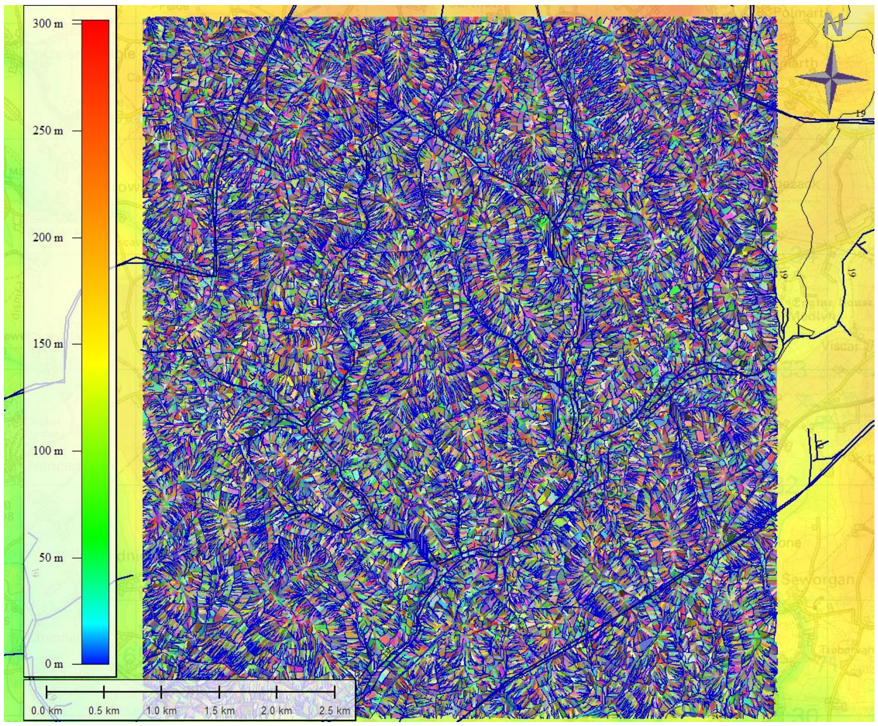
An investigation into mine pollutants and drainage mapping in the upper Cober Catchment, Cornwall.



Submitted by Ella Rosser to the University of Exeter as a dissertation towards the degree of Master of Science by advanced study in Surveying/Land and Environmental Management, August 2017

Declaration:

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:………………………………

Acknowledgments

Thank you to Neill Wood for supervising and guiding me throughout the course and for the duration of the project. Also thank you to James Richardson for assisting in fieldwork data collection for the project

Abstract

The River Cober has flooded the town of Helston, Cornwall, for centuries having social, economic and ecological consequences. This investigation explored the role of the upper catchment as a contribution to flooding in the lower catchment. Sub-basins in the watershed were mapped using LiDAR data to delineate drainage areas that may need mitigation to reduce the concentration of drainage, in turn reducing flooding downstream. The Rolling Ball model was utilised, to map the surface flow over land and into the river. A geochemical survey, consisting of 126 soil samples showed that abandoned mine sites still show elevated concentration of heavy metal pollutants close to the sites, with the highest value for arsenic found at 843 parts per million (ppm), lead 2669 ppm, tungsten 338 ppm, copper 2241 ppm, tin 14,429 ppm and iron 20,7060 ppm. A discussion on the toxic effects to organisms and humans from these concentrations of pollutants, lead to exploring the mitigation measures against pollutants in the soil from abandoned mines and linking this mitigation with the flood attenuation measures upstream.

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Glossary

AMD: Acid Mine Drainage

BAS: British Antarctic Survey

BGS: British Geological Survey

CaBa: Catchment Based Approach

CAP: Common Agricultural Policy

CCMP: Cober Catchment Management Plan

CEH: Centre for Ecology and Hydrology

CSM: Camborne School of Mines

DEFRA: Department for Environment, Food and Rural Affairs

DEM: Digital Elevation Model

DSM: Digital Surface Model

DTM: Digital Terrain Model

EU: European Union

GES: Good Ecological Status

LLFA: Lead Local Flood Authorities

LPF: Loe Pool Forum

NERC: Natural Environmental Research Council

PPM: Parts Per Million

RBD: River Basin Districts

RBMP: River Basin Management Plans

WFD: Water Framework Directive

1. Introduction

Flooding is an ever-increasing natural hazard that has effects socially, economically and environmentally. However, along with the obvious damage that occurs from a flood event, contamination is an added concern that could cause negative adverse consequences for those affected.

This study will investigate the flooding that occurs within the Cober Catchment, an area with many diverse geographies. Located in Cornwall, the catchment is a diverse area, encompassing towns, villages, the River Cober, agricultural land and a once booming mining industry. Flooding in the town of Helston has been problematic for many years, and the Cober Catchment Management Plan (2017) aims to improve water quality and reduce flood risk in the catchment. This study will investigate some of the techniques used to analyse flood risk and present the areas in the upper catchment that are the main drainage areas for the catchment. This in turn should provide extended data for the analysis of whether the upper catchment and the watercourse flows are exacerbating the flooding downstream.

Another major aspect of the catchment is the underlying geology that led to mining in the area. The Wendron mining district once hosted over 600 mine sites, and the catchment would have been a different landscape in the peak of the mining activity. Although the mining once bought wealth to the area and boosted the economy, the environmental damage left behind is something that has been poorly researched. This study undertook a geochemical survey of the area, backed up by secondary data sources to assess the level of contamination still within the catchment.

A desk-based study leading to the analysis of whether the contamination has affected the floodwater will be presented, along with maps of where the major contamination occurs in the upper catchment and the main drainage areas of the catchment and its watercourses. Any soft mitigation measures that may beneficial will be investigated that could prevent flooding and even be a secondary benefit to contamination in the area.

2. Objectives and scope of work

Below are the aims of the study that outline the intended outcome of the investigation and the methods adopted to achieve the aims:

1) **Investigate the geochemistry in the upper catchment**
   A geochemistry survey will be conducted in the upper catchment to assess any contamination in the catchment. This data will then be used in conjunction with secondary geochemical data to look for correlations and 'hot-spots' of contamination. The results will be related to areas prone to flooding in the upper catchment also.
2) **Delineate the watersheds in the Cober catchment**
   A desk-based study and secondary data collection will be utilised to model watersheds in the catchment. Data provided by the Tellus South West Project and the 'Rolling Ball Model' data will help to build up a DEM (Digital Elevation Model) in order to generate and analyse the watershed in the catchment. This will help to define problem areas that suffer increased drainage in the upper catchment, providing evidence that the upper catchment watercourse flows could be leading to flooding downstream.
3) **Assess the mitigation for flooding and contamination**
   Soft engineering mitigation measures will be put forward for the Cober catchment and an investigation into if these defences can defend against any contamination found in the geochemical survey.

3. Literature Review

Flooding in the UK is an ever-increasing hazard and ongoing research aims to understand these events in an attempt to prevent environmental and anthropogenic damage to the surrounding and affected areas. The changes in land use that may have affected flooding will be explored, along with the types of practice (surveying), that can be used to minimise flood risk, model and survey the land and the technology that would allow better prediction and modelling of these events.

As an area of Cornwall that was once massively influenced by the mining industry, a reflection on the impacts of mining on the environment will be looked at along with how historical practices may still negatively affect pollution in the area. Measures of testing for pollution will be investigated and previous studies will be explored. The negative connotations of mining and the pollution/contamination that may have been caused by this industrial activity will be investigated in relation to the flooding in the area. Contaminated floodwater would be an enormous environmental risk, so the likelihood of this occurring will be investigated.

3.1 Flooding

It is reasonable to expect flooding to occur on any river as it is a naturally arising hazard (Holden, 2005). As a frequent hazard, flooding is one of the world's most major natural disasters, causing damage to infrastructure, the environment and leading to the loss of human life (Cook & Merwade 2009).

Flooding can simply be defined as an unexpected covering of land from a water source (Centre for Ecology & Hydrology, 2017). An interaction of land topography, rainfall, surface run-off, and rising sea level are some of the main factors that contribute towards flooding (McMichael, 2006). Flooding is a natural process, which means that both benefits and harm can occur from flooding. For example, benefits to ecosystems and habitats can incur from flooding and formation of the environment. The reason flooding has become an issue for humans, is that we want to populate areas prone to flooding and create travel paths across them. These areas include river flood plains and tidal zones (Cornwall Council, 2014).

There are several types of flooding and they are dependent on the location of the flood. For example, urban flooding is caused by a lack of drainage in towns and cities, coastal flooding is due to a rise in the natural level of sea water and river (fluvial) floods are when water bursts the natural banks of a river (Centre for Ecology & Hydrology, 2017).

To be able to understand the source of a flood, the local environment must be fully understood. A catchment area (or drainage basin) is where the precipitation drains into particular streams or rivers in that area. The topography of the land is important in defining the catchment area. Hill slopes and channels make up the main features of the catchment, which in turn determines the efficiency of water flow through the channels due to the proportion of hillslope to channel density (Holden 2005).

Global Flooding

On a global scale, flooding has caused some of the most devastating natural disasters in history. Recent flooding disasters include Hurricane Katrina, when flood defences failed and an inundation of water caused flooding of New Orleans, USA in 2005. In Central Europe flooding, in the summer months of 2005, led to a loss of many lives. In July of the same year, Mumbai, India suffered flooding which caused 1000 deaths (Wheatear, 2006). Exceptional rainfall in Beijing, China in 2012 caused 1.9 million people to be affected by flooding and 77 people died in the disaster. Economic loss from this flood was sunstantial as the flooding covered an area of more than 16,000 km^2 (Zhou *et.al*, 2013).

UK Flooding

On a global scale, flooding in the United Kingdon (UK) is not on the same scale as in China and the USA, as its flood catchments are much smaller (Wheater, 2006).

In the UK, flooding is the most serious natural hazard, with the Association of British Insurers (ABI) claiming that for the winter of 2016 alone, £1.3 billion of insurance claims for damage caused by floods was claimed (BBC News, 2017).

In the UK, major flooding events have caused adverse damage to the economy, populations and resulted in a loss of life. For example, in 1953a storm surge left devastating effects in Lincolnshire, Suffolk, Norfolk and Essex as 19 people were killed from flooding in the area. Spring tides and high winds resulted in extensive flooding and millions of pounds of damage (Met Office, 2017). Understanding the effects of previous events can help to prevent and mitigate against future ones.

Hazard and Risk

The risk of a flood or the chance of a hazard occurring are at the forefront of officials minds, as they look at ways of preventing and mitigating outcomes. The magnitude of a flood event can be described by the risk and the hazard of the flood, which can often be confused to be the same thing. When talking about the natural disaster of flooding, risk can be defined as:

*"Combination of the probability of a flood event and the potential adverse consequences to human health, the environment, cultural heritage and economic activity associated with a flood event" (*Van Alphen et.al. 2009)

while a flood hazard can be described as:

"the probability of the occurrence of potentially damaging flood events" (Schanze, 2006).

Climate Change

Considerable research has been carried out to understand the relationship between climate change and flooding, due to the belief that flood risk is increasing with climate change. Predictions and modelling together current perceptions suggest that climate change will have greater impacts on fluvial flooding in the UK (Wilby *et.al*

(2008); Wheater 2006). There is some evidence (sometimes contested) to support this belief, however more scientific evidence is needed to ultimately prove or dismiss this theory. It is difficult to define any trends in the recent history of flooding, as the impacts of changing land use, reservoirs, flood schemes as well as changes to the climate are contributing to an increase in fluvial flooding (Prudhomme, 2003).

Land Use

Together with climate change, land use and the effects of land use changes have on flooding is a heavily debated topic. As human populations have increased, our need to develop the land has also increased. Land use and land management techniques affect the hydrology of an area. This in turn determines flooding hazards, the water resources and the transport of pollutants in the surrounding environment (Wheater & Evans, 2009). Wilby *et.al* (2008) recognised that land management practices and climate change could either intensify local flooding, or if used appropriately, land management practices could mitigate against the problem.

The Common Agricultural Policy (CAP) was developed by the European Union (EU) in the early 1960’s after the second world war, to encourage self-sufficiency in food production. However, these changes meant the landscape developed and changed more rapidly than ever (O’Connel *et.al* 2007). With an increasing need to develop land for farming, other changes to the land use; deforestation, urbanisation and cultivation also occurred. The mechanisms by which these changes enhanced flooding are reduced infiltration capacity; loss of vegetation; lower evapotranspiration due to lack of trees and lower soil porosity (Tollan, 2002). Now the CAP policy aims to encourage farmers to provide safe, sustainable and affordable food whilst safeguarding a decent standard of living for all workers in the industry (Agriculture and rural development - European Commission, 2017).

3.2 Mapping flooding

Different countries around the world take different approaches to mapping flooding and analysing the associated risk. The approach depends on the geography of the county, the average magnitude of floods experienced, legislative systems and their culture (Pottier *et.al*. 2005). Prior to mapping, a verbal description may have been used to describe a flood, followed by preparation of a diagram or another visual presentation. However, the development of flood maps has been valuable in providing information for all stakeholders and displays of the effects of flooding, defences and management (Merz *et.al* 2007).

Different types of maps can display different parameters of a flood. Research into the projected changes of water levels and hydrological discharge in the future has increased in response to climate change and flood mapping is a crucial part of this research. With populations growing globally, flood risk maps are encouraged as means of managing floods, as flood prone areas remain attractive for urbanisation as they can support social and economic activities. The EU Flood Directive aims to reduce flood risk in all its member countries (Moel *et.al* 2009).

Flood maps can come in a variety of forms, but they can be generalised into flood hazard maps and flood risk maps (See Figure 1 & 2). Flood inundation maps are used to represent areas where the flooding has surpassed specific levels for that area (Bales and Wagner, 2009). These inundation maps can then be used to identify where the hazards and risks are, and maps can be produced to portray the areas most at risk to the hazard. Moel *et.*al 2009 defines the difference between a flood hazard map and a flood risk map:

"Flood hazard maps contain information about the probability and/or magnitude of an event whereas flood risk maps contain additional information about the consequences (e.g. economic damage, number of people affected)". (Moel *et.al,* 2009).

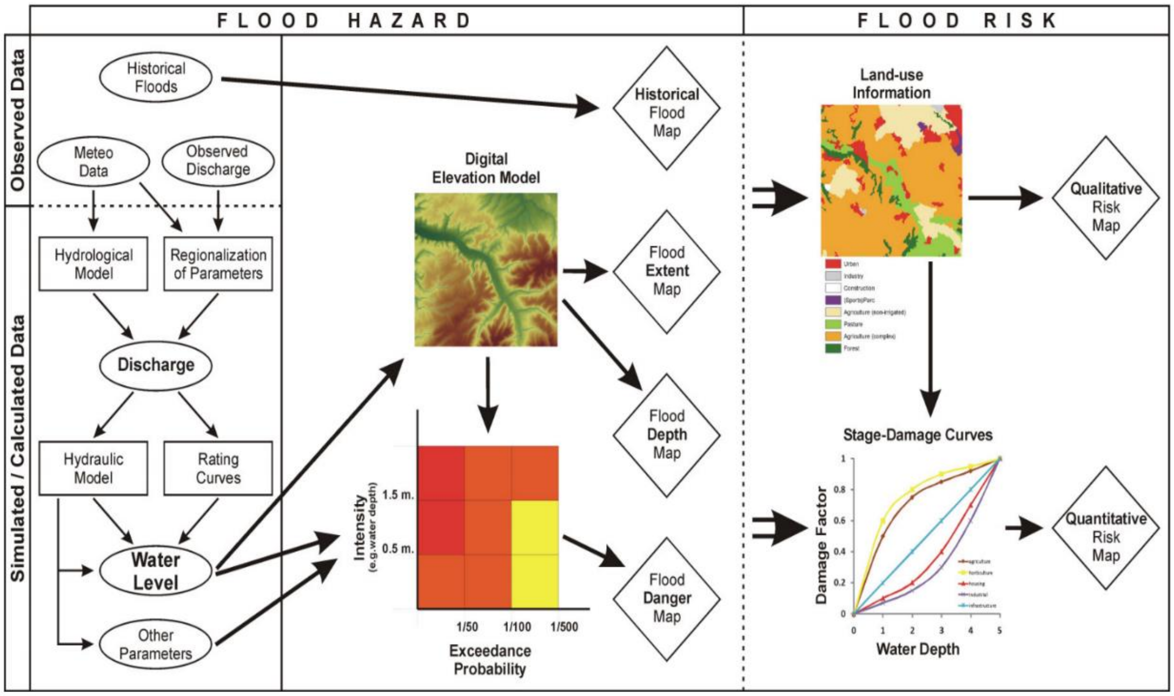


Figure 1: Theoretical outline of developing flood hazard and risk maps (Source: Moel *et.al* 2009)

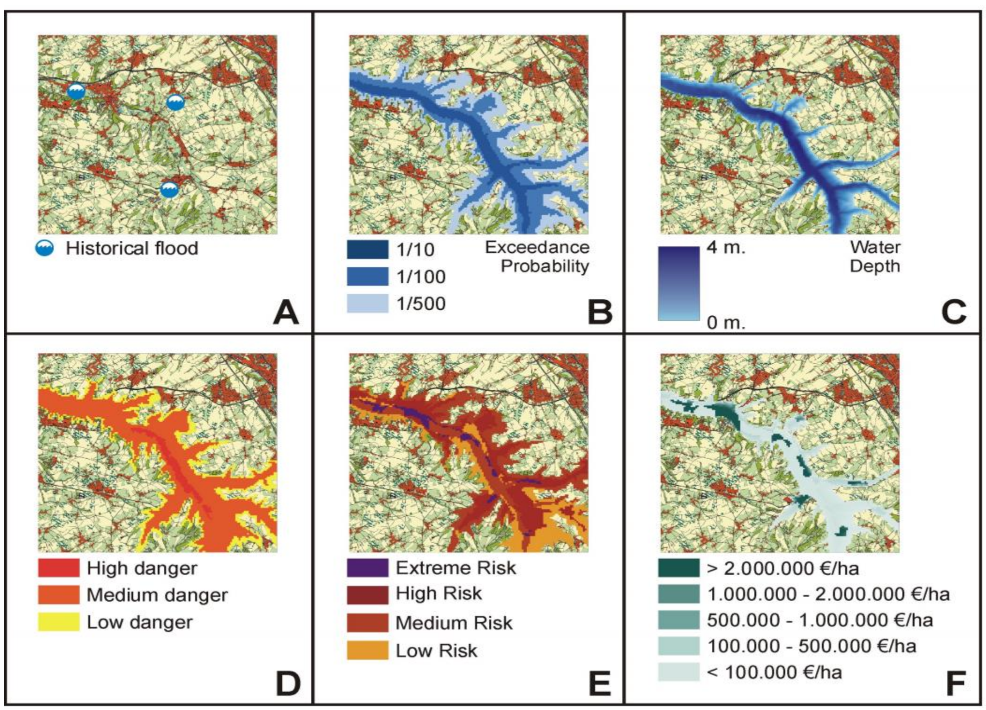


Figure 2: Six types of flood maps. **(A)** historical flood map; **(B)** flood extent maps; **(C)** flood depth map; **(D)** flood danger maps; **(E)** qualitative risk map; **(F)** quantitative risk (damage) map. (Source: Moel *et.al*, 2009).

Flood Site (2008) provides an overall review of the mapping common in EU countries. Flood plain extent maps usually relate to a specific flood frequency, where England and Wales separate flooding from the sea (1/200) and flooding from rivers (1/100) into separate maps. Flood hazard maps are available for England and Wales, however flood risk maps that indicate where damage may occur are rare and are only available in a handful of countries in the EU.

Flood maps in the UK

Formed in 1996 as a non-departmental public body and sponsored by the government's Departments for Environment and Rural Affairs (DEFRA), the UK the Environment Agency (EA has a role to protect and improve the environment. This includes the management of the risk of flooding from rivers (as well as reservoirs, the sea, estuaries etc.). Policies on flood risk are finalised by DEFRA, who in turn fund the responsible authorities with grants to manage flood risk. As well as the EA, other authorities are accountable for managing flood risk, including Lead Local Flood Authorities(LLFAs); District Councils, Water and Sewerage Companies; Regional flood and Coastal Committees; and Highway Authorities etc. (Gov.uk, 2017).

LLFA's, who are the unitary authority or county council, are responsible for developing a strategy that will manage flood risk for their area. The EA worked with LLFA's to produce flood maps for surface water, last updated in 2013 as the third national surface water map. It is the EA's role to provide tools for the LLFA's, for example data and guidance, which will enable them to accurately manage flood risk. Following 'Sir Michael Pitt's review of the 2007 summer floods', it was urged that local authorities urgently mapped areas most at risk to flooding, which led to surface water flood mapping. It was also required as part of the EU Floods Directive, which is implemented by the Flood Risk Regulations 2009 (Environment Agency, 2013).

The mapping developed by the EA and LLFA's enables members of the public to search for their own address and access the maps to display the probability of surface flooding in their area (Flood map for planning service.gov.uk, 2017). Figure 3 shows the results of searching for flooding in Wendron (UK) that was created using the flood map service (Flood map for planning service.gov.uk, 2017).

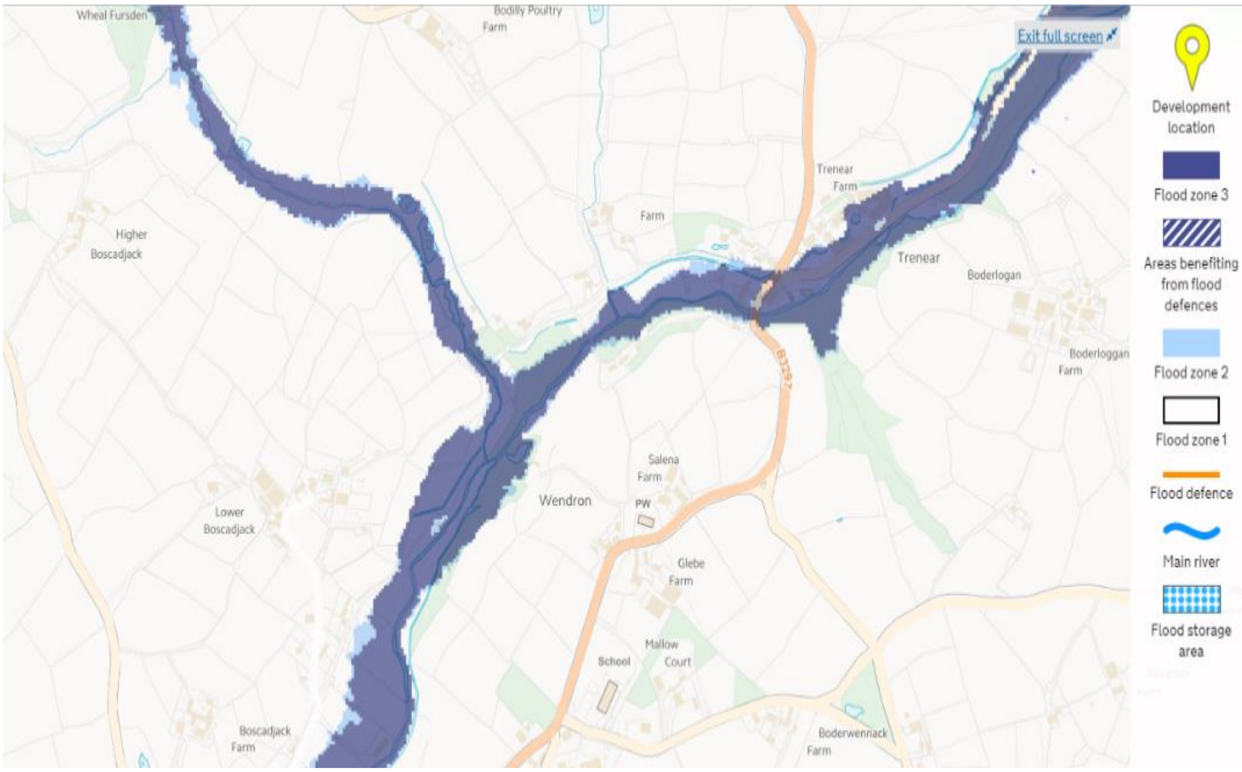


Figure 3: Flooding map for Wendron

Although this is a useful tool for defining areas at risk to flooding, the maps do not fully represent flooding from all sources (watercourses, groundwater, rivers and drainage systems). The model produces maps that show flooding from local rainfall by depicting depressions in the ground surface, floodplains, flow paths between buildings, rivers and natural drainage channels (Environment Agency, 2013). Nevertheless, as a preliminary technique for outlining areas at risk for flooding, it is a useful tool and there is scope for development in regards to the modelling and representing a wider range of sources for flooding.

Modelling Flood maps

The process of creating flood inundation maps is dependent on several parameters. The type of model, topography data that is used to create the model, along with the design flow, and the description of the river geometry for the model are all important, meaning that the process can be relatively subjective (Cook & Merwade, 2009).

Developing a flood hazard map initially involves the collection of data to make a *digital terrain model* (DTM). The DTM is built from laser scan data and/or geographical survey data (*details on laser scanning can be found later on in the literature review)*.

Flood risk maps are created when there is enough information to combine the hazardous information on the flood event and the consequences of that flood. However most hazardous information is qualitative, and the result is a qualitative risk map (see figure 2) (Moel *et.al*. 2009).Maps are then made for the public use, local authorities and professionals using sources of data from hydrology, hydraulic, inundation pathways and maps (Flood site, 2008).

Topographic data for producing flood maps

Light Detection and Ranging (LiDAR) provides an opportunity to improve topographic information, which in turn enables a more accurate method for mapping floods, or flood inundation mapping. This alternative remote sensing technology senses the target surface and calculates the distance from the sensor to the surface. This is "*calculated by determining the elapsed time between the emission of a short duration laser pulse and the arrival of the reflection of that pulse (the return signal) at the sensor's receiver"* (Lefsky *et.al*, 2002).

Topographic heights at a vertical accuracy, that are in proportion with the requirements of a flood model, can be produced though LiDAR data. Filtering is a method used in the processing of LiDAR data to separate all the ground points from the non-ground points. This is because when scanning, the LiDAR instrument may reflect off the ground or from the top of a semi-transparent object, or anywhere in between these two points. This in turn creates a bimodal distribution of heights, whereby the topographic layer and overlying object height can be assembled. A DEM (Digital Elevation Model) is the name given to interpolation of all the ground points from a LiDAR scan. (Cobby *et.al.* 2001).

In the United States (US), a study investigated some of the issues surrounding flood mapping. LiDAR data is not yet available for the whole of the US and even for the areas where it is available; other technical issues with the modelling are not well studied. Cook & Merwade (2009) considered maps that were developed with a different modelling approach to the LiDAR mapping method and compared them with modern flood inundation maps that had been derived from LiDAR data. The investigation concluded that creating flood inundation maps is a problematic process that not only relies on detailed topographic data but also requires the exploration of the approach to the modelling and the geometric representation (Cook & Merwade, 2009).

Sanders (2007) conducted a study that evaluated DEMs (Digital Elevation Models) for flood inundation modelling. It was concluded that although highly accurate topographic data is not readily available to model flood inundation, online DEMs could be utilised. DEMs based on LiDAR was a favoured data set to map topography due to the horizontal resolution, ability to separate the natural earth shape from buildings and vegetation and the vertical accuracy (0.1 m). The evaluation also found that interferometric synthetic aperture radar (IfSAR) was also useful due to its high resolution however to be able to model flooding, further processing would be required as gridded elevations reflected any built structures including vegetation (Sanders, 2007).

Tellus

The Natural Environment Research Council (NERC) funds the Tellus South West Water project a partnership consisting of the British Geological Survey (BGS); the

Centre for Ecology and Hydrology (CEH); the University of Exeter Camborne School of Mines and British Antarctic Survey (BAS). They carry out environmental surveys and research projects to provide scientific data to improve the local economy, environment and businesses in the South West of England. The survey aims to help with creating legislation, policy and any decisions about development in the region by providing information on the resources in the South West, environmental change and natural hazards (Tellus, 2017).

The initial Tellus South West Water survey was completed in 2013, consisting of five main components:

- A high resolution airborne geophysical survey (carried out by BGS);
- An airborne LiDAR survey (carried out by BAS);
- Geochemical sampling of soils and stream sediments (carried out by the BGS G-BASE project for South West England);
- Soil and habitat survey (carried out by CEH);
- Stakeholder liaison programme to connect with local government, business and research centres (carried out by the University of Exeter Camborne School of Mines) (Tellus, 2017).

The Tellus project has provided information on the environment, geology, landscapes and ecosystems. This data has been useful to help manage the risk from natural hazards and help in planning the future of these landscapes (Tellus, 2017).

The airborne LiDAR survey was completed by the British Antarctic Survey (BAS) between July and August 2013 in Devon and Cornwall. A BAS Twin Otter aircraft (VP-FBL) was used, with the Optech ALTM 3100 EA scanning laser fitted into the aircrafts camera bay. The laser scanner was fitted with an integrated Applanix GPS/INS positioning system hired from an Italian remote sensing company called Helica (Ferraccioli *et.al.* 2014).

The Environment Agency then processed the datasets into Digital Terrain Model (DTM) and Digital Surface Model (DSM) datasets. The DTM (representing the topographic model of the bare earth i.e. height) and DSM (representing the height of features on the bare earth) (see Figure 4) covered an area of 9424 km^2, which includes all the land to the west of Exmouth. A total of 26 flights were needed to acquire the data set that consisted of 14817 line km of new LiDAR data, meeting the specification for accuracy and spatial resolution provided by the CEH and BGS, which is 1 point per m^2 data density and 25 cm vertical accuracy (Ferraccioli *et.al.* 2014). Figure 5 shows a map of the topographic data collected as a result of the Tellus South West LiDAR project.

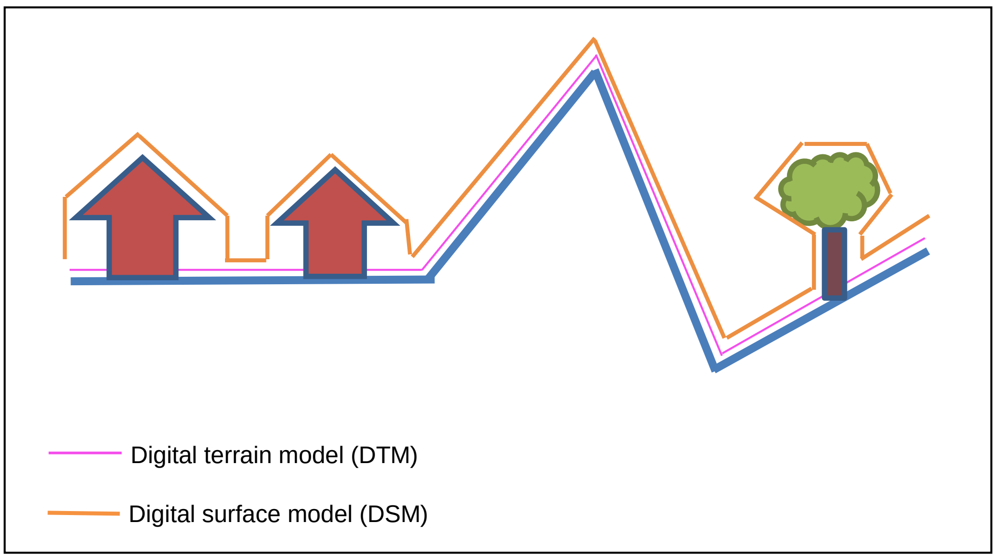


Figure 4: Diagram displaying differences between DTM and DSM

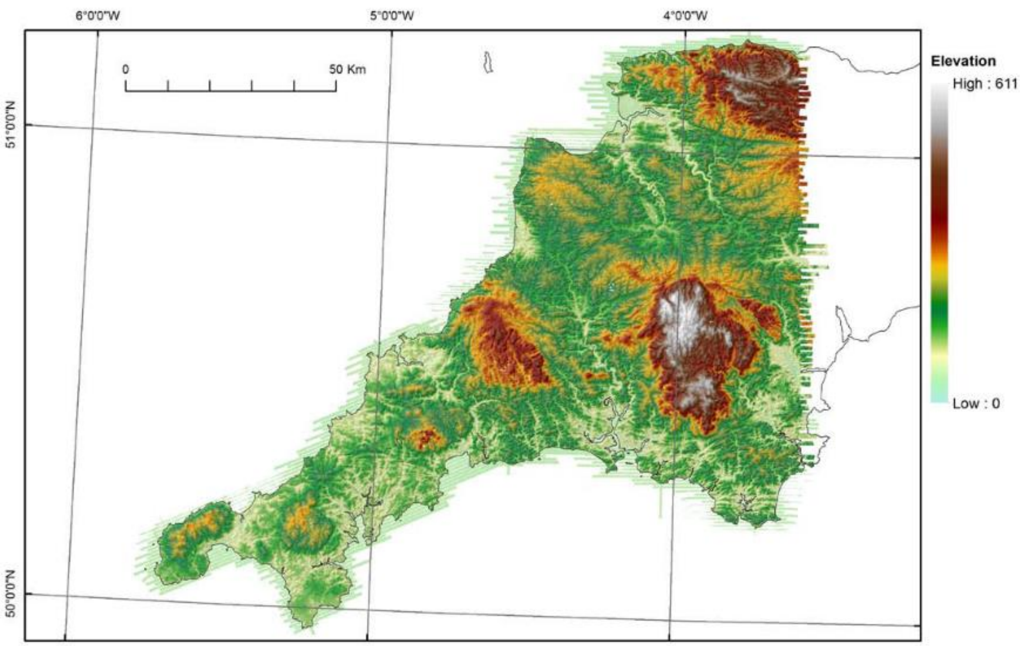


Figure 5: LiDAR dataset for Tellus South West Project (Source: (Catalogue.ceh.ac.uk, 2017)

Uncertainties with flood inundation maps

Previous research has investigated the limitations and uncertainties with flood inundation maps, but the Bales & Wagner (2009) review investigated more than once source of uncertainty. Firstly, topographic data can provide good data representation if it is of good quality. However, the type of topographic data is important as there can be errors affecting the flood inundation map. LiDAR data for example can create errors when the laser reflects on solid surfaces that are not natural, for example a road. In an example, Bales & Wagner (2009) explain that if the LiDAR data is representing the road as the natural surface then a discontinuous stream channel is created, in which the road has become a 'dam'. Errors like this can cause errors in the inundation map. To prevent this, the best process is to ensure the DEM (Digital elevation model) is ‘Hydro-controlled’, meaning flow path is continuous along streambeds and any low-lying areas.

Secondly, hydraulic modelling is an important parameter for an accurate inundation map. The model requires topographic data, boundary conditions upstream and downstream, friction values and model validation data. All of these parameters need to be appropriate for the specific inundation map to create a good model. Bales & Wagner’s (2009) study shows that there are many factors that must be considered to ensure there are no uncertainties in the model and creation of a flood inundation map.

Rolling Ball model

The EA has a duty to protect and enhance the environment and as part of this duty, they must protect the environment from flooding. The EA commissioned JBA Consulting to undertake an ‘Arc Hydro analysis of Cornwall and Wessex. The project was created to develop stream and catchment models that would be used in an attempt to mitigate against flooding in the region. The following parameters were assessed:

- Stream slope
- Average altitude
- Catchment area
- Catchment aspect
- Average catchment slope
- Stream network density

By using ArcGIS, the company was able to carry out an analysis of the Cornwall region by obtaining DTM data and using the computer programme to model the aspects listed above. The methodology included using the following functions on the programme: Fill sinks; Flow accumulation; Stream segmentation; Flow accumulation; Flow direction; Adjoint catchment processing; Catchment grid delineation; Catchment polygon processing and Drainage line processing.

Once this was completed the results from the Arc Hydro Analysis, or Rolling Ball Model, were then used to create a Rapid Response Catchment Analysis. Included in the rapid response catchment analysis were; Average catchment slope; Modelled stream density; Average altitude; Catchment exposure; Stream slope; Average stream slope; and Actual stream density. Using the results from this analysis, catchment and watercourse metrics can be used to identify areas that are in need of rapid response.

The completed data sets are a useful tool for supporting the assessment of flooding in Cornwall (Environment Agency, 2012).

3.3 Surface run-off and flooding

Surface run-off is one of many aspects of the water cycle. Surface runoff comes from the surface of the land, from precipitation and fills up streams and rivers. The definition of 'Surface run-off' from the Flood and Water Management Act 2010 (FWMA) is as follows:

"The flooding that takes place from the 'surface runoff' generated by rainwater (including snow and other precipitation) which: (a) is on the surface of the ground (whether or not it is moving), and (b) has not yet entered a watercourse, drainage system or public sewer." (Flood and Water Management Act, 2010).

Depending on geographic location, time and geology etc., the interaction between precipitation and surface run-off can change. Meteorological factors that affect the surface runoff include the intensity of the rainfall (duration and amount), the distribution of rain in the river basin, time, season and temperature. The physical characteristics affecting surface runoff include the topography, elevation, soil type, vegetation, the drainage area, shape of the basin and land use. Human activities changing land use also play a big role in the changes to surface runoff. Urbanisation means impermeable materials are being used more, reducing infiltration into the ground. The removal of vegetation is also a contributing factor to peak discharge into streams in the area as the frequency of floods is increasing (Water.usgs.gov, 2017).

A national review of the impacts of rural land use and management on flood generation was conducted after several large floods in the UK led to debates over soil saturation linked to loss of soil structure though compaction. The review was conducted by Defra/EA and called the R&D Project FD2114, combining the knowledge of numerous agricultural, soils, hydrology and hydrogeology experts (O'Connell *et.al*, 2007). The report established that agricultural land use has intensified from incentives provided by agricultural policy and this has had significant changes in land use and management practices in the last 50 years in the UK. This has led to complex run-off generation at a local scale. The report suggest that grass buffers could be beneficial in delaying run-off and that an 'integrated approach' is needed to apply these measures. By doing so a reduction in erosion can be achieved, along with pollution mitigation and flood prevention (DEFRA/EA, 2004).

The types of modern agricultural land use can influence surface run-off. The practices that encourage these negative consequences include increasing stocking densities on grassland; production of fine seed beds; maize crop increases; and increases in autumn sown cereals. These practices can result in reduced infiltration that in turn leads to increased surface runoff (O'Connell *et.al*, 2007).

Substantial modifications of river channels should be considered when assessing evidence for local runoff generation. Land drainage schemes and flood protection for urban areas has meant that, depending on the situation, river channels may have been modified to resolve problems. Straightening or restoration of channels, embanking, and re-sectioning are all examples of changes to natural river morphology (O'Connell *et.al*, 2007).

A study of the Camel catchment in Cornwall determined the impacts on the river flow from rainfall trends and land use changes in the catchment. The catchment is primarily agricultural, with stock farming and cereal production. The study looked at annual rainfall averages and Agricultural Census data, which depicted the number of stock and the area of cereal faming in the study area. The daily mean discharge of the river Camel was also studied from 1965 to 2000. The study revealed that no single factor was responsible for the increase in the frequency of flooding. It was concluded that any subtle changes could be attributed to climatic change, agricultural intensification and cumulative urbanisation in the area (Sullivan *et.al* 2004).

Further investigation of surface run-off affecting soil erosion from polluted soils is investigated in the 'Abandoned mines and pollution' section of this literature review.

3.4 Flood defences

With specific reference to Cornwall, flooding is a major concern, with 1 in 6 properties at risk from tidal, fluvial or surface water flooding (Cornwall Council, 2014). In recent years, the lead authorities dealing with flooding in Cornwall have taken an overarching management policy to manage flood risk. This means that instead of dealing with floods by building flood defences alone, other approaches are also used. Thus, improving flood risk mapping, making sustainable decisions about land development as well as nurturing existing flood defences, all contributed towards managing flood risk in Cornwall (Environment Agency, 2008). Structural engineering for flood mitigation (hard) is often questioned for its effectiveness as a measure of reducing flood patterns, and governments and steering towards non-structural flood risk management strategies (soft). Reviewing upstream land management practices and constraining floodplain development are typical 'soft' approaches (Levy *et.al*, 2007).

This section of the literature review will now analyse several options for soft mitigation measures against flooding.

Watershed management involves 'modifying the formation of floodwater', by managing the land use and conserving soils, which in turn minimises sediment transport and surface run-off. This can be achieved by contour ploughing of farmland, terracing land, afforestation and increasing vegetation cover. By enhancing the infiltration of rainwater through storage (ponds or artificial storage measures), and reducing impermeable areas of land, flooding can be expected to decrease (Bruk, 2001).

Thomas & Nisbet (2007) assessed the theory that using trees and associated woodland debris to increase the hydraulic roughness of the floodplain can reduce flood risk. Their research used two dimensional and three dimensional (2-D and 3-D) modelling to simulate a 1 in 100 year flood in an area of river in south-west England along a 2.2 km stretch of the river Cary in Somerset. . As expected, the woodland reduced the water velocity and the flood peak travel time was increased by 30 to 140 minutes. Water storage was also increased by 71 % due to the coverage of woodland along the right bank of the floodplain. The assessment proved to be successful and it believed that there was considerable scope for this type of soft engineering to reduce the adverse effects of flooding. It must also be noted that the scale of the modelled woodland was small in relation to the size of the catchment, suggesting that a larger woodland would have had a greater impact.

Nicholson *et.al* (2012) assessed sustainable flood mitigation through soft engineering features in the Belford catchment, Northumberland, UK. The investigation assessed the potential reduction of surface runoff through the development of 'Runoff Attenuation Features' (RAF) upstream from towns and villages prone to flooding. Using LiDAR and GIS, the topography of the land was studied to find the appropriate location for the feature. Firstly, a permeable timber barrier capable of storing 800 m^3 of floodwater was constructed in the catchment. This 'weir' like feature penetrates the ground and allows water to slowly percolate through the wood diverting the peak flow from the stream (see Figure 6).

Figure 6: Permeable timber barrier (Nicholson *et.al*, 2012).

A second feature used in the investigation were 'Offline diversion ponds'. By diverting flow from the main channel during a flood event, the RAF was able to increase the lag-time of the flood hydrography and decrease the flood peak. When the stream reached a peak flow, then the RAF situated next to it filled up and reduced peak stream flow. Another RAF was an 'Overland flow disconnection pond', which intercepts and stores overland flow. The final RAF featured in the study was the use of 'large woody debris', to slow down the flood peak. The woody debris was constructed over the stream and in a flood event; the wood causes the stream to flood creating friction from increased vegetation in the floodplain. This then benefits nutrient cycling, the formation of microenvironments and geomorphologic processes (see Figure 2) (Nicholson *et.al*, 2012).

3.5 Abandoned mines and pollution

Mining of coal, metal and other minerals has been an anthropogenic activity since the Bronze Age, with a large peak during the industrial revolution in the eighteenth and nineteenth centuries, when demand was at an all-time high. However, competition and importation of minerals meant that the mining industry in England and specifically Cornwall largely ceased during the last century with only few working mines remaining. Abandoned mine workings are a complex issue that need to be managed to ensure the quality of the drinking water is acceptable (Environment Agency, 2017), as the effects from underground mining can influence the groundwater and affect pollution levels. With a continuously growing population and increasing pressures from the government to maintain a clean and sustainable environment, the provision of clean, healthy drinking water is a key issue.

Much of the material mined from a metalliferous mine is processed in the milling and processing operations, separating the desired valuable metal product from the waste. However not all metals are extracted, leaving a small portion in the waste material which is then left in the tailings deposits. This mining waste has the potential to last for ever and is still a source of pollution and potential contamination and hence an environmental problem (Silva *et.al* 2005).

A major concern for current and abandoned mines is the environmental pollution due to the effects of acid mine drainage (AMD). The mining industry is the major producer of acidic and sulphur rich wastewaters, which pose a risk to the environment through both high acidity and by often containing high concentrations of metals and metalloids, including iron, manganese, arsenic & aluminium (Johnson & Hallbery, 2005). AMD risk is caused when sulphide bearing material that usually occurs in iron sulphide aggregated rocks is exposed to oxygen and water. This process occurs naturally but is also generated through the mining process. The potential for and effects of AMD differ from site to site, thus the mitigation measures also vary. As a serious environmental consequences of mining, AMD has become the focus of research initiatives suggested by a selection of stakeholders such as mining companies, governmental agencies, environmental groups, research institutes and the general public (Akcil & Koldas, 2006).

The problem of AMD mine water pollution from current mines is an ongoing environmental issue with more research to prevent such damage. However, the major issue lies with abandoned mines where there is no clear ‘owner’ of the problem. This means that polluted waters are sometimes left to run their own course, as the mine voids flood due to withdrawal of the pumping system and dissolution of soluble, pollutant minerals as they become submerged by the water table (Younger *et.al. 2005).* One of the worrying issues of the mine sites in Cornwall is that there is no specific company or person responsible for damage created by mine sites that may not have been worked for well over a century.

Studies are continuously being conducted in relation to contamination of land from abandoned mine sites, with particular emphasis on contamination by heavy metals. Metalliferous mines produce elevated levels of heavy metals as the material not needed after mineral extraction (tailings/mine waste) becomes dispersed into nearby fields and soils from precipitation and wind. As mentioned previously, water pollution from mines is linked to the production of AMD (Navaro *et.al.* 2008).

For example, the Lousal mine in Portugal has shown evidence of environmental damage and landscape disturbance since its closure in 1998. AMD and soil contamination are among the serious environmental damage sources, with high levels of lead, copper, zinc, mercury, cadmium and arsenic occurring in the soils near the tailing deposits and in the sediments tested downstream from the tailings site. According to the permissible levels of contamination in Portugal, these results all exceed the maximum recommended levels (Silva *et.al* 2005). The reason these metals in tailings pose such a risk to the environment is because they can promote a series of chemical reaction. Firstly AMD can be produced (as mentioned above), which in turn can pollute the local water system, including groundwater and stream sediments (Silva *et.al* 2005). In this particular study, the geochemical data showed that the contamination of soils and sediments was mainly distributed downstream or downslope from the site with the tailings. It is believed that the transportation of the contamination was from erosion in the area and from AMD. The dissolved metals were found to adsorb to the precipitate rich in aluminium and iron (Silva *et.al* 2005).

Within rivers and floodplains, heavy metal contamination is a serious environmental problem. Sediments that have become contaminated as a by-product of mining are persistent in the environment and can become widespread. Coulthard & Macklin (2003) describe the 'TRACER' model, which is a catchment sediment model used to accurately predict the patterns of contamination at present and in the future using historical mining records. The model is a useful tool for locating 'hot spots' of contamination if the right information is provided. The best sources of information to create a good model is a digital elevation model (DEM), rainfall information, soil, basic geology information and data on contamination volumes. Using this model they predicted that >70% of contaminated sediments deposited after the mine closure will remain in the river system for over 200 years. Thus proving how important it is to monitor the landscape and river systems around abandoned mines for centuries after their closure.

To be able to accurately assess contamination levels and their dynamics, an understanding of both the deposition and remobilisation are needed. In rivers with a neutral to alkaline pH, the metal ions from the waste material in the mines becomes adsorbed onto sediment particles in the river system, which in turn can be deposited onto flood plains from floods or deposited in river channels. As catchment areas can be large and rivers extensive, the contaminated material can be found hundreds of kilometres from the source and remain there for hundreds of years. The study concluded that monitoring is needed around river basins in England that have been affected by metal mining in the past or currently. The model suggested that the contamination remained widespread in flood plains long after the mine closed and that in some circumstances the floodplains became more contaminated than the mine site itself. They suggested that remediation may be better targeted downstream at 'hotspots' within floodplains. The model could also predict river contamination dispersal and mining disasters that lead to catastrophic environmental damage such as tailing dam failures in Spain, Bolivia and Romania (Coulthard & Macklin 2003).

Healy (1996) reported on the evidence relating to mine waste specifically its production and disposal in Cornwall. In this work, Healy conducted a pilot survey in

1995 examining several sites of Cornish coastal lowlands, including Loe Pool, and the connections between the physical and chemical character of sediment sequences and mine waste materials. Reconnaissance of Loe Pool consisted of retrieving sediment cores that were subsequently examined in the laboratory for sub-sampling and analysis. Two sites were used to collect samples, Loe Pool Lake and a Cober river channel. Stratigraphy in the lake sample showed the three metals measured, iron (Fe), copper (Cu) and tin (Sn), were present in high concentrations. Fe was the most abundant at 30,000 parts per million (ppm) in the upper segment of the core, while Cu (5,000 ppm) and Sn (1,000 to 3,000 ppm) levels were also high. Five metals were measured in the Cober River channel sequence. Fe values were high at 10,000 ppm, while Cu concentrations were generally lower than in the lake and were consistently around 1,000 ppm. Lead (Pb) concentrations were high at 500 to 1,000 ppm. Sn showed a peak concentration of 1,850 ppm, .but zinc (Zn) concentrations were generally low. The concentrations of these metals are worrying, as any concentration of metal higher than 1,000 ppm is thought to be toxic to the flora, fauna and anthropogenic receptors (Healy, 1996).

Understanding and managing these problems in coastal environments poses a challenge as they are caused by several factors. For example, hydrological transfer routes, erosion, biological processes and sedimentation are all contributing to high concentrations of metals in coastal areas. The problem can also be increased by the disturbance of the contaminated sediment through anthropogenic sources, highlighting the importance of the coastal management of these sites and prevention of disturbance (Healy, 1996).

3.6 Geochemical surveying

To build up an understanding of the environment, geochemical surveys can increase our knowledge of the elements and the composition of the soil. A geochemical survey can include analysing the chemical composition of rocks, soils, stream, plants, water and sediments. In this report, a chemical survey is an appropriate method for analysing the minerals within the catchment and assessing any contamination in the area.

There are several methods for completing a geochemical survey and a study of literature reviewing these methods is discussed below.

Pxrf

Portable X-Ray Fluorescence (Pxrf) technology has become increasingly widespread in industries like mining and mineral exploration. The technology allows the user to measure the chemical composition of a sample by the instrument emitting x-rays of a known energy to the sample (this could be a rock or soil sample). Atoms within the sample emit fluorescent x-ray energies that are characteristic of its elemental composition, allowing the chemical composition of that sample to be determined (The Field Museum, 2017).

Gazley & Fisher (2014) reviewed the applications of the Pxrf. It is widely used by the mining industry for mineral exploration and also by biologists, archaeologists and soil scientists. As it is such a new and evolving technology, Gazley & Fisher clearly mention that there were limited case studies on the applications of pxrf but further studies were anticipated. The portability of the instrument is beneficial allowing users to carry out on site analysis, proving a quicker and more efficient method for analysing geochemistry.

However, there are several factors to consider when using Pxrf analysis. The type of instrument is key factor forgetting the right analysis for the survey. Older instruments are less accurate as they have smaller detectors than modern instruments. Secondly, calibration of the instrument is important and using the correct unit system must be installed for the purpose of the survey. Gazley and Fisher (2014) also emphasised the uncertainty of the analysis due to energy emission lines. The element should emit energy lines characteristic of that element, however some pairs of elements emit similar energy and the two can overlap. This can affect iron (Fe), zinc (Zn), lead (Pb), tungsten (W), arsenic (As), gold (Au) and barium (Ba).

Another consideration when using Pxrf, is the nature of the material being analysed. Homogeneity is an important aspect of this sort of analysis and for an accurate representation of data, many samples may need to be homogenised. A Pxrf unit has a window that measures approximately 10 mm in diameter, but the user cannot presume that this is an accurate representation of the whole sample or core. Like arsenic in arsenopyrite, trace elements can present themselves in single-phase minerals. As previously mentioned, the small window to the XRF unit also means that the depth of penetration of the Pxrf is minimal. Thus, to gain a true representative survey, several readings are needed to get a good average value. Moisture within the sample can also affect the analysis. Gazley & Fisher recommend that samples be dried out for effective analysis as moisture attenuates the x-rays and low concentrations will be recorded.

The use of PXRF for determining the extent of pollutants in the environment is increasing. The Pxrf saves time and money as large number of metals can be detected, compared to more tradition methods of geochemical analysis.

3.7 BGS data

G-Base

A major systematic survey of the UK, has been undertaken by The Geochemical Baselines Survey of the Environment (G-BASE), aiming to provide geochemical data covering the whole of the UK by 2020. To establish geochemical baseline, data has been collected, principally from stream sediments at a density of one sample every 1-2 square kilometres, (BGS, 2017).

Prior to G-Base, the only geochemical sampling work was undertaken by the British Geological Survey (BGS). Previously known as the Institute of Geological Sciences

(IGS), BGS was mainly involved with uranium reconnaissance work. In 1968 BGS, started a regional geochemical sampling programme, although this was only undertaken in the Highlands of Scotland. Work was funded by the UK Department for Trade and Industry between 1975 and 1990, as the surveying progressed south from Scotland. The emphasis of the work is now more environmentally focussed compared to previously being used to identify minerals, although other applications relate to land use, planning, agriculture etc. The digitalisation of the data has meant that the geochemistry data can be integrated into Geographical Information Systems (GIS) to combine with other layers of information. Technology has evolved to be able to analyse samples quickly and efficiently using PXRF (History of the G-Base project, 2006).

The completion of the South West G-BASE data means that the region's geochemical data has been collected and analysed. The data is significant and can be used in medical geology to assess the relationship between the health of humans and animals and their surrounding environment, with specific relations to geology and the geographical distributions of these health problems. Other applications of the South West data include land-use planning, development of mineral exploration, contaminated land legislation and regulation, soil fertility and agriculture (BGS, 2017).

3.8 Concluding thoughts of literature

There is vast literature and research on the effects of flooding in different catchments around the world. Flood mapping technology is increasingly developing and the importance of high quality topographic data is vital for generating a high standard flood map. As there is a significant interest in the results of flood maps, as leading authorities, citizens living in flood plains or coastal areas, and industries like insurance companies need reliable flood maps to plan for future events. Broadly, literature is widely available for mitigating flooding, however there is little research in the effects of mitigating upstream in a catchment to improve the situation downstream.

In regards to abandoned mines, there are many studies describing the effects of mining on the environment. An understanding of the environmental dynamics surrounding pollution is key to being able to understand the mobility of the pollutants. Geochemical surveying is a useful tool for assessing the chemistry makeup for the soils and stream sediment samples. The completion of the BGS G-BASE southwest survey has significantly helped assess the problem with pollution in the region. AMD is a huge environmental issue that is continuously being investigated. However abandoned mine pollution remediation is difficult to plan for as there if often no person held responsible and the remediation is down to local government or national organisations such an natural England, the national trust etc.

4. Study Area

4.1 Cornwall

Lying at the very south west of England, the coastal county of Cornwall has 1086 km of coastline (Ordnance Survey Blog, 2017). Water is a significant geographic aspect to the county. This has meant that the tourism, industrial and economic industries have relied on water to sustain the growing population, which stood at 549,400 in 2015 (Cornwall.gov.uk, 2017). In relation to rivers in Cornwall and 15 catchments, the main rivers are the Fal, Hayle, Lynher, Camel and Fowey (Catchment Based Approach, 2017).

Annual Rainfall statistics show that the coastal areas in the south west region experience an annual total rainfall of 900-1000 mm but further inland (Dartmoor, Exmoor and Bodmin Moor) there can be double the annual rainfall (Met Office, 2017).

4.2 Cornwall geology

Cornwall's rich and diverse geology has led to the development of its landscape, creating unique habitats and environments, as well as providing metals and minerals that has led to the mining heritage site (Catchment Based Approach, 2017). The geological processes that formed Cornwall millions of years ago meant that the geology at present day consists of a spine of granite running from the Isles of Scilly up to Dartmoor in Devon to the East. Not only is there a granite geology running through central Cornwall, other features include some carboniferous sandstones and shales located in the North of Cornwall, the Lizard peninsular has revealed some serpentine which is rare and the Devonian Slates are also found within the county (Cornish Mining World Heritage, 2017). Minerals veins, or lodes, were formed that have deposits of tin and copper that fuelled the booming mining industry (Geevor.com, 2017).

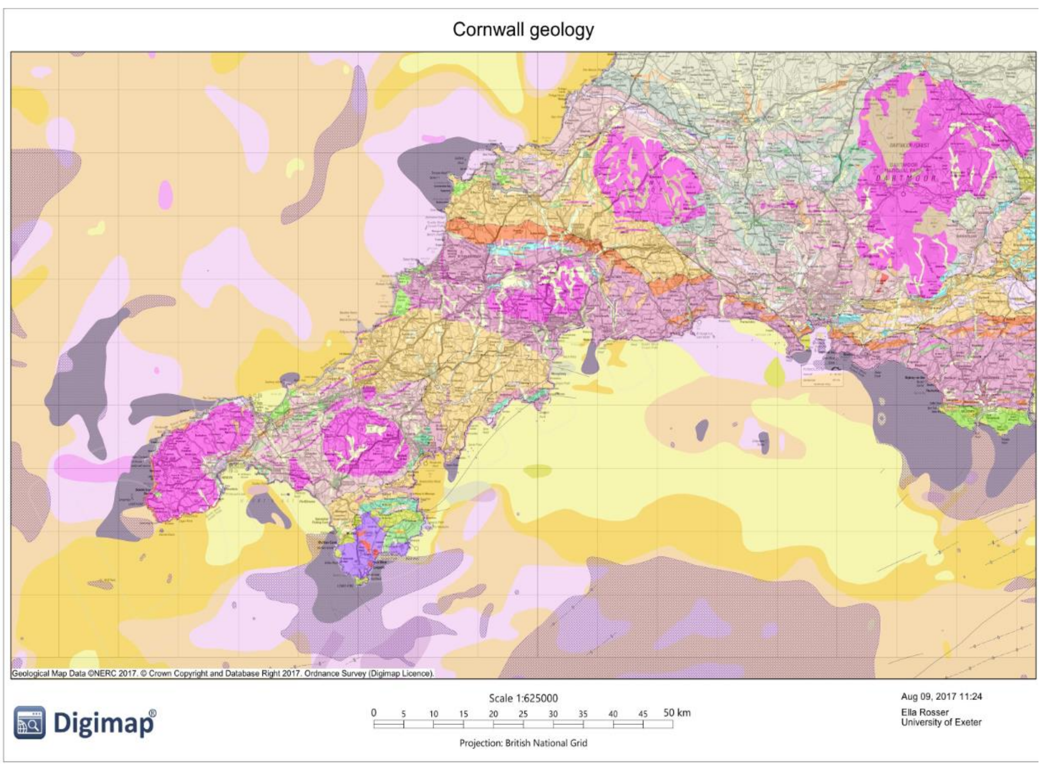


Figure 7: Cornwall geology (Digimap, 2017) See appendix A for the legend

4.3 Cober Catchment

Located in the south west of Cornwall, the Cober catchment is a varied landscape, encompassing the River Cober, Loe Bar and Loe Pool. The river runs from the central granite ridge in Cornwall down into the Atlantic sea, flowing through the town of Helston (Loe Pool Forum, 2017). Figure 8 shows the location of the catchment within Cornwall.

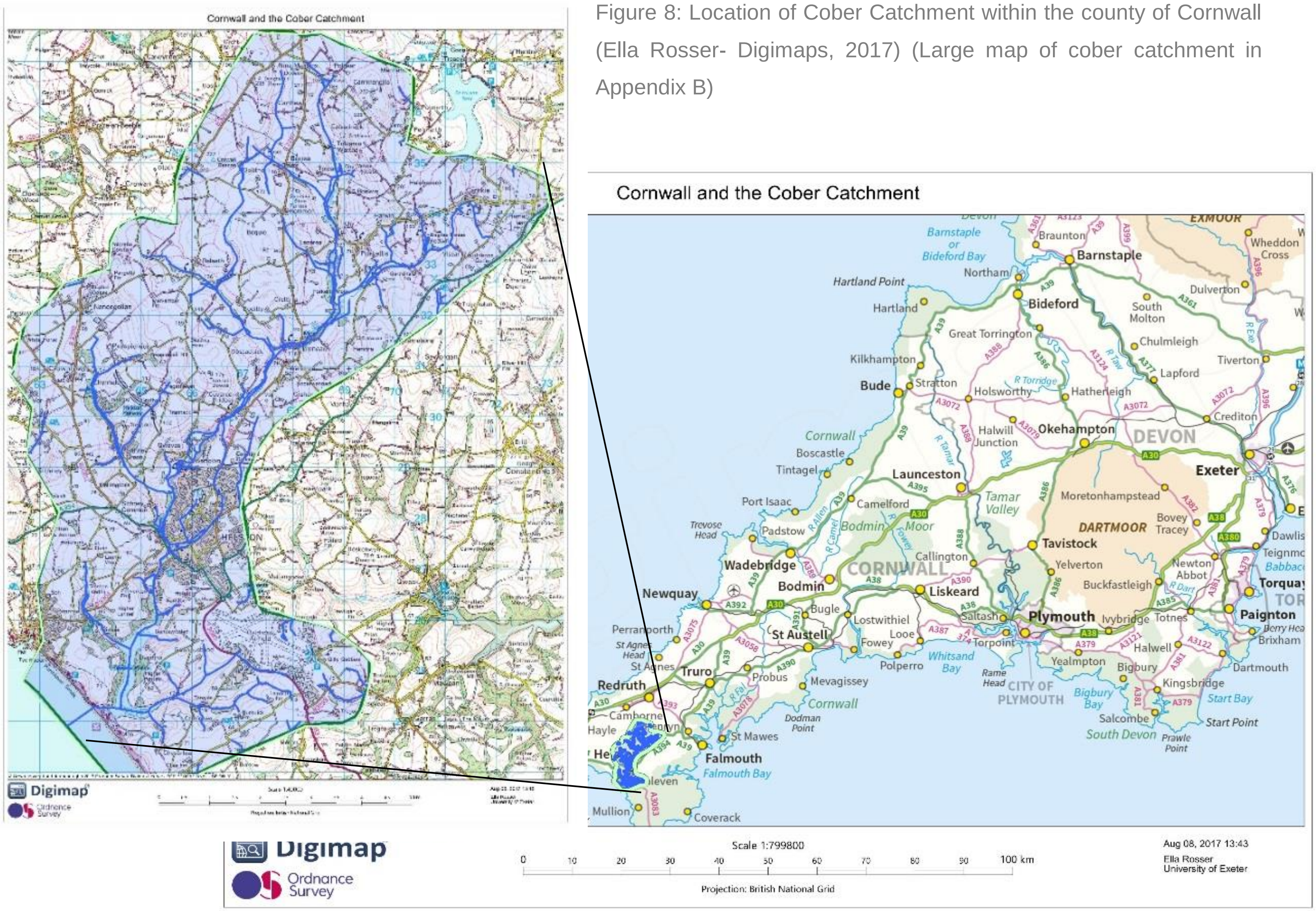


Figure 8: Location of Cober Catchment within the county of Cornwall (Ella Rosser- Digimaps, 2017) (Large map of cober catchment in Appendix B)

Geography

Once a tidal river, the Cober is now cut off from the sea by the shingle bar called Loe Bar. Behind the shingle bar is a freshwater lagoon called Loe Pool. Loe Pool was once mined for tin and copper in previous times, the spoil heaps, and adits have become important habitats (Cornwallriversproject.org.uk (2017).

The source of the river Cober is thought to be at two locations, 1 km southwest of the hamlet Four Lanes. The grid locations for both are Eastings 168198 (m), Northings 037031 (m) and Easting 167741 (m), Northing 036852 (m), according to the map produced by Natural England displaying the catchment boundary and watercourses (Loe Pool Forum, 2017). The mouth of the River Cober is at Loe Bar, where the river meets the Atlantic Ocean. The Cober catchment is roughly 80 km^2 in area (Digimaps, 2017).

Land use

In relation to land use within the catchment, at present agricultural practices dominate the land. The exact number of farms within the catchment is difficult to determine as many farms have land within and outside of the catchment boundary. There are also difficulties in determining the number as many farmers have retired but rent their land out to neighbours. Thus in 2014, Natural England suggested there were 170 farms in the catchment but Catchment Sensitive Farming (CSF) and Soils for Profit (S4P) in 2015 suggested there were only 70 farms (the discrepancy being explained above). There is no data that outlines the exact proportions of the catchment that is dedicated to a particular land use or type of farming, however a UsT (Upstream Thinking) Farm Advisor made these assumptions about the catchment's economy:

- **15 % other uses** rough ground/moors, smallholdings, ponds, ex-industrial holdings and woodlands.
- **25 % arable**: bulbs, cereals for animal feeds, cropping veg and potatoes
- **60 % grass**: small dairy farms, small amount of sheep, mainly beef and fodder, very small selection of pigs, goats and horses.

  (Loe Pool Forum, 2017).

Changes in the land use and management of the land in a catchment area can have significant effects on flood risk and water supply as the pathways for water to flow may have been altered from its natural course. As mentioned previously, urbanisation, agriculture, deforestation and afforestation can all be factors influencing the timing, volumes and quality of water flowing through the catchment. Thus, careful management of the land must be endeavoured as to minimise flood risk (Holden 2005).

Management Plans

The Environment Agency has written a report on the West Cornwall Catchment Flood Management Plan (CFMP). Their summary report from June 2013 outlines the current and future flood risk in the area. The Environment Agency is currently managing the risk by implementing several measures:

- Flood risk mapping
- Flood defence schemes
- Managing development
- Flood warning
- Maintenance

Sub-area 3 (South Coastal Rivers) covers the River Cober. The nature of the area, and the Cober Catchment means that field-run off is prone to happen here, and land-management is an issue that can aggravate the issue. Over 200 properties are at risk from flooding in the town of Helston (population 11,700: 2011 Census Cornwall Council.gov., 2017), which lies at the south west of the Cober catchment, and the river Cober runs along the North West of the town. The flood warning in place within the catchment are specific to the River Cober between Wendron and Loe Pool. The flood warnings give less that two hours' notice of an incoming flood. A major incident plan has also been prepared which will provide less than six hours notice to residents in the town of Helston (Environment Agency, 2012).

Loe Pool Forum

Loe Pool Forum (LPF) is an environmental partnership based in the River Cober Catchment, aiming to reduce flood risk in the area and improve water quality. Encompassing the River Cober, Loe Bar and Loe Pool the catchment is important for the economy, environmental habitats and community wellbeing. Their catchment based approach (CaBa) to managing the local issues surrounding flooding is a collaborative working between stakeholders in the local area and environmental agencies. This co-operative organisation can then decide on sustainable management plans for the area (Loe Pool, 2017). The CaBa focusses on bringing together local communities, knowledge and expertise to improve water environments (Catchment Based Approach, 2017). DEFRA (Department for Environment, Food and Rural Affairs) created a policy document establishing catchment partnerships to work together to improve water quality in all of England's 83 catchments, all within the context of the European Water Framework Directive (WFD) (DEFRA, Catchment Based Approach, 2013).

The LPF in constituted of three subgroups, each with different responsibilities. Natural England chairs the 'Catchment subgroup and its members include the Environment Agency, National Trust, South West Water, RNAS Culdrose, University of Exeter, Rural Payments Agency and Cornwall Wildlife Trust (Loe Pool Forum, 2017).

The Cober Catchment Management Plan (CCMP) is subject to review and their 2017 Management Review includes a 'strategy for action' as there are numerous challenges that have occurred in recent years. Declines in dairy farming and the expansion of horticultural farming are at the forefront of land use changes as new ways of working are being developed. The recent status on the UK's position in the EU and the BREXIT decision has provided an uncertain approach to the Loe Pool Forum (LPF) as funding may be scrapped. New stakeholders to the area need to be integrated into the plan and other approaches, such as the launch of the 2011 Catchment Based Approach (CaBa). The review has been provoked by these changed and an adaption of the CCMP is necessary to deal with the social, environmental and political changes.

Many of the objectives focus on the water quality of Loe Pool, however further recognition is being made for the wider catchment and pollution risk, along with flood alleviation (Loe Pool Forum, 2017)

There is also statutory legislation that must be considered in relation to the Cober Catchment. The Water Framework Directive (WFD) was initiated in 2000 and implements objectives across all EU member countries. The main aim is to improve the water quality in the EU in a range of water bodies (sea, canals, rivers, streams, lakes etc.) to a rating of 'good', which symbolises a '*slight deviation from 'high')* on the scale of water quality in the EU, as well as to prevent the deterioration of all water bodies. This status of 'good' is also referred to as GES (Good Ecological Status).

River Basin Management Plans (RBMP) have been created for all River Basin Districts (RBD). The South West RBD, which includes all of Cornwall and covers an area of 21,000 km^2 was updated in 2015. Due to Loe Pool being given a status of 'surveillance' for its environmental complications, a long-term monitoring programme for the Cober Catchment has been set up. One of the main failing elements of GES was due to the high levels of metals across the tested water bodies (Loe Pool Forum, 2017). Table 1 depicts the WFD classicisation's for water bodies in the Cober Catchment:

Table 1: WFD classification* of areas in the Cober Catchment.

WFD Classifications: 'High' (no human impact); 'Good' (slight deviation from 'high'); 'moderate'; 'poor'; and 'bad' (highly toxic). Source: Cober Catchment Management Plan 2017 (Loe Pool, 2017)

Water body	2009 Cycle 1	2015 Cycle 2	Objectives
Upper River Cober (overall)	Moderate	Moderate	Moderate by 2015
Ecological	Moderate	Moderate	Moderate by 2015
Chemical	Not required	Good	Good by 2015
Lower River Cober (overall)	Moderate	Moderate	Good by 2027
Ecological	Moderate	Moderate	Good by 2027
Chemical	Not required	Good	Good by 2015
	2013 Cycle 2	**2015 Cycle 2**	**Objectives**
Carminowe Creek (overall)	Good	Moderate	Good by 2027
Ecological	Good	Moderate	Good by 2015
Chemical	Good	Good	Good by 2015

Drinking Water

Across the southwest, there are seven drinking water suppliers. Surface water provides 71% of the water for the region, which is abstracted from the following rivers: Severn, the Hampshire Avon, Exe, Fowey, Dart, Tamar and Dorset Stour. Another 27 % of drinking water in the region is supplied from valuable groundwater, whereby boreholes abstract the water (DEFRA, 2012). The upper part of the Cober

Catchment plays a significant role for clean drinking water as South West Water abstract here to supply to Helston and the Lizard (Loe Pool Forum, 2017). Wendron WTW treat water from the River Cober here, that has been extracted from Trenear (Cober Catchment Management Plan, 2017).

Flooding in the Cober Catchment

Flooding in Cornwall has much to do with the topography of the land. Most of the rivers in West Cornwall have a steep gradient, which means that flooding peaks close to settlements located downstream and the water flow in the rivers is fast. However due to the nature of the country, the river gradient lessens closer to the coastline and thus the river flow slows down once it reaches the sea and where many settlements lie (Environment Agency 2008). Figure 9 shows the risks to properties from flooding in Cornwall. The map takes into account flood defences, but shows areas where properties are at risk in a 1% annual probability river flood (Environment Agency, 2012). As the map shows, Helston has roughly 201-400 properties at risk to this flood event. As the major town in the catchment, this is a significant hazard.

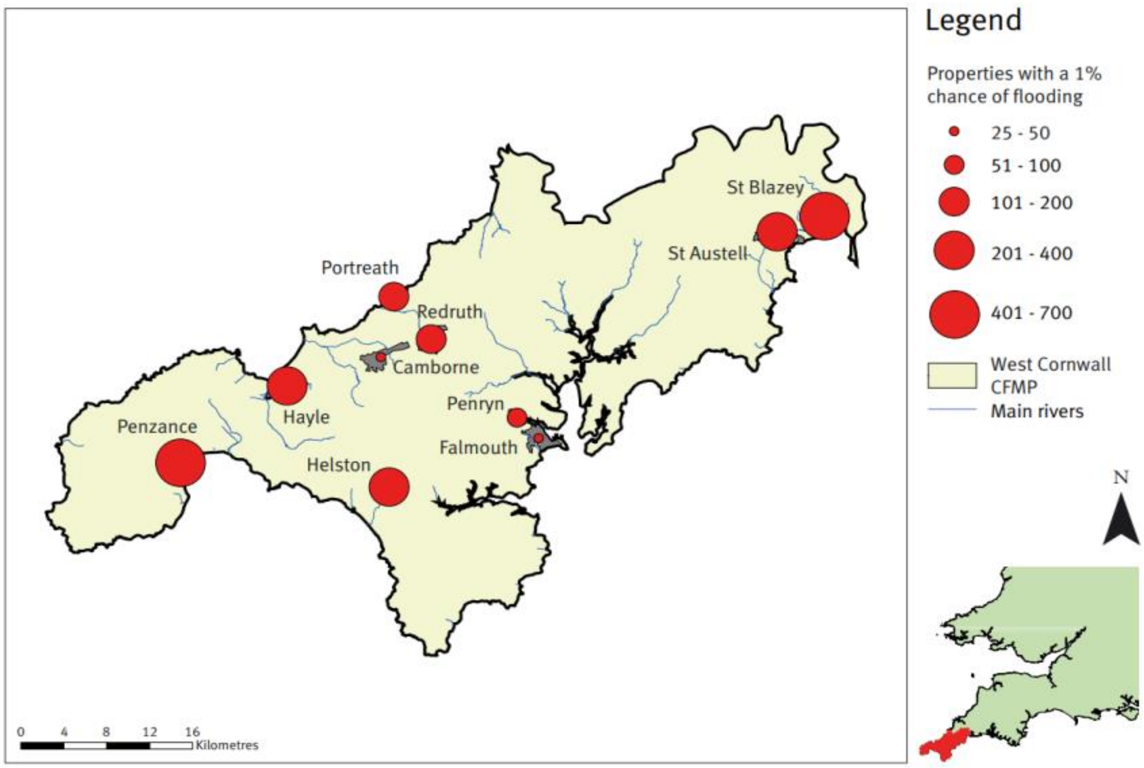


Figure 9: Taking into account current flood defences, a map showing the risk to properties in a 1% annual probability river flood. (Source: Environment Agency 2012)

Flooding in the town ofHelston has been an issue for many years and below is a summary of the major flooding events in Helston over the past 70 years:

- **1952** – December, fluvial flooding
- **1970** – Helston flooded three times this year
- **1976** – September, severe storms and flooding
- **1977** – October, river flooding
- **1979** – February, fluvial and surface water sources
- **1979** – Mid-December, fluvial flooding
- **1988** – January, storms and high tides
- **1992** – August, severe storms and high tides
- **1993** – June, torrential rainfall. Again on June 12th.

- **2002/2003** – New Year's Eve, heavy rainfall.
- **2003** - July, heavy rainfall
- **2004** – August, heavy rainfall

(Cornwall Council, 2011).

Flood alleviation schemes in Helston have been organised through the West Cornwall Catchment Flood Management Plan (CFMP). As 200 properties are at risk, the town has been given status of "high levels of risk" by the Environment Agency. Preferred options for sustainable flood risk management have been produced by the engineering company Black and Veatch, the chosen scheme for Helston can be found in the Cober Catchment Management Plan, 2017).

As the main flooding problem seems to be in Helston, there is scope for extensive research into the source of the flooding. Environment Agency modelling of the Cober catchment has shown that flood events are connected to the overflowing of Loe Pool lake levels, and subsequently the water backing up the river towards Helston, causing a flood. However little research into the potential role of the upper catchment causing flooding has been explored. An alternative research question is that upstream catchment flows are exacerbating the flooding in Helston. The Loe Pool Forum (LPF) are keen to construct upstream attenuation features that provide natural flood management mitigation. Having considered the risk and benefits to these 'soft engineering' approaches, the Upstream Thinking Project (UsT) are trialling flow attenuation features in some areas of the upper catchment. These ongoing investigations are making use of the 'Rolling Ball model' to map areas where overland flow is an issue and combining data from possible contamination sources of phosphate and ammonia i.e. dairy farms. An issue that has arisen from the project is further walkover of the catchment are needed as the rolling ball model incurred some inaccuracies (Loe Pool Forum, 2017). It can be concluded that the LPF are steering towards more natural mitigation of flooding within the catchment and aiming to focus their work in the upper catchment to see if it makes a difference downstream, but further study is required.

4.4 Landscape designations in the area

Cornwall is a diverse county and with such an extensive history encompassing the landscape, environment and towns. There are some protections in the area that need to be considered and highlighted.

The Cornwall Council Interactive Map allows the user to view different map layers, showing different areas that have been given certain designations. For example historical, environmental and transportation designations. Figure 10 shows the amount of environmental designations that cover Cornwall and specifically the Cober catchment. Below is a list and description of the types of protections/designations in the area:

- Tree preservation order points (TPO) – these may apply to any individual tree, group of trees or woodlands. They will have been selected if it is believed that the tree(s) provide a contribution to the public amenity. In turn, for any tree with a TPO, one must apply for consent to work on the tree.
- Areas of Great Landscape Value (AGLVs) – designated due to their importance within the county of Cornwall.
- Areas of outstanding Natural Beauty (AONBs) - an area designated for conservation due to its significant landscape value.
- Conservation Areas – places that have special character (usually in towns and villages).
- County Wildlife Sites – these sites provide a wildlife refuge for most of the UK's flora and fauna and have a role in meeting national biodiversity targets.

- Sites of Special Scientific Interest (SSSI) – protection of an area that exemplfies the best of the UK's flora, fauna or geological or physiographical features.
- Zones of influence natura 2000 – for rare and threatened species, a network of core breeding and resting sites all of which are protected.

(Cornwall County Council Interactive Map, 2017).

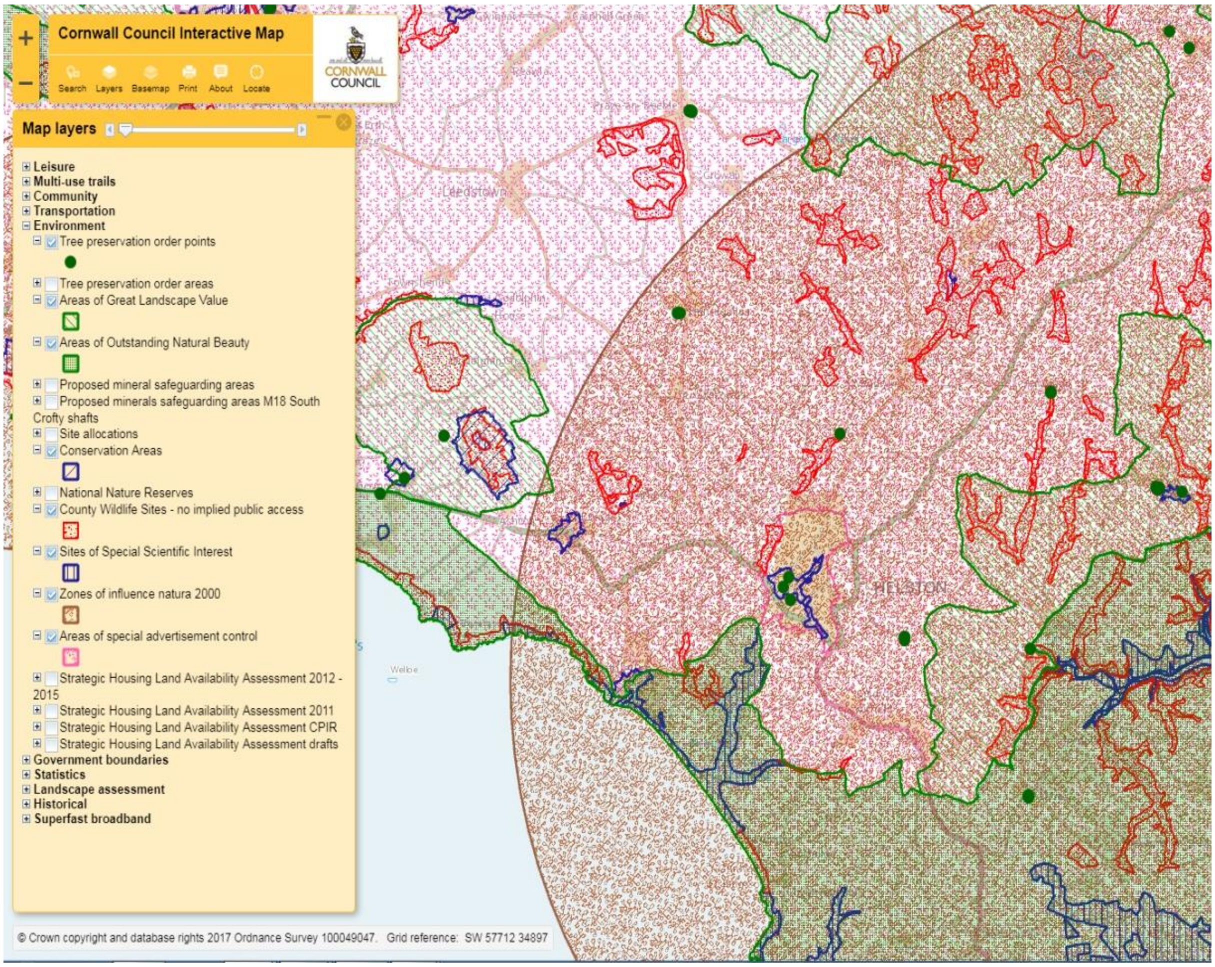


Figure 10: Environmental Designation around the Cober Catchment (Cornwall Council Interactive Map, 2017)

In July 2006, UNESCO World Heritage named selected mining landscapes across Cornwall and West Devon as one of their sites. The historical landscape is now a place of significance and value to all of humanity encompasses ten areas for the make up the World Heritage Site (Figure 11). Over the whole site there are over 200 Cornish engine houses, mining buildings, transport networks, monuments and more (Cornish-mining.org.uk (2017) & Cornwall and West Devon Mining Landscape World Heritage Site Management Plan 2013-2018). Further background information of the mining history can be found in the next sub-section.

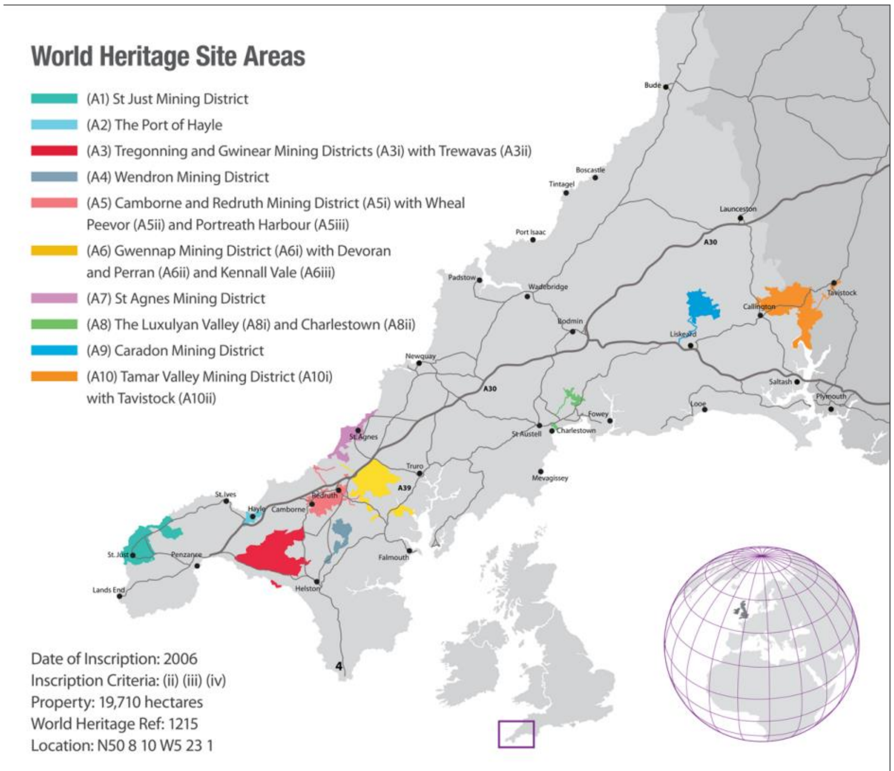


Figure 11: The ten UNESCO World Heritage areas (Cornish-mining.org.uk, 2017)

4.5 History of mining in area/ Wendron mining district

As one of the oldest mining districts in Cornwall, Wendron mining district is one of ten areas to be named a Cornish Mining World Heritage Site. The Cober Valley provided a boom in tin mining in the late 1700’s, where some 800 people were employed in the parish (Wendron: Ghosts of mining amidst peaceful pastures, 2017).

There is estimated to be around 640 tin bounds (land claims) and mine workings recorded in the Wendron Parish. Due to the geology of the vertical lodes of granite, minerals such as tin, tungsten and copper, were easily accessible as the erosion of rocks carried the deposits of ore downstream, where it settled in sand and gravel. Miners were able to dig out the minerals, where they would separate waste material from the valuable ore. As time went on, advanced and more sophisticated systems were set up along the River Cober, with leats used to divert water to power machinery and channels and reservoirs constructed around streams and rivers in the catchment. The river Cober was a hub of industry and thus meant the district was an industrial mining landscape for an extended period in history. In 1779, 9,000 people lived in the Wendron district, the most populated mining district in Cornwall at the time (Wendron: Ghosts of mining amidst peaceful pastures, 2017). Figure 12 & 13 shows the area of the Wendron Mining District and the extent of some of the mining in the area.

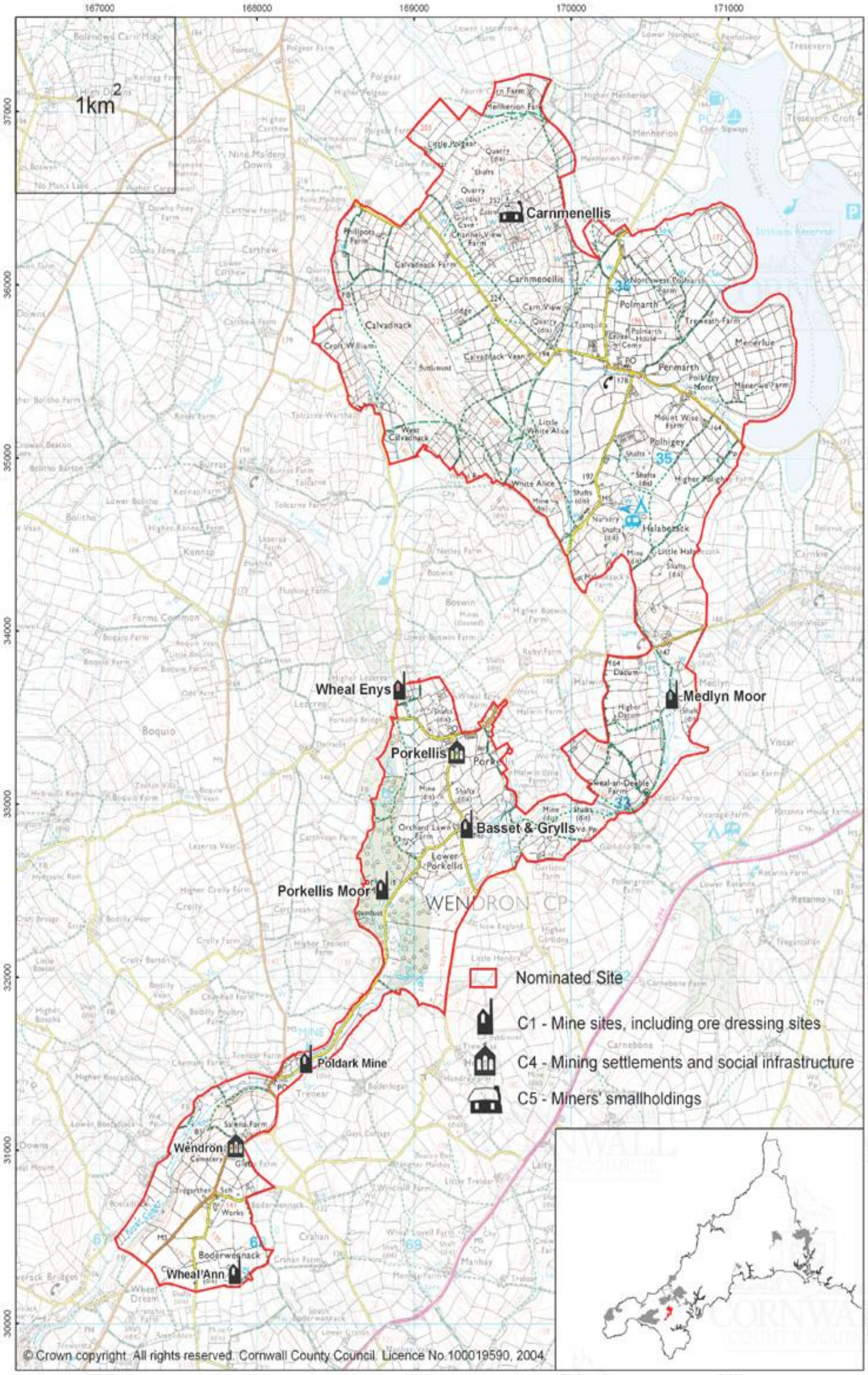


Figure 12: Wendron Mining District (Cornish-mining.org.uk, 2017)

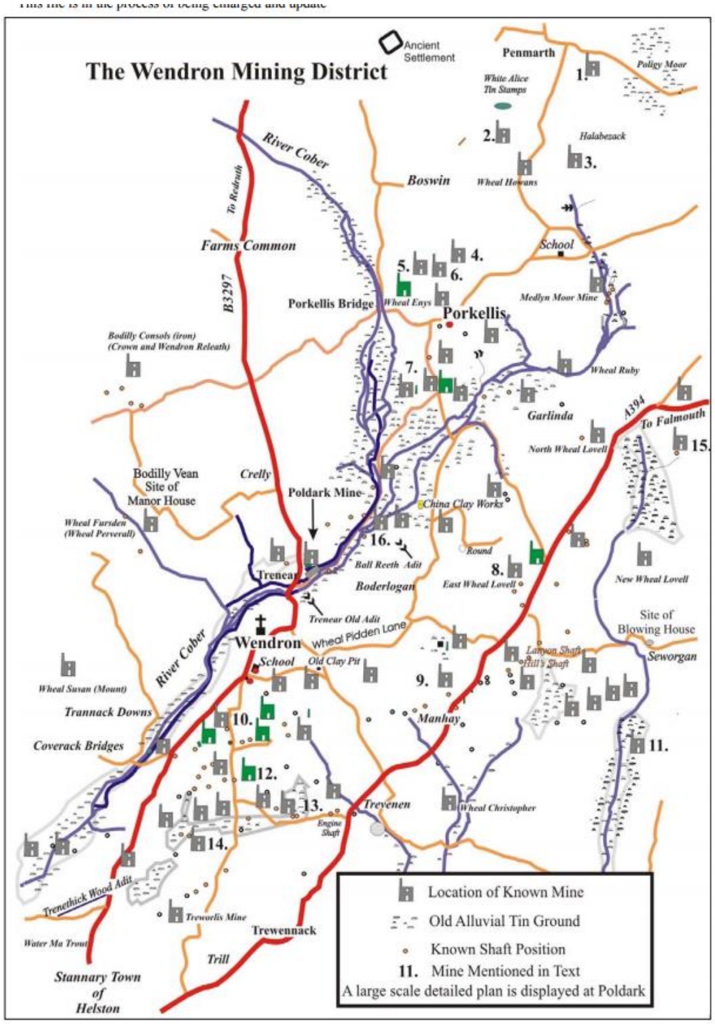


Figure 13: The Wendron Mining District (Cober Catchment, Loe Pool Forum, 2017)

The extent of the mining in the district has been estimated, but there are many un-mapped shafts and mines. Figure 14 provides a historical map, displaying mine sites and the extent of 'Lodes' of mineral around Wendron (Dines, 1956).

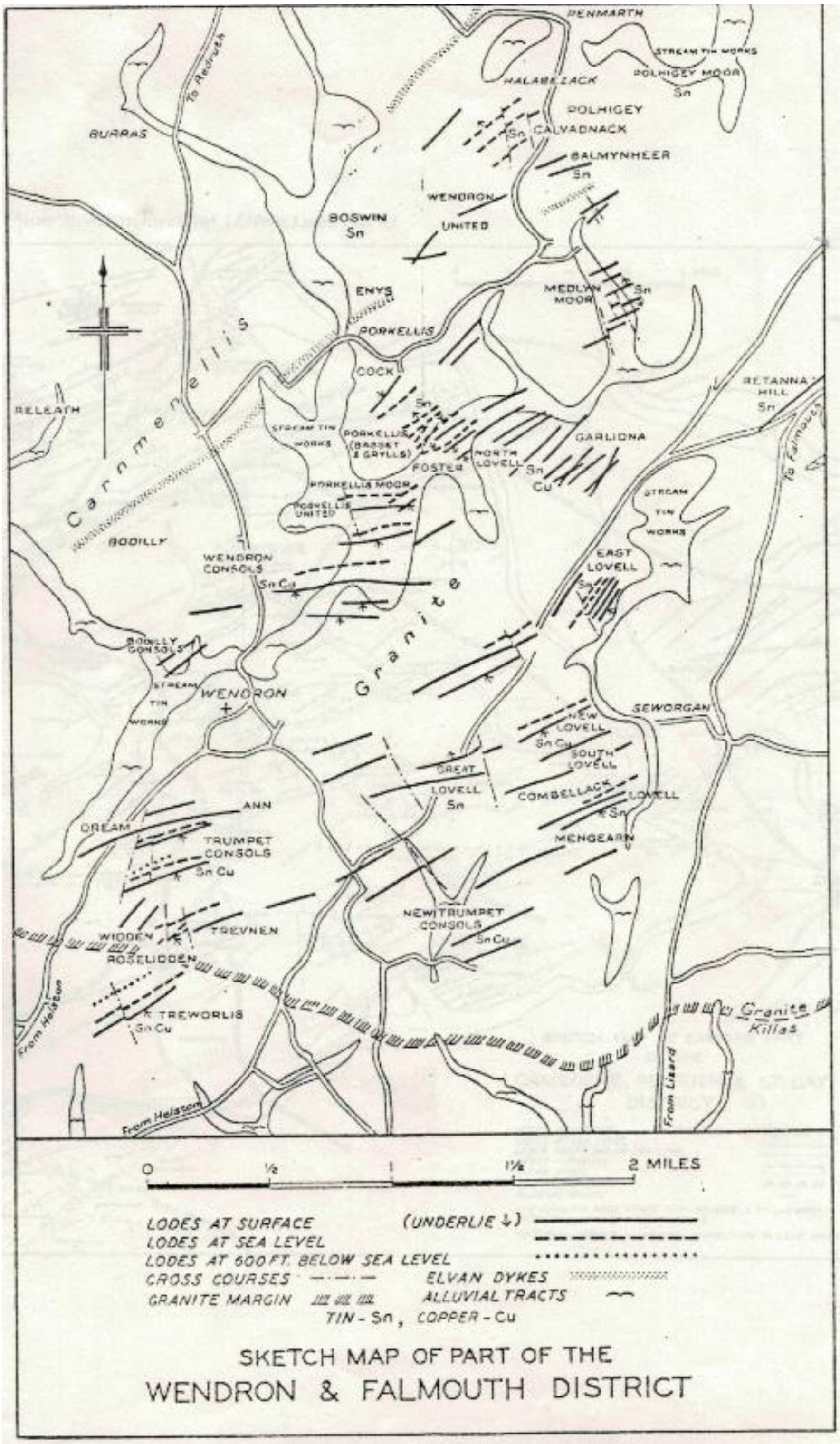


Figure 14: Historic map of mines and mineral Lodes around Wendron (Dines, 1956)

5. Methodology

5.1 Desk Based study

Initially, to conduct the investigation, a desk-based study was required to research the area and explore the resources already available that were related to the theme of the study. Varieties of sources were used to compile data, maps and information in relation to the study including:

- Digimaps
- Cornwall Council
- Tellus South West Project
- BGS G-BASE
- Global Mapper
- Surfer (Golden Software, LLC)

5.2 Primary data

Geochemical survey – Soils

The author of the report collected the data with a field assistant over a week in July 2016. A health and safety check was carried out prior to the fieldwork and all necessary precautions were taken. The data collection took place within the Cober Catchment and was used in conjunction with secondary data, detailed below.

Equipment List:

- Soil Auger
- Handheld GPS
- Soil sample bags
- Olympus Delta X handheld pXRF

Site selection for the geochemical data was completed prior to data collection. The desk based study allowed an overview of areas within the catchment that were susceptible to drainage issues within the watershed and showed where mine sites were within the Wendron Mining District. Combining these elements with the secondary data from the BGS G-BASE data, locations were decided on to collect soil samples. The upper catchment was the focus of the study due to the size of the catchment. A second reason for only focussing on this area is the lack of data to support the hypothesis that the upper catchment flows are contributing to flooding downstream in the lower catchment. As the geochemical survey is being linked with investigating the watercourse flows in the upper catchment, sites were selected in Helston, but mainly focussing on the watercourse above Wendron.

Each site was given an identification of Site A, Site B, Site C etc. A strategic sampling method was adopted for the survey, whereby soil samples were taken along a transect, at 30-50 metre intervals. As far as possible, all soil samples were taken away from obvious contamination such as roads etc. The transects were along public footpaths that were situated as close to the River Cober as possible.

A handheld soil auger was used to collect soil samples as close to the river as possible, at a depth of 30 cm. The soil was then deposited in a small plastic bag and each sample was georeferenced using the handheld GPS. Once collected each sample was taken to the lab to be tested for contamination.

Each sample was dried out in the oven at 60° c for a few hours to ensure all samples were universal in dryness. Each sample was then sieved to a consistency that was similar for all of the soil. Each sample was scanned using X-Ray Fluorescence Spectrometry (the handheld portable XRF(pXRF)), with a piece of Clingfilm between the laser and the sample so as to protect the laser screen on the pXRF from any dirt.

The samples were then scanned twice, shaking and displacing the soil sediment between each scan. The average of the two scans was used for analysis. The Pxrf revealed each samples chemical composition. X rays are directed to the sample, which causes atoms in the material to show their fluorescent x-rays at energies characteristic of its elemental composition (Gazley and Fisher, 2014). The Pxrf takes about 30 seconds to read each sample and then lists and stores the chemical composition of each sample (measuring at parts per million).

The Pxrf tested for: Sn, W, Ta, Fe, Nb, Th, U, Si, Mn, Cu, Zn, LE, As, Pb, S, Ag, Mg, Al, P, Cl, K, Ca, Ti , V, Cr, Co, Ni, Se, Rb, Sr, Y, Zr, Mo, Cd, Sb, Hg, Bi, Ga, In, Ba.

The elements that will be discussed for this study are tungsten (W), arsenic (As), tin (Sn), iron (Fe), lead (Pb) and copper (Cu). Each of the elements datasets were formatted for post processing in GIS software. Primarily the geolocations of each soil sample and the concentrations of the elements in the sample were organised. Using Surfer, a 2D, 3D mapping, modelling and analysis software (Golden Software Product), the concentration of each elements in the soil samples was mapped. The map was created to show the proportional size of the mineral at each survey point.

5.3 Secondary data

G-BASE

In addition to the primary soil samples collected for this investigation, a secondary source of data was used to back up the evidence. Below is an outline of the methodology used by the G-BASE for the southwest survey.

The G-BASE data comprises of soil and sediment samples. Soil samples were taken at a depth of 5-20 cm and taken on average one sample every 3 km^2. The sampling density was dependent on the underlying parent material, and the minimum sample was one per 5 km^2., whilst the maximum was one sample per 2 km sq. The stream sediments were taken at an average density across the south west at one sample per 2.5 km^2. All samples were georeferenced to a six figure Eastings and Northings in metres in the coordinate system, British National Grid. All samples were taken away from any potential sources of contamination (houses, roads etc.).

Each soil sample is an amalgamation of five samples collected within a 20 cm grid/square (one in each corner and one in the middle). Using a handheld soil auger, soil samples were retrieved at a depth of 5-20cm, removing any organic matter.

Sediment samples were collected upstream from any potential contamination, which constituted roads, industrial activity etc. Oxidised surface material was removed and a wet screening was conducted on site for each sample. This method uses water to collect the sediment, which was finer than 150 µm. This resulted in 100 g on material being collected.

Soil samples were dried in the lab and sieved to create a universal consistency. The soil and sediment samples were then analysed using X-Ray Fluorescence Spectrometry.

A licence was applied for to enable access to the BGS G-BASE geochemical point data for the survey. Once the data was received, the data was post processed using GIS. In total, 1,154 soil samples and 3,799 stream sediment samples were collected. Ten of the soil sample locations were collected within the Cober Catchment, while twelve of the stream sediment samples were collected within the catchment. The same metal elements to analyse as the primary soil data (Sn, W, Fe, Cu, As, and Pb).

Global Mapper

The River Cober was located and thus the Cober Catchment boundary and watercourse found (Natural England & Loe Pool Forum 2017). Using Digimap (2017), and the 'Map Tools', an outline of the Cober catchment and it's water courses was created, enabling a diagram of the exact location on the watercourse and catchment to be laid over top of an Ordnance survey map of the area. This outline could then be exported from Digimap (2017) as a shape file and imported into Global Mapper (2017). Global Mapper is a GIS (Geographical Information System) software package application. In this instance, the software has been used to create maps with different GIS layers to be able to analyse data and look at many environmental elements in one place.

Digmaps (2017) was also used to download maps onto Global Mapper as a background map. Another useful tool that Digimaps has was used to investigate the historical maps of the area using the 'Historic' map application that allows the user to access OS maps and data from 1843 to 1996. This was useful for mapping mine sites in the catchment and Wendron mining district. The map used to create the background map was a raster 50 k map.

The Cornwall Council Interactive Map was another useful means for locating mine sites in the area. The Cornwall and West Devon Mining World Heritage Site Project worked closely together to process all existing information about known mine sites within the area. They produced a preliminary dataset of existing mine sites and have stated that they believe the dataset is incomplete (Cornwall Council, 2017). This data was manually added to the GIS layers in global mapper to locate all the mines within the Cober Catchment and Wendron Mining District. The Cornish Mining World Heritage was also a useful tool in providing information on mining within the area and the locations of any other mines were added to the GIS layers in Global Mapper.

Using Global mapper and the ‘Generate Watershed Command’, the user is able to analyse the catchment for watershed areas when loaded into terrain data. In this instance, the command was applied when using the LiDAR data from the Tellus South West project.

The LiDAR data is available from the Tellus South west website as DTM or DSM in 5km by 5km squares. Both file types were downloaded for this study for the squares that cover the Cober catchment. These were SW 62, SW 63, SW 72 and SW 73, with 5 x 5km tile being downloaded (ne, nw, se, sw). The LiDAR data has been produced with an accuracy of +/- 0.25m in elevation and an RMSE (root mean squared error or 0.95 m in coordinate (Environment Agency, 2014). The data files were then uploaded into the GIS software, Global Mapper, to generate the watershed.

Global Mapper (2017) defines the calculation as “ *The watershed calculation uses the eight-direction pour point algorithm (D-8) to calculate the flow direction at each location, along with a bottom-up approach for determining flow direction through flat areas and a custom algorithm for automatically filling depressions in the terrain data”.*

A watershed can be defined as the upslope area to the drainage basin that contributes to the flow of water to a common outlet in a concentrated drainage area. The watersheds can be divided into sub basins, as a large watershed may also contain smaller watershed. Drainage divides, or boundaries between the watersheds separate each section within the watershed (Pro.arcgis.com, 2017).

When generating the watershed, Global Mapper allows the user to set parameters for the watershed. Metrics can be changed of the resolution; stream threshold and the depression fill depth. For the purpose of this study, the watershed command was used with the default generation options.

Rolling Ball Model

The Upstream Think Project (UsT) and Loe Pool Forum (LPF) have used the rolling ball model to map overland flow in the upper catchment of the Cober basin. For this study, access to the rolling ball data was provided by the Environment Agency (EA) and shape files with different resolutions of stream definitions (250 m, 5000 m and 50,000 m) were given. These shape files were imported into Global Mapper to map where the stream definitions are for the catchment. Combining the rolling ball data and the watershed data can mean that drainage areas under particular stress can be mapped and the appropriate mitigation suggested.

6. Results

The section displays the results from the primary and secondary data collected for this investigation. Figure 15 is a map created in Global Mapper by the author. The mine sites have been mapped with reference to the Cornwall Council Interactive map (2017).

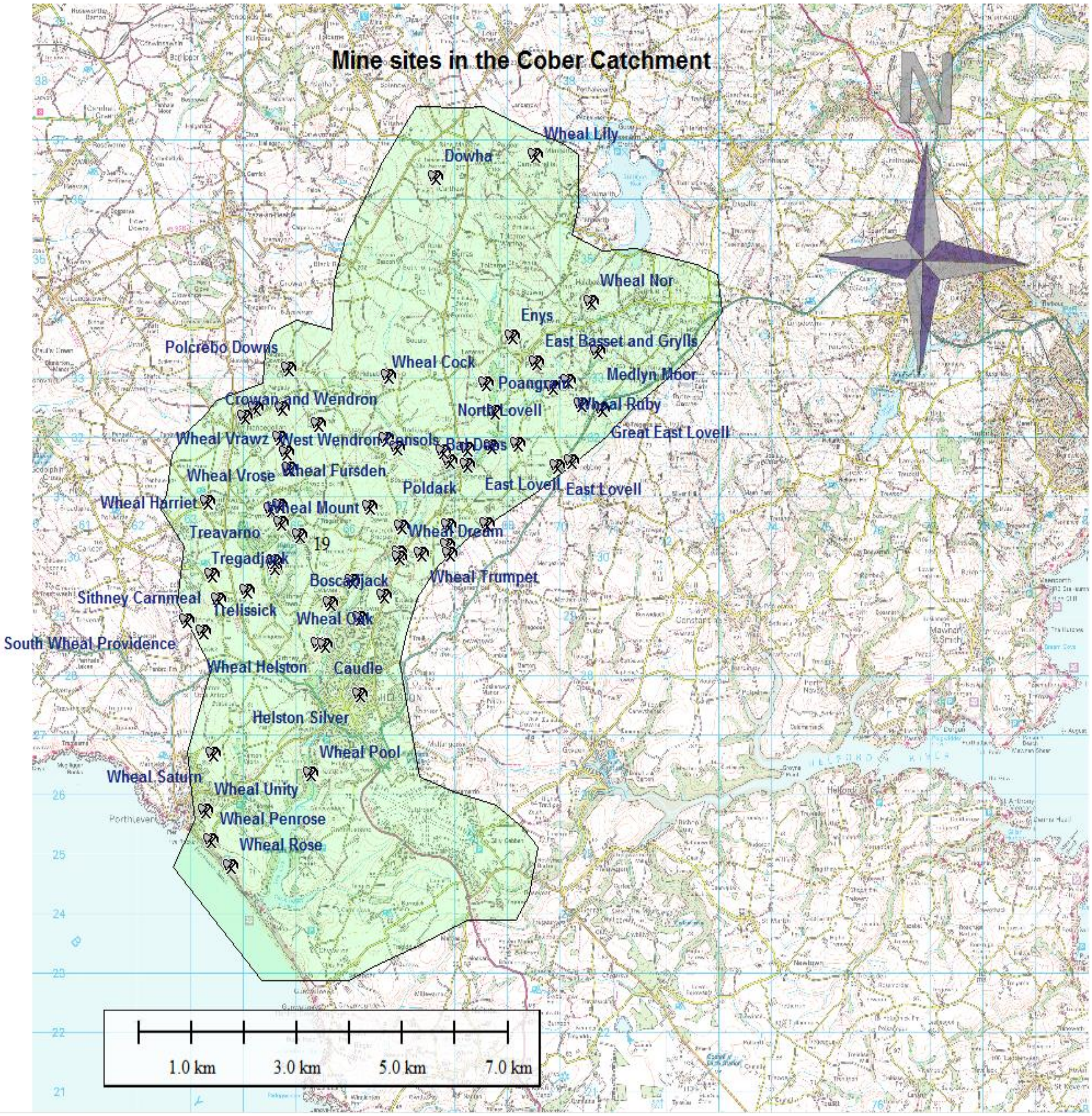


Figure 15: Mines sites within the Cober Catchment (Made in Global Mapper, 2017, by Ella Rosser)

6.1 Soil samples

Figure 16 shows the 126 points that soil samples were taken for the geochemical survey. The orange dots represent each of the soil sampling location at each of the eight sites. Appendix C shows individual maps of the sites with the locations of each sample, whilst the table showing each metal value from the Pxrf for each soil sample is in appendix D

Figures 16-21 all show the concentrations (proportionally) for each element within the catchment at the survey sites. These maps were created in Global mapper, with the data being processed and initially mapped on Surfer.

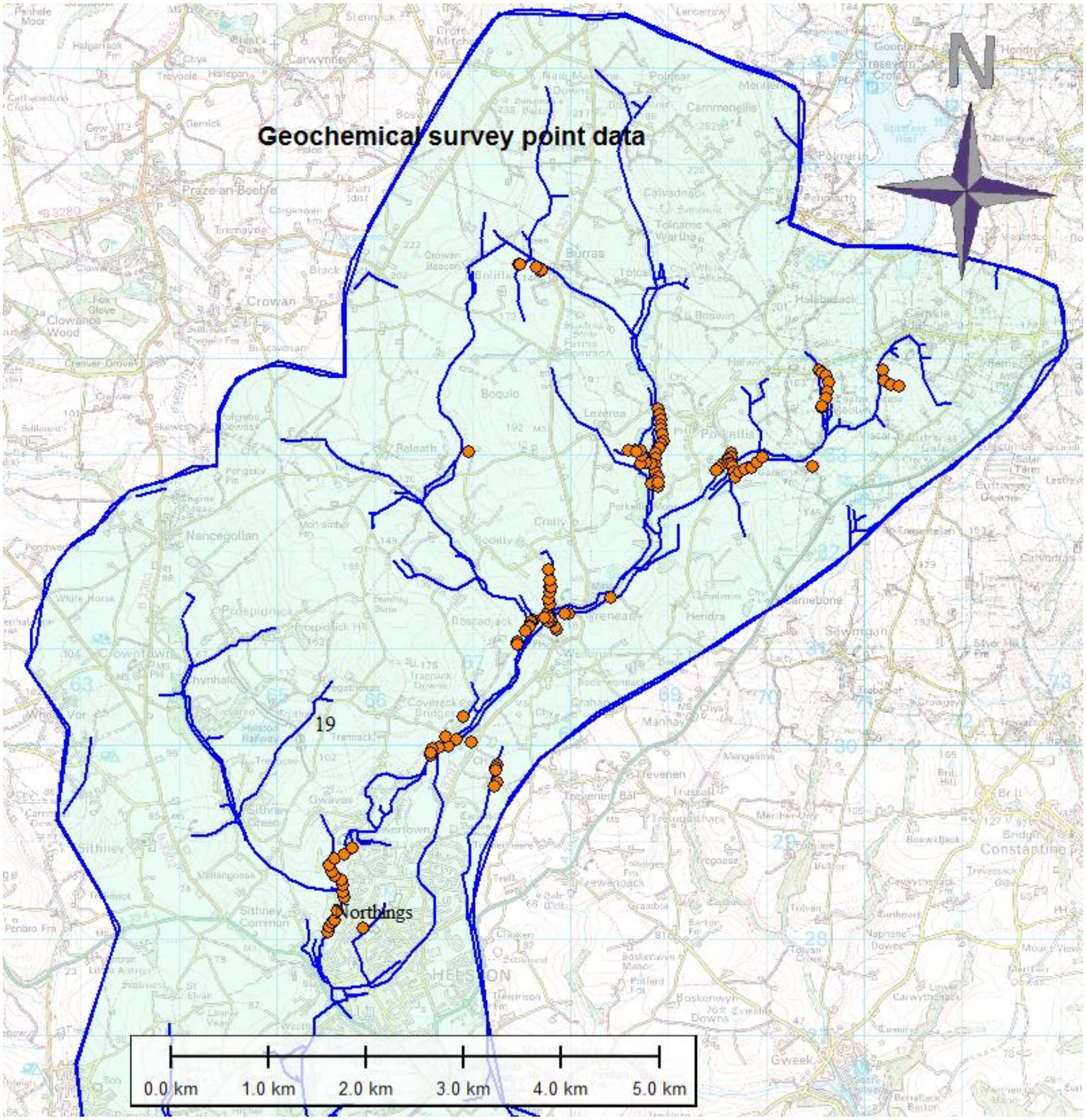


Figure 16: Locations of soil sampling sites within the Cober Catchment (Made in Global Mapper, 2017, by Ella Rosser)

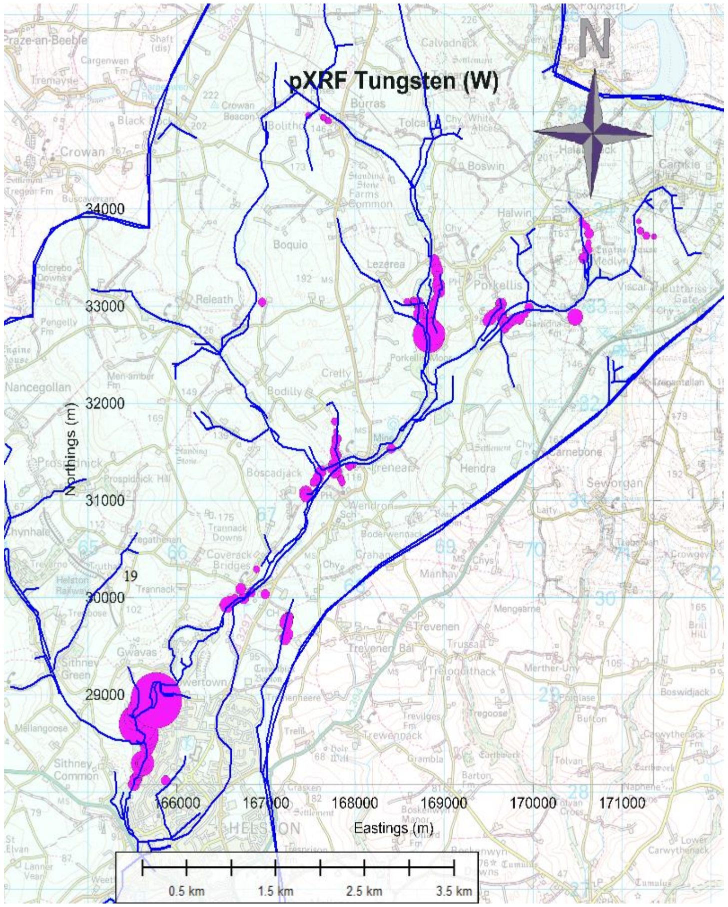


Figure 17: Deposits of Tungsten (measured in part per million (ppm)) across the Cober Catchment. This map shows the proportional size of the mineral at each survey point.

Smallest value = 14.5 (ppm) Largest Value = 338 (ppm)

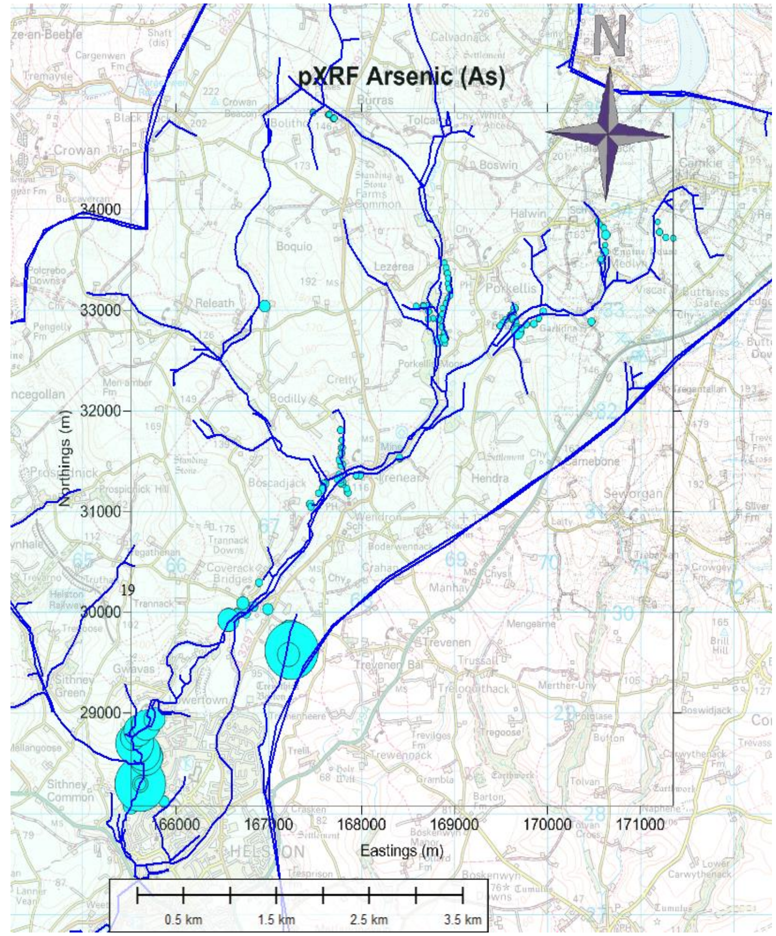


Figure 18: Deposits of Arsenic (measured in part per million (ppm)) across the Cober Catchment. This map shows the proportional size of the mineral at each survey point.

Smallest value = 8.2 (ppm) Largest Value = 843 (ppm)

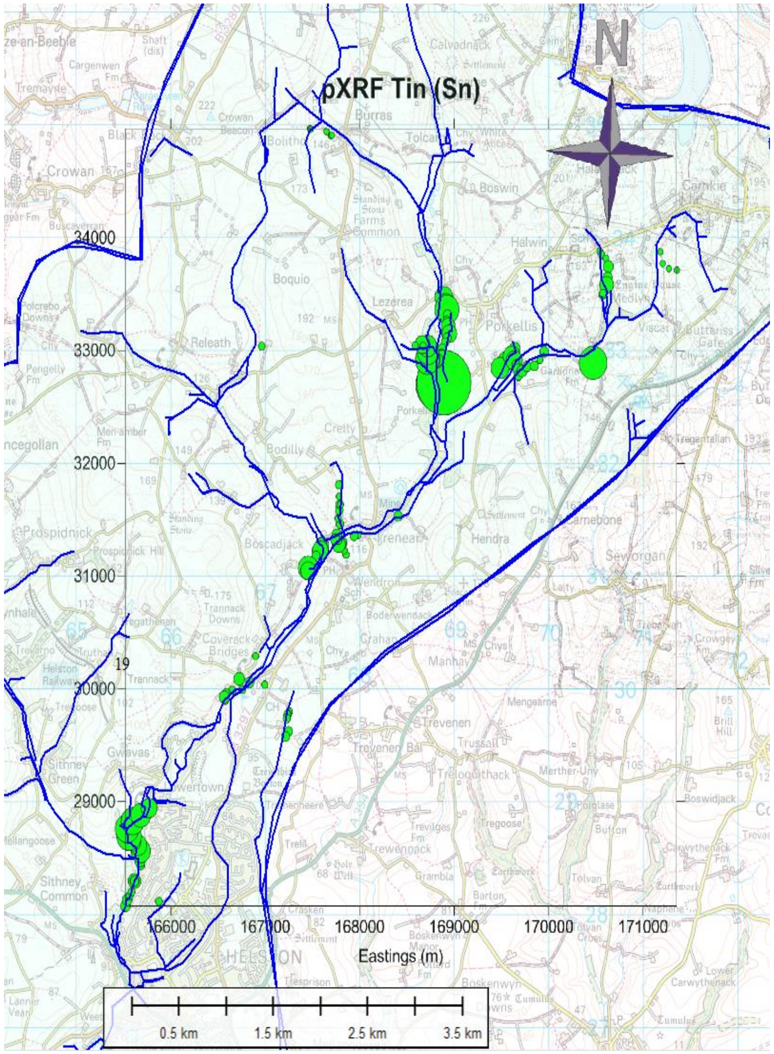


Figure 19: Deposits of Tin (measured in part per million (ppm)) across the Cober Catchment. This map shows the proportional size of the mineral at each survey point.

Smallest value = 27.5 (ppm)   Largest Value = 14429 (ppm)

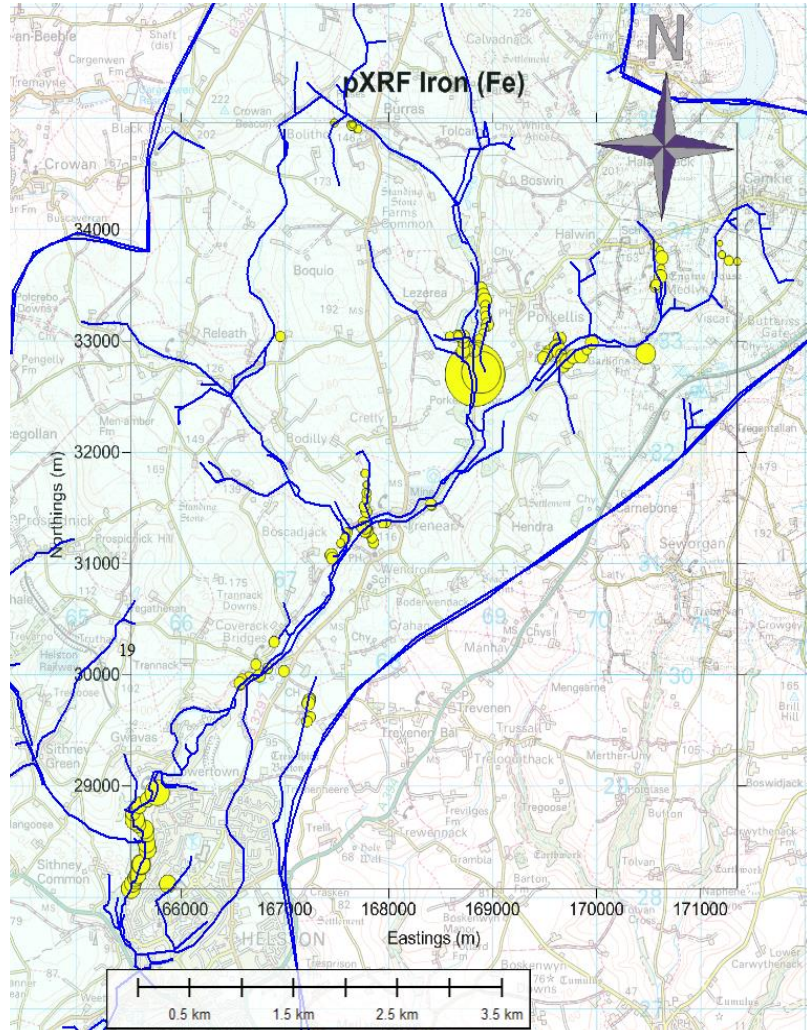


Figure 20: Deposits of Iron (measured in part per million (ppm)) across the Cober Catchment. This map shows the proportional size of the mineral at each survey point.

Smallest value = 5977.5 (ppm) Largest Value = 207060.5 (ppm)

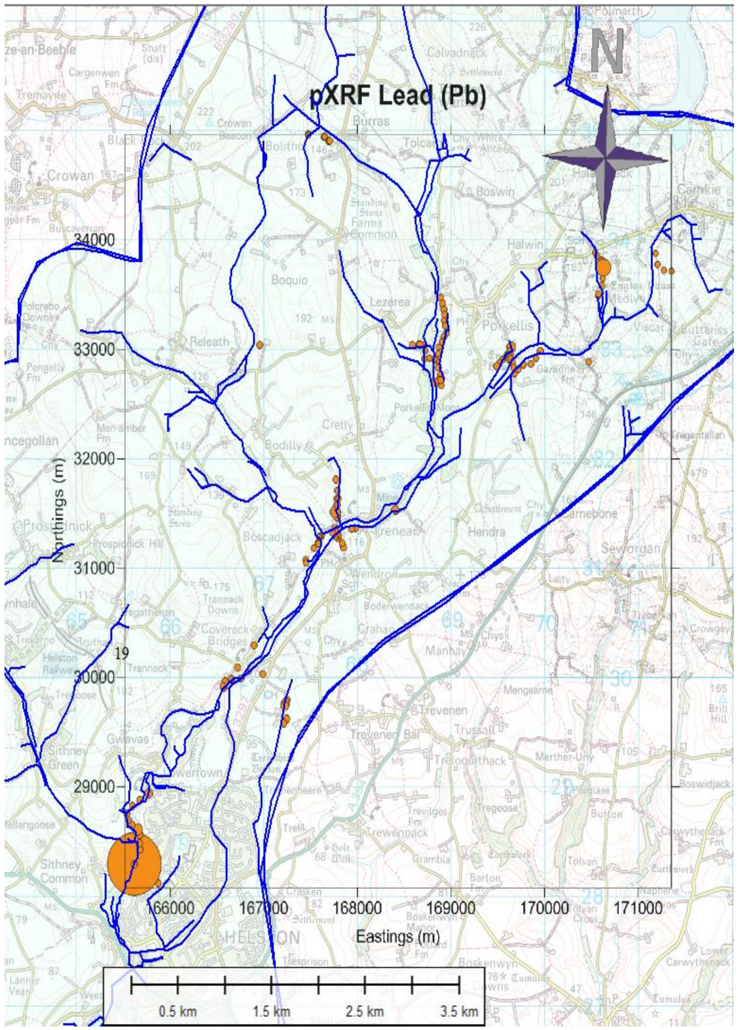


Figure 21: Deposits of Lead (measured in part per million (ppm)) across the Cober Catchment. This map shows the proportional size of the mineral at each survey point.

***Smallest value = 13.9 (ppm) Largest Value = 2670**

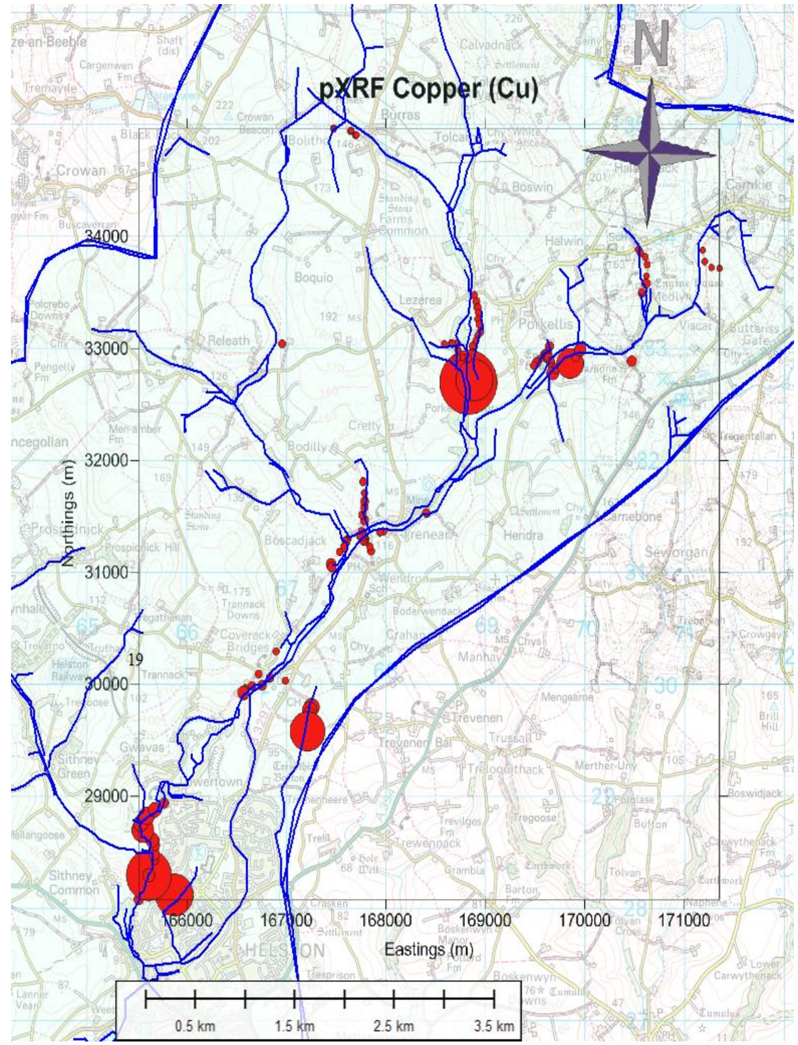


Figure 22: Deposits of Copper (measured in part per million (ppm)) across the Cober Catchment. This map shows the proportional size of the mineral at each survey point.

Smallest value = 11.45 (ppm) Largest Value = 2241 (ppm)

6.2 G-BASE

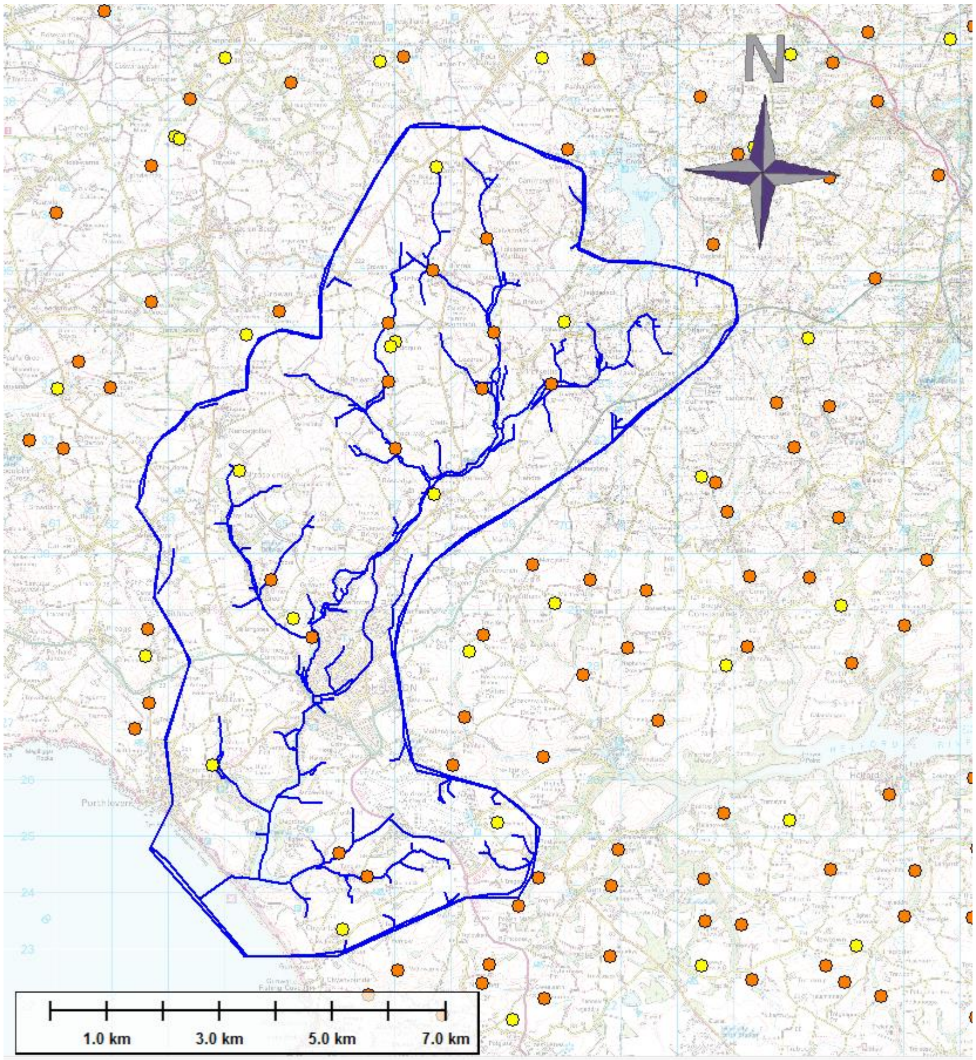


Figure 23: G-BASE soil (yellow) and sediment (orange) point data within the Cober Catchment (Made in Global Mapper, 2017, by Ella Rosser)

SAMPLE	SAMPLE TYPE	EASTING	NORTHING	Cu	As	W	Pb	Sn	Fe2O3
470357	Stream Sediment	164810	29526	47.4	50.1	24.3	57.3	1207.1	3.48
470369	Stream Sediment	165536	28506	184.4	349	82.3	158.8	>2000	6.9
470381	Stream Sediment	166025	24694	24	38.8	4	45.2	94.5	6.07
470363	Stream Sediment	166513	24277	28.5	33.9	8.1	49.7	736.5	5.79
470244	Stream Sediment	166886	33033	25.3	25.8	48.8	50.4	2206.9	2.64
470221	Stream Sediment	166897	34068	65.1	40.8	26.1	55.2	837.6	3.02
470220	Stream Sediment	167022	31852	68.3	49.8	101.5	73.7	>2000	3.02
470224	Stream Sediment	167673	34999	31.2	27.6	15.7	42.9	544.8	2.16
470210	Stream Sediment	168550	32905	61.2	48.1	31.2	63.3	>2000	5.03
470239	Stream Sediment	168639	35560	90.6	53.3	13.6	52.1	216	2.27
470286	Stream Sediment	168750	33905	72.6	18.6	62.1	62.2	>2000	6.81
470264	Stream Sediment	169772	33003	764.6	73.9	55.5	51.9	>2000	7.21

SAMPLE	SAMPLE TYPE	EASTING	NORTHING	Cu	As	W	Pb	Sn	Fe2O3
478606	Soil	163776	26255	85.3	124.3	5.3	390.3	155.6	10.02
478634	Soil	164263	31455	72.4	143.2	16.7	97.6	>2000	4.95
478660	Soil	165214	28851	47.3	95.1	13.8	86.4	334.2	6.11
478690	Soil	166070	23360	27	21.1	3.4	31.2	30.4	4.89
478693	Soil	166935	33662	8.5	21.9	5.4	35.4	36.3	2.32
478688	Soil	167013	33746	4.9	19.3	5.3	31.1	29.5	1.93
478640	Soil	167704	31047	50.8	38.1	13.5	65.8	593	3.4
478603	Soil	167731	36823	43.9	42	6.9	66.9	118.1	1.71
478651	Soil	168818	25242	30.6	30	2.2	55.3	22.9	5.42
478635	Soil	170004	34099	14.1	24.1	9.5	41.3	158	3.14

Figure 24: G-BASE Stream Sediment and Soil concentrations

Figure 23 and 24 show the locations of the G-BASE geochemical survey, with the concentrations of metals at each of the sample points. Maps showing the results of the G-BASE survey in the whole south-west can be found in Appendix E, displaying only the six metals being investigated for this report. The British Geological Survey (BGS) produced all maps.

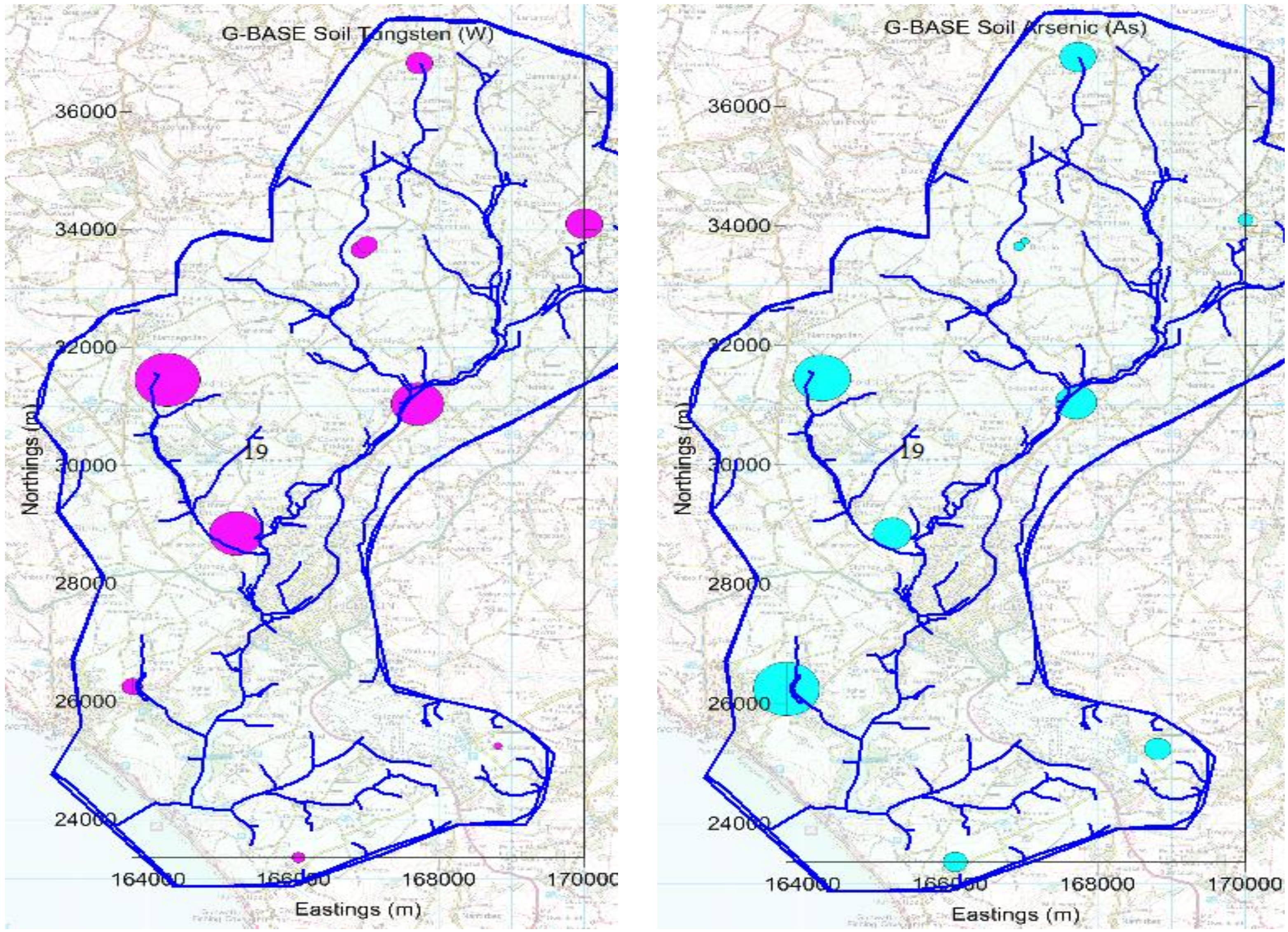


Figure 25 A: G-BASE soils- metal concentrations for Cober Catchment

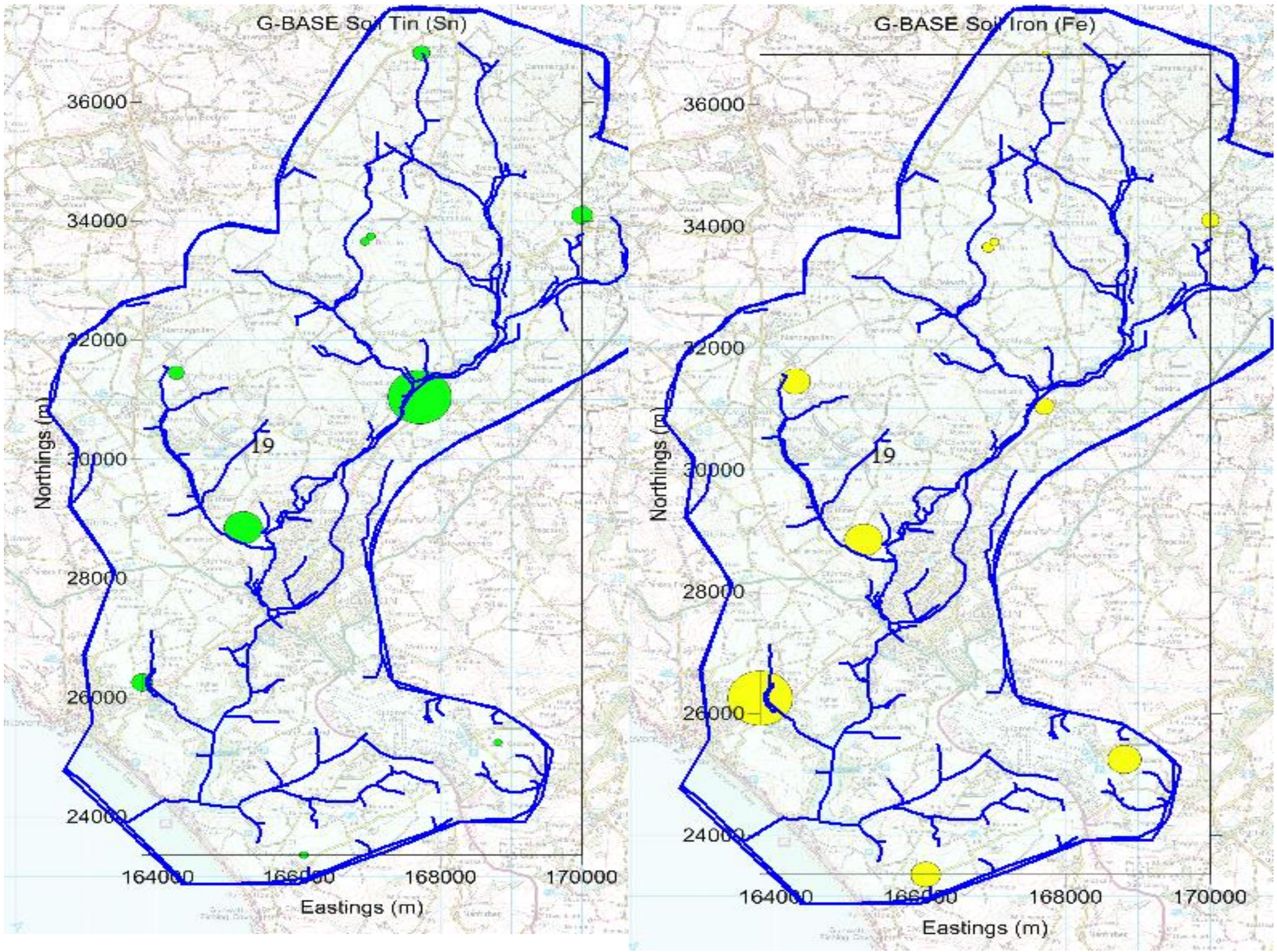


Figure 25 B: G-BASE soils- metal concentrations for Cober Catchment

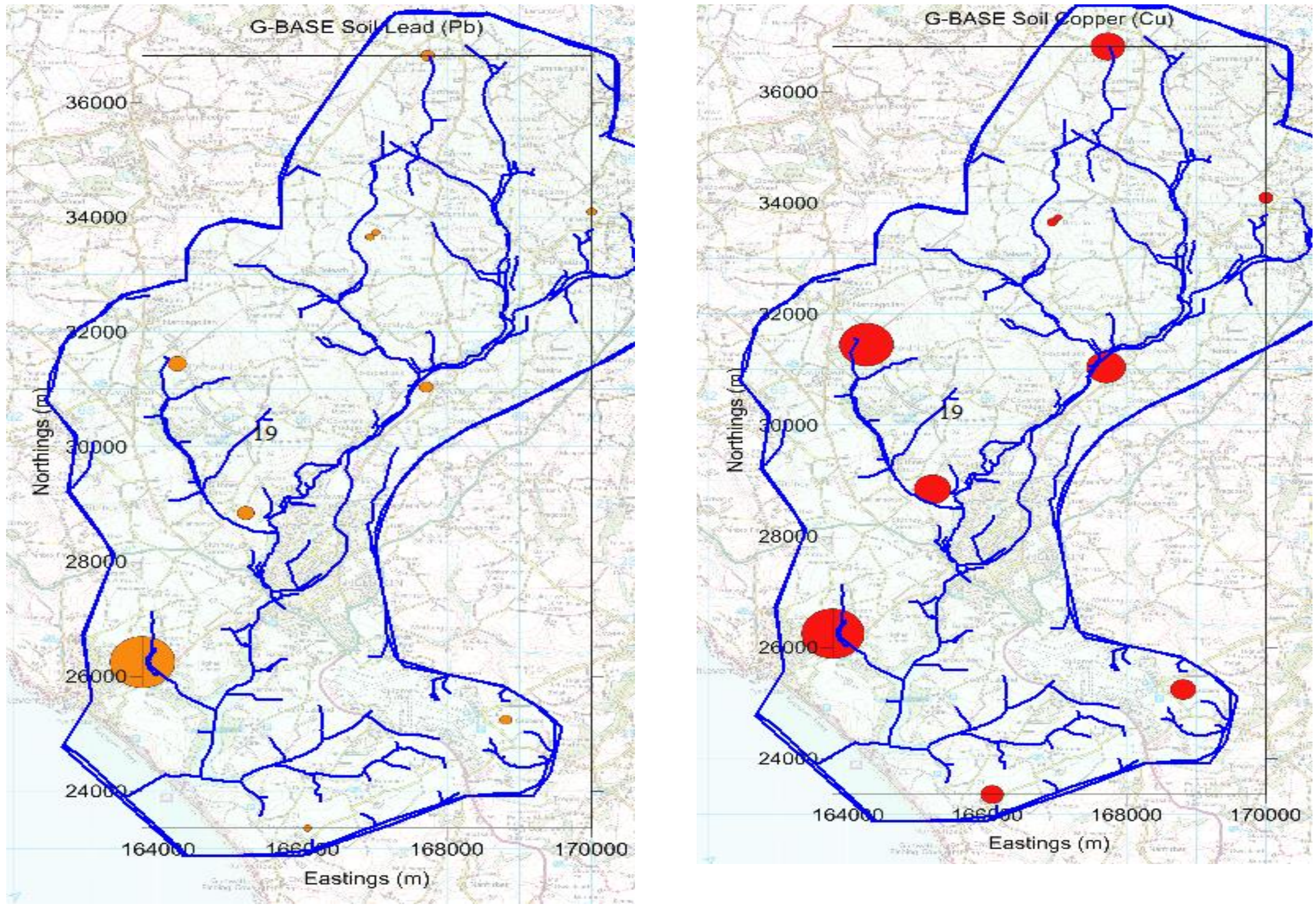
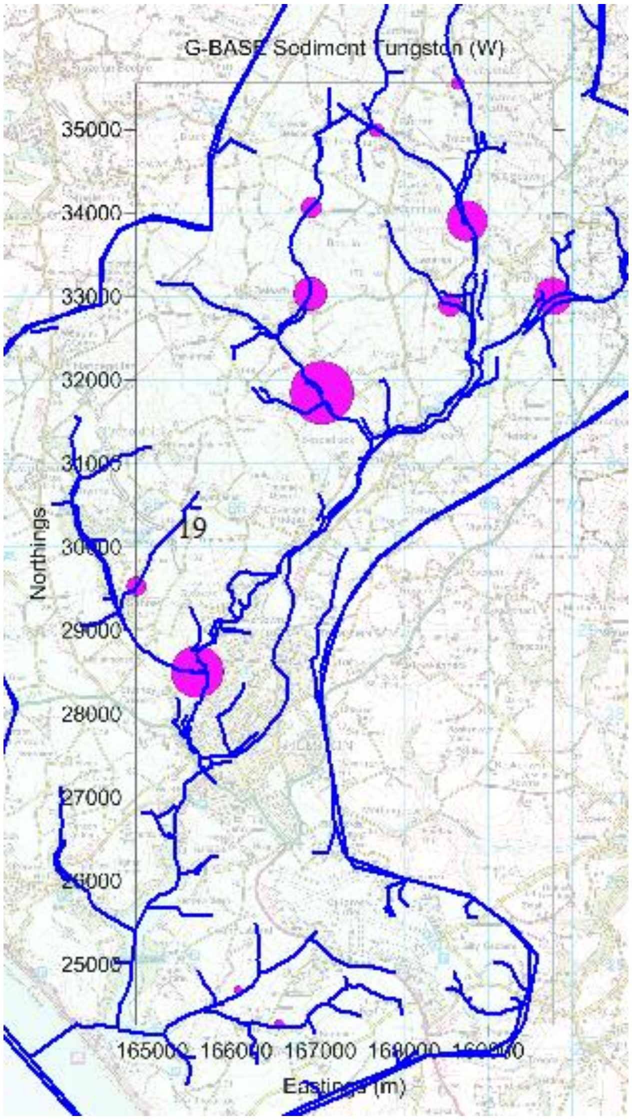


Figure 25 C: G-BASE soils- metal concentrations for Cober Catchment



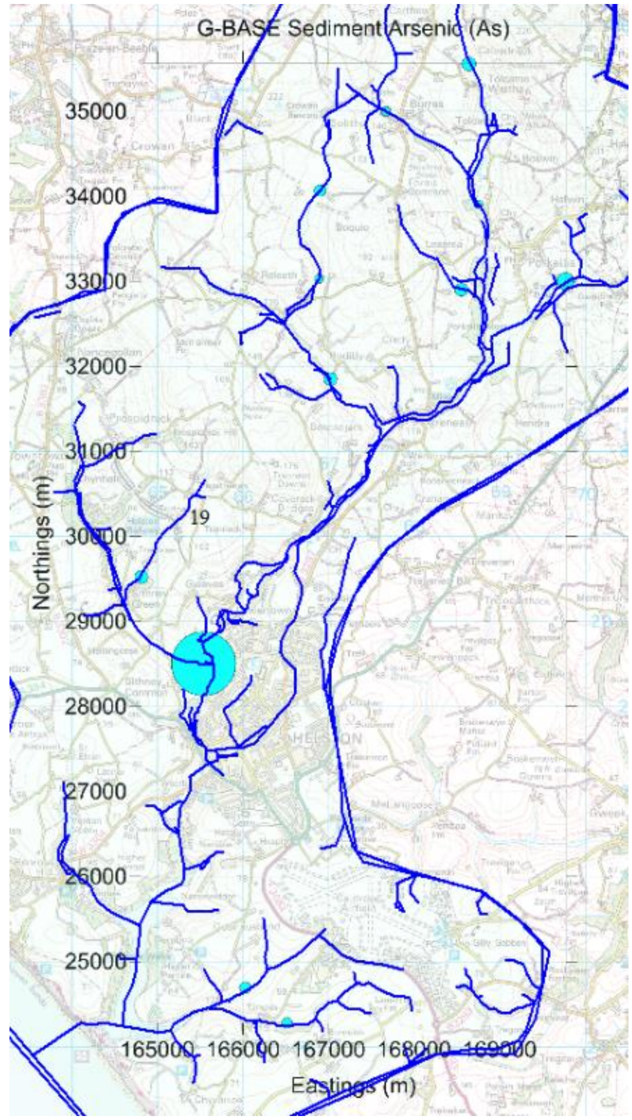


Figure 26 A: G-BASE stream sediments – metal concentrations for Cober Catchment

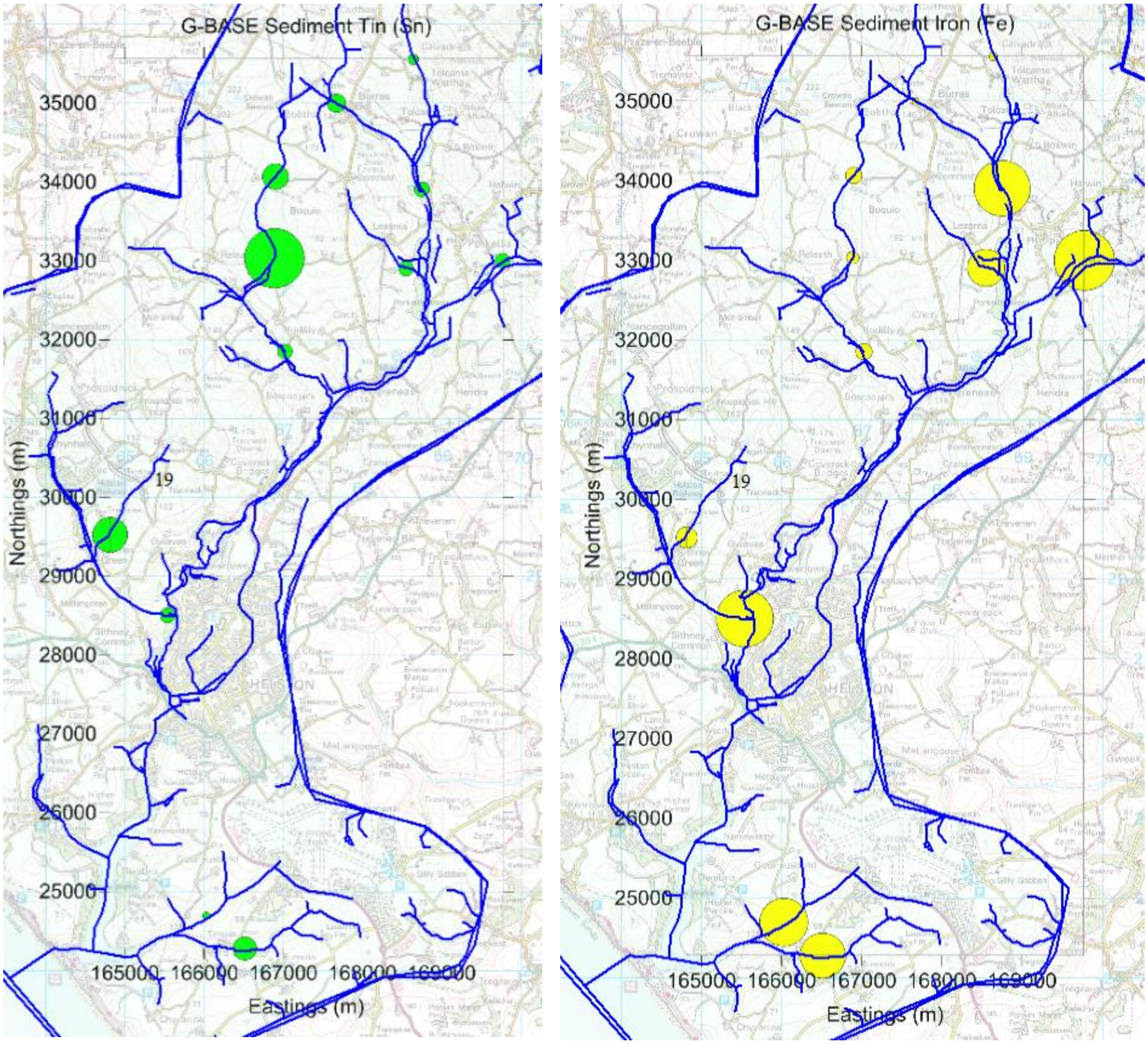


Figure 26 B: G-BASE stream sediments – metal concentrations for Cober Catchment

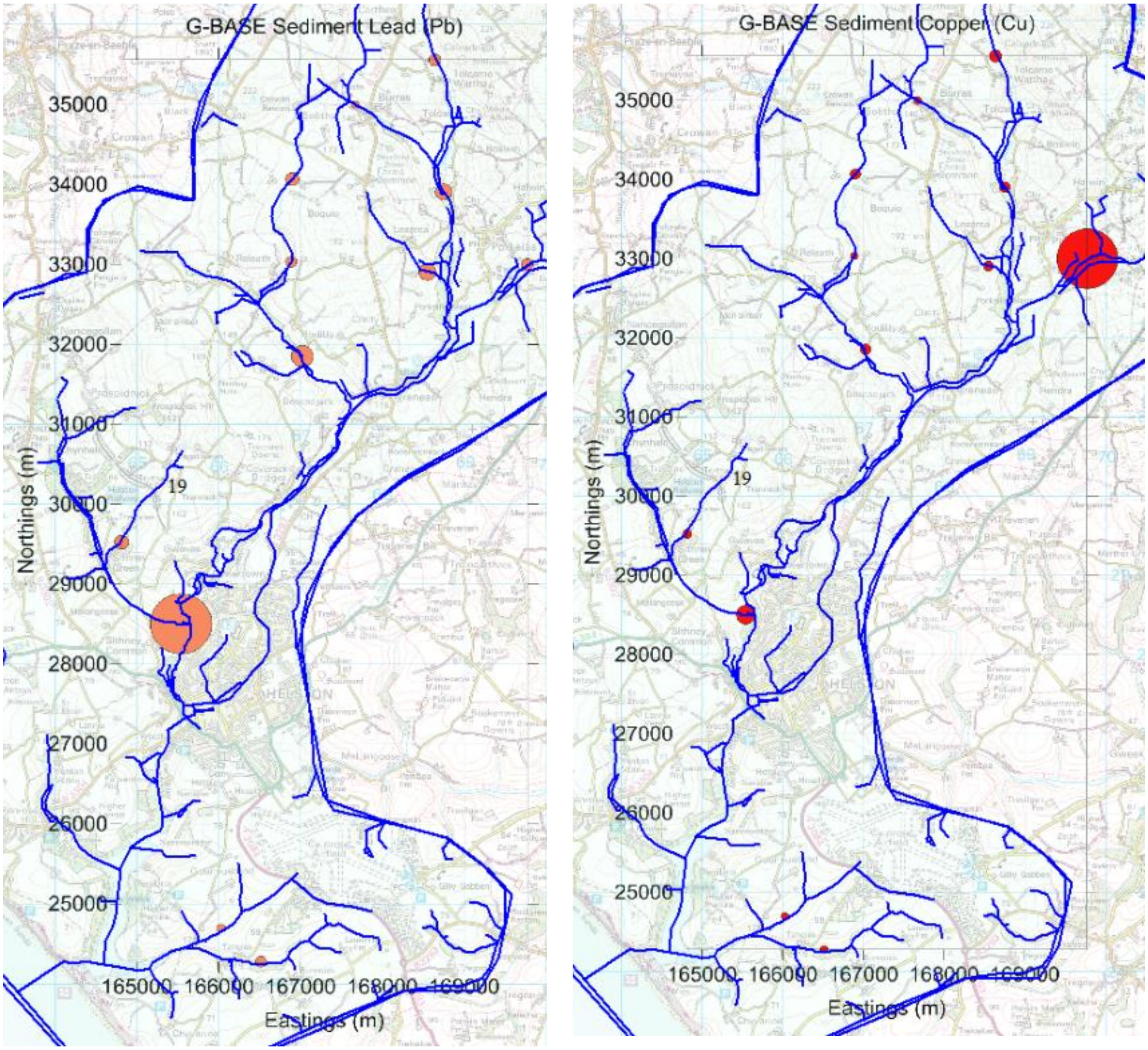


Figure 26 C: G-BASE stream sediments – metal concentrations for Cober Catchment

6.3 LiDAR maps

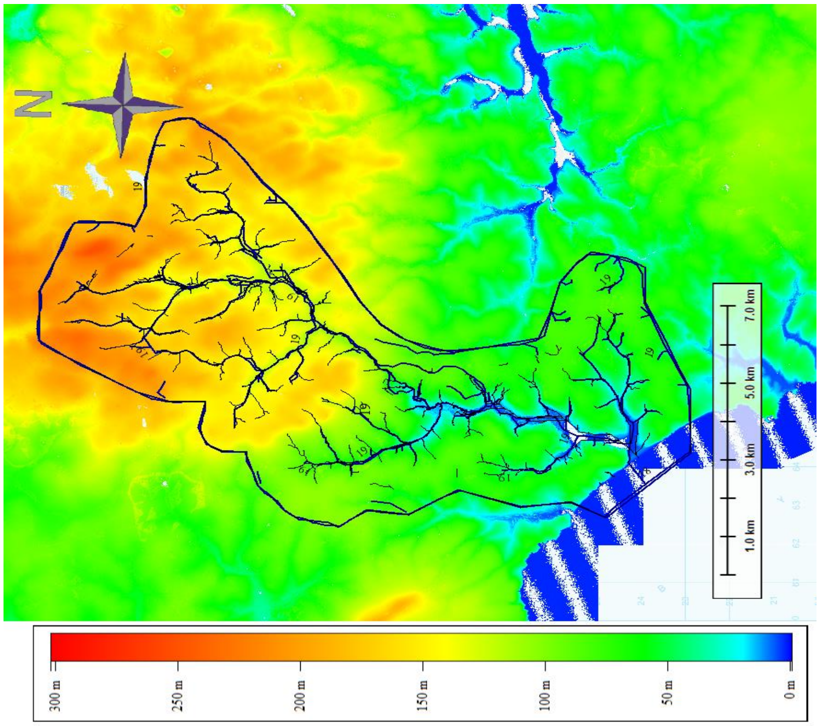


Figure 28: DSM from Tellus Lidar data.

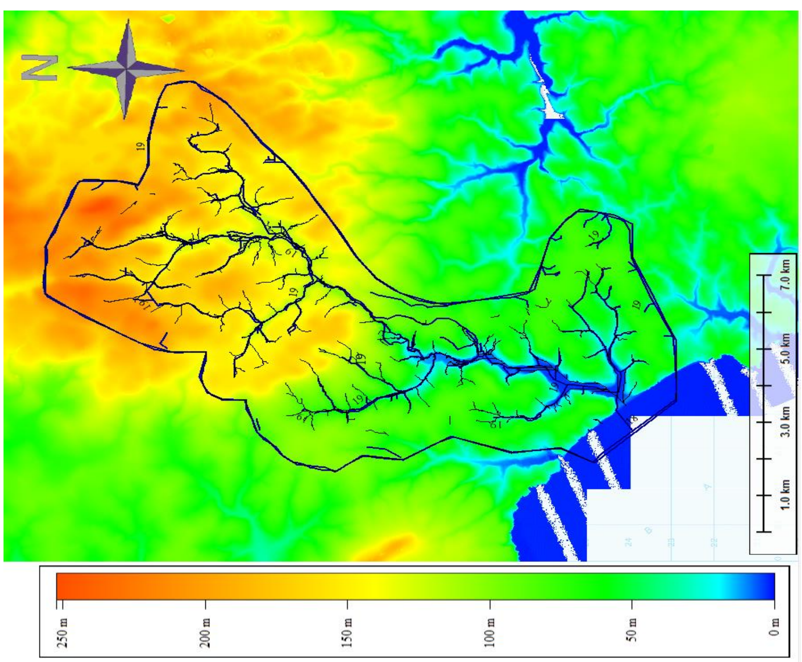


Figure 27: DTM from Tellus Lidar data.

6.4 Watershed maps

Figure 29: Site A watershed. White dots represent soil sample locations within the watershed catchment.

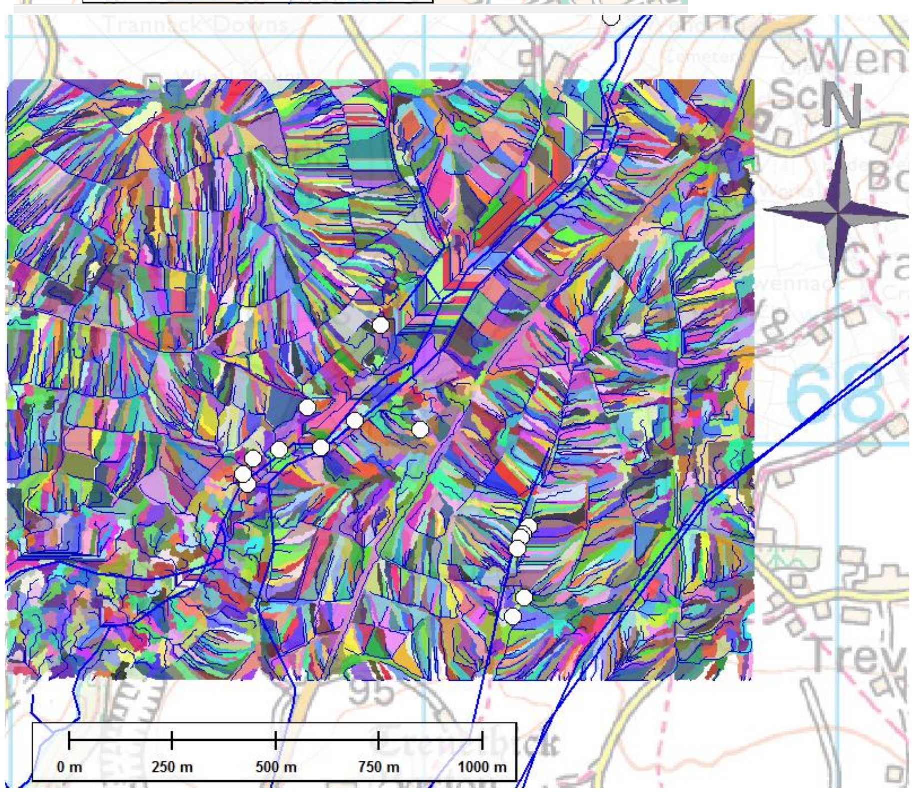


Figure 30 : Sites B & C watershed.

White dots represent soil sample locations within watershed

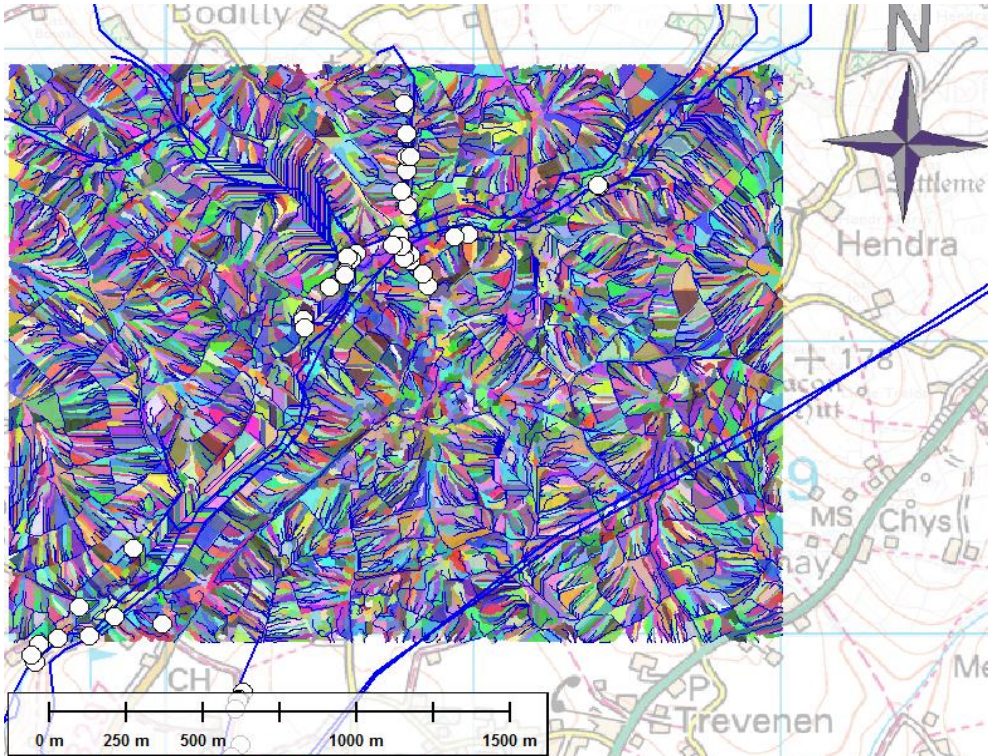


Figure 31 : Sites D watershed. White dots represent soil sample locations within watershed catchment

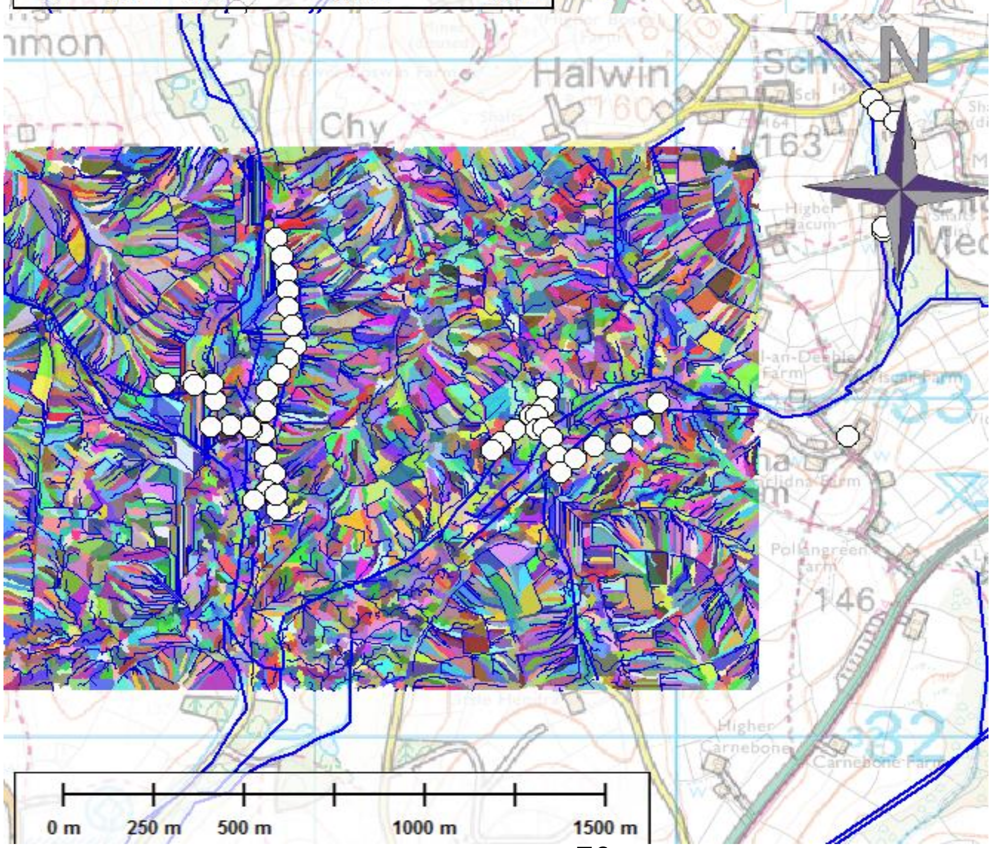


Figure 32 : Sites E & F watershed. White dots represent soil sample locations within watershed catchment.

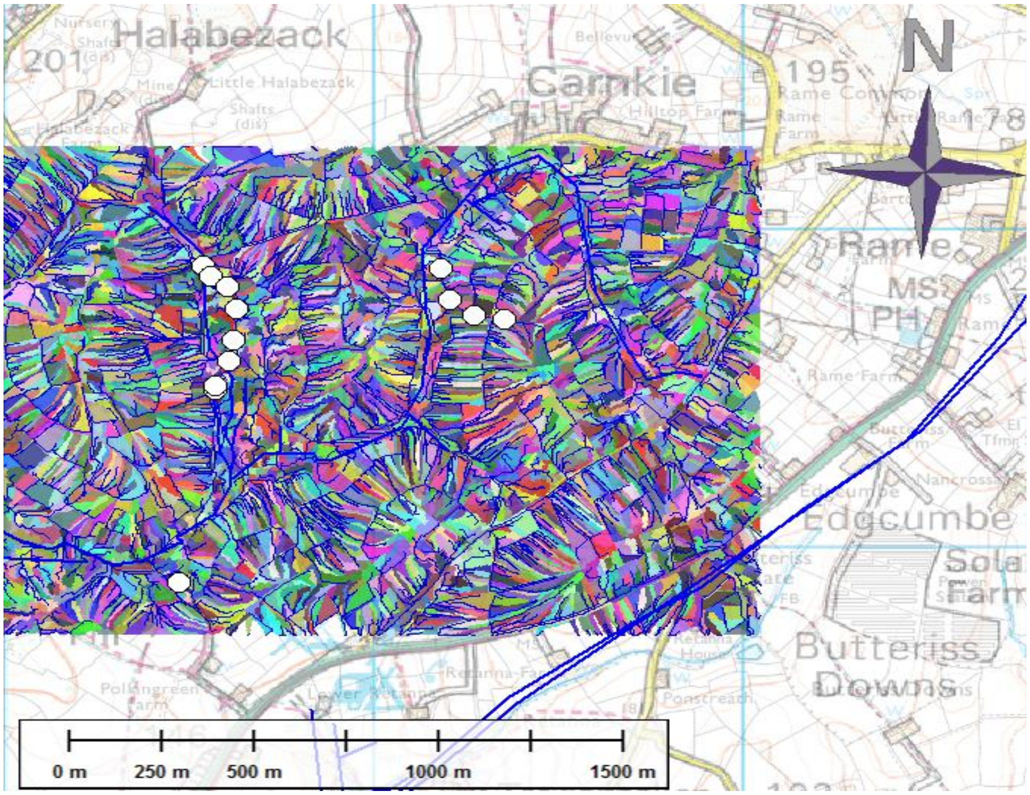


Figure 33 : Sites G watershed . White dots represent soil sample locations within watershed catchment

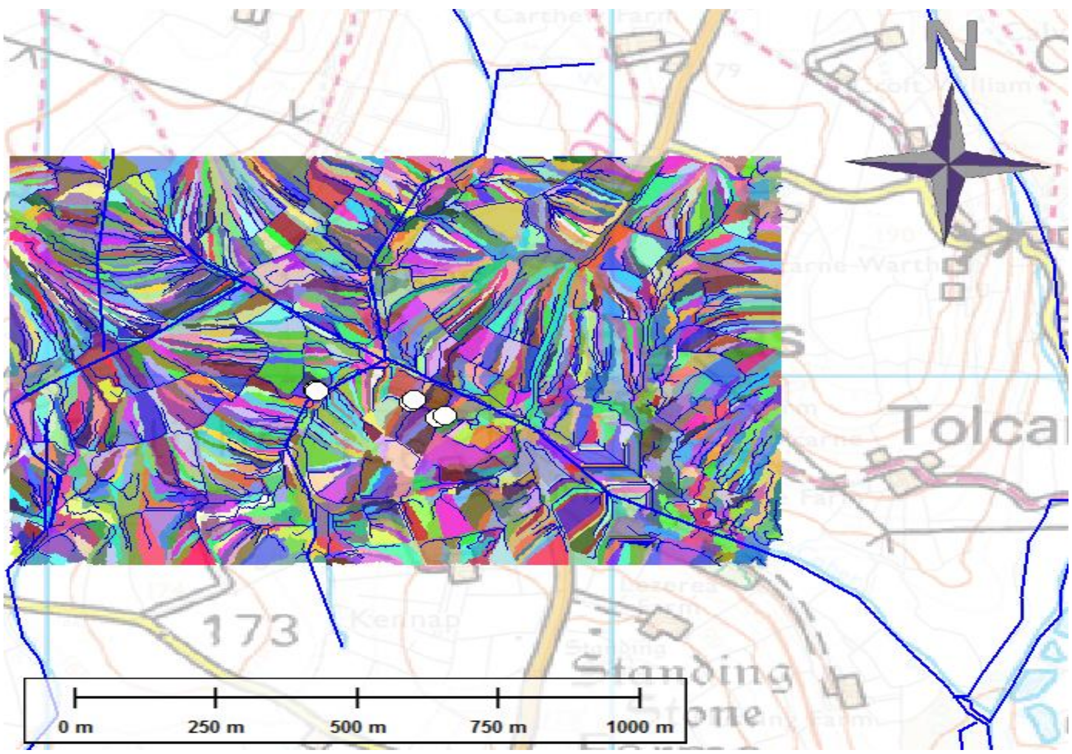


Figure 34 : Sites H watershed. White dots represent soil sample locations within watershed catchment.

6.5 Rolling ball

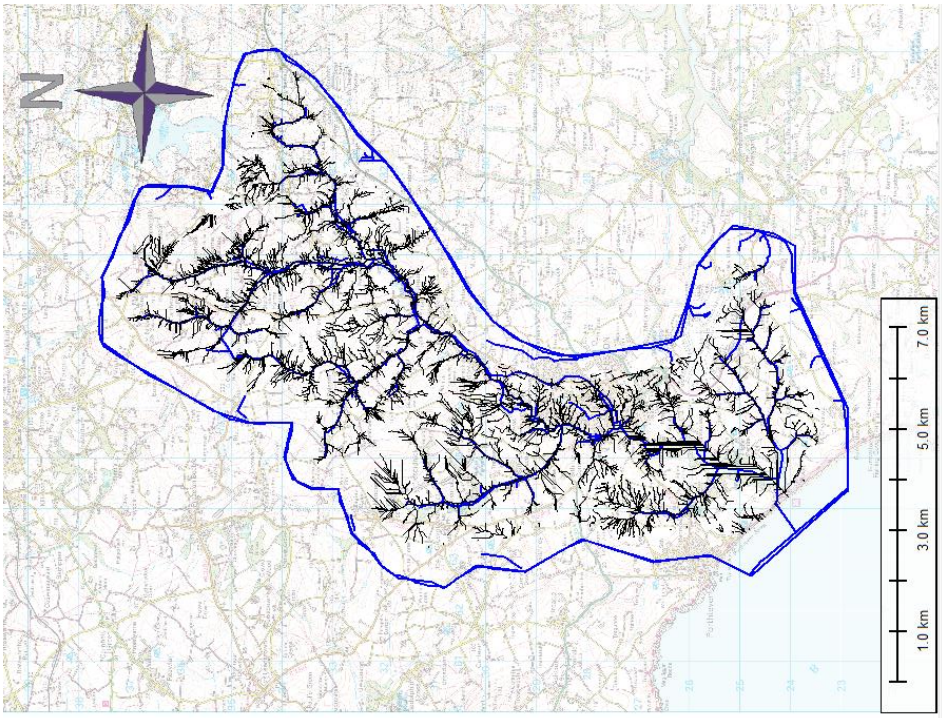


Figure 36: Rolling Ball at 5,000 m

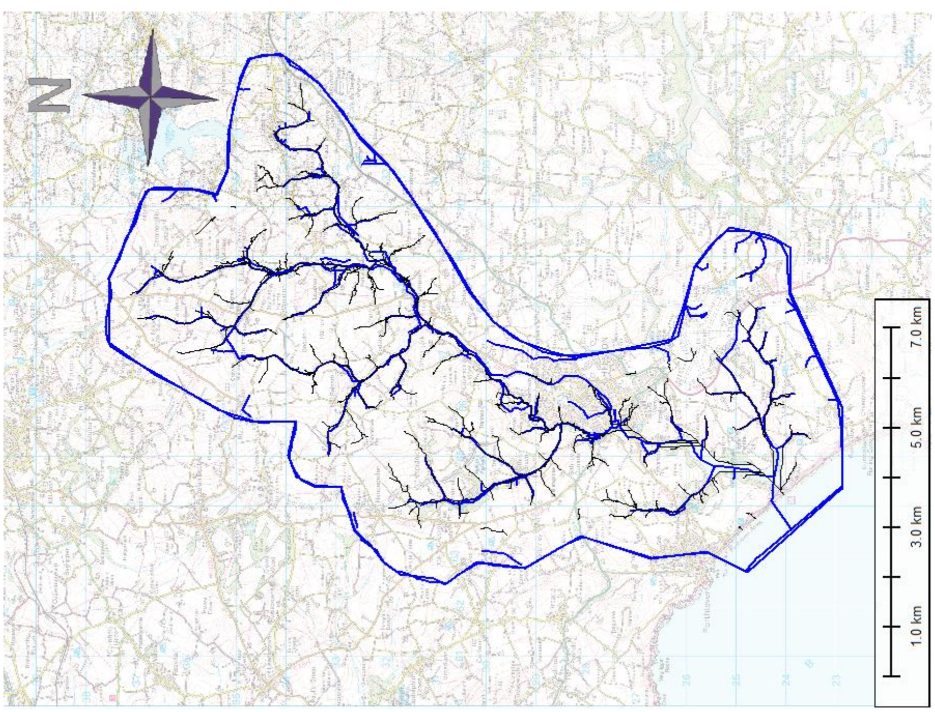


Figure 35: Rolling Ball at 50,000 m

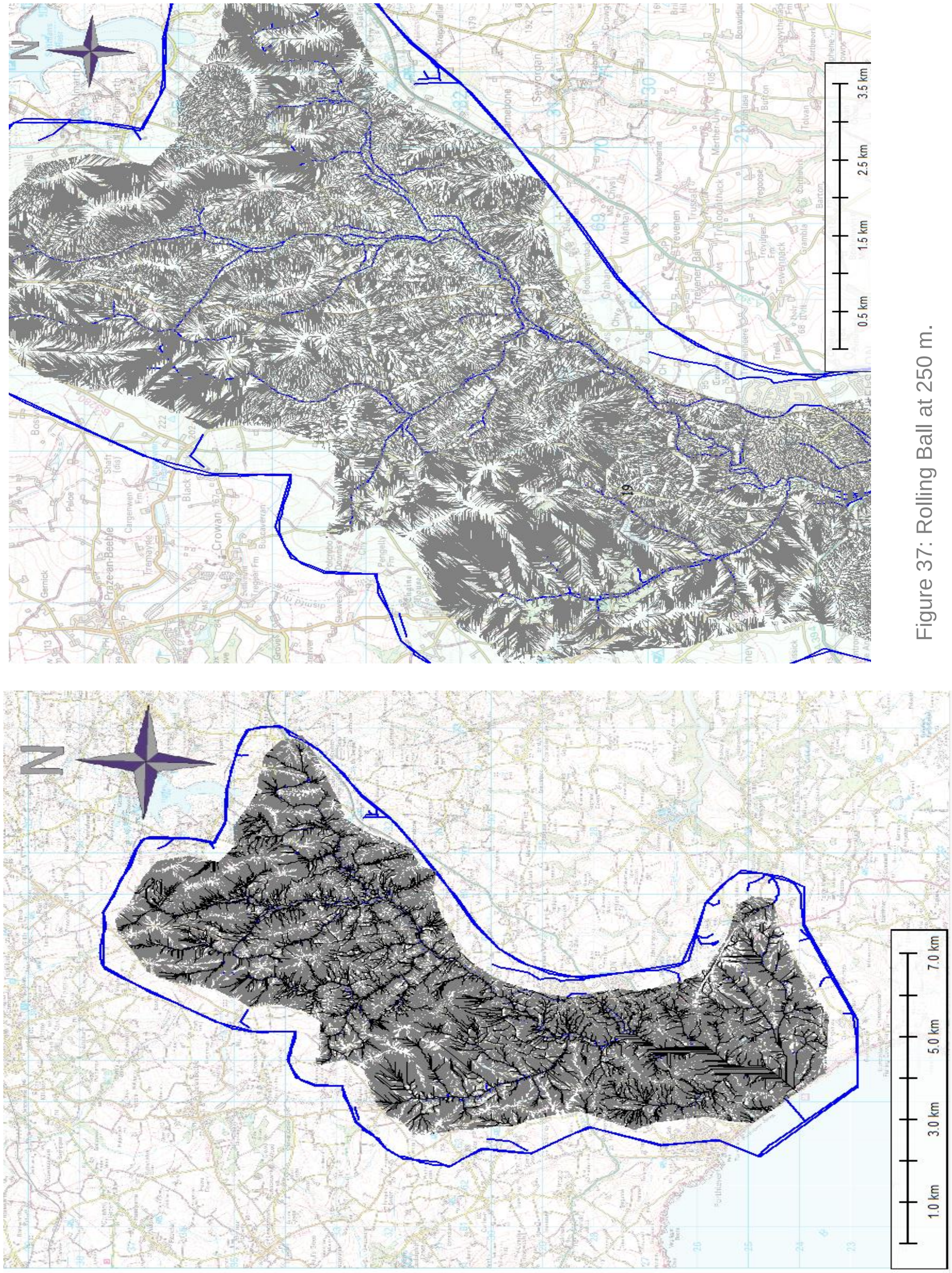


Figure 37: Rolling Ball at 250 m.

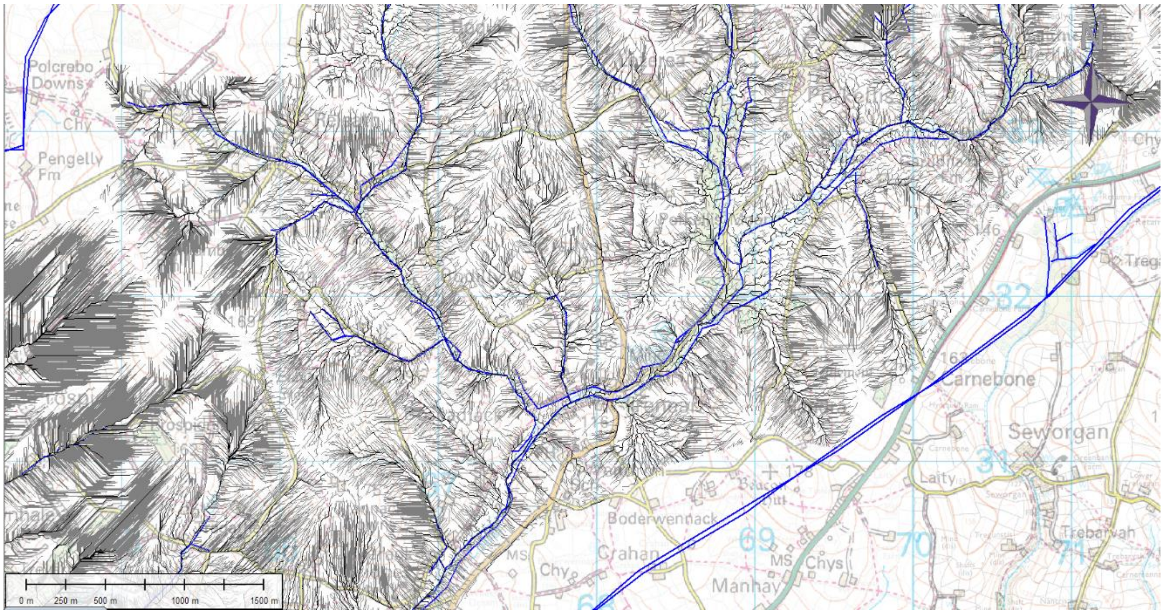


Figure 38: Rolling Ball at 250 m in Wendron

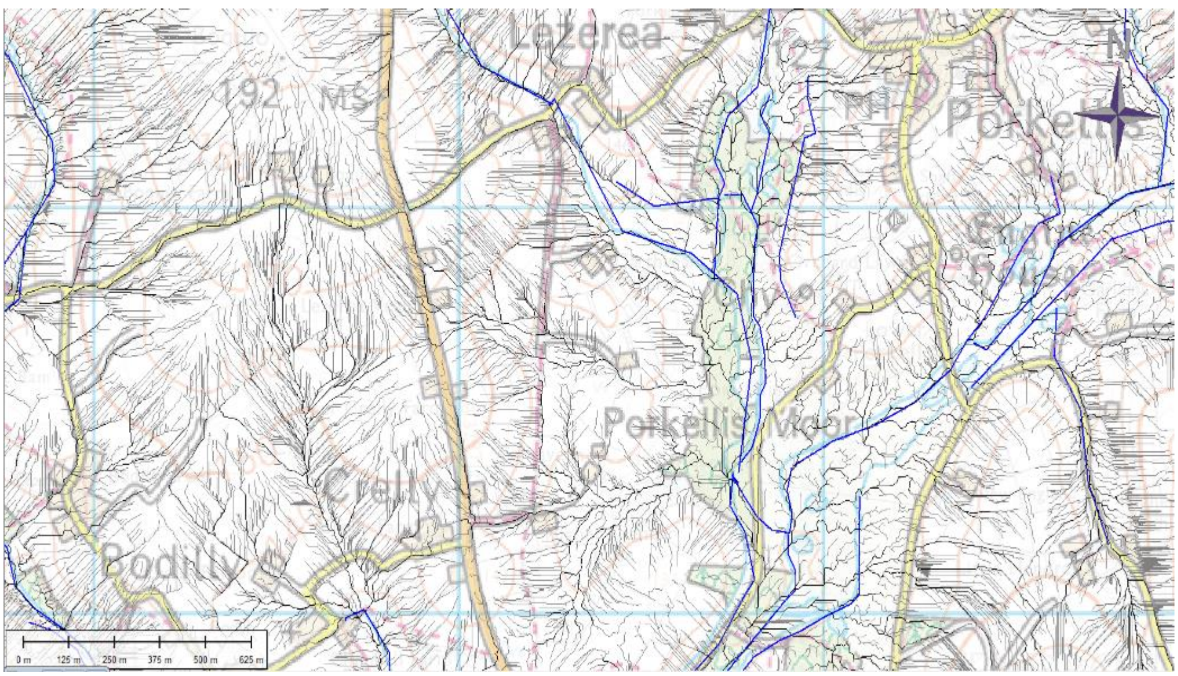


Figure 39: Rolling Ball at 250 m in Porkellis Moor

7. Discussion

7.1 Interpretation

Geochemical survey

Due to the geology and mining history in Cornwall, and specifically the Cober Catchment, which encompasses the Wendron Mining District, it is expected that there will be elevated levels of metals within the soils. This also means that the background levels in the area will naturally be higher than most places in the UK, and hence also attracted miners for its rich metal mining potential.

Overall, 126 soil samples were surveyed that showed a variety of results across the upper catchment. This discussion will investigate the levels for each metal element and the consequences of the levels of that element.

Overall, the geochemical survey showed that there are trends in the data, showing high elevations of metals where the samples were taken in close proximity or on an abandoned mine site. This was expected, as mineral processing plants in the area would have been located adjacent to the mine site or on the mine site. Figure 15 shows the mine sites mapped for this study. Specifically mine sites close to Site A are Caudle mine, Wheal Helston, Wheal Trannack and Wheal Oak are all within one kilometre of the soils samples taken along the transect at site A. Site B and C (Coverack Bridges) hosts Wheal Dream, Boscadjack and Wheal Trumpet, where there are remains of old mining buildings. Other shafts are located within the vicinity of the area also. Site D (Wendron) is located close to West Wendron Consols, Wheal Roots, Poldark Mine, Chenhall and numerous other mineshafts. Sites E and F, which were close to the village of Porkellis are also close to mine shafts and sites, including Wheal Cock, Enys, East Basset and Grylls, North Lovell and Wheal Ruby

(Cornwall Council, 2017). Sites G and H were not visibly within close proximity to any mine sites but as Cornwall has many un-marked mine sites there is a high possibility that shafts and workings are within the area but may not be marked on the map.

Tungsten- Figure 17 displays the levels on Tungsten found at the soil sampling sites across the catchment. The smallest value found was 14.5 ppm, whilst the largest value was 338 ppm. Within the geochemical survey, some of the largest values were found at site A, which was adjacent to the town of Helston. Concentrations were between 150 ppm and 338 ppm. A second high reading of Tungsten was found at Site E, located near the Porkellis Moor, which read 203 ppm. This soil sample was taken close to an abandoned mine working, close to Wheal Cock. The abandoned site is presumed to be the processing area of the site.

Tungsten has no official role or benefit to humans, plants or animals, although it is an essential nutrient for some bacteria. Thus, the long terms exposure to tungsten can have implications on human health (Tungsten, 2011).

Arsenic – Figure 18 shows the levels of Arsenic found across the catchment. The smallest value for arsenic was 8 ppm, whereas the largest value was 843 ppm. This sample was taken at Site B, close to where there are several known shafts and close to Wheal Trumpet. Arsenic was a popular secondary mineral to process in the mines in Cornwall, thus the high levels in the background geology and the reason for mining it.

However, the health implications from arsenic contamination can be severe. Table 2 shows the Soil Guideline Values (SGV's) for arsenic. (SGV's) are a generic assessment criterion for assessing the risk to human health from chemicals in soil

(Environment Agency 2009). The survey showed 26 soils samples recorded over 100 ppm arsenic.

Table 2: Soil guideline values for Arsenic. (Environment Agency 2009)

Mineral	**Soil Guideline Value (mg kg -1 DW)**	
Arsenic	Residential	32
	Allotments	43
	Commercial	640
DW = Dry Weight ***1 mg kg equivalent to 1 part per million (ppm)**		

Tin – Figure 19 shows the levels of tin recorded in the survey. The lowest value was 27.5 ppm, whilst the highest was 14429 ppm. The highest value was found at Site E, along with three other high value for tin. Referencing back to the historic map of mines and mineral lodes around Wendron (Figure 14), it is clear to see that Tin was mined in the area due to the tin lode at surface level, and Wheal Cock is the closest mine in the area.

Although tin is widely used for anthropogenic resourced in everyday life, there is no evidence that tin is an ‘essential element’ to humans. Tin can naturally be found within soils, and thus creeps into the food chain through vegetables and fruit etc. However should ingestion of tin occur through high levels of a contaminated source, then there may be health implications. Yet, tin enters and leaves the body rapidly after ingestion and small amount of the elements are not deemed adversely harmful to humans (Atsdr.cdc.gov, 2017).

Iron – Figure 20 shows the levels of iron found in the survey. The lowest value was 5,978 ppm and the highest levels was 207061 ppm. This level was found at site E, similarly to the high levels on tin, which were all found at the abandoned mine workings on the Porkellis Moor.

Iron is considered an essential trace element in humans and other living organisms. Due to its abundance in the earth's crust, iron is commonly found in nature and is essential to human nutrition. An intake of 0.4-1 mg/kg is unlikely to cause negative effects to a healthy human. However, it should be noted that there can be a lethal dose of iron to humans, which is between 200-250 mg/kg or 200/300 ppm (World Health Organisation (WHO), 2013).

Lead – Figure 21 shows the concentrations of lead within the catchment. The smallest value found was 14 ppm and the largest value was 2670 ppm. This value was found at site Site A. This appeared to be an anomaly value as the second highest reading for lead was 534 ppm collected at site G and the third was 281 ppm collected again at site A.

Lead is highly toxic and can be particularly harmful to young children. The exposure of lead in humans can be tested through a blood sample, as the lead will be distributed throughout the body as it accumulates over time. Mining is one of the main anthropogenic sources of contamination from lead. The main exposure route though is through inhalation of dust particles and ingestion of contaminated dust, water and food containing lead particles (World Health Organization, 2017).

Copper – Figure 22 show the distribution of copper across the catchment. The lowest value was 12 ppm, whilst the largest value was 2,241 ppm which was found at site E. This is the same location for the high values for iron and tin, at the location of the abandoned processing mine site on Porkellis moor. The lowest values are notably found at predominantly sites G and H, which is further up the catchment and watercourse network.

Copper is recognised as an essential trace elements; however, the acute lethal dose for adults is between 4 and 400 mg of copper per kg on body weight. Lower doses can cause less adverse consequences but can still affect human health and symptoms include similarities to food poisoning (World Health Organisation (WHO), 2004).

The G-BASE geochemical survey was extensive, however only 12 stream sediment samples and 10 soils samples were taken within the catchment. As this survey was conducted to build up the data for the south west, samples were taken systematically but were not biased in surveying directly above sources of contamination – the purpose of the geochemical survey undertaken for this report. Thus, the concentrations are lower that the concentrations from the primary survey.

Tungsten showed for the soil samples readings all below 17 ppm, while the stream sediment samples showed the highest concentration was 102 ppm. This was taken near Wheal Fursden, North West of Wendron, the location of several tin mines.

Arsenic presented itself in relatively low concentrations compared to the primary survey. The soil sampling showed a high concentration of 144 ppm and the highest stream sediment sample was 349 ppm, located very close to the transect of soil samples at Site A in Helston. However, these are still relatively high levels of arsenic and according to the SGV (table 2); these are hazardous levels in the natural environment.

Tin showed much higher concentrations within the stream sediments, with all values between 95 and 2000 ppm, whilst the soil samples showed 5 samples below 100 ppm and the other 5 above 100 ppm.

Iron showed low concentrations in both the soil and sediment samples, with the highest-level 10 ppm in the soil samples.

Lead presented in all concentrations below 100 ppm apart from one soil and one sediment sample above this level. The soil sample at 390 ppm was taken north of Porthleven on the Penrose estate. This is the lower catchment and not the focus of this study. The stream sediment sample reaching a concentration of 159 ppm was taken at the same place as the high Arsenic stream sediment sample, close to Helston at Site A.

Copper displayed low concentrations in the soil samples, but slightly higher levels within the stream sediment samples. The highest value was 185 ppm, taken again to the west of Helston, close to site A and on the River Cober.

Metal compounds can be transported into the soil from abandoned mine sites by the process of wind or water pathways. This can include surface runoff, groundwater seepage, or surface water in floodplains. The result is soil contamination not only within the boundaries of abandoned mine sites, but often many miles away from the source (Aslibekian & Moles 2003). The second movement of metal compounds can be through erosion, defined in relation to mining as *"the dislodgement and transportation of soil materials through the action of water and wind, with potentially significant direct and indirect adverse impacts, both onsite and offsite"* (Spitz & Trudinger, 2008).

The Universal Soil Loss Equation (USLE) is a widely accepted formula, relating the average loss of soil to (1) rainfall and runoff; (2) soil erodibility; (3) combined slope length and steepness factor; (4) vegetative ground cover; and (5) cover management. Soil loss can be estimated by using these five factors and basing them on average rainfall condition (Spitz & Trudinger, 2008). The USLE could be used to predict soil erosion in the Cober catchment, using the results of the geochemical survey to map where the problematic areas are and determine where soil erosion is at its worst in the catchment.

Metal properties, soil properties and the environment can all influence the mobility of heavy metals (He *et.*al, 2004). If a metal is mobile then a chemical transfer of the metals during surface run-off can occur through diffusion, whereby the metal is transferred through a stagnant film during surface run-off. This theory is known as the 'film theory', developed by R.Wallach (Zhang *et.al* 1997 secondary source: Wallach *et.al*., 1988).

Although varying concentrations of metals have been surveyed in the Cober Catchment, they are not guaranteed to cause pollution unless they are bioavailable (readily available for uptake by living organisms). The point at which a mineral becomes bioavailable, is dependent on the '*biological interface*', stimulation or being provoked of other chemicals and external factors (temperature) (Eggleton & Thomas, 2004).

The worrying issue with concentrations of metals in the soils from the survey, is that chemical transfer to the streams in the catchment could create adverse consequences. Drinking water is extracted at Trenear and treated in Wendron, which is where some of the highest levels of metal contaminants were. Although the drinking water is extracted from groundwater, the percolation from the soil sediments into the groundwater could be detrimental to the standard of drinking water.

The main concern for the Cober Catchment is metal contamination seeping into the river and polluting the watercourses. As the river Cober is publicly accessible, the impacts of polluted water could be a health risk. Further investigation into the mobility of metals within stream sediments would need to be conducted, but the G-BASE survey is an intimal indication of the levels of metals in the streams sediments.

The geochemical survey suggested that metal contamination was trending towards the higher concentrations being downstream, with few high concentrations being found in the upper catchment. This would contest the theory that in river systems the concentrations of metal contamination decrease from the pollution source (Hudson-Edwards *et.al*, 1995). However, it is difficult to truly define any trends, as mineral processing techniques would have utilised the river Cober for treatment or metal ore, leading to mine sites across the whole watercourse.

Watershed generation

Figures 27 and 28 show the DTM and DSMs for the Cober catchment. Both similar in topography, they show that the upper catchment is much more diverse in height, with the upper catchment between 150 -200 m. This is typical for a watershed and both models show how the topography decreases in gradient down the catchment. Using the DSM and DTM LiDAR data, the watersheds were generated for each of the sites of the geochemical survey (Figures 29-34). An enlarged map of the watershed generation can be found in Appendix F. These maps show just how complex the catchment is, as each coloured polygon represents a sub-watershed or sub-basin. The smaller the sub-watershed and the more sub-watersheds compacted into an area suggests that drainage from the watersheds in that area is under pressure. If all the watercourses are draining at one tributary or contributory of the river Cober, then the pressures of the drainage could have implications for flooding downstream. The shape of the watershed is also a consideration as a long thin sub-basin means that rainfall will take longer to reach the river than a short round sub-basin. Mitigation against the increased drainage areas could withhold the flow of water during high rainfall, and the measures appropriate to mitigate drainage will be discussed later.

The Rolling ball maps are also a useful indication of where the watercourses are situated within the catchment. As the name would suggest, the roiling ball model processed using GIS software depicts where the water would naturally flow over the land where depression are situated, a ball would theoretically roll where the water would naturally flow. Figures 36-39 show the rolling ball model at resolutions of 50,000 m, 5,000 m and 250 m. The 250 m resolution of the model shows the extent of the potential pathways for water within the watershed. Similarly to the watershed maps, any areas of high concentrations of watercourses could result in a congested drainage area, potentially creating flooding issues further downstream. Particular attention should be made to the model at 250 m resolution at Wendron. The water flow here is very condensed and in the event of high rainfall, the surface water flow over the land and into the river Cober would be extensive in the area.

Linking drainage in the watershed to contamination

The quality of water within the watershed is dependent on the hydrological attributes of that watershed. As the sub-basins are extremely compact in the upper catchment and there are many watercourses contributing to the river Cober, the drainage areas are under increased pressures at certain tributaries along the watercourse. With the effects of soil erosion and surface run-off, areas with high drainage are not only at risk from creating flooding downstream, but are also at risk from increased surface run-off causing erosion of polluted soils into the river watercourse.

Mitigation

Reclamation of abandoned mine sites (AMS) could mitigate against the dispersal of contaminated metals on the site and to the surrounding areas. Mine sites in present day will have reclamation schemes as part of their planning permission as legislation requires it. However, the issue for the Cober Catchment is that extent of abandoned mine workings means the responsibility of reclamation is unknown.

The USLE can help to assess the impact of water erosion and mitigate against it in the Cober. To reduce the impacts of soil erosion, it is essential to retain soil cover and prevent erosion (Spitz & Trudinger, 2008). One method to sustain soil cover is increased vegetation. Vegetation cover is a popular choice for reclamation of AMS, as the stability of plants can restrict dispersal of contaminated particles by wind and particle update of contaminated water, along with the aesthetics vegetation provides.

To initiate plant regrown there are several chemical, physical and biological properties of soil that will engage revegetation. Adapted from the review of soil reclamation of abandoned mine sites (Sheoran *et.*al 2010), Table 3 shows typical soil properties and suggestions for instigating plant regrowth:

Table 3: Soil properties important for plant regrowth (Sheoran *et.al* 2010).

Chemical Properties	Soil Ph	• Optimal mine soil ph for forage regrowth & agricultural use is <6.0-7.5 ph • It has been reported that a ph <5 and the presence of Fe increases bioavailability of nickel, lead and cadmium
	Soil fertility	• Significant fertiliser is required to establish and maintain plant grown on mine soils

		• Consider that some metallic micronutrients are essential for plant grown (Fe, Mn, Cu, Zn)
Physical properties	Rock content	• Soils with coarse fragments means larger pores are in the soil, which restricts water hold.
	Soil texture	• Sandy textures soil cannot hold as much water than finer soils • Ideal soil texture is the particle size and distribution of soils with loamy textures
	Soil aggregation	• Soil aggregation may reduce erosion
	Slope, topography & stability	• Slopes with a gradient >15 % unsuitable for intense land uses (good for grazing of reforestation) • Slopes with a gradient <2 % can become saturated
	Bacteria	• Generate decomposition in organic materials
	Soil microbe	• Plays a major role in aggregate stabilisation as active soil microbe communities and stabilise the soil aggregation

However, revegetation this is not a widespread resolution, as many plants will not thrive in such harsh environments, as there are too many growth-limiting factors. Physical and chemical analysis is essential to assess each site prior to revegetation (Tordoff *et.al* 2000).

Loe Pool Forum (LPF) are keen to enhance upstream flow attenuation features to benefit the pollution to Loe Pool, create habitats upstream and flood attenuation. UsT have already implemented plans to create attenuation features upstream and the creations of ponds as one of these features. Along with the benefits they believe the attenuation features will hold, the features could also restrict the levels of pollutants from soil to streams by preventing and/or reducing soil erosion and surface runoff. The latest grant for UsT of £11 million could really benefit the attenuation of the River Cober. Alongside the LPF management plan, Catchment Sensitive Farming (CSF) is supporting farmers in reducing the diffuse water pollution from agriculture. This scheme used in collaboration with the UsT project could mitigate agricultural diffuse pollution and abandoned mine soil pollution (Loe Pool Forum, 2017).

7.2 Issues with data collection and presentation

The data collection for the geochemical survey was restricted for several reasons. Not as many samples could be collected as planned due to access, weather and the quality of the public footpaths. Several of the footpaths chosen to survey along were not visible when out in the field, either as they were overgrown or the direction was unclear, and without trespassing, some samples sites were not available or easily accessible. Other limitations of the survey was the ground resistance, and some locations the ground was so dry it became increasingly difficult to retrieve a sample at the required depth. For site selection, there were limitations with the number of footpaths within close proximity to a mine site and the river Cober meant not all potential sites could be accessed.

There were boundaries with the G-BASE data, as although there were thousands of samples taken across the whole south-west, there were less than twelve soil and stream sediment samples across the Cober catchment, limiting the amount of data available for analysis.

Background metals concentrations for the southwest and particularly Cornwall are high naturally, so the soil survey expected higher levels of metal contaminants than other areas in the UK regardless of pollution from abandoned mine sites.

8. Conclusion

The purpose of this study was to investigate the geochemistry in the upper Cober Catchment. With 126 soils analysed for their geochemical contents of heavy metals, the G-BASE soil survey conducted by BGS has been contributed towards. The primary survey expected to see elevated metal pollution within close proximity to abandoned mine sites and this was the case for the six elements tested. There were high levels of arsenic at Site A and B, the location of abandoned mines with a peak value of 843 ppm. This concentration massively exceeds the residential SGVs and as all of the soil samples were taken along public footpaths, this concentration of a highly toxic substance is alarming.

A preliminary mitigation measure against soil contamination impacting humans would be to alert the public of the potential of pollutants in the environment. Public notice boards located on walkways could be an initial measure to make people aware of the pollution in such a public place. Although not all concentrations were high, further research into the geochemistry of the upper catchment could prove otherwise. Stream sediment samples could be utilised to assess water pollution directly in the Cober watercourse to look for pollution.

In relation to the drainage areas in the Cober catchment, the mapping assisted in showing where the water is concentrating in the catchment by analysing the sub-basins in the catchment. Areas with high numbers of sub-basins would benefit from soft engineering measures to reduce the flow of the watercourse and prevent flooding downstream. However, it has been noted by the LPF that the upper catchment and its attenuation needs further attention to assess the potential role of the upper catchment in reducing flood risk.

A combination of mitigating against flooding in the upper catchment and mitigating against pollution in the upper catchment can be a dual mitigation programme. Natural measures of mitigation, i.e. revegetation and development of ‘Runoff Attenuation Features’, as trailed in the Belford catchment by Nicolson *et.al* (2012) could reduce the impacts of flooding and pollution downstream. This included the use of a permeable timber barrier and diversion ponds. Revegetation of abandoned mine site seems to be the most prevalent mitigation measure. The benefits include reducing surface run-off, uptake of metals via the plant and vegetation also creates an aesthetic purpose.

Due to the newly stated UNESCO World Heritage site of the mining areas in Cornwall and west Devon, there may be legislation preventing total regeneration of abandoned mines. Thus, a medium needs to be created between preventing flooding and pollution within the Cober catchment, but also preservation of this diverse and historical landscape.

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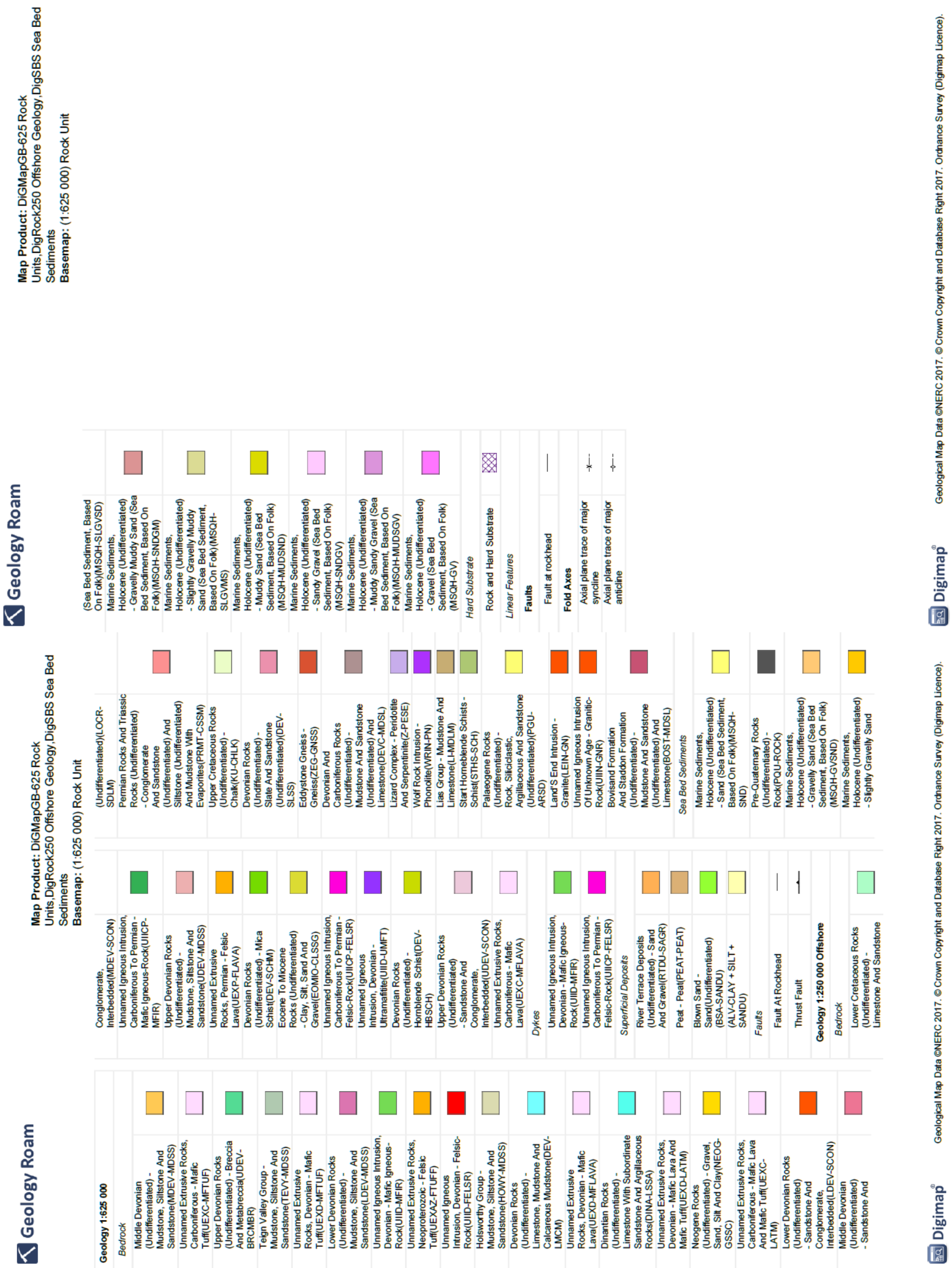
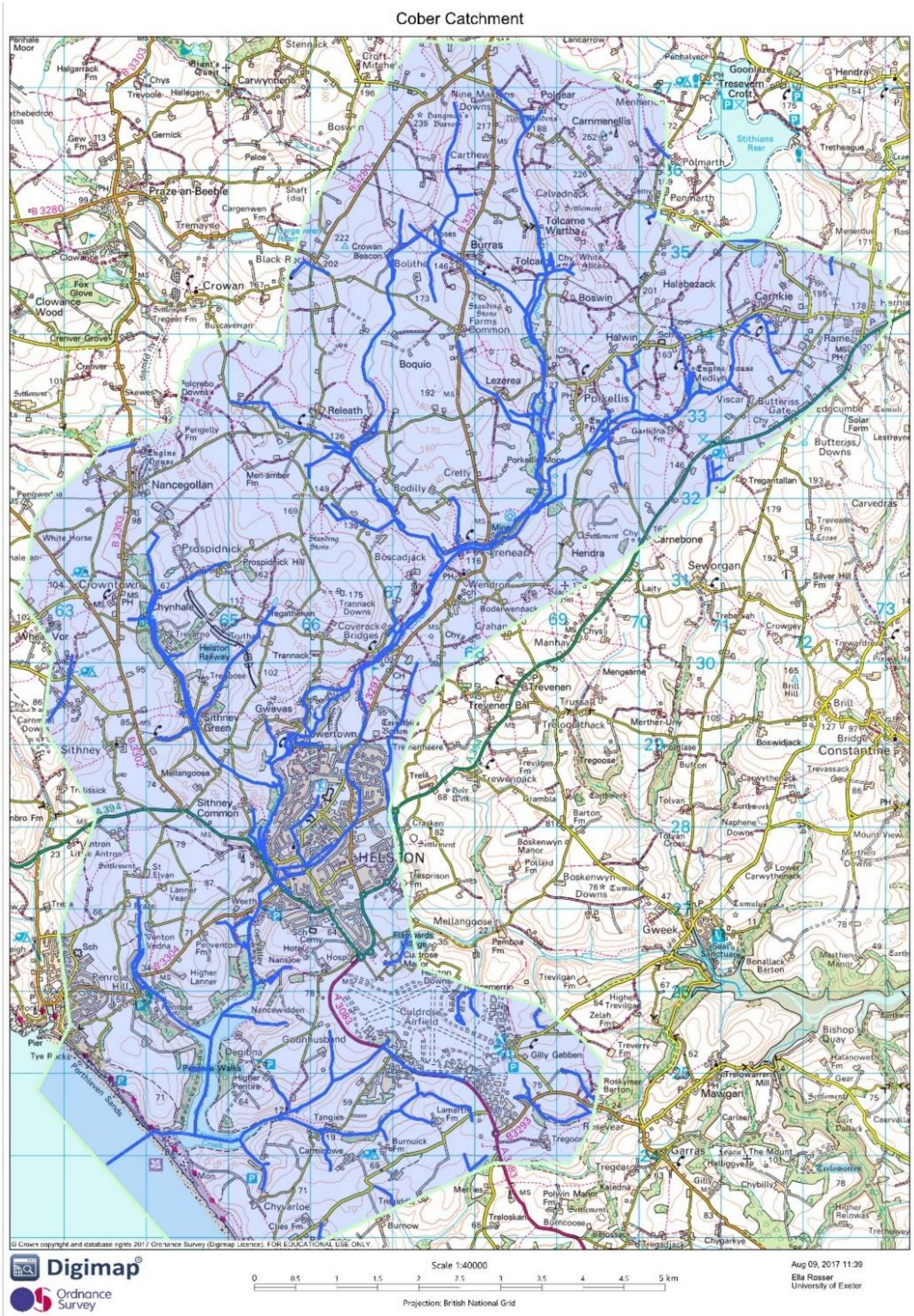
10. Appendicies

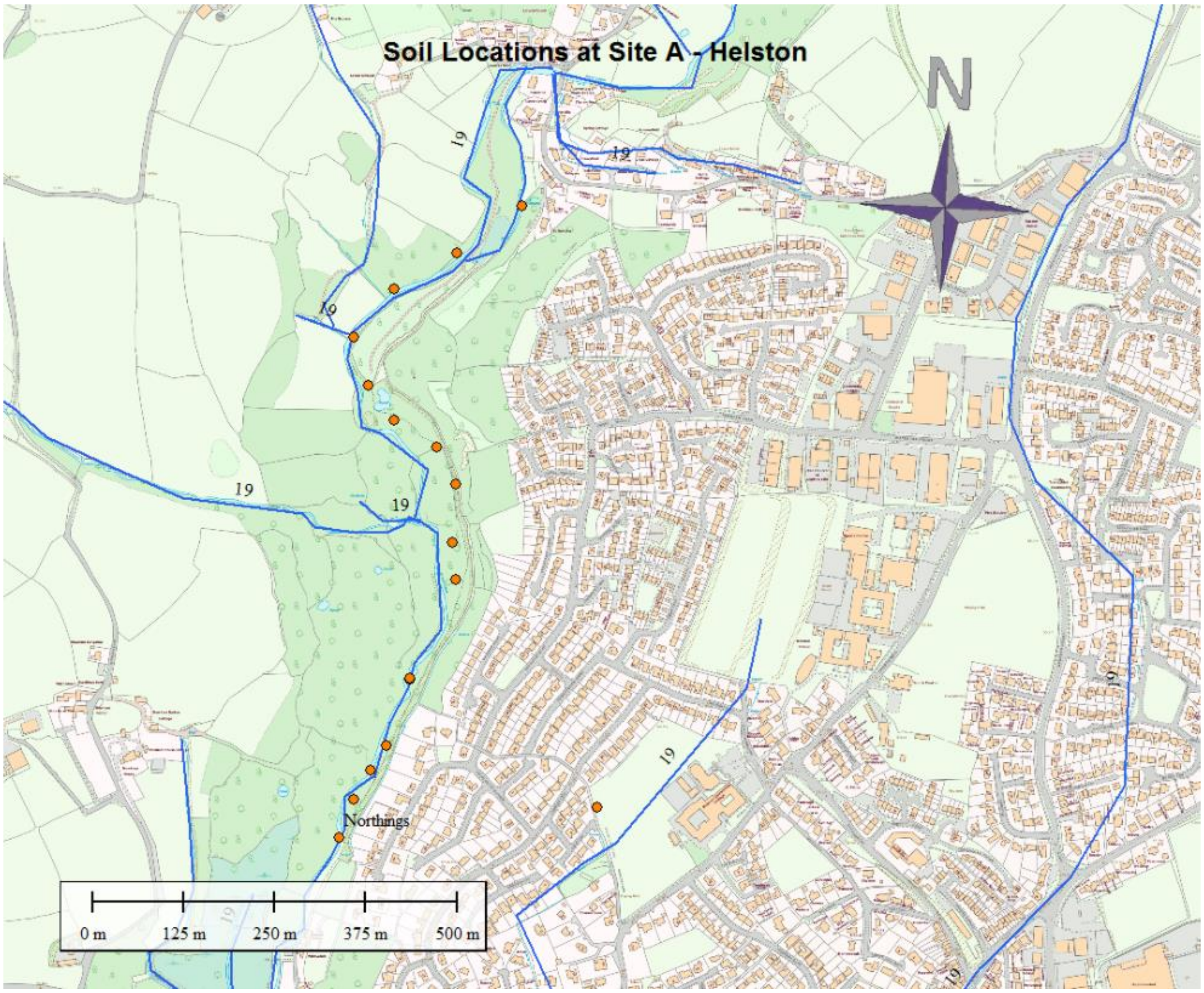
10.1 Appendix A – Legend for map of Cornwall's geology

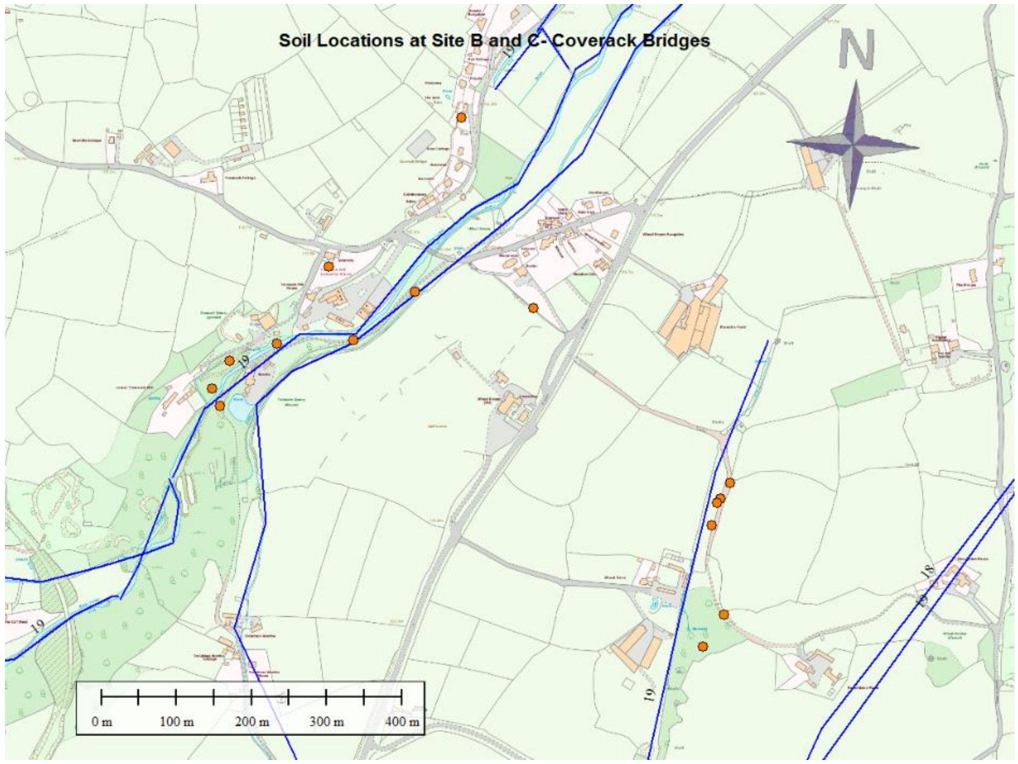


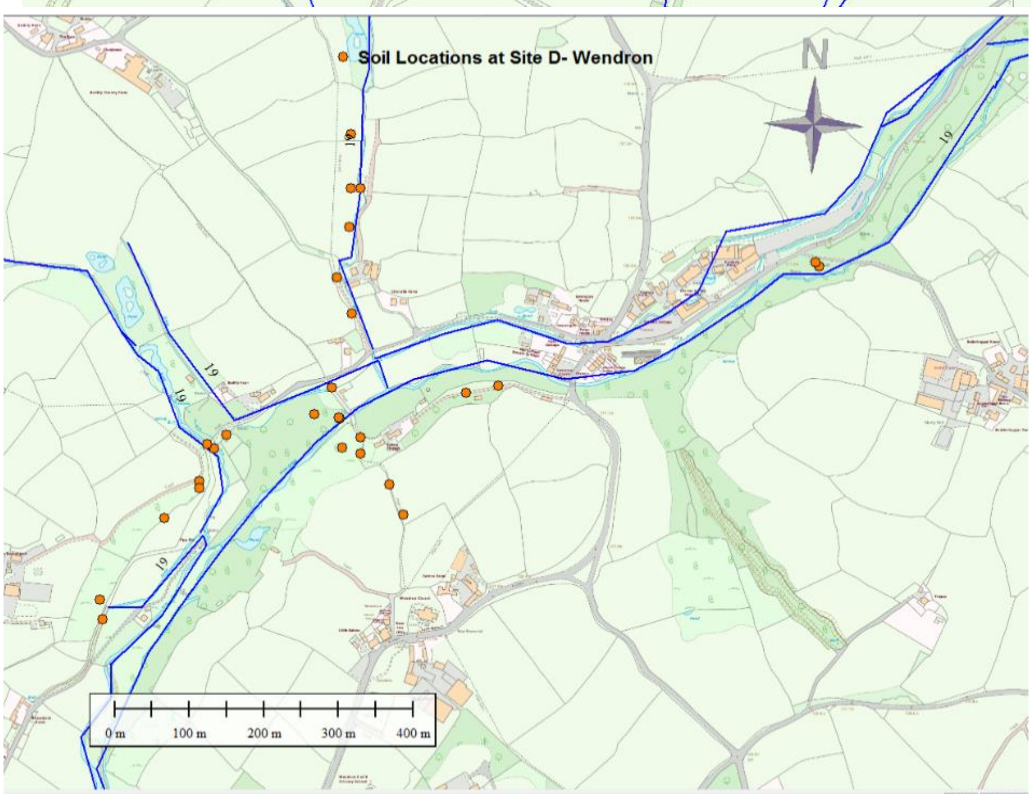
10.2 Appendix B – Map of Cober Catchment boundary & watercourses

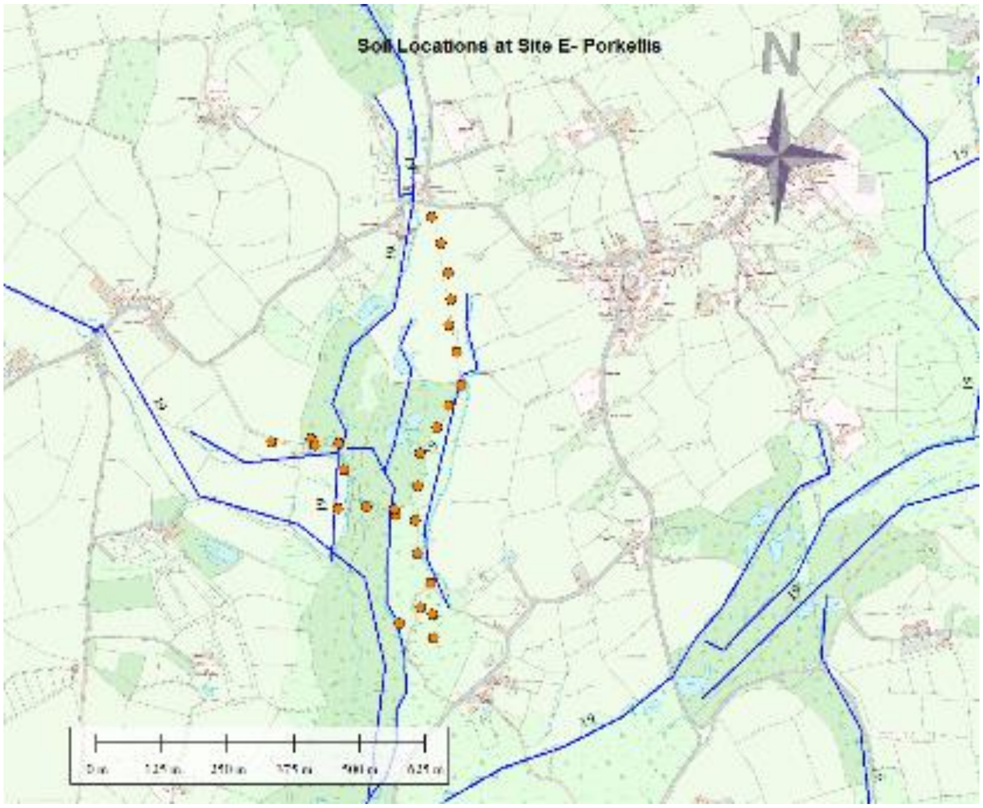


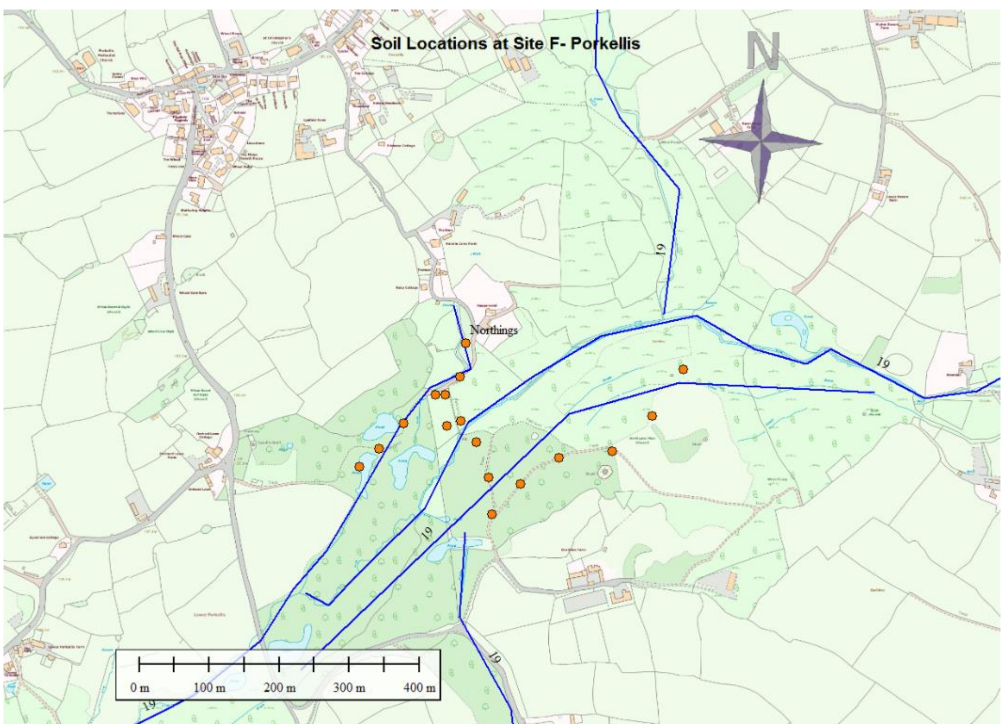
10.3 Appendix C: Point Data of soil sampling sites

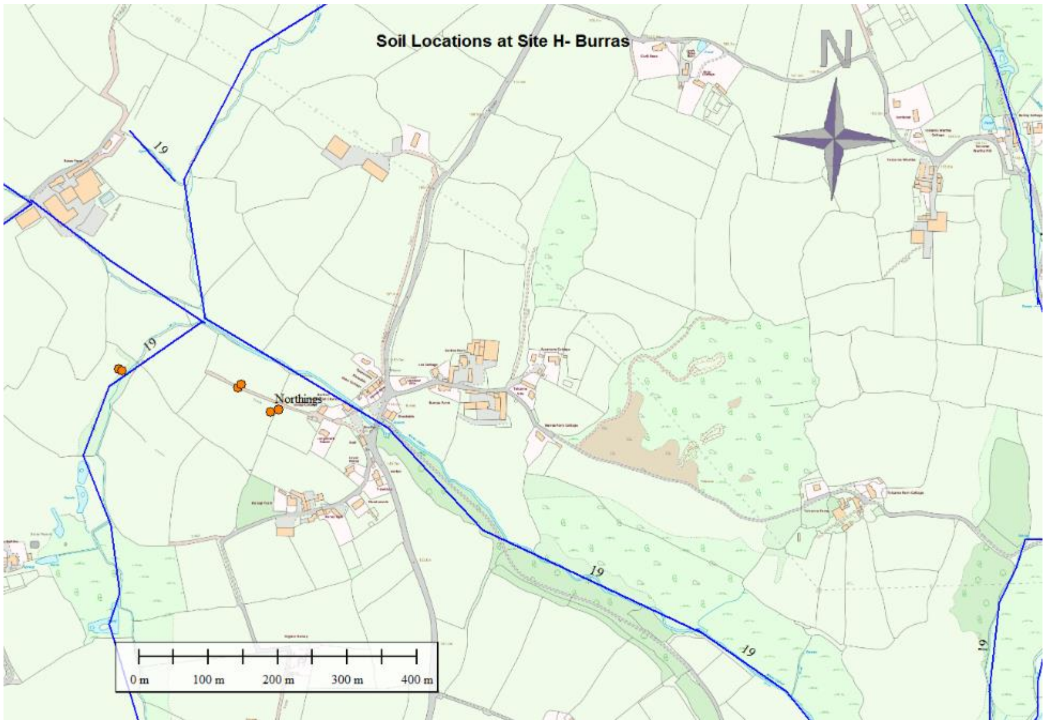


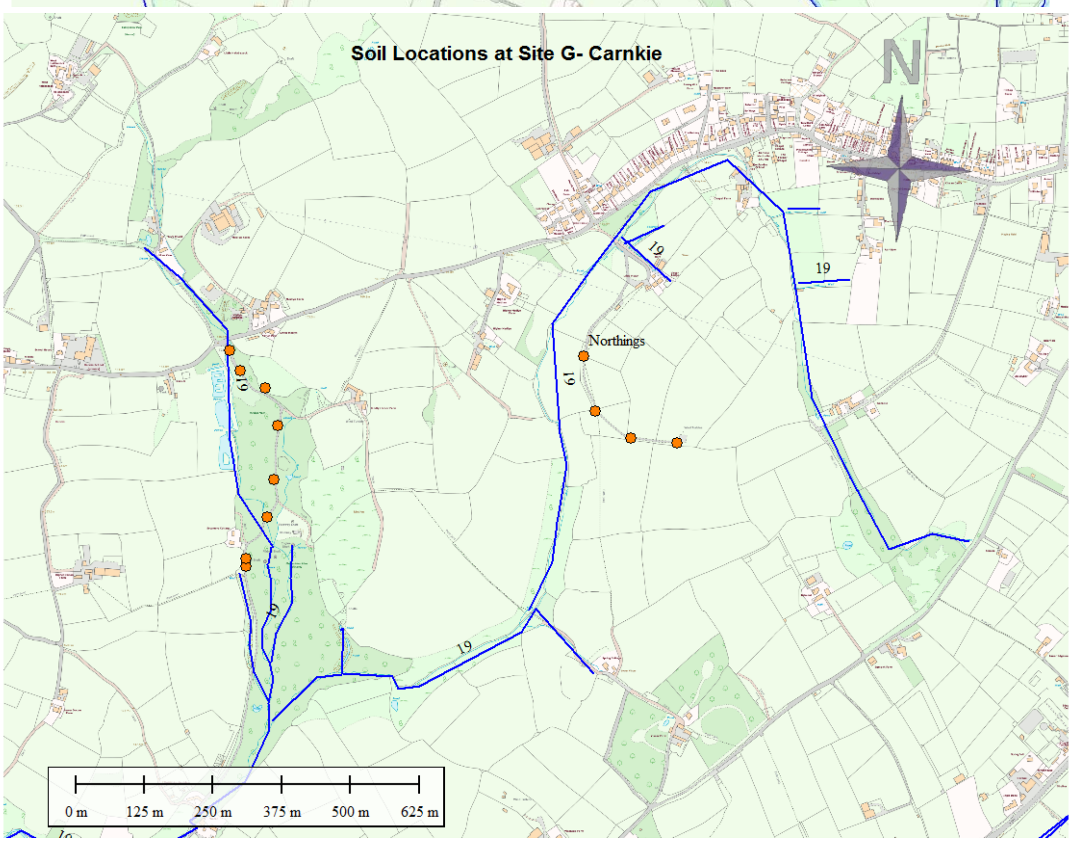

Soil Locations at Site B and C- Coverack Bridges
N
0 m
100 m
200 m
300 m
400 m


Soil Locations at Site D- Wendron
N
0 m
100 m
200 m
300 m
400 m


Soil Locations at Site E- Porkellis
N
19
0 m
125 m
250 m
375 m
500 m
625 m


Soil Locations at Site F- Porkellis
N
Northings
19
0 m
100 m
200 m
300 m
400 m


Soil Locations at Site H- Burras
N
19
19
Northings
19
19
19
0 m
100 m
200 m
300 m
400 m

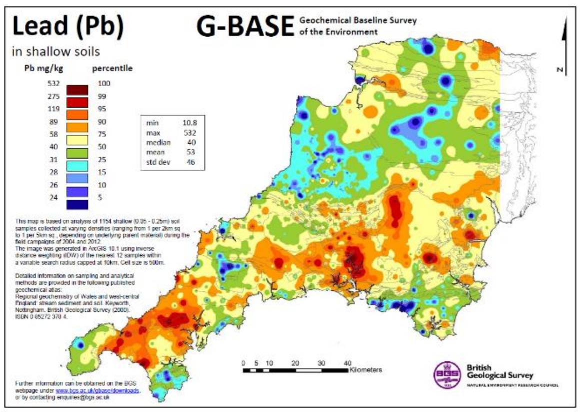

Soil Locations at Site G- Carnkie
N
19
19
Northings
19
19
19
19
0 m
125 m
250 m
375 m
500 m
625 m

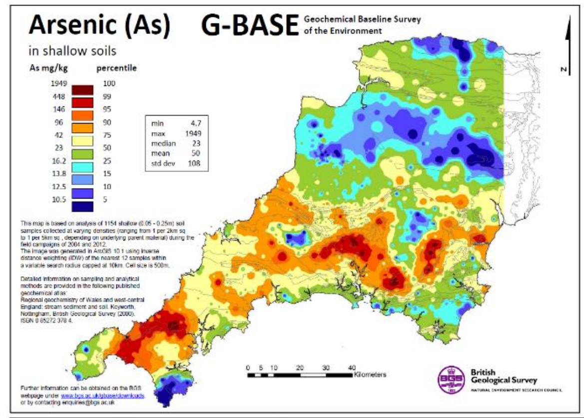
10.4 Appendix D: Table showing each metal value from Pxrf for each soil sample and its geolocation

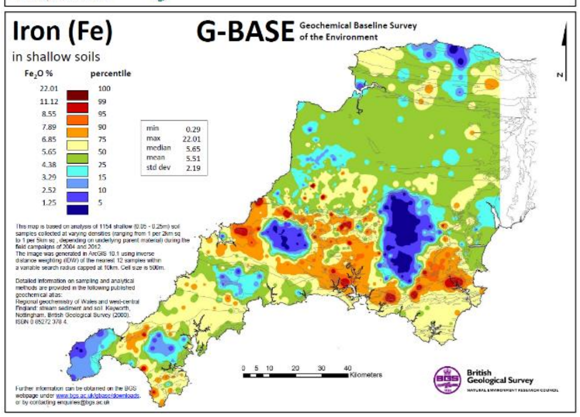
Site	Eastings	Northings	Sn Average	W Average	Fe Average	Cu Average	As Average	Pb Average
A1	165519	28077	1314.5	61	54153	179.5	186	125
A2	165539	28128	1270.5	64	45464.5	145.5	164.5	86.5
A3	165561	28169	550	49.5	41801.5	478.5	86.5	55.9
A4	165872	28117	508	41	46777.5	1395.5	99.55	64.2
A5	165583	28202	573	46.5	45200.5	188.5	78.5	74.7
A6	165615	28293	2174	140	35194.5	1716	796.25	2669.5
A7	165615	28294	1072	77.5	54756.5	253	184	68.5
A8	165615	28294	1040	54.5	50687.5	281.5	113.5	84
A9	165679	28429	591	47.5	47224.5	93	93.75	81
A10	165673	28480	1586	87.5	46919.5	222.5	196.5	88
A11	165678	28560	4225	121.5	36228.5	203	506	79.5
A12	165652	28611	3544	151.5	49525	337	511.5	281.5
A13	165593	28647	3209	123	39117.5	271	406	97
A14	165559	28695	5735	238.5	56433	711	575.5	47.1
A15	165539	28761	5483.5	138	38278	387	342	66.45
A16	165594	28827	5210.5	169.5	40890	440	418	65.5
A17	165680	28877	4318.5	153.5	37213	326.5	405	85
A18	165769	28941	3241	338	75564.5	150	285	156
B1	167253	29798	449.5	49.5	14127.5	434.5	83.95	45.8
B2	167240	29777	455.5	51	14459.5	286.5	103.3	39.65
B3	167235	29771	502	66.5	30303	405.5	417	168
B4	167228	29741	658.5	71.5	31380	249	286.5	159
B5	167244	29621	824.5	57.5	21280.5	350.5	843	77.5
B6	167216	29577	910.5	59	23229.5	1277	300.5	84.35
C1	166834	30056	1132	41	22132	107.5	78.95	31.9
C2	166896	30291	236.5	25.5	23060.5	43.5	42.25	48.4
C3	166752	29991	538	50.5	28638	151.5	78.1	58.9
C4	166719	30090	1617.5	52	22754	77.5	125.8	50.35
C5	166651	29986	574	40	18380	109.5	90.8	65.45
C6	166587	29963	547.5	44	19582	49.5	126.95	74.15
C7	166575	29902	726.5	48	18814	142.5	193	41.35
C8	166564	29925	1554	80	27660	263.5	287.5	55.1
C9	166958	33041	435.5	34.5	21549.5	63.5	107.7	50.6
C10	166991	30034	317	40.5	24402.5	48	102.65	51.05
D1	167855	31190	268	28	24003.5	83.5	38	69.2
D2	167837	31231	198	28	20331	57.5	27.05	50.75
D3	167798	31273	205	30.5	12885	27.85	21.95	24.8
D4	167798	31295	2144.5	48	26247.5	54.5	33.2	48.95
D5	167770	31320	1840	40	36043.5	199	19	22.75
D6	167774	31281	2392.5	48.5	23330	97.5	36.2	29.9
D7	167760	31362	1449.5	57.5	27010	89	38.9	83.5
D8	167769	31322	659	39	30644	103	50	165.5
D9	167737	31326	1110	38.5	20919.5	62	34.1	55.7
D10	167619	31298	442	54.5	9788	71	18.35	72
D11	167602	31280	2282	39	20015.5	114.5	54.65	24.95
D12	167593	31285	1429	35.5	12038	45	21.55	28.45
D13	167582	31235	976	31	17065.5	48.5	38.25	35.95
D14	167582	31226	3117	54.5	21694.5	98.5	52.7	47.8
D15	167536	31185	734.5	33	14438.5	52	25.45	37.9
D16	167450	31074	4313.5	74	30905.5	195	52.1	43.8
D17	167453	31047	2905.5	62	26195.5	142.5	35.65	38.65
D18	167787	31463	667	49.5	24634	130.5	58.65	98
D19	167767	31512	400	44.5	22805	94.5	44.5	280.5
D20	167783	31581	711	37.5	17610	91	28.15	56.05
D21	167786	31633	500	37.5	18980	110	30.6	57.5
D22	167798	31633	230.5	38.5	9391	34.7	11.2	25.65
D23	167786	31707	221.5	16	9001.5	38.65	16.65	32.45
D24	167775	31812	413	29	14717.5	71.5	29.5	59.85
D25	168412	31527	397.5	30	23487	73	26	55.85
D26	168407	31533	1006	39	23781.5	92.5	35.45	136.5
D27	167983	31365	142.5	19	14002	38.75	50.1	53.15
D28	167940	31356	818.5	36.5	14778.5	43.3	22.45	22.7

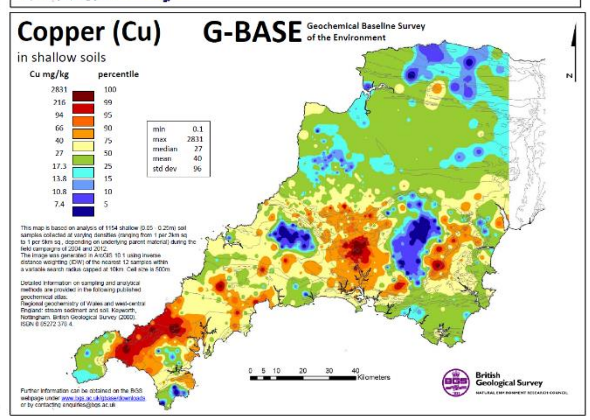
E1	168891	33474	3720	50	28018.5	52.5	14.5	41.5
E2	168909	33422	3112.5	58	28996.5	77.5	23.75	49
E3	168922	33366	5572.5	62	36934	78.5	27.1	51.1
E4	168927	33316	888.5	36	21061.5	47	15.9	38.35
E5	168925	33267	675	36.5	19343.5	40.25	8.7	28.05
E6	168938	33216	2493	65.5	24576.5	54	11.9	35.1
E7	168947	33153	2811.5	60	30345	76	24.3	47.9
E8	168925	33115	994.5	28.5	15523.5	33.2	10.8	39.6
E9	168901	33072	734	27.5	14731	35.2	12.6	31.8
E10	168868	33024	706	33.5	16820.5	55	9.6	30.05
E11	168865	32960	1252	31.5	18771.5	84.5	12.35	33.85
E12	168859	32896	3256.5	39.5	39355.5	71.5	8.4	13.9
E13	168863	32832	3328	44	38616	175.5	18.9	45
E14	168889	32776	5239	61	55820.5	477	26.8	60.7
E15	168894	32716	9568.5	97.5	102246	914.5	42.5	53.5
E16	168870	32729	10382.5	89.5	82400	768	31.95	42.15
E17	168830	32700	11612.5	202.5	207060.5	2241	103.5	119.5
E18	168895	32671	5316.5	63	46904	421	15.7	41.25
E19	168892	32717	14429	131	130538.5	1368.5	51.2	44
E20	168823	32907	1640.5	22	17951.5	59	13.55	37.95
E21	168819	32917	1813	38	29403	103	32.7	52.3
E22	168767	32922	3111	40	15598.5	24	15.45	27.3
E23	168713	32918	5551	53.5	33934	75.5	19.35	24.05
E24	168724	32992	4706	44.5	25510	38.5	22.05	30.8
E25	168715	33043	3875	44.5	32110.5	87.5	45.05	35.4
E26	168661	33051	2934	37	22636	53	19.55	68.8
E27	168586	33045	314.5	24	17793	34.85	20	44.15
E28	168668	33040	340.5	24	18002	43	19.4	75.45
F1	169641	33023	1456	56	32411	128.5	48.5	208.5
F2	169633	32975	1261	46.5	23665.5	88.5	25.3	136.5
F3	169597	32950	1397.5	45	27310	125	22.9	63.3
F4	169552	32909	3108	53.5	31095.5	64.5	22.25	35.2
F5	169517	32873	1999.5	64	29743.5	142	28.4	56.85
F6	169489	32847	3754.5	47	30196.5	70	26.05	83
F7	169612	32950	3481	51	33694	105.5	25.75	67.25
F8	169614	32906	1952.5	38.5	23985.5	63.5	19.05	55.7
F9	169634	32912	3263	63	40200	152.5	51.05	51.6
F10	169656	32882	789	39	23423	119.5	33.9	35.4
F11	169673	32832	1258.5	51	29327.5	92.5	34.5	46.6
F12	169678	32779	937	48.5	33392.5	283	129.95	43.15
F13	169719	32823	1436	56	37603.5	160.5	27.9	47.5
F14	169774	32860	1059	49	33109.5	192.5	25.8	44.6
F15	169849	32869	887.5	46	35916.5	925	36.1	39.9
F16	169907	32920	279.5	31.5	18928	108.5	23.3	46.15
F17	169951	32986	1091	41	32920.5	261	36.25	58.7
F18	170473	32889	6652.5	87	57639	170.5	43.9	39.9
G1	171185	33875	29	14.5	6033.5	11.45	8.2	14.05
G2	171206	33775	58.5	26	10726.5	30.55	27.3	34.1
G3	171272	33726	43	29	18855	19.1	23.8	25.95
G4	171355	33717	27.5	17	11186	16.6	18.5	22.6
G5	170541	33885	234	17	5977.5	48	14.7	23.2
G6	170561	33849	430.5	29.5	14879.5	37.3	20.65	34.15
G7	170607	33817	271	24.4	12310.5	37	24.5	33.55
G8	170629	33749	1415.5	43.5	32275	42	66	534
G9	170623	33651	1208.5	21.5	15396	12.6	10.35	15.2
G10	170610	33582	2567.5	47.5	32011	144.5	60.15	55.35
G11	170571	33494	716.5	50	31172	92	41.65	60.35
G12	170572	33508	562	33.5	21998	39.5	15	30.55
H1	167692	34907	48.5	17.5	12665.5	22.2	22.75	55.75
H2	167704	34910	49.5	21	14042.5	31.95	25.55	47
H3	167645	34942	51	23	20387	20	23.7	41.4
H4	167650	34946	59.5	18.5	9069	21.9	21.5	40.1
H5	167474	34969	52.5	16	8092.5	21.2	20.4	51.05
H6	167478	34966	38.5	22.5	13649.5	23.85	22.8	35.45

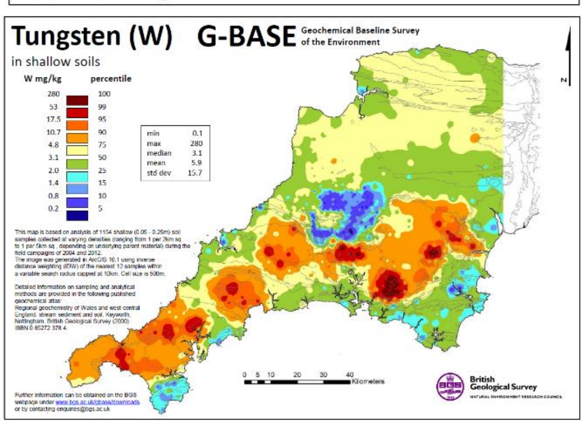
10.5 Appendix E: G-BASE maps of mineral concentration in the south-west for soil and sediment

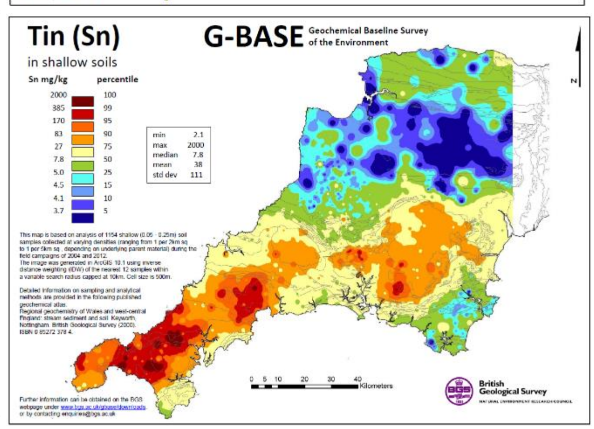


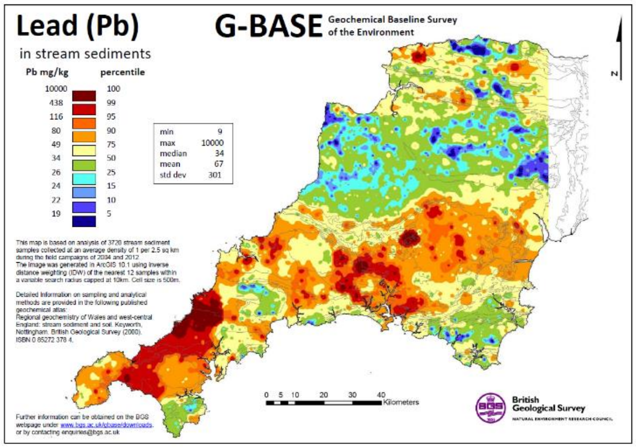


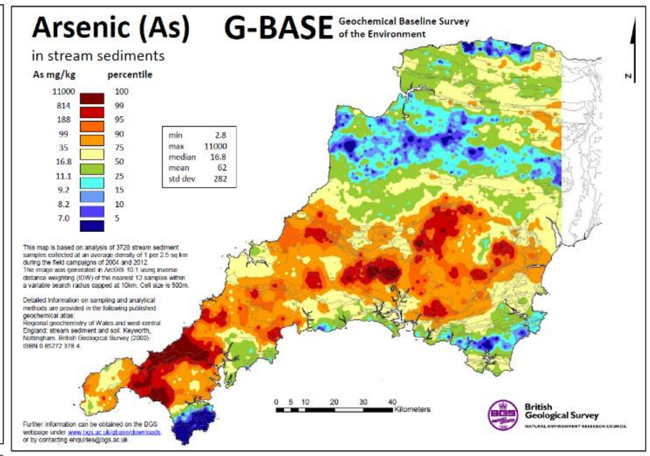









Lead (Pb)
G-BASE Geochemical Baseline Survey of the Environment
in stream sediments
Pb mg/kg percentile
10000 100
438 99
116 95
80 90
49 75
34 50
26 25
24 15
22 10
19 5
min 9
max 10000
median 34
mean 67
std dev 301
This map is based on analysis of 3720 stream sediment samples collected at an average density of 1 per 2.5 sq km during the field campaigns of 2004 and 2012.
The image was generated in ArcGIS 10.1 using inverse distance weighting (IDW) of the nearest 12 samples within a variable search radius capped at 10km. Cell size is 500m.
Detailed information on sampling and analytical methods are provided in the following published geochemical atlas:
Regional geochemistry of Wales and west-central England: stream sediment and soil. Keyworth, Nottingham. British Geological Survey (2000). ISBN 0 85272 378 4.
Further information can be obtained on the BGS webpage under www.bgs.ac.uk/gbase/downloads, or by contacting enquiries@bgs.ac.uk
0 5 10 20 30 40 Kilometers
N
British Geological Survey


Arsenic (As)
G-BASE Geochemical Baseline Survey of the Environment
in stream sediments
As mg/kg percentile
11000 100
814 99
188 95
99 90
35 75
16.8 50
11.1 25
9.2 15
8.2 10
7.0 5
min 2.8
max 11000
median 16.8
mean 62
std dev 282
This map is based on analysis of 3720 stream sediment samples collected at an average density of 1 per 2.5 sq km during the field campaigns of 2004 and 2012.
The image was generated in ArcGIS 10.1 using inverse distance weighting (IDW) of the nearest 12 samples within a variable search radius capped at 10km. Cell size is 500m.
Detailed information on sampling and analytical methods are provided in the following published geochemical atlas:
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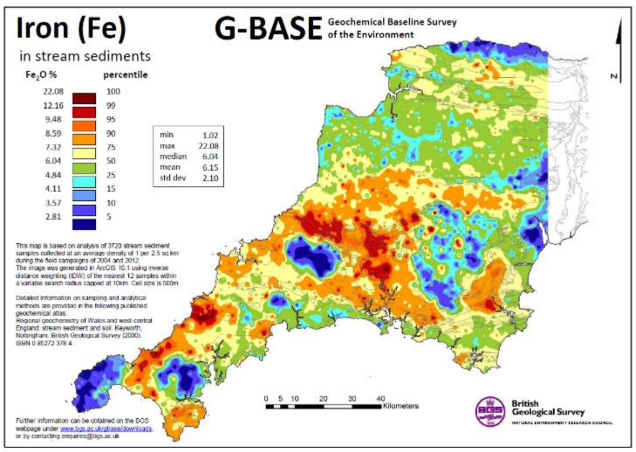
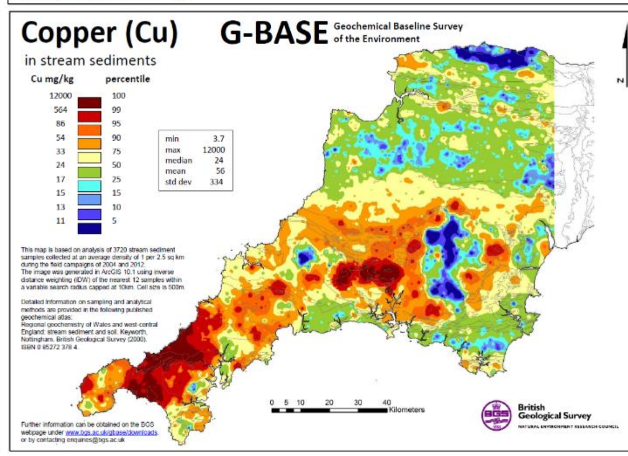
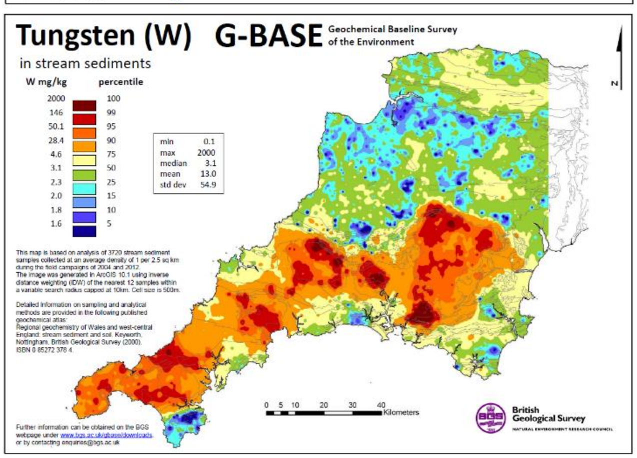
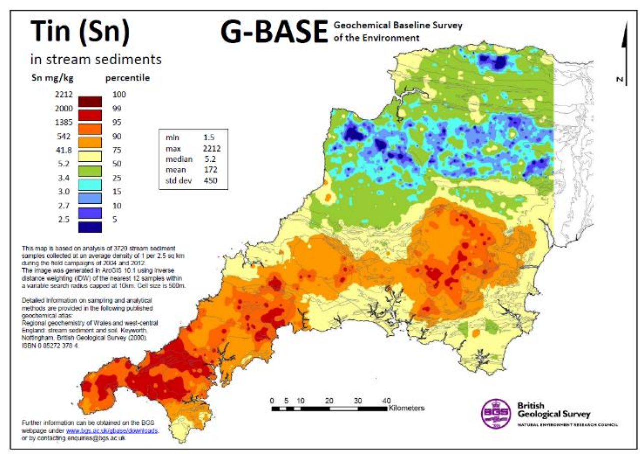
Further information can be obtained on the BGS webpage under www.bgs.ac.uk/gbase/downloads, or by contacting enquiries@bgs.ac.uk
0 5 10 20 30 40 Kilometers
N
British Geological Survey


Iron (Fe)
G-BASE Geochemical Baseline Survey of the Environment
in stream sediments
Fe_2O % percentile
22.08 100
12.16 99
9.48 95
8.59 90
7.32 75
6.04 50
4.84 25
4.11 15
3.57 10
2.81 5
min 1.02
max 22.08
median 6.04
mean 6.15
std dev 2.10
This map is based on analysis of 3720 stream sediment samples collected at an average density of 1 per 2.5 sq km during the field campaigns of 2004 and 2012.
The image was generated in ArcGIS 10.1 using inverse distance weighting (IDW) of the nearest 12 samples within a variable search radius capped at 10km. Cell size is 500m.
Detailed information on sampling and analytical methods are provided in the following published geochemical atlas:
Regional geochemistry of Wales and west-central England: stream sediment and soil. Keyworth, Nottingham. British Geological Survey (2000). ISBN 0 85272 378 4.
Further information can be obtained on the BGS webpage under www.bgs.ac.uk/gbase/downloads, or by contacting enquiries@bgs.ac.uk
0 5 10 20 30 40 Kilometers
N
British Geological Survey


Copper (Cu)
G-BASE Geochemical Baseline Survey of the Environment
in stream sediments
Cu mg/kg percentile
12000 100
564 99
86 95
54 90
33 75
24 50
17 25
15 15
13 10
11 5
min 3.7
max 12000
median 24
mean 56
std dev 334
This map is based on analysis of 3720 stream sediment samples collected at an average density of 1 per 2.5 sq km during the field campaigns of 2004 and 2012.
The image was generated in ArcGIS 10.1 using inverse distance weighting (IDW) of the nearest 12 samples within a variable search radius capped at 10km. Cell size is 500m.
Detailed information on sampling and analytical methods are provided in the following published geochemical atlas:
Regional geochemistry of Wales and west-central England: stream sediment and soil. Keyworth, Nottingham. British Geological Survey (2000). ISBN 0 85272 378 4.
Further information can be obtained on the BGS webpage under www.bgs.ac.uk/gbase/downloads, or by contacting enquiries@bgs.ac.uk
0 5 10 20 30 40 Kilometers
N
British Geological Survey


Tungsten (W)
G-BASE Geochemical Baseline Survey of the Environment
in stream sediments
W mg/kg percentile
2000 100
146 99
50.1 95
28.4 90
4.6 75
3.1 50
2.3 25
2.0 15
1.8 10
1.6 5
min 0.1
max 2000
median 3.1
mean 13.0
std dev 54.9
This map is based on analysis of 3720 stream sediment samples collected at an average density of 1 per 2.5 sq km during the field campaigns of 2004 and 2012.
The image was generated in ArcGIS 10.1 using inverse distance weighting (IDW) of the nearest 12 samples within a variable search radius capped at 10km. Cell size is 500m.
Detailed information on sampling and analytical methods are provided in the following published geochemical atlas:
Regional geochemistry of Wales and west-central England: stream sediment and soil. Keyworth, Nottingham. British Geological Survey (2000). ISBN 0 85272 378 4.
Further information can be obtained on the BGS webpage under www.bgs.ac.uk/gbase/downloads, or by contacting enquiries@bgs.ac.uk
0 5 10 20 30 40 Kilometers
N
British Geological Survey


Tin (Sn)
G-BASE Geochemical Baseline Survey of the Environment
in stream sediments
Sn mg/kg percentile
2212 100
2000 99
1385 95
542 90
41.8 75
5.2 50
3.4 25
3.0 15
2.7 10
2.5 5
min 1.5
max 2212
median 5.2
mean 172
std dev 450
This map is based on analysis of 3720 stream sediment samples collected at an average density of 1 per 2.5 sq km during the field campaigns of 2004 and 2012.
The image was generated in ArcGIS 10.1 using inverse distance weighting (IDW) of the nearest 12 samples within a variable search radius capped at 10km. Cell size is 500m.
Detailed information on sampling and analytical methods are provided in the following published geochemical atlas:
Regional geochemistry of Wales and west-central England: stream sediment and soil. Keyworth, Nottingham. British Geological Survey (2000). ISBN 0 85272 378 4.
Further information can be obtained on the BGS webpage under www.bgs.ac.uk/gbase/downloads, or by contacting enquiries@bgs.ac.uk
0 5 10 20 30 40 Kilometers
N
British Geological Survey

10.6 Appendix F: Watershed map covering upper Cober Catchment

10.7 Appendix G Map of Cober Catchment, Wendron mining district and mine sites