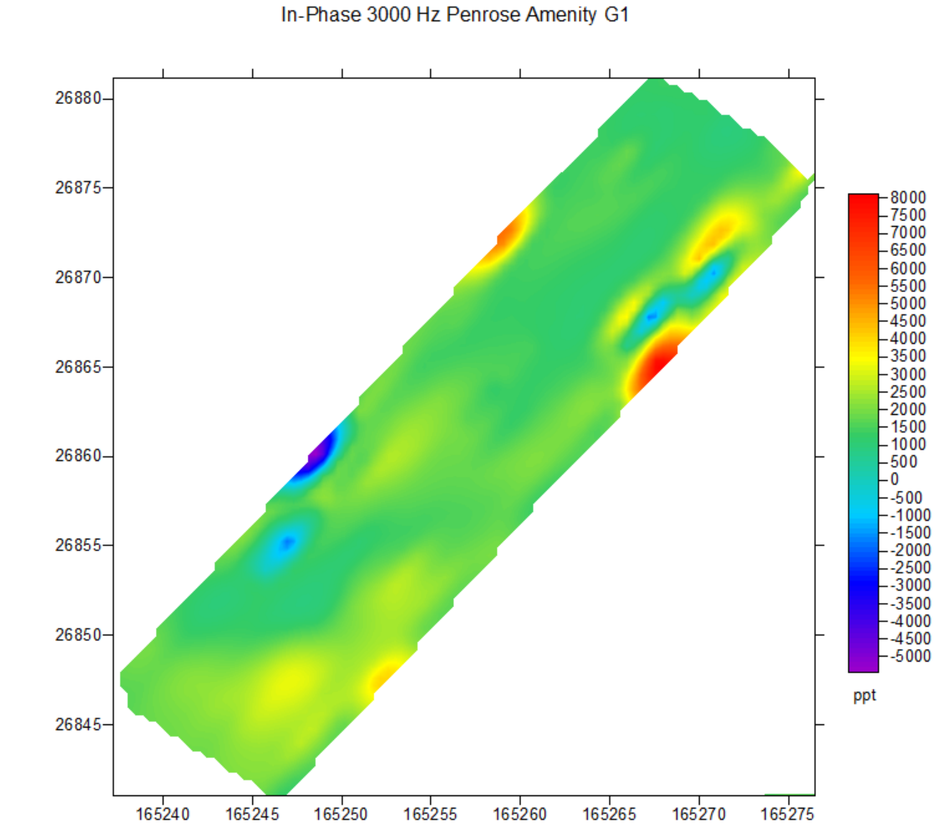
Appendix 7- Apparent Conductivity 3000Hz in car park



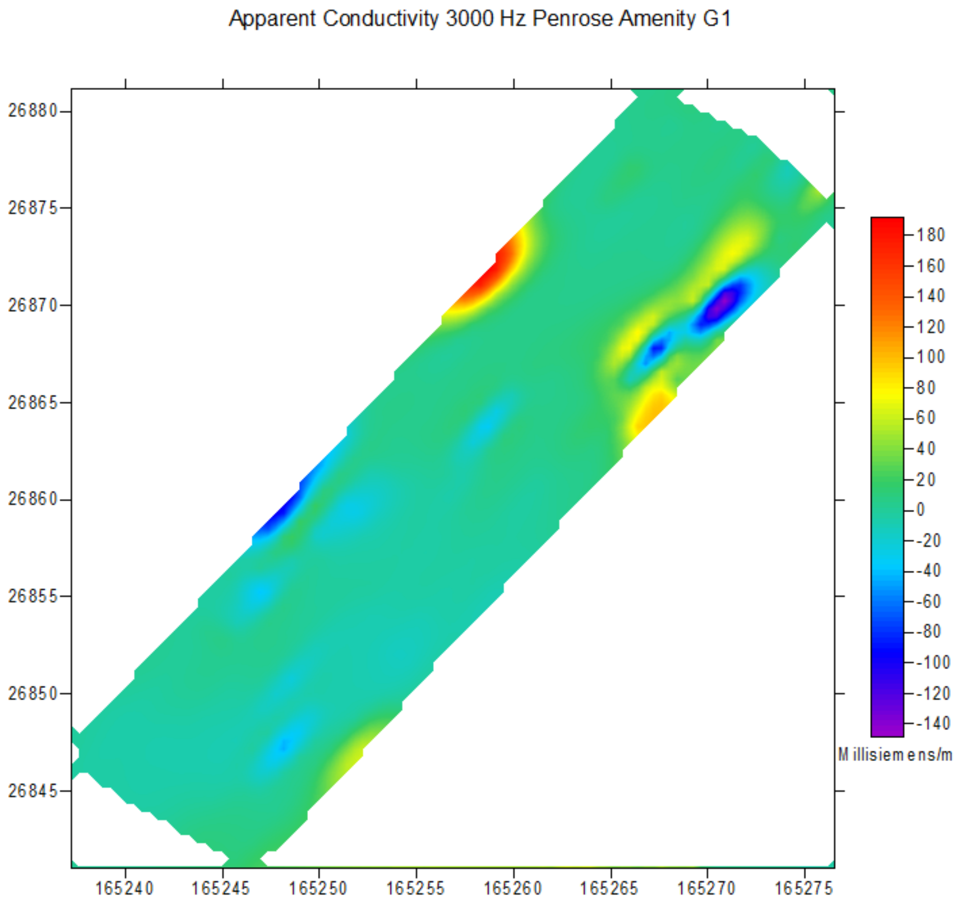
Appendix 8- Quadrature 3000Hz in Penrose Gird 1



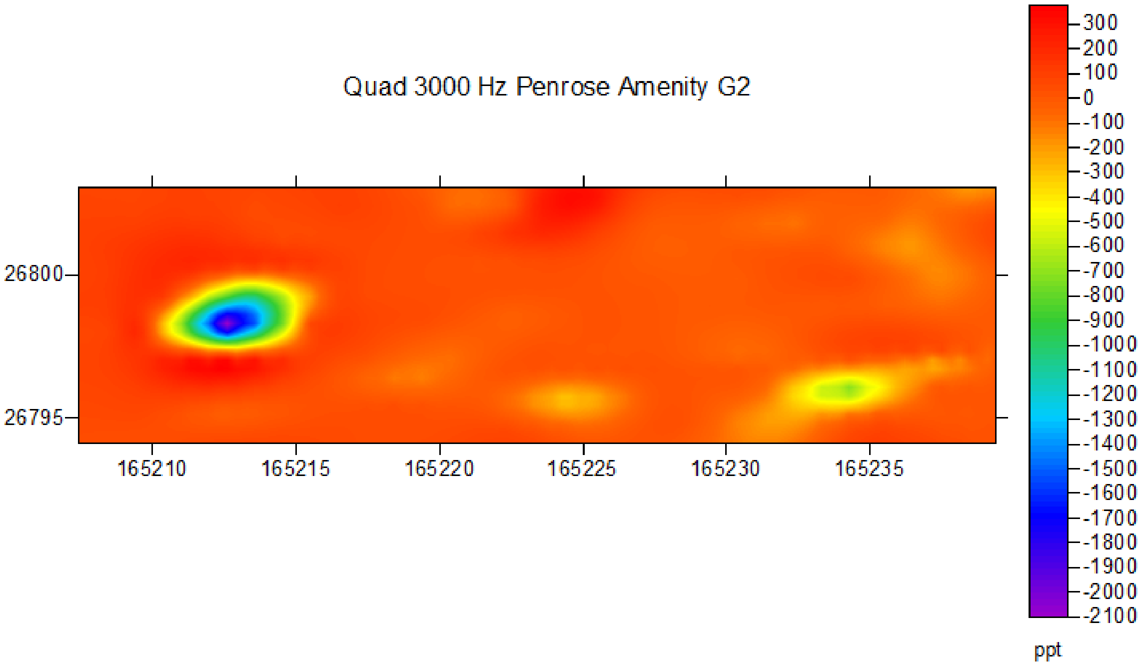
Appendix 9- In-phase 3000Hz Penrose Gird 1



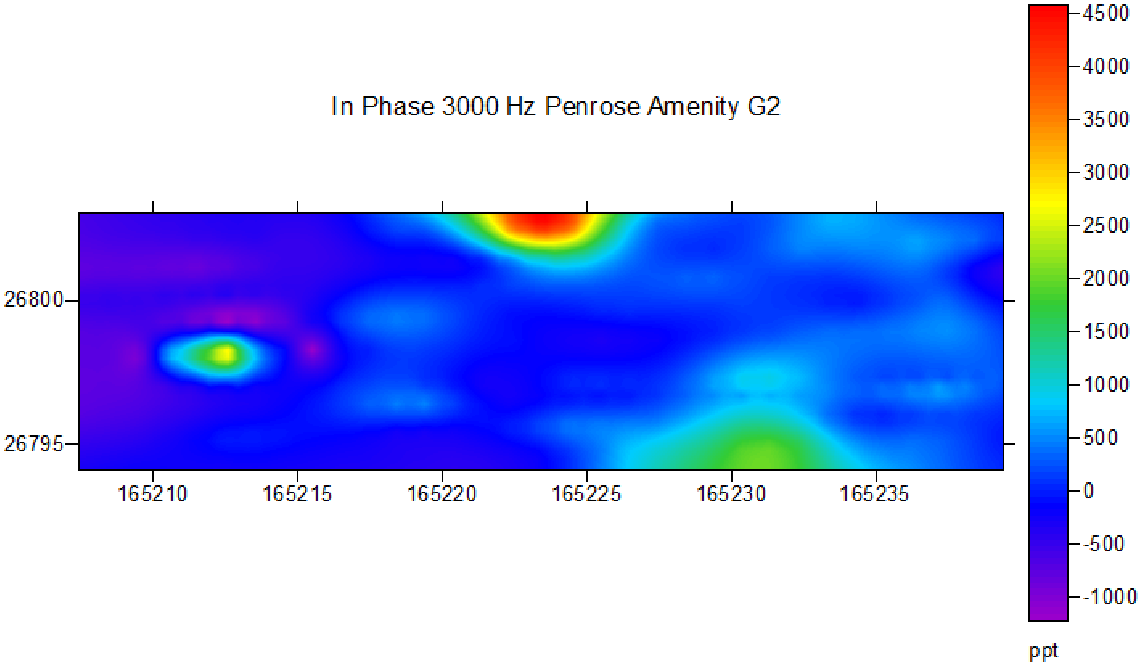
Appendix 10- Apparent Conductivity 3000Hz Penrose Grid 1



Appendix 11- Quadrature 3000Hz Penrose Grid 2



Appendix 12- In-phase 3000Hz Penrose Gird 2



Appendix 13- Apparent Conductivity 3000Hz Penrose Grid 2