FLOOD CAPACITY MODELLING AND FLOOD INUNDATION ON THE RIVER COBER, HELSTON, CORNWALL

Submitted by Catherine Judith Nichol to the University of Exeter as a dissertation towards the degree of Master of Science by advanced study in Surveying/Land and Environmental Management, September 2016

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……………………………………………………………………………………..

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ABSTRACT:

This work is focused on flood inundation and capacity modelling along the River Cober, Helston, Cornwall. Conclusions are drawn as to whether the current flood practices used along the River Cober are the most suitable for alleviating the flooding problem within Helston.

Helston frequently floods particularly in the St Johns area. The main cause of this flooding is overtopping of the River Cober, which runs south to north on the west side of Helston. This work uses surveying techniques to research as to whether it is the river conveyance and flow that are causing the flooding issues.

The Conveyance Estimation System (CES) software developed by HR Wallingford outputs determine that the River Cober at a peak flow rate during flood conditions can have conveyance of 500 m^3/s and a flow rate of 10 m^3/s. This suggests that the flooding within Helston is caused by the slow rate not allowing the river water to flow quickly enough and therefore the conveyance is exceeded. The flood inundation prediction in Helston is demonstrated using DTM data.

The CES outputs suggest that hard engineering could be the better solution because of the problematic slow flow on the River Cober. Hard engineering has already been completed within Helston in the form of channelisation. However historic evidence and literature suggests that soft engineering solutions would be the preferred option.

This work concludes that in Helston the best option for flood alleviation is reconnecting the floodplains with the river and having a more natural hydrological system. This has already been suggested by the National Trust the primary landowner in the lower reaches of the River Cober. This needs to be completed by removing the barriers obstructing the potential flood flow. These barriers include the manmade footpaths seen in the carr habitat.

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CHAPTER 1: INTRODUCTION**:**

Flooding in Europe is considered one of the most significant natural disasters (Moel et al., 2009). Many centres of population are affected by the impacts of flooding. Helston in Cornwall, South West England is no exception to this. The Environment Agency (2016) report flooding in Helston in: 1894, 1945, 1952, 1970, 1971, 1973, 1976, 1979 (twice), 1988, 1992, 1993, 2002, 2003 (twice), 2004, 2012 (twice) and 2013. Although the cause of some flooding in Helston is surface water runoff the main cause is overtopping of the River Cober banks. Helston has therefore been subject to various flood alleviation schemes and monitoring. As well as reports relating to the flooding from other interested parties for example the National Trust. The differing agendas of the parties mean that the various reports suggest differing ideas for flood alleviation within Helston.

Flood alleviation and risk management are now a focus for many settlements. However knowledge of a river's water level, flow and capacity is essential to flood risk management tasks (Gahey et al., 2006). This work aims to review and assess these parameters through surveying in relation to flooding alleviation in Helston.

The capacity of the river is an essential parameter in flooding. This work uses traditional surveying techniques in combination with the Conveyance Estimation System (CES) software developed by HR Wallingford (an independent civil engineering and environmental hydraulics organisation, with a historic reputation for excellence, (HR Wallingford, 2016)) to access the River Cober capacity. By assessing the capacity and flow using the CES software outputs a comparison can be made to the flood inundation created from Digital Terrain Model data. This information together will be used to synthesis why there are such issues relating to the River Cober flooding in Helston.

The collection of this output data has allowed solutions to be suggested to the apparent flooding problem within Helston. These solutions aim to move away from the traditionally engineered flood alleviation that has been used before in Helston.

CHAPTER 2: AIMS and SCOPE OF WORK:

This work has reviewed academic literature (Chapter 3) and the problems of flooding in Helston (Chapter 4) to create the aim below.

- **To make a study of the issues of flooding along the River Cober, South West Cornwall, England.**

By reviewing the historic documents available the issues of flooding in the Helston area will become apparent.

- **To look in to the conveyance capacity of the River Cober in relation to flood inundation in two key study areas around Helston.**

The HR Wallingford Conveyance Estimation System (CES) software will be used in conjunction with traditional surveying techniques to assess the conveyance of the River Cober. The conveyance is the discharge capacity of the watercourse. The outputs from the use of the CES software will allow some of the parameters of flooding to be assessed as to whether they are a cause of flooding in Helston.

- **To observe flood inundation mapping along the River Cober particularly around Helston**.

The issues surrounding flood inundation modelling will be discussed through the use of the academic literature. Flood inundation for the Helston area will be modelled using a digital terrain model (DTM) data and compared with the Environment Agency flood inundation mapping.

- **To review current flood alleviation practises in Helston and suggest new ideas based on the outputs of this work.**

The current flood alleviation schemes in Helston will be reviewed and other options considered. New options will be suggested using the data collected during the work; that will work most effectively for the River Cober catchment.

CHAPTER 3: LITERATURE REVIEW:

Flooding is a common occurring natural hazard that effects a vast amount of the anthropogenic environment. The act of flooding can be defined as the temporary covering of land by water that is normally exposed (Alphen et al., 2009). There are various different types of flooding but all flooding results in inundation of areas outside of the normal watercourse (Moel et al., 2009).

This literature review aims to briefly consider the issues surrounding flooding relating to both risks and hazards. Before moving onto examine monitoring techniques with a particular focus on flood inundation mapping and flood monitoring techniques that can relate to geomatic surveying. It is then possible to use the academic literature to review the best surveying techniques relating to flood inundation and capacity modelling. This will allow for more meaningful focus within the later chapters of work.

General problems surrounding flooding: Many geographical regions suffer with the problems and effects of flooding. Europe is currently experiencing a flood rich period temporally, with a spate of major flood experienced across the continent (Wilkinson et al., 2015). The flooding of rivers is considered to be one of the most prevalent natural disasters in Europe; having been approximately calculated to have caused over €100 billion of damage within Europe from 1986 to 2006 (Moel et al., 2009). The United Kingdom (UK) is included within this area significantly affected by the impact of flooding. Flooding within the UK causes a risk to: people, the surrounding landscape and the economic environment (DEFRA, 2006). Globally during the 20th century floods accounted directly for 12% of deaths relating to natural disasters. The amount of deaths recorded connected to flooding during the 20th century is recorded at 93000.

The UK only has small scale rivers compared to rivers globally, for example the River Severn and River Thames have catchment areas of approximately 10,000 km^2, whereas the River Nile (Egypt) has a catchment area of 3.3million km^2 (Wheater, 2006). However even with small scale rivers the effects of flooding events in the UK can be devastating to the communities involved. In Carlisle, (North West England) both the River Petteril and River Caldew combine into the River Eden. In 2005 widespread rainfall meant that in Carlisle over 2000 properties were flooded, two lives lost and an estimated £450 million worth of damage (Wheater, 2006).

Within the topic of natural hazards risk and hazard are often defined separately. The hazard is what causes the risk, and the risk is what the anthropogenic community are potentially concerned by. Within flooding a flood hazard can be described as the flood conditions in which people are likely to be swept over or drowned (DEFRA, 2006). Flood risk is defined by DEFRA (2006) as the probability of a flooding event multiplied by the consequence of the flooding event. Alphen, et al., (2009) describe flood risk as a combination of the probability of the flood event and the potential for adverse consequences on the environment, cultural heritage, economic activity and human health. Moel et al. (2009) agree with this suggesting that all definitions of flood risk come to an agreement in that risk is a combination of the physical characteristics of the flood event and its potential consequences. "Flood forecasting and warning, emergency planning, land use planning and the operation of flood defence systems have all contributed to reducing [the] risks" (DEFRA, 2006. p. 1) of flooding. However it is often the case that these risk reducing measures are not completely effective, hence comprehensive reviews of these risk reducing methods is often required.

Potential of flood maps for studying flooding: One source of flood forecasting, prevention and monitoring that uses surveying is the use of flood maps. Flood maps can have several definitions and uses. Displaying the data on maps has many positive aspects and "maps give a more direct and stronger impression of the spatial distribution of the flood risk than other forms of presentation" (Merz et al., 2007. p. 231). There are several purposes for flood maps these include simply raising awareness among the local community at risk, providing an information source to land-use planners and developers, helping to assess the feasibility of flooding control measures, allowing emergency situations to be prepared for and to serve as a base for deriving flood insurance premiums (Merz et al., 2007).

The importance of flood maps is demonstrated within the European Union (EU) Flood Directive created in 2007. In order to meet the requirements of the EU Flood Directive all member states have to include flood mapping within the assessment and management of their flood risk framework (Moel et al., 2009). There are many types of flood maps created and utilised (Moel et al., 2009). Alphen et al., (2009) suggest there are two types of flood maps that can be utilised; flood risk maps and flood hazard maps. Flood risk maps should aim to demonstrate the potential negative consequences associated with a flood (Alphen et al., 2009). Food hazard maps depict where the physical flood can happen spatially. Flood risk maps can be utilised by a wide variety of stakeholders, Alphen et al., (2009) suggest that flood risks maps can be adapted and employed by land use planers who are interested in the position of flood prone areas, authorities in charge of flood protection design and installation, companies responsible for providing important services such as natural gas and oil, members of the public who are looking to purchase or sell property and insurance companies who are need to know the potential damage of an areas and the related probability of that damage.

Moel et al., (2009) suggest there are up to six different types of flood maps that can be created (flood extent map, flood depth maps, maps displaying other flood parameters, flood danger maps, exposure and coping capacity, flood risk maps). Flood extent maps display the inundated areas of specific flooding events, flood depth maps can be created when flood extents are calculated for specific return periods (Moel et al., 2009). Maps displaying other flood parameters normally include velocity, duration, propagation and rate of the rising water. Flood danger maps are displayed with aggregated qualitative classes, exposure and coping capacity and are dependent on the damage potential of the region and flood risk maps. Moel et al., (2009) agree with Alphen et al., (2009) suggesting flood hazard maps need to combine the information from flood extent and flood hazard information.

The vast quantity of types flood maps available starts to demonstrate the issues of flood mapping. They are not an exact science and there are uncertainties involved in many aspects of their creation. Merz et al., (2007) adds further to this argument by suggesting a possible four categories that flood maps could be created within. These categories are: flood danger maps, flood hazard maps, flood vulnerability maps and flood damage risk maps. Flood danger maps display the spatial distribution of the danger of the flood scenario, flood hazard maps also display this but with a statement on the extent on the flood including information about the intensity and occurrence of the flood (Merz et al., 2007). This suggests that Moel et al., (2009) are displaying both flood extent maps and flood depth maps in replacement for one flood hazard maps as described by Merz et al., (2007). A flood vulnerability map attempts to include the effect on the anthropogenic environment and looks to demonstrate information about the exposure and the susceptibility of flood prone elements (Merz et al., 2007). Whereas a flood damage risk map displays the spatial distribution of the flood damage risk for a specific scenario (Merz et al., 2007).

Flood maps like other cartographic products will need updating. Merz et al., (2007 p.245) suggests that “It is required that every community is screened at least once every five years to determine the need for map revision”. It may be the case that this review demonstrates no changes are needed as there are no changes to the parameters that have an effect on flooding. Burby (2001) suggests that a lack of revision of flood maps is one of the problems with the effectiveness of flood insurance policies.

The most important producers of flood maps are government institutions, transboundary river authorities and the insurance industry (Moel et al., 2009). Flood maps are particularly useful to insurance companies. Flood maps created and utilised by the insurance industry are used to determine: insurability, differentiate premiums and assess long-term financial solvency (Moel et al., 2009). Often a multicriteria approach is used where the total value of the asset that is at risk and its spatial distribution are estimated based on values assigned to the land-use categories (Meyer et al., 2009). The theory of potential flood insurance is simple, but putting effective flood insurance into a flood risk management scheme is more complicated (Surminiski and Eldridge 2015). Flood risk and hazard maps help with the completion of this, the production of models and maps can only aid the effectiveness of insurance practices but also the risk management practices (Kobayash et al., 2014). A normal flood insurance policy will aim to cover direct physical loses caused by the flood as well as losses resulting from flood-related erosion from waves or currents of water (Burby, 2001). Problems have been identified with the maps and tools used by insurance companies and there is subsequently an issue with the insurance policies that are issued. Burby (2001) suggest several issues that the United States (US) are having relating to flooding insurance policies. For a flood insurance policy to be effective an accurate estimate of the flooding risk is required. The US National Flood Insurance Programme has had problems relating to three areas: an inability to fund revisions of flood insurance maps when conditions have changed, areas with no mapping of localised storm water drainage many maps lacking enough details to facilitate the integration with any other data source and therefore can only be used on one polar environment (Burby, 2001). Within the US these issues have meant that there are insurance premiums and policies that do not reflect the actual value of the property if it was to be lost in floods (Burby, 2001). This has led to a "public misperception of flood risk" (Burby, 2001 p.118); the majority of properties have comprehensive fire damage insurance but the chance of a property that is built on an 100 year flood plain suffering fire damage is 1% whereas the chance of getting damaged by floods is 26% (Burby, 2001). But in 2001 many houses still had incorrect insurance policies relating to flooding (Burby, 2001). A flood insurance scheme needs to be applied correctly otherwise the problem could become worse (Burby, 2001).

On the other hand Haygarth (2016) suggests a different problem for flood insurance policies in the UK. Speaking about the recent flooding in the North West of England Haygarth (2016) noted that the flood maps were incorrect, so the insurance policies people could afford were not representative of their property. The Council of Mortgage Lenders predict that in the UK the insurance claims from flooding damage to properties are £2.1 billion, and they are predicted to rise between £2.1 and £12 billion in 70 years' time (Clarke, 2016). The large variation in this future prediction further suggests an issue with the UK flood insurance industry. The launch of Flood Re in April 2016 is trying to overcome issues within the industry. The intention of Flood Re is to ensure that domestic property insurance is widely available and affordable for homes at risk of flooding in the UK (Clarke, 2016).

Problems with flood mapping in previous studies: The issues the insurance companies face are exacerbated by the uncertainties within flood hazard maps. Problems with flood hazard maps are mentioned and discussed in numerous articles. Bales and Wagner (2009) suggest that flood hazard information could be improved if information was available in more locations, if information on inundated areas was provided over a full range of river stages (from bankfull scenarios to extremely low probability events) and if there was an improved interface with digital flood insurance rate maps. Alphen et al., (2009) also commented on the same issue in the same year; the work suggested that uncertainties in flood hazard maps can be caused by natural phenomena which there is a lack of knowledge of and a great amount of variability, uncertainties at the margins of extents, in accuracies in mapping and instruments used. Moel et al., (2009) suggest that the major sources of uncertainty in flood maps are because of statistical determination problems, issues with spatial extrapolation of data, difficulties with the digital elevation model (DEM) and the presence and or the failure of flood defence structures. Merz et al., (2007) suggested similar sources of uncertainty to Moel et al., (2009). Sighting potential errors in flood mapping due to: problems with the quality of data causing issues with the DEM resolution and issues with the data processing algorithms. Moel et al., (2009) agreed with Merz et al., (2007), suggesting errors could occur due to extrapolation of a limited amount of data and the vulnerability of the elements that are at risk due to the flooding. However despite these problems with the data used in flood hazard maps, they are still widely used in the industry to distinguish flood inundation areas from dry areas during flood scenarios.

Although the literature has different ideas on the problems faced in flood hazard maps or flood inundation maps; a large majority of the literature agrees on the importance of topographic data for the maps. Flood mapping has in the past been “constrained by the limited spatial resolution of available topographic data sources of the cost of acquiring such data through ground surveys” (Bates et al., 2003). Bales and Wagner (2009, p. 141) state that “the quality of the resulting inundation maps is highly dependent on the quality of the topographic maps used to create the map”. Sen et al., (2013) completed their research in a very different environment; wadis in arid regions, however they also suggest that connection with a detailed and good topographic map helps to delineate any flood inundation area. Hohenthal et al., (2011) also suggest that detailed fluvial topography data is required to allow for accurate modelling of flood extent. The importance of topography is furthered in that it is suggested that direct monitoring of the channel topography is a useful tool which allows better understanding of the river processes (Brasington et al., 2000) and hence indirectly flood inundation.

When considering topography relevant to flood inundation maps it is necessary to consider both the normal land surface topography but also the bathymetry. Bathymetry is the surface or topography submerged by the water in this case it could also be called the river bed. When detailed bathymetric data is included within a model there is a significant reduction in the inundation area of the flood scenario (Cook and Merwade, 2009). Hence it seems important that bathymetry is taken into account. Whether currently bathymetry is taken into account on flood maps used and produced seems unclear. Although it is clear from other literature the topography is important for flood inundation and hazard maps, the exact effect of topography is dependent on the scale of the river, bathymetric description and modelling approach being used (Cook and Merwade, 2009).

Further parameters of flood studies: Also essential to flood risk mapping is the knowledge of river water levels and capacity (Gahey et al., 2006). Although some flood insurance maps and inundation maps are often created by assuming steady flow conditions (Bales and Wagner, 2009), adding uncertainty to the maps output. Bales and Wagner (2009) suggested that there is a requirement to understand and include in flood mapping more than just steady flow models. In order for calculation of flow to be taken into account, and more than a steady flow to be used cross section geomatics, hydraulics and material properties need to be taken into account (Sen et al., 2013). Cook and Merwade (2009) also agreed with this suggesting there is a need for an interplay between topography, geometric description and hydraulic modelling.

Synthetic rating curves can help to aid flood and depth calculations of cross sections, all synthetic rating curves appear in a power function which relates the flow depth to discharge in a given cross section (Sen et al., 2013). Other ways to calculate flow capacity include: hand calculation methods, dimensional analysis, additional energy losses due to bends and the energy loss method (Gahey et al., 2006). This capacity of the water course can be considered as conveyance. Conveyance is a “quantitative measure of the discharge capacity of a watercourse” (Samuels et al., 2002). Conveyance relates total discharge to a measure of the gradient of slope of a channel (Samuels et al., 2002).

As with inundation mapping an approximation of conveyance of a river is an extremely important component of flood management, water level prediction and flood defence design (Samuels et al., 2002). A further method for estimating flow capacity or conveyance is the use of the Conveyance Estimation System (CES). The CES method utilises “the ‘as surveyed’ river cross sections and the observed roughness features” (Gahey et al., 2006) to quantify river flow. The CES methodology is effective for real life river engineering practise, it incorporates parameters that can be applied to channels over a large range of scales, geometries and roughness features (Gahey et al., 2006). It provides a method of calculating flow within the river over a range of channel types, flow conditions, vegetation and substrate cover (Gahey et al., 2008).

Surveying techniques utilised in previous studies: There are numerous ways for topography to be taken into consideration when producing and calculating flood inundation map however it does not seem apparent as to what the industry standard practice is. Consistent across some literature and studies is the use of traditional surveying techniques to create cross sections of the river that the inundation is being calculated for. The United States Geological Survey (USGS) (2014) took cross sections at 400 locations along the Kootenai River (British Columbia, Canada) using a total station and prism on pole method where the river was shallow enough. Another study that used this method was Sen et al., (2013); in order to calculate the cross-section geometry a total station instrument was placed in the middle of the cross section and a sequence of right and left readings taken at suitable distances from the instrument set-up location. This data was used to develop a cross-section DEM with the combination of other data sets (Sen et al., 2013). However the type of data collection used needs to reflect the environment which is being observed. Placing the instrument in the centre of the cross section being calculated was perhaps suitable with the work carried out by Sen et al., (2013) because of the arid dry wadi environment the work was related to. In other environments this might not be possible.

Brasington et al., (2000) also understand the importance of topography within cross sections and flood inundation studies, however they choose to use a Global Positioning System (GPS) based survey. Current advances in analytical photogrammetry techniques means that it is now possible to get good resolution of both macroform and microform channels in all three dimensions (Brasington et al., 2000). Although this technique differs little from the technique used by Sen et al., (2013) and the USGS (2014), a control network is still required to be set up, with the second stage detailed topographic survey being completed by a GPS rover unit (Brasington et al., 2000). Although the use of GPS does allow the work to be completed by one person.

Light detection and ranging units (LiDAR) uses laser technology to measure distances, this can be used to determine topography of the landscape that is scanned. Cook and Merwade (2009) use information from LiDAR scanning to gain topographic data to help with the construction of a more accurate flood inundation map. As with the data collected by Sen et al., (2013) and the USGS (2014) the LiDAR data is used as a skeleton to derive the underlying topographic data by using a DEM or a triangulated irregular network (Cook and Merwade, 2009). Using LiDAR data integrated with survey data and DEM's on average reduces the width of the river channel and bed and therefore the inundation decreases (Cook and Merwade, 2009). Henceforth suggesting that the use of LiDAR improves flood inundation studies. It is therefore reasonable to assume that the flood inundation predicted by a two dimensional model using LiDAR is more realistic and accurate than a one dimensional approach simply using existing mapping products (Cook and Merwade, 2009). Bates et al., (2003) further agree that the use of remote sensing data to obtain topographic data has allowed flood inundation maps to become data rich and spatially complex.

Beyond the use of LiDAR Hohenthal et al., (2011) research whether laser scanning techniques should be utilised within flood surveying. Within laser scanning there are several techniques that can be utilised; fine resolution close range laser scanning, an airborne approach to laser scanning or terrestrial laser scanning (Hohenthal et al., 2011). Fine resolution close range laser scanning can be utilised to measure a riverbed surface characteristic within flume experiments, whereas terrestrial laser scanning can be used when accurate microtopography of the actual landscape is required (Hohenthal et al., 2011). To gain an "an accurate description of the topography of the scanned areas, laser scanners can be mounted on a tripod on river banks" (Hohenthal et al., 2011, p. 6), this can provide up to 1 to 2 millimetres of accuracy. Airborne laser scanning is only suitable for use when long stretches of the river need to be studied (Hohenthal et al., 2011). A further option considered by Hohenthal et al., (2011) is boat mounted "laser" scanning techniques. Although unclear it assumed this utilises sound navigation and ranging techniques (SONAR). The use of a boat mounted scanner allows the collection of point cloud data of the river bed topography allowing detailed cross sectional data. This kind of technique is used widely in hydrographic surveying. However the use of boat mounted laser scanning is defined by the quality and accuracy of the GPS system used on the boat (Hohenthal et al., 2011).

Concluding Remarks: The literature clearly demonstrates that both "high quality topographic data, along with the appropriate application of hydraulic modelling" are essential when looking to study flooding (Bales and Wagner, 2009). Evidently it is essential to include both factors with some considerable accuracy when looking for a high accurate output of the flood prediction. However the effect of each parameter is perhaps unknown or needs to quantified, separately and differently for each location being considered for flooding. Overall the process of producing a flood inundation map needs a more thorough assessment to investigate the effect of other factors such as modelling approach (Cook and Merwade, 2009).

After reviewing the literature it is evident that there are a wide variety of issues within geomatic surveying relating to studying flooding. One clear issue is the definitions and disparity between different flood inundation maps. It seems clear that there is a need for better maps and mapping techniques. Improving flood maps would help various industries for example insurance companies. One clear way to improve these issues is through using different surveying techniques. The surveying techniques that could be utilised to create flood inundation maps are: GPS based surveys, use of a total station, LiDAR data or SONAR. The best method to use depends on the end use of the map.

This work is mainly going to utilise a total station detailing work for data collection. This will not only allow collection of topographical data but also data to create cross sections. This cross section data can be used within the previously mentioned CES software to consider flood capacity. The recent development of the CES software seems the most accessible and practical for use within surveying when considering flood capacity. Further to this with the literature in mind this work is also going to consider the use of DEM data for large scale mapping.

The literature has allowed the varying methods to surveying floods and rivers to be recognised. As well as some more broad issues surrounding flooding being identified. With the most appropriate technique for the surveying within this work being discussed and decided upon, to be used further in the chapters below.

CHAPTER 4: STUDY AREA:

Helston is a small town located in West Cornwall with a population of approximately 11,700 (Cornwall Council, 2016). First existing as a settlement in the 6th century, Helston was officially charted as a town in 1201 by King John (Helston History, 2016). Helston is the largest town on the Lizard peninsula, acting as entrance to this popular tourist area. The location of Helston is demonstrated in Figure 4:1.

Figure 4:1 - 1:250,000 Ordnance Survey map demonstrating the location of Helston (red box) within South West Cornwall. (Source: Edina Digimaps, 2016 [11/07/2016])

Helston developed significantly through the mining industry as a stanary town. During the 19th Century mining boom in Cornwall there is recorded to be over 100 active mines in the wider Helston area; including Wheal Vor thought to be the largest tin mine in the world at the time (Cornwall Council, 2002). Further significant expansion in housing was seen immediately after World War Two, and continued to rise steadily because of the development of Royal Navy Air Service base; Culdrose which is the main source of employment in Helston and added an estimate £60 million to the Helston economy in 1995/6 (Cornwall Council, 2002). It is still one of the fastest growing centres of population in Cornwall (Cornwall Council, 2002) and numerous housing developments can be observed in the local area. Helston is essential to the local community as a source of amenities for West Cornwall and as a road transport infrastructure hub.

Immediately adjacent to the west of Helston is the River Cober; the town is positioned on the steep slopes leading away from the Cober. The Cober is the only river to flow through Helston. Historically the river was tidal however the shingle of Loe Bar and the Loe Pool formation now means it is cut off from the sea (Cornwall Rivers Project, 2006).

The River Cober sits within the Loe Valley, and like many rivers in South West England is a drowned river valley or Ria. The previously mentioned tin mining as expected has provided the river valley with a varied history. However the valley is now mainly used for pastoral farming. Cornwall Rivers Project (2006) suggest the River Cober drains 53.75 km^2 of the valleys surrounding Helston; Penny Anderson Associates (2014) suggest that the River Cober is draining an area of 43 km^2. The source of the River Cober is south-west of the village of Four Lane approximately 11 km from Helston (Figure 4:2). The River Cober is approximately 16 km in length and Helston is approximately 4 km from the mouth of the River Cober. However unusually the river does not directly flow into the English Channel but instead enters Cornwall's largest freshwater lake; Loe Pool. This has formed behind Loe Bar which is a shingle bar blocking salt water entering Loe Pool (Penny Anderson Associates, 2014).

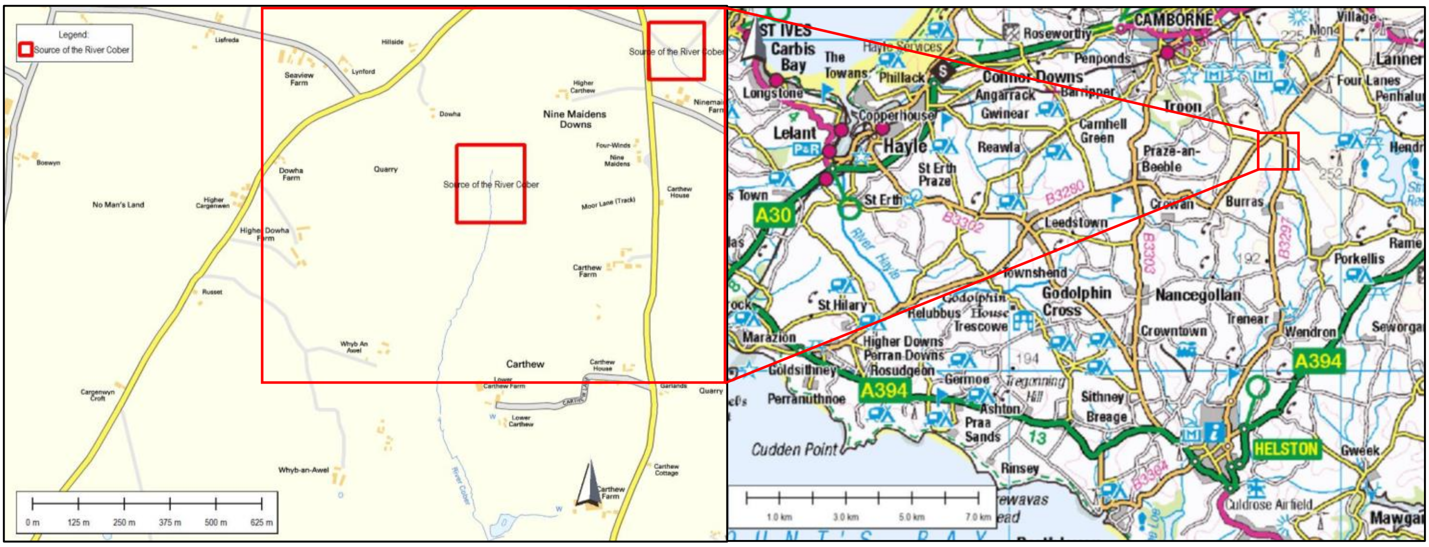

Figure 4:2 - The source of the River Cober, near Nine Maidens Cornwall. (Source: Edina Digimaps, 2016 [11/07/2016])

Flooding in Helston:

There is a significant history but also current issues relating to flooding of the River Cober in and around Helston, hence why this work has been completed at two locations near Helston.

In West Cornwall the risk to life and community disruption due to flooding can be significant (Environmental Agency, 2012). This has caused the creation of the West Cornwall Catchment Management Plan (CFMP). This covers 1500 km^2 of land, with the average rainfall per annum being over 1400 mm and 1000 mm on the coast, the average in England being only 920 mm per annum (Environmental Agency, 2012). Perhaps giving an indication of the flooding issue that can arise within this geographic area.

Problems of flooding in Helston have been mentioned historically, Toy (1936) wrote that flooding had “always been a serious menace to the town” (p.385). The flooding issue may suggest that some of the rivers in the area cannot cope with the full flow capacity of the catchment area, whether they can will be concluded later in this report. The Environment Agency (2016) have a comprehensive list of historic flood events within 1 km of Helston, as well as the areas flooding has affected historically (Figure 4:3). The historic flooding events have numerous causes however the majority are related to the River Cober the other main cause being surface water runoff (Table 4:1).

Table 4:1- Information about past flooding events within 1 km Helston. (Source: Environment Agency, 2016)

Date of Flood	Source of Flood	Details
12/11/1894	Unknown	Serious flooding in main street- no specific details known.
12/12/1945	Unknown	Flooding around Zacharys Road Bridge
03/12/1952	Surface water runoff	Roads to Camborne and Penzance were flooded.
01/01/1970	Surface water runoff	Mill Lane was flooded
01/01/1971	Assumed River Cober overtopping	One property in Helston affected
12/10/1973	River Cober and St Johns Bridge	Penzance and St Johns Road area flooded.
26/09/1976	Surface water runoff	Porthleven Road, Momument Road, Goldophin Road, Cross Street, Lismore Cross and Castle Green all flooded.
13/02/1979	River Cober and Surface water runoff	St Johns area flooded
26/12/1979	River Cober, St Johns Bridge and Loe Pool	St Johns area flooded
27/01/1988	River Cober and St Johns Bridge	Penzance Road and St Johns road area affected
22/08/1992	River Cober	Church Street flooded

09/06/1993	Surface water runoff	Due to the town leats.
31/12/2002	River Cober	St Johns area flooded along with numerous other areas
25/072003	Surface water runoff	Trevenen Road flooded
28/08/2003	Unknown	Cades Parc flooded
17/08/2004	River Cober	Widespread flooding; cattle market, Coronation Park, St John’s area, Cades Park, Osborne Parc, Manor Close, Loe Bar Road, Grange Road and Loe Valley Road
24/11/2012	River Cober	St Johns Road area flooded
22/12/2012	River Cober	St Johns Road area flooded
24/12/2013	Surface water runoff	Lowertown flooded.

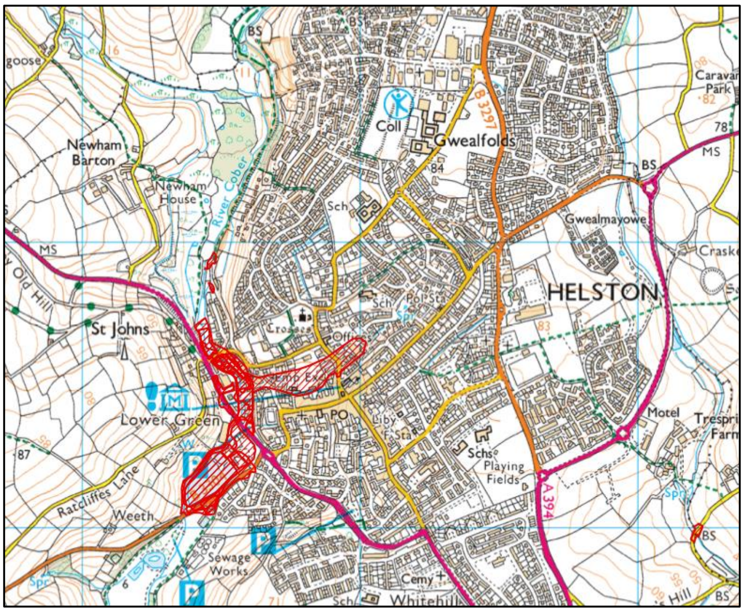

Figure 4:3 - Ordnance Survey 1:25,000 map with Environment Agency editions. The red hatching demonstrates the areas where historic flood inundation has been recorded. (Source Environment Agency, 2016b).

The historic problem of flooding is made clear with the evidence of a traditional anthropogenic flood engineering scheme (Dinsdale, 2009). This channelisation and reprofilling is particularly evident in the areas below Helston in The Carr habitat which is in the Penrose Amenity area. The progression of this change from a more natural river regime to an engineered system can be seen through the overlaid historic map within Figure 4:4. The majority of this flood alleviation work took place 70 years ago. The straightening and channelisation of the River Cober through The Carr happening during 1946 and then further reprofilling during 1988 (Penny Anderson Associates, 2014). The River Cober has also been desilted in 1992 and 1998 as part of the flood alleviation scheme (Penny Anderson Associates, 2014).

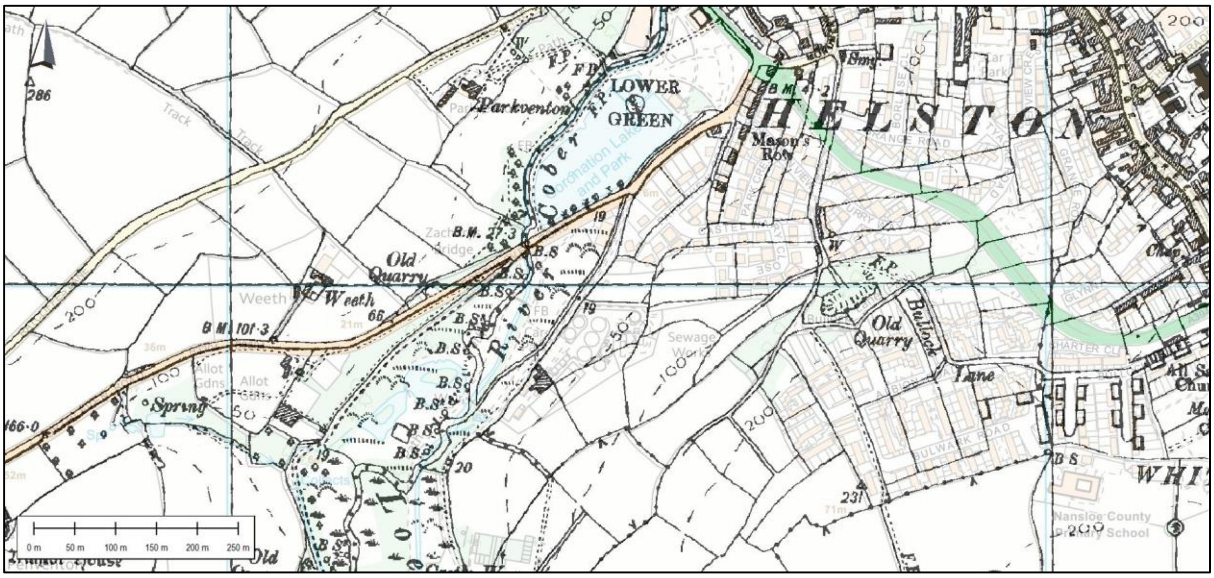

Figure 4:4- County Series 1888 over modern Ordnance Survey Street Map demonstrating the more naturally meandering River Cober against the current channelisation. (Source: Edina Digimaps, 2016 [11/07/2016])

One of the reasons Helston is prone to flooding is unique to its geography and history. The distinctive formation of the Loe Bar and Loe Pool combined with the historical mining sedimentation means that Helston 4 km upstream is more prone to flooding than it perhaps otherwise would be (Penny Anderson Associates, 2014). The River Cober is prone to flooding due to the combined effect of high river flows and water backing up due to the Loe Bar (Penny Anderson Associates, 2014). Loe Bar is a shingle bar situated on the coast 4 km south south west of Porthleven at the end of the River Cober (Figure 4:5). The bar is a rare example of a bay-bar formation (May, 2007). It is composed and formed mainly (over 90%) of chalk flints, despite the adjacent cliffs being mainly killas and quartz based and there being no other sources of flint locally (Toy, 1934). The sediment that makes up the bar can be categorised into two class sizes: medium to very coarse sand and small pebbles (May, 2007). Due to the orientation of the beach and reduced amount of sediment on the beach, incoming

Figure 4:5 - Loe Pool and Loe Bar from an aerial image, allowing the unique geographical feature to be seen in its entirety. Helston can be seen in the top left of the picture. (Source: Visit Cornwall, 2016.)

sediment tends to move towards the centre of the Loe Bar. The bar is currently a sediment sink in relation to the overall beach budget (May, 2007). There are several theories about the formation of Loe Bar, ranging from two giants dropping a bag of sand; to elongated coastal spit formation combined with longshore drift. The various theories are discussed in May (2007). It is mostly accepted that the formation is more complicated than normal bar formation. Toy (1934) suggests that a spit formed with the entrance being further blocked by longshore drift. May (2007) seems to agree this suggesting that the orientation the beach is ideal for longshore drift.

The Loe Bar completely cuts of the Loe Valley and River Cober from the sea; hence the formation of the Loe Pool. Water from the River Cober can very slowly in some seasons percolate through the bar, in other examples of bar formation water can easily percolate through in all seasons. However the aforementioned recent mining history within the Helston area has meant that Loe Bar has become 'blinded' by mining related sedimentation so less river water can percolate through. This increases the height of the Loe Pool, and also helps with the formation of the pool. Also inflaming the flooding issue on the River Cober further. Due to the rare and unique nature of this formation Loe Pool creates a unique environment and habitat and is now classified as a Site of Special Scientific Interest (SSSI). The significance of the Loe Bar and flooding in Helston has been recognised over a long period of time. Leland wrote that in the 16th century the River Cober would have to breach the bar if the River Cober and Loe Pool were at full capacity (May, 2007). Further to this in the 19th century the Wheal Pool mine cut an adit through the north west bar in recognition that the Loe Pool water level increased greatly due to the mining activity and this was having an effect on the River Cober (Toy, 1934). The adit once the mine closed was maintained and kept opened by the owner of the Penrose estate; and then has since been enlarged and improved by the Environment Agency (Figure

Figure 4:6 - The mine adit that now prevents water levels being too high in the Loe Pool and in turn helps reducing flooding along the River Cober. (Source: Helston History, 1999.)

4:6). After the improvements and more recently it became the case that the velocity and pressure of the water was great enough that a stoppage would be rare if not impossible. The implication the bar has on flooding in Helston is further reinforced by the historic requirement and tradition to break the bar. There was a traditional ritual for The Mayor to present a stout leather purse to the Lord of the Penrose estate with 3 halfpence in to ask permission to break the Loe Bar (Toy, 1934). The breaking of the bar stopped the bar acting like a dam for the River Cober and hence alleviates flooding. Loe Bar was cut in the Winter of 1867 and 1868 (Toy, 1934). More recently the bar had to be cut though because the mine adit got blocked by storm water in 1979 (Figure 4:7) (Helston History, 1999).

Figure 4:7 - Photograph demonstrating the cutting of Loe Bar by South West Water machinery; 15th February 1979. (Source: Historic Helston, 1999.)

However this historic flooding is now an ongoing current problem in Helston, with the potential to get worse. Within Helston there are over 200 properties at risk from the impact of flooding as well as critical infrastructure to the town including a water treatment works, electrical substation, the mainline railway to Penzance and other transport infrastructure essential to access the settlements further west. (Environmental Agency, 2012). The level of risk for properties in Helston has the potential to increase; future possible predicted scenario within West Cornwall are (Environment Agency, 2012):

- A 20% increase in peak flow in all water courses because of climate change.
- An 11% increase in river flow due to the change in land use that has been granted.

- A 5% increase in river flows in certain locations due to specific urban development.

Hence the requirement to be able to fully understand the current flooding situation is necessary before the possibility of flooding in Helston gets worse. There are currently several trains of thought from different organisations as to how flood alleviation should occur. These are discussed later in more detail.

The entirety of the River Cober catchment is included within the previously mentioned West Cornwall Catchment Management Plan. The West Cornwall Catchment Flood Management Plan is split into Sub Areas and Policies depending on location and severity of the flooding previously experienced. Sub-Area 3 contains Helston, which is going to be focused on within this work. Other places within Sub-Area are: Gulval, Penzance, Nancledra, Lamorna, Chyandour, Ludgvan and Burras (Environment Agency, 2012). Helston is classified within Policy 5, this means it is an area of moderate to high flood risk where further action can generally be taken to reduce the flood risk (Environment Agency, 2012).

Two Specific Study Areas:

With the aims of this work and information above in mind two areas along the River Cober were chosen to study in detail. These areas are in the Willow Carr habitat (Area 1) and immediately upstream of the St Johns Bridge (Area 2). Both areas are marked on Figure 4:8.

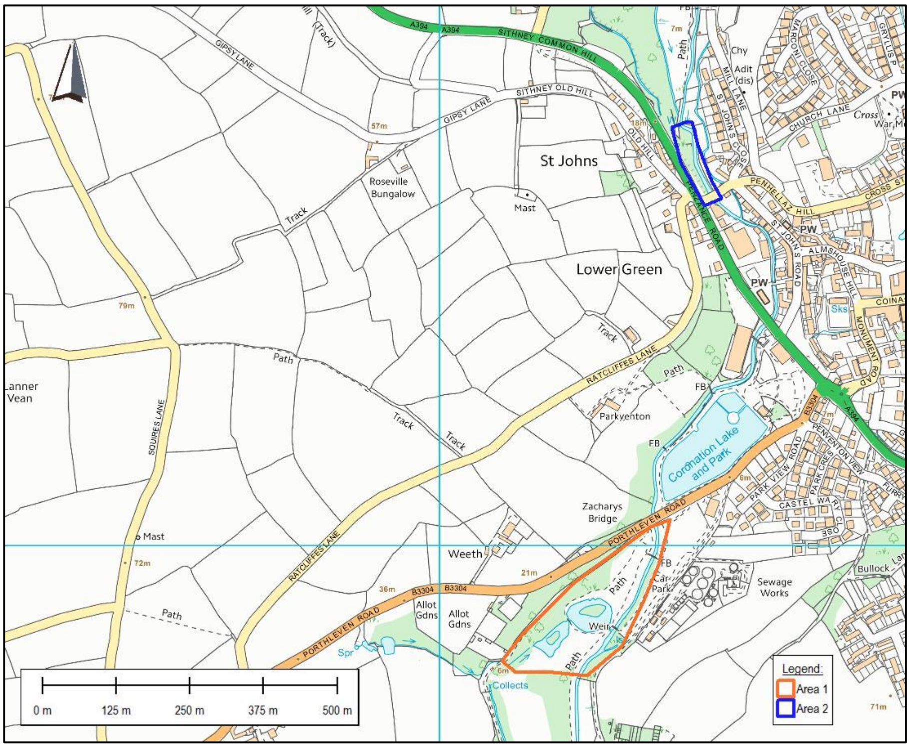

Figure 4:8 - Ordnance Survey Street Map demonstrating both study areas near Helston, South West Cornwall. (Source: Edina Digimaps, 2016 [8/07/2016])

Area 1:

Area 1 is the larger of the two study areas and is approximately 14,723 m^2 in size. It also has greater influences by numerous designations and is part of the National Trust Penrose Estate; Penrose Amenity area. It is immediately adjacent to the Loe Pool SSSI and is therefore within the risk zone, and is also included within the Historic Coastal designation (Figure 4:9i and 4:9ii).

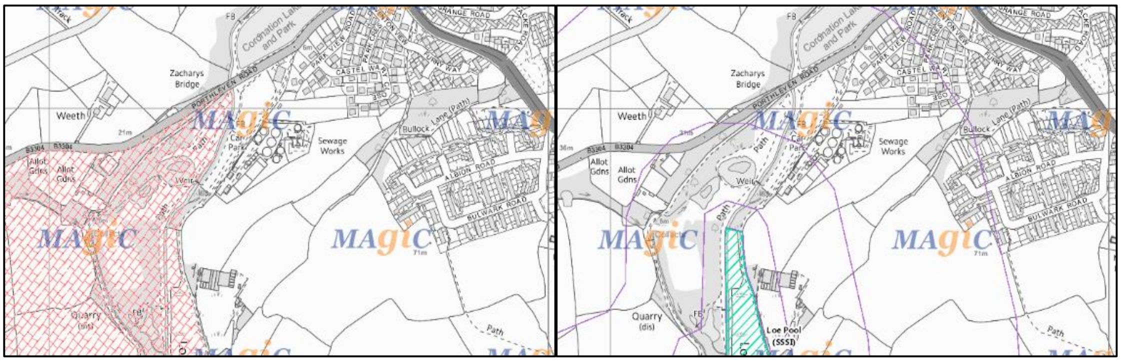

Figure 4:9 (i and ii)- The various areas of designation within on near Area 1. Figure 4:9i- The area designated as Historic Coast is hatched in red rectangles. Figure 4:9ii- The area in green hatching is the Loe Pool SSSI, with the purple lines suggesting the different risk zones relating to the Loe Pool SSSI. (Source: Magic Map Applications, 2016 [09/07/2016].)

The Loe Pool SSSI is a protected area of approximately 1.287 km^2 land incorporating the Loe Pool and surrounding land. The pool supports locally rare aquatic plants, benthic invertebrates and rare migrating birds; whilst the surrounding landscape supports reeds, ancient oak woods and willow carr habitat (English Nature, 2013). The willow carr habitat extends into and makes up a large proportion of Area 1. A carr habitat is a wet woodland where the soil remains waterlogged and will at times be flooded (Woodlands, 2008). Hence a large majority of Area 1 is submerged by stagnant water. The formation of this willow carr habitat (The Carr) is a relatively modern feature in terms of geomorphological timescales. It mainly formed during the 20th century due to increased sediment input from the mining within the River Cober catchment. However despite its modern origins The Carr is still considered of great ecological interest particularly the reed beds, shaded pools and decaying grey willow trees (Loe Pool Forum, 2016).

A considerable portion of Area 1 is maintained grass and meadow land. With anthropogenic made and maintained paths intersecting across being heavily used for leisure activities in particular dog walking. The River Cober flows down the eastern side of Area 1. With steep banks on both sides, although the western bank gives the illusion of previous attempts of terracing as there are two distinctive layers to the banks. Within Area 1 there is one foot bridge to allow pedestrians to cross the River Cober, as well as the remains of a further footbridge. The area is bordered on one side by the B3304 (road to Porthleven). Before entering Area 1 the River Cober has been heavily managed to allow the formation of the Coronation Lake, a boating lake created in 1912 built to commemorate the coronation of George V a year earlier in 1911.

Area 2:

The second area within the work is further upstream along the River Cober; than Area 1. It is approximately 1565 m^2 in size, so is considerably smaller than Area 1. Although both Area 1 and 2 are a short walk from Helston town centre; Area 2 is in more of an urban environment. The western border is the A393 (the main road to Penzance), the southern border is the St Johns Bridge and the eastern border is residential properties. The River Cober runs through the middle of Area 2, north to south. The River Cober at this point has steep immediately adjacent banks on both sides, both covered with woodland vegetation. At the base on the banks on both sides of the river there is evidence of human channelisation with both banks bordered with short wooden edging.

Area 2 includes the St Johns Bridge. The bridge was built in 1813 as a crossing point of the River Cober in Helston. However it seems apparent that it has often been a source of flooding in the St Johns area of Helston (Figure 4:10). The area seen in 4:10i is St Johns road in Helston. The area had significant flooding during 1812. Whether St Johns bridge is the cause of this is unclear. The area is still developed as can be seen from 4:10ii a capture of a 2015 street view. Modern developed can be seen on the left of the road. The street also has further housing developments currently. A simple visual analysis of this development can see that the damp course is being placed at a high level in the houses, and the ground level of the houses is raised above street level. Clear evidence of flood mitigation in the area, due to an issue with flooding in the area. The information on historic flooding provided by the Environment Agency in Table 4:1 frequently mentions the St Johns area as an area inundated by flooding. It is still a regularly used road bridge however the lack of modern engineering design for river flow could possibly be one of the reasons or is a reason as to why Helston has a problem with flooding. This historic flooding information highlights why Area 2 is an ideal place to complete the methodology within this work.

Figure 4:10 i and ii- St Johns Road, 1812 and 2015. (Source 4:10i: Helston History, 2016, 4:10ii Google Maps, Street View, 2016)

Current flood alleviation practices in the River Cober catchment:

As aforementioned the River Cober has been managed through heavy engineering practices. The current channelisation delivers flood water rapidly and efficiently through Helston into Loe Pool (Dinsdale 2009). This channelisation was completed in 1946 and 1988; Dinsdale (2009) suggests that the current approach to flood management plan still continues to meet the original design brief. These schemes still require regular de-silting to be maintained. The flood scheme in place is in good condition however it does not provide protection for greater than 4% annual probability flood events (Environment Agency, 2008). The maintenance Dinsdale (2009) reported occurring on the River Cober was researched from the River Cober Draft Maintenance Plan (2007) however this report was unfortunately unavailable for this work and no further information was provided; the contact with the Environment Agency is reported below:

"Due to our retention schedule we are unable to find a copy of the River Cober Draft Maintenance Plan - March 2007."

Subsequently to the River Cober maintenance plan the Environment Agency commissioned the previously mentioned Catchment Flood Management Plan (CFMP) in 2008. The River Cober is included within the West Cornwall plan, South Coastal River area. The CFMP document states that further action can be taken within the area to reduce flood risk, although these additional actions need to be assessed to check they are socially and environmentally sustainable, technically viable and economically justifiable (Environment Agency, 2012). The suggested action that the Environment Agency plan to undertake in relation to the River Cober is (Environment Agency, 2012):

- Review the quality of the flood warning criteria along the River Cober and implement the recommendations.
- Commence the surface water management plans
- Review the current channel maintenance procedures to ensure that the targeted maintenance undertaken is reducing the flood risk.
- Consider the creation of upstream storage facilities
- Investigate the feasibility of improvements to the current flood alleviation scheme in Helston.

- Further research the links between land management practices, runoff and flood risk.
- Progress with the outcome of the Rapid Response catchment study.

Alternatively, The National Trust who own and maintain the land surrounding the lower reaches of the River Cober and Loe Pool commissioned their own review of flood mitigation. Their land is effected by the previous flood defence scheme; the channelisation and desilting of the River Cober previously mentioned. With this in mind The National Trust conducted their own hydrological study relating to the hydrological management of the Loe Valley by Penny Anderson Associates (2014). This work is summarised below, as an alternative to the Environment Agency flood maintenance plan.

Penny Anderson Associates (2014) suggest two methods to tackling flooding on the River Cober:

1. Manage hydrology; principally surface water availability and extent on the floodplain area.
2. Manage the River Cober channel habitat and enhancement schemes.

The main principal around hydrological management (method 1) is the connectivity between the river hydrology and the floodplain areas. These floodplains are located within the willow carr habitat (Area 1). This would be completed by: installing flow conduits, culverts from adjacent higher land, installation of floodplain flow control structures at locations where raised footpaths are breached and removal of flow restrictions. These restrictions to flow include the gravel paths seen and heavily used by the public within Area 1.

Further to this hydrological coupling should also take place. The principle techniques for this to occur are: open water level control structures, levee management, bank scalloping, buried water level control structures, berm creation, coarse woody debris, raising river bed levels and a change in design to the footbridges seen along the River Cober.

These schemes would allow the capture and storage of more river flows under a wider range of the flow conditions seen on the River Cober. These schemes will enhance the flood storage in the willow carr area, which in turn will prevent the accumulation of flow along the River Cober and in the Loe Pool which further exacerbates the flooding in Helston.

Method 2 of habitat management is more favoured in this report and is a type of assisted natural recovery. The principle methods involved in habitat enhancement are: hydrological management, promotion of growth and regrowth of vegetation, minimal maintenance of channel and banks, monitoring of non-native invasive species, leaving areas undisturbed and management of invasive species.

These methods promote more of a ‘do-nothing’ approach to river management. This will allow the bed level of the River Cober to accrete over time which will reduce the channel storage so there will be more over bank storage. This report suggests that this will allow a more naturally functioning fluvial system, and therefore the flow will dissipate across the floodplain and the energy within the flood will be reduced and the water will be less restricted.

A further idea within the plan outlined in method 2 by the Penny Anderson Associates (2014) to further improve the natural function of the fluvial system is to reintroduce more trees next to the River Cober channel. This extra vegetation act as a flow direction and will promote lateral channel migration so more natural sinuosity develops.

The Environment Agency have also investigated growth of vegetation on the banks and with the combination of this report have recommended the National Trust have taken control of the lower River Cober.

CHAPTER 5: METHODOLOGY:

Desk-based Study:

A desk based study was completed before any practical work was undertaken. The desk based study research was used to compile Chapter 4. The desk based study used a variety of sources to collect relevant information. These sources included: academic journals, Environment Agency reports, consultancy reports, maps and GIS resources, web-based resources, historic photos, satellite images, government resources and publications. The use of these resources help to shape the methodology below.

Site Selection:

The site was selected based on the requirement to study flow capacity, and the apparent problem each location maybe causing to the flood risk in Helston. Each site needed to have public accessible footpaths to allow access onto the site. Before the exact sites were selected a site investigation was completed of areas selected from looking at Ordnance Survey maps and resources. The site investigation was simply a walk over with notes taken on the benefit of each site for a full survey. This allowed the selection of Area 1 and Area 2 previously described in Chapter 4.

Primary Data collection:

The majority of data collected and utilised in this work was primary data collection recorded in Area 1 and Area 2. The data was collected primarily by the author and various volunteer field work assistants, over a one week period in June and July 2016.

Kit List:

- Trimble R10 GNSS Receiver
- Mini Tripod
- Survey Station Stakes
- Lump Hammer
- Leica 1200 Total Station
- 3 x Leica Tripods
- 2 x Tribrach
- 2 x Leica Circular Prisms
- Leica Detail Pole

Survey Control:

In order to spatially reference the primary data it was necessary to set up control points across the sites. These control points needed to be located across the site to allow for maximum coverage. Control points are points on the ground surface marked by a survey station or nail. The survey stations were marked using nails with stakes in the top. These were placed firmly as low to ground level as possible so they were not a trip hazard, or removed or knocked by any other users of the area. The location for each survey station was chosen. Each location was chosen in relation to tree canopy coverage above the survey station and the possible view across the site. They all required X, Y and Z coordinates i.e. Eastings, Northings and Elevations. These coordinates are specified in OSGB36 coordinate system.

For this work control points were defined using the Trimble R10 GNSS Receiver and Mini Tripod. At the five locations chosen for survey stations a stake with a nail in or a nail was placed firmly into the ground. The R10 receiver was then placed on the nail and made both level and steady using the mini tripod. The Real Time Kinematic (RTK) Network was then utilised in order to obtain the coordinates for the survey station in question. Global Navigation Satellite Systems (GNSS) allows the position of the survey station stake to be obtained in three dimensions by receiving and processing signals from orbiting GNSS satellites (Uren and Price, 2010). To locate the desired position of the survey stations the GNSS receiver (Trimble R10) calculates the distance to a number of satellites which is used to determine the three-dimensional coordinates (Uren and Price, 2010). The Trimble R10 uses local base station RTK, the connection is made with a base station through a mobile phone connection. This connection via the mobile phone connection allows corrected data to be transmitted to the rover station and hence recorded for the survey station (Uren and Price, 2010).

There are many errors associated with the use GNSS to place survey control. These errors can be split into three categories: satellite dependent errors, receiver dependent errors and signal dependent errors. Within categories of errors multi-path can be the most difficult to detect (Uren and Price, 2010); however in this work it will not be a problem due to no tall or reflective buildings being located next to or near the survey stations. If other errors for example satellite geometry errors occurred these would have been detected by the Trimble R10 receiver when in use. Any errors can be tested and quantified using tests suggested in: ISO 17123 Part 8 GNSS Field measurements systems in real time kinematic (RTK). With this work these test were not undertaken, no error messages were received and the R10 receiver was always connected to a suitable number of satellites due to location of the stations. The expected accuracy of the control stations using the RTK network and Trimble R10 is ±10 mm + 1 ppm horizontally and ±20 mm + 1 ppm vertically (Uren and Price, 2010). These accuracies should have been achieved for this work due to the favourable location of the survey stations.

The control network was located as so that it allowed setting up for further parts of the methodology. The approximate location of the control points is demonstrated in Figure 5:1.

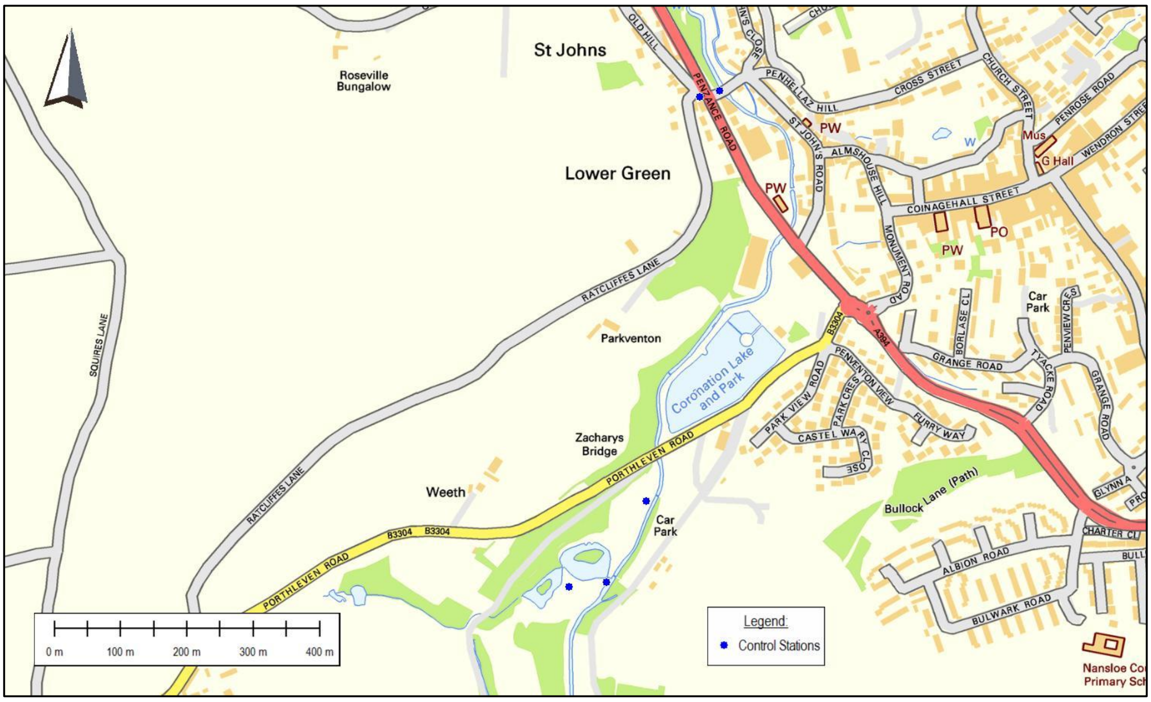

Figure 5:1- Location of the five control stations used within this work. (Source: Edina Digimaps, 2016 [05/08/2016])

Topographic Survey:

The initial primary data collection took place as a topographic survey. This required the use of a Leica 1200 Total Station, Leica Circular Prisms, Detail Pole and Leica Tripods. Before any detailed surveying could be undertaken it was essential to set the total station up properly and as precisely as possible. This was done using two methods both of which utilise the control stations put in place previously. The two methods used were: Resection and A Known Backsight. The method was chosen based on which method was most suitable for the setup, for example whether two control stations could be seen.

Figure 5:2- Tripod and Leica Circular Prism set up (centred and levelled) over the control station Bridge, for use in resection. (Source: Authors Own.)

Using the resection method requires two control stations to be seen from the point of setup. Resection calculates the location of a point by taking measurements to two other points within a control network that are known (Uren and Price, 2010); hence the requirement to be able to see two control stations. To perform the resection tripods with tribrach's and circular prisms were set up over the control stations (Figure 5:2), and both levelled and centred accurately. The total station is set up on an unknown location and measurements are taken to both the prisms set up over the control stations. In order for the total station to determine the coordinates of its setup the distance and bearings of the lines making up the triangle between the three stations are calculated utilising the know coordinates. Using this information combined with the cosine rule the angles of the triangle can be solved. By calculating the whole circle bearings of the lines using polar conversion the coordinates of the total station can be calculated. When the resection was undertaken care was taken not to exceed the recommended errors accepted on the Leica 1200 Resection programme.

Alternatively, to the resection method the Known Backsight method was used. This was used when the total station could be set up on the location of the control stations. For this method to be complete there needs to be a clear line of sight to another control station. As with the resection method the total station needs to be setup and levelled, and in this case centred over a known point (Figure 5:3). Further to this as with the resection method a prism needs to be set up over a control point and centred and levelled correctly. The coordinates of both the total station and the prisms are known. Therefore only the orientation of the total station is required. This is calculated by taking a bearing and distance measurement to the prism over the known control point. The total station will then be completely orientated in the correct position according to the control network.

Figure 5:3- Leica 1200 Total Station setup and levelled over control station- Pavement, in order to setup using the known back sight function. (Source: Authors own.)

From both methods of total station setup the topographic survey can take place. This was completed with two operatives, one using the total station and one using the detail pole. Although with the use of automatic tracking rover it could be completed by one person. The detail on this survey is aiming to have an accuracy of ±10 mm. There are four categories of detail that features can be classified as in topographic surveys. These are: hard detail, soft detail, underground detail and overhead detail (Uren and Price, 2010). In this work the majority of the detailing work is soft detail. Soft detail is when features are being captured that are not well defined (Uren and Price, 2010). Hence the precise location is defined by the surveyor. In this work the soft features include: the top of the River Cober bank and the edge of the carr habitat and vegetation. Some hard features were included within the detailing, for example footbridges, kerbs and concrete blocks. The detail survey utilised a traditional surveying techniques of capturing the features through placing the detail pole with circular prism on top around the edge or on the feature depending on the type of feature.

The LSS code list was utilised during the detail survey to give an identity to the different features captured within the survey. For example the top of the bank of the River Cober was coded with the same string number so the feature could be clearly picked out as a linear bank feature. There is no universal standard symbols for surveys and plan production, however it was decided the LSS code list provided the best range of codes and symbols for this work, out of the code list available for use.

Cross Sections:

Cross section data was taken to submit into the CES software. The data needed to include elevations along a perpendicular line to the flow of the River Cober. This was completed in a similar manner to the topographic survey data collection. A detail pole was placed at intervals along the cross section line chosen; therefore the total station took accurate measurements of the elevation. Each cross section was given a string number and therefore the distance between measurements could be measured in retrospect using Computer Aided Design (CAD) software. The cross section lines went cross from the top of the left bank to the top of the right bank, when looking in the direction the river was flowing in.

Each cross section was labelled with a letter, with A being the furthest upstream along the River Cober. The number of points along the cross section varied with the topographic variation seen on the river bed and banks. 17 cross sections were taken along the River Cober in three locations. Cross sections A to G were taken in Area 2. The intention was to take 5 cross sections in each location. However 7 were taken within Area 2 because of the vast variation seen in topography and manmade features in a small area that needed to be identified along the cross sections. Cross sections H to L were measured in the southern part of the River Cober within Area 1 and cross sections M to Q were taken further south on the River Cober still within Area 1.

Roughness:

The measurement of conveyance (a measurement of the discharge capacity of the river) needs to be based on the channels potential to resist flow through surface friction and channel morphology (Fortune et al., 2004). The channel morphology is considered within the measurements taken during the cross section data collection. However, surface friction still needs to be considered through the evaluation of surface roughness. Any flow of water along any substance will encounter resistance. A river is much the same in that the flow will encounter resistance from the river bed and river banks that is proportional to the roughness of the bounding river banks and bed (Souders and Hirt, 2014).

Roughness was collected using traditional fieldwork observation techniques. At each location the detail pole was placed observations and remarks relating to the surface material and particle size were collected in a field notebook. Each remark was listed in the same code as the total station recorded when the cross section elevation data was recorded. At each location a picture of the surface was also taken to provide further information for the post processing of the data. This data and information was then further used in the post processing of the cross section data.

Secondary Data collection:

Digital Terrain Model:

Ordnance Survey (OS) Terrain 5 data was used for three dimentional modelling. OS Terrain 5 is the digital terrain model for Great Britain. Terrain 5 is gridded height data at values of 5 m horizontal intervals, calculated from the centre of the pixel. The data is at a scale of 1:10,000. The data is easily downloadable from Edina Digimaps. In this work it was utilised in watershed analysis as described below in the post processing section.

Post-Processing:

Conveyance Estimation System (CES) Software:

The CES software is a software tool that has been developed by HR Wallingford for the Environment Agency. It is designed as a software tool that can estimate the conveyance/ the carrying capacity of a river channel (Environment Agency, 2013). This is completed by taking into account the river bed and bank morphology as well as surface friction. Hence the requirement to record the cross section elevation data and roughness values described previously.

The cross section data is input into the CES software in two dimensions. Each point that was measured in the surveying of the cross sections is given a distance offset from the furthest measurement on the left bank (as looking down the river in the same direction as flow). The correct elevation is then assigned to this offset value (Figure 5:4).

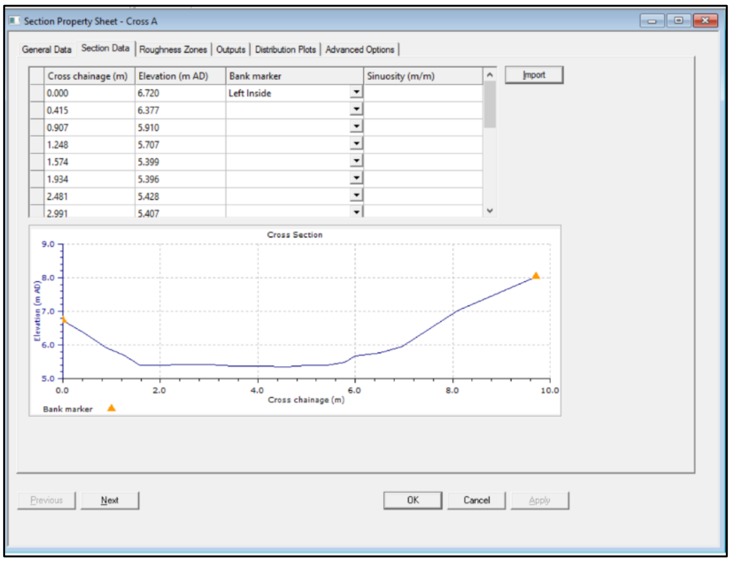

Figure 5:4- Screenshot demonstrating the input of distance and elevation data using the CES software.

The distance offset demonstrated in Figure 5:4 then creates a chainage to assign the roughness values which were collected in the field too. Roughness values have to be created in zones previously assigned in a different CES file. In this work the Roughness advisor within the CES software was utilised. Each type of surface material encountered is categorised within a roughness zone. Each type is entered a bed material, vegetation, and grain size category chosen. These roughness advisor then populates a minimum and maximum roughness value possible according to the description entered. These roughness values are based on findings completed within an extensive literature review by HR Wallingford (Environment Agency, 2013). The roughness advisor can be overwritten; however in this work the heavily researched values have been used in relation to the roughness data collected along the River Cober cross sections. Each roughness category is then assigned to a particular chainage along the cross sections (Figure 5:5).

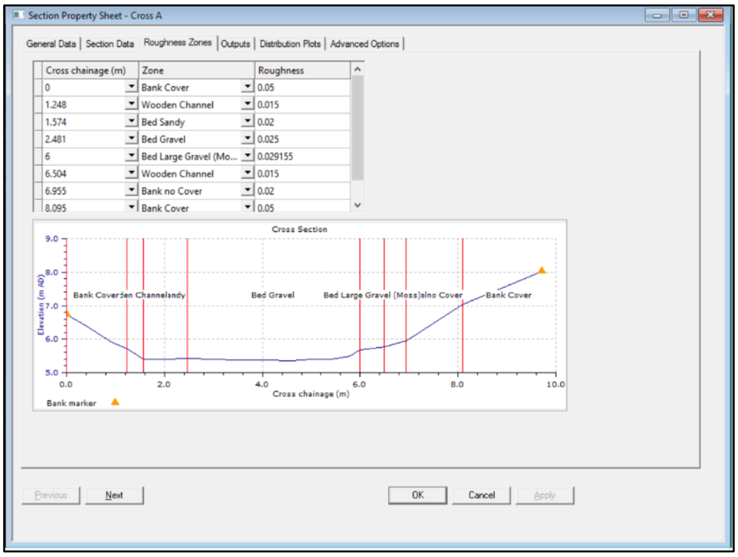

Figure 5:5- Screenshot demonstrating the roughness categories associated with the cross section chainage with the CES software.

Sinuosity of the river is a measure of the channels tendency to meander, defined in this work as the thalweg length over the valley length (Environment Agency, 2013). This work uses a sinuosity value of 1.0 which indicates a straight channel. A sinuosity value greater than 1.0 indicates a channel with some degree of meandering (Environment Agency, 2013). In the case of the River Cober the channel has been straightened hence the low sinuosity value.

Once both sections have been inputted, the CES software calculates the conveyance as well as other outputs such as: flow, velocity, and Mannings value of the cross section. These outputs are completed by using already inputted equations so there is no need for user manipulation. The background behind these equations is beyond the scope of this work however further information can be found with the Environment Agency (2013) publications relating the CES software.

Globalmapper:

Globalmapper is a GIS software package that particularly focuses on three dimensional data processing including watershed analysis. The watershed analysis and flooding modelling was utilised for this work.

For both globalmaper tools it was essential to use a Digital Terrain Model (DTM) this provided the three dimensional topographic data required. The watershed tool is activated by loading the DTM layer and utilising the topographic data, the tool then predicts stream lines and the catchment area surrounding each streamline. The parameters are set by the user and in this work parameter like stream threshold were kept within average values allowing for the most normal predictions. The same tool was then used to calculate the total catchment area of the stream layer i.e. the River Cober.

The creation of the predicted streamline as layer meant that flood inundation could be modelled using the 'simulate water level rise/ flooding' tool. The streamlayer simulating the location of the River Cober was transferred into a surface layer. An increase to this surface was created using the tool and the predicted inundation of the chosen rise projected onto the base map.

LSS:

LSS is a surveying software program that can be used to convert DXF files in to a file compatible to use with the AutoCAD software. DXF files are taken directly from the Leica 1200 Total Station, and 'ran' through LSS to process for any errors. Any errors that are seen as minimal will be accepted in order to visually display the data on LSS. The conversion of the file can then take place from DXF to DWG.

AutoCAD:

The software AutoCAD 3D Civils 2016 was used to create detail survey plans and to take information for the cross section work with the CES software. The converted DWG files containing the detail captured during the topographic survey were loaded onto AutoCAD to allow visual representation of the area. From this the detail work could be completed, for example ending string lines and scaling trees. Contours were created and drawn. Contours were drawn from the spot heights taken during the topographic survey. They were drawn using the Triangulated Irregular Network (TIN) function on AutoCAD Civils.

Further to this AutoCAD provided the tools to create completed survey plans of both Area 1 and Area 2; with the requirement to include: title, scales, date of survey, north arrow, a legend, control grid, control station coordinates and surveyor's names.

CHAPTER 6: RESULTS**:**

Topographic maps:

The results presented below are produced according to the work listed in the methodology above. The two areas have both been subject to a comprehensive topographic survey.

To complete the topographic survey control points were placed across the both sites. The coordinates and orthometric heights are displayed with Table 6:1, and also marked on the topographic survey plans (Appendix 1 a and b).

Table 6:1- Control station coordinates used within the work.

Station ID	Eastings (mE)	Northings (mN)	Height (m)
Bridge	165345.451	26973.147	6.500
Island	165285.509	26850.248	4.910
Meadow	165228.810	26844.074	6.570
Pavement	165456.530	27590.635	8.157
Collector	165426.101	27581.690	9.545

The topographic survey for Area 1 is displayed within Appendix 1a. It demonstrates how the area is for the most relatively flat, with the only notable topographic interest being steep banks on both side of the River Cober. The River Cober runs north to south down the area. The right bank (looking downstream) from the contours clearly shows it is a steep short bank with a flat terrace below. This gives a suggestion of made ground and landscaped ground running parallel to the river. The area is mainly short maintained grass or The Carr habitat. Due to the nature of this habitat only the perimeter of it was surveyed and is marked on the topographic survey (Appendix 1a). The path marked is significant feature on the surface it is has been created by anthropogenic sources and is heavily used by the local community. Two sets of cross sections were taken in the area above and below a manmade entry/tributary to the river from the large pond within the Carr habitat. The location of each cross section is marked on the topographic map (Appendix 1a).

Area 2 is significantly smaller than Area 1. The survey plan (Appendix 1b) of area demonstrates the issues with surveying the area. The area is a narrow area surrounding the River Cober, west of Helston. There are extremely steep banks on either side of the river with dense vegetation and woodland. The main feature of the area is the St Johns road bridge with its two arches at river level. The survey plan also identifies the channelisation system in place as wooden boards either side of the channel, which is prominent away from the bottom of the river bank. A further set of cross sections was taken in this area, in this set more cross sections were taken due to the varying nature of the channel.

Flooding Inundation:

Clearly flooding within the Helston area is a significant problem. As to where the flood inundation occurs can be modelled by using a digital terrain model (DTM) for the area. The DTM for the area demonstrates the topography of the entire catchment area of the River Cober (Figure 6:1).

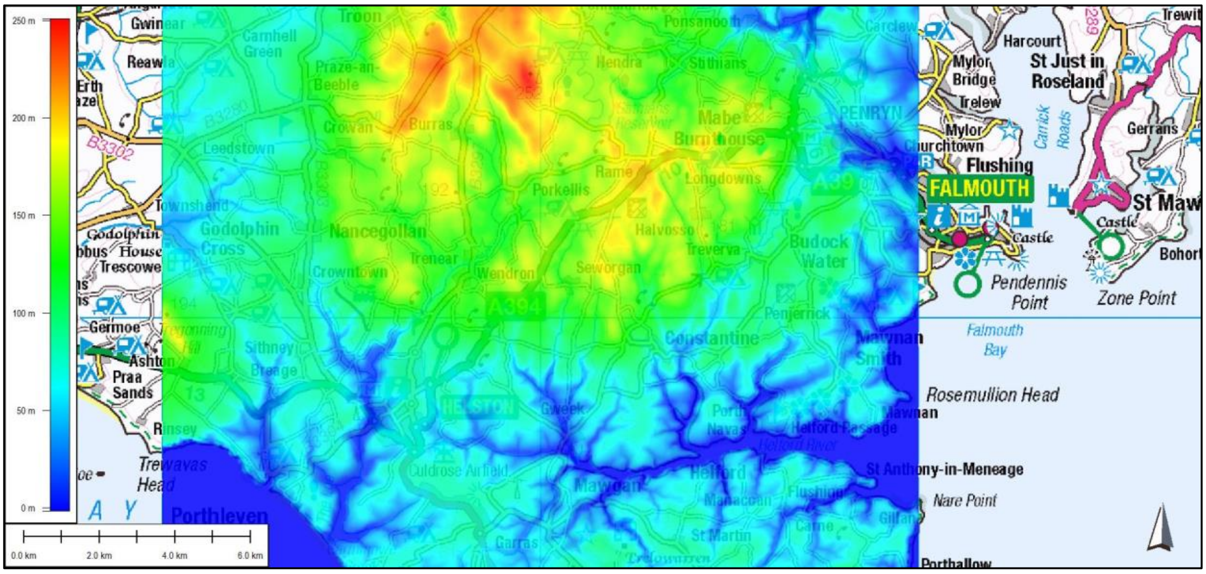

Figure 6:1- DTM Model and OS 1:250,000 of the River Cober catchment. (Source: (both) Edina Digimaps, 2016 [12/07/2016]).

As would be to be expected the upper parts of the catchment (shown in Figure 6:1) have a higher elevation than lower catchment near the mouth of the river (Figure 6:1). However the entire catchment never exceeds 250 m in height, and the majority of the catchment is much lower than this. At both locations where the surveys were completed (Appendix 1a and 1b) the height of the land surface never exceeded 10 m.

The data within Figure 6:1 combined with the surface of the River Cober saved as a layer within the GIS can produce a coarse map of flood inundation (Figure 6:2).

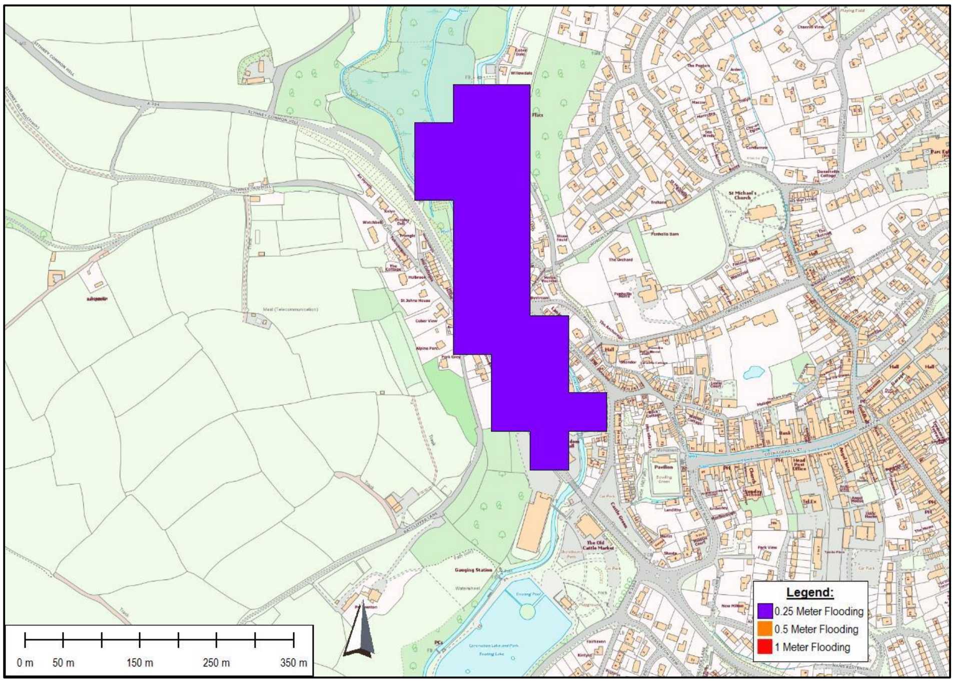

Figure 6:2- Possible flood inundation around Helston if the River Cober was to increase in water level by 0.25 m. (Source: Edina Digimaps, 2016 [10/07/2016]).

The use of pixels and squares to define flood inundation means that only a coarse estimation of flood inundation is available through the use of Globalmapper (Figure 6:2). However it is still possible to demonstrate that even with a small 0.25 m increase in river surface level the River Cober has the potential to flood the St Johns area of Helston. Figure 6:2 only considers topography as a parameter effecting the influence of flooding inundation, the topography being taken from the DTM model (Figure 6:1).

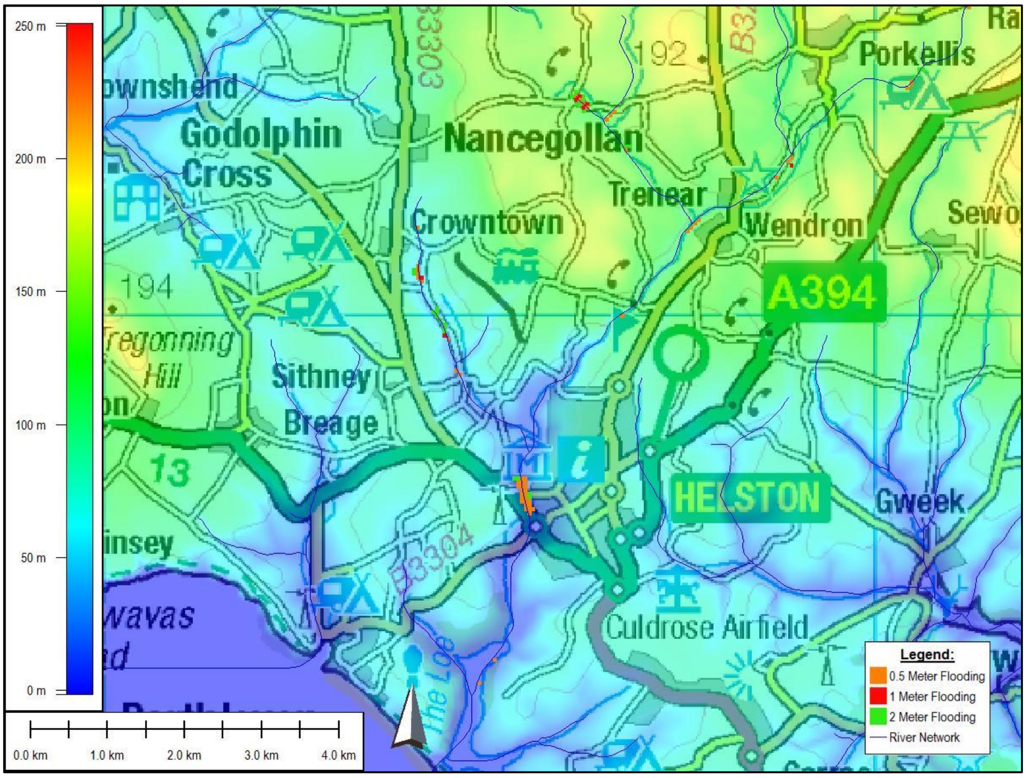

Figure 6:3- Possible flood inundation if the River Cober was to increase in water level by 0.5 m, 1 m and 2 m. (Source: Edina Digimaps, 2016 [10/07/2016]).

Figure 6:3 follows the same pattern of problems as Figure 6:2. However it demonstrates a higher level of flooding along the full length of the River Cober. As with 0.25 m of water level rise (Figure 6:2) the St Johns area of Helston will be effected worst. However the area effected does not alter significantly from the area seen in Figure 6:2. This suggests that the area is sensitive to even a small fluctuation in water level and hence prone to flooding.

Cross Sections:

The locations of the 17 cross sections of the River Cober taken during this work are shown on the survey plans (Appendix 1a and 1b). The cross sections are taken from the left bank perpendicular to the flow of the river (as explained in the methodology). The height and distance data was used to create cross sections in the CES software (Figure 6:4).

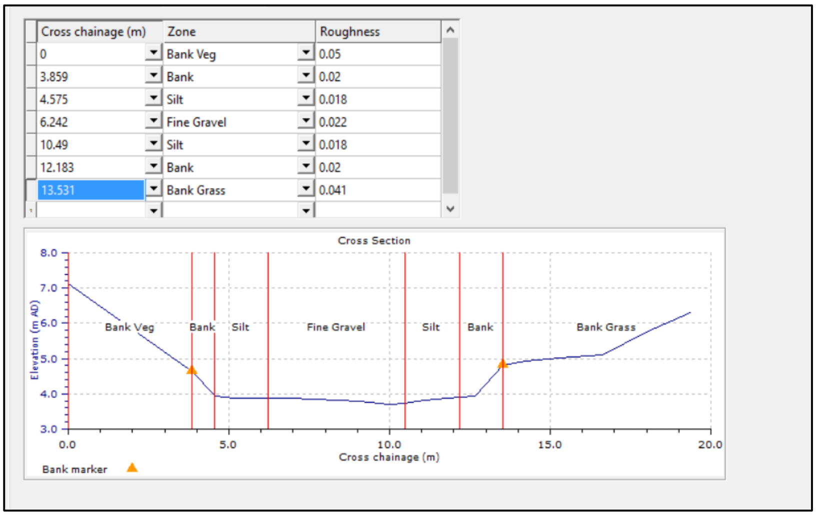

Figure 6:4- example of cross section and roughness data imputed into the CES Software; Cross Section I. For other cross section data see Appendix 2.

The CES software allowed a visual two dimensional demonstration of the cross section data, this was combined with the roughness data collected (Figure 6:4). Many cross sections within Area 1, (the carr) follow a similar pattern of roughness. With the left bank having dense vegetation the main channel being a mixture of gravel and silt and the right bank being mixed height grass. The cross sections in Area 2 vary more with there being a mixture of concrete, masonry and vegetation on the river banks. Cross Section I is demonstrated above (Figure 6:4) all other cross section data is included within Appendix 2.

There are roughness descriptions of each point of the cross sections, each of these description then has a roughness value according to the CES software. The roughness descriptions are included within Appendix 3.

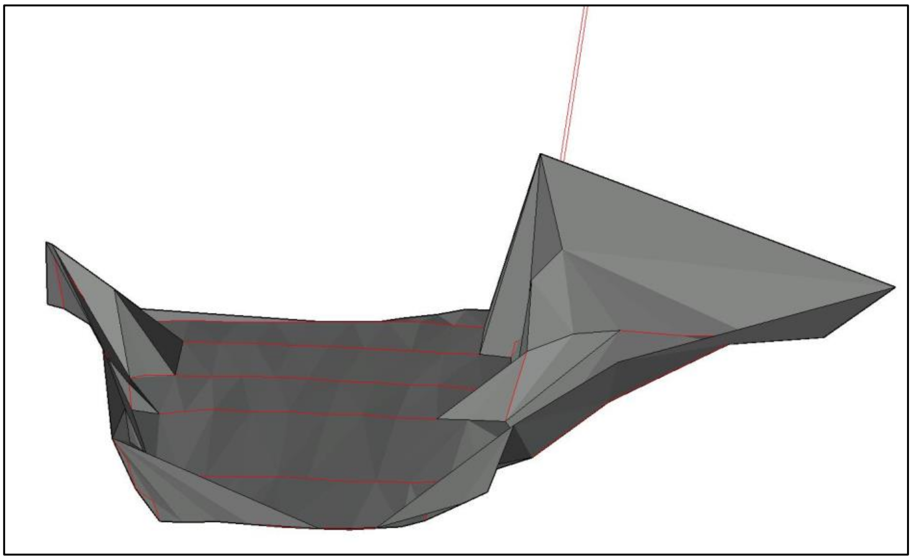

Figure 6:5- Three dimensional view of the River Cober from cross section A to G. The location of the cross sections is the red lines seen on the diagram. Looking from cross section A downstream to G.

Due to measurements taken along a X,Y and Z axis it is possible to model the cross section data three dimensionally (Figure 6:5, 6:6 and 6:7). The three dimensional view allows a rough interpretation of the flat river bed with the variations in the banks on either side. However the formation of the triangulated irregular network (TIN) surface allows for obvious distortion of the surface (Figure 6:6). To get a more realistic interpretation of the surface spot heights of the areas in between the cross section data should be taken to reduce the need for extrapolation.

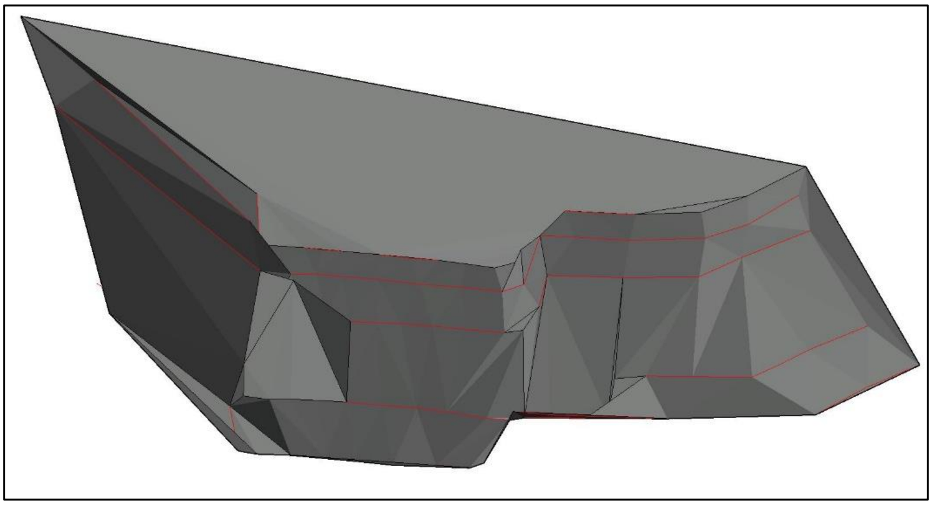

Figure 6:6- Three dimensional view of the River Cober from cross section H to L. The location of the cross sections is the red lines seen on the diagram. Looking from cross section H downstream to L.

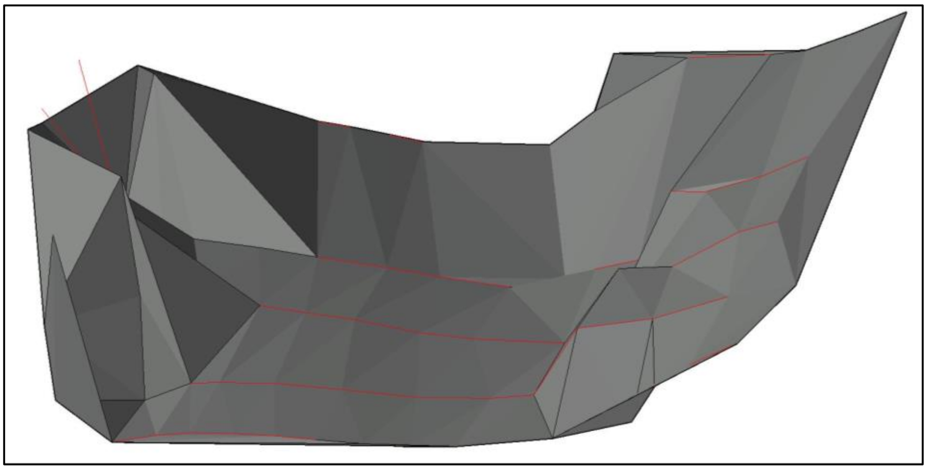

Figure 6:7- Three dimensional view of the River Cober from cross section M to Q. The location of the cross sections is the red lines seen on the diagram. Looking from cross section M downstream to Q.

As with Figure 6:5; 6:6 and 6:7 both show the River Cober in three dimensions for the areas where cross sections were taken. The three dimensional element allows the tiered right bank to be depicted, compared to the stepper left bank. A similar pattern is also seen in Figure 6:5 although in this case the alternative topography of the left bank is due to anthropogenic reasons. As with Figure 6:5 the use of the TIN surface interpolation means the surfaces are not completely realistic, for example the left bank in Figure 6:6 seems to form partly as a square based pyramid however it most likely that one higher height is recorded in this area giving this impression of the surface.

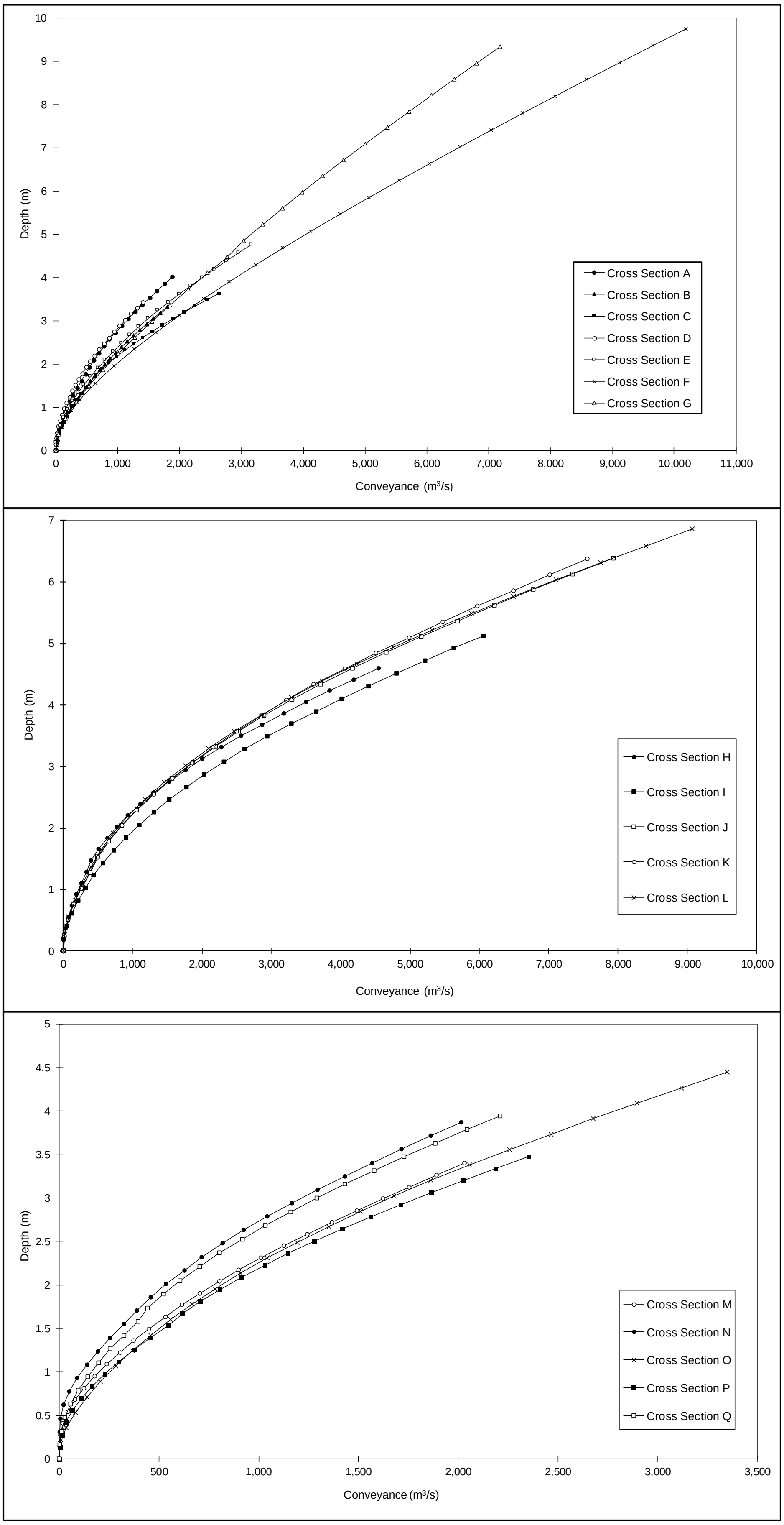

Figure 6:8 (i,ii,iii)- Conveyance (m^3/s) of the River Cober at the location of cross sections A to Q. Figure 6:8i cross sections A to G, Figure 6:8ii cross sections H to L and Figure 6:8iii cross sections M to Q. Note the differing axis scales.

Conveyance is the discharge capacity of the water course. The conveyance is displayed in m^3 per second against depth of the water (m). By using the CES software conveyance of the River Cober is calculated for 25 evenly distributed depths that range from the lowest elevation to the highest elevation from the cross section data. Therefore the lowest depth would be no water in the river and the highest depth the maximum amount of water in the river before it would go over bank height. The calculation of conveyance takes into account the roughness of the stream bed and banks as well as the shape of the cross sections and area.

Figure 6:8i is the cross section data from Area 2 and Figure 6:8ii and 6:8iii are the cross sections that are within Area 1. The cross sections are labelled from A to Q following the stream, hence cross section A is the furthest upstream and cross section Q is the closest to the mouth of the river. The cross sections from Area 2 (Figure 6:8i) first look to have a much greater conveyance and therefore discharge capacity; however it seems more the case that cross section B and F have extremely large conveyance values or perhaps are anomalies.

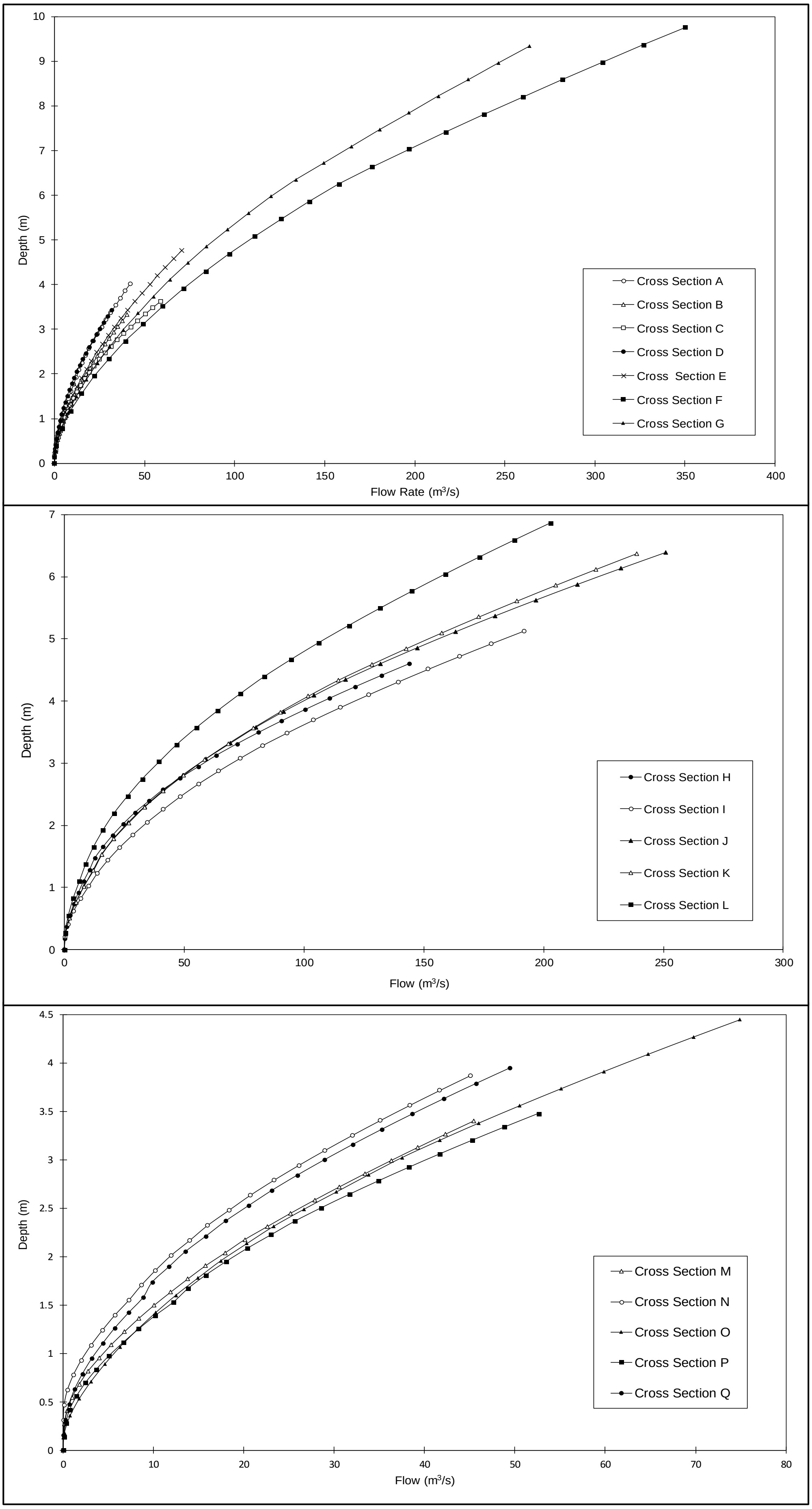

Figure 6:9 (i,ii,and iii)- Flow rate (m^3/s) of the River Cober at the location of cross sections A to Q. Figure 6:9i cross sections A to G, Figure 6:9ii cross sections H to L and Figure 6:9iii cross sections M to Q. Note the differing axis scales.

Flow is the speed of the movement of the water within the channels. Flow rates can be estimated using the CES software and plotted against the depth of the water (Figure 6:9). Flow rates vary greatly across the areas where cross sections were taken. With the greatest flow rates being seen at the location of cross section F, although the flow is so abnormally large this may be an error. However possible causes could be due to the roughness values on this cross section. The cross section is the only cross section which is bordered by a wall on both sides; the wall of the St Johns Bridge and a wall made to support the bank. It therefore has particular low roughness values which means the water has less frictional forces working against it to increase flow rate.

Both the conveyance and flow rate follow similar patterns (Figure 6:8 and 6:9). With the flow and conveyance being lowest at cross sections M to Q (Figure 6:8iii and 6:9iii). Likely causes of this could be the lower banks heights, low angle of the right hand bank or the amount of vegetation on both banks increasing the roughness and therefore friction.

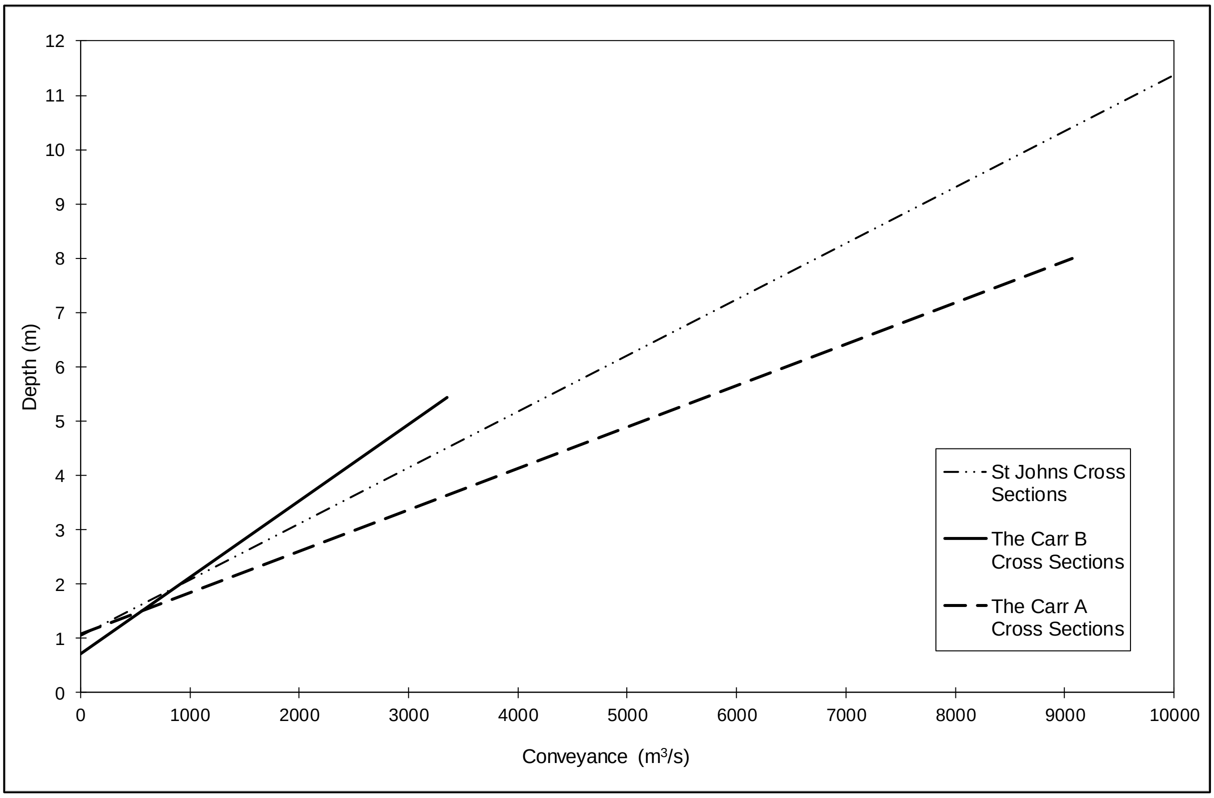

Figure 6:10- Average conveyance against depth for the three different areas cross section data was taken.

By using three areas of cross sectional data it is possible to calculate what the average of each area would predict for conveyance on the River Cober (Figure

6:10). At realistic depth values for the River Cober the trend lines have similar values, as the depth gets greater (and less realistic) the trend line predictions move further apart.

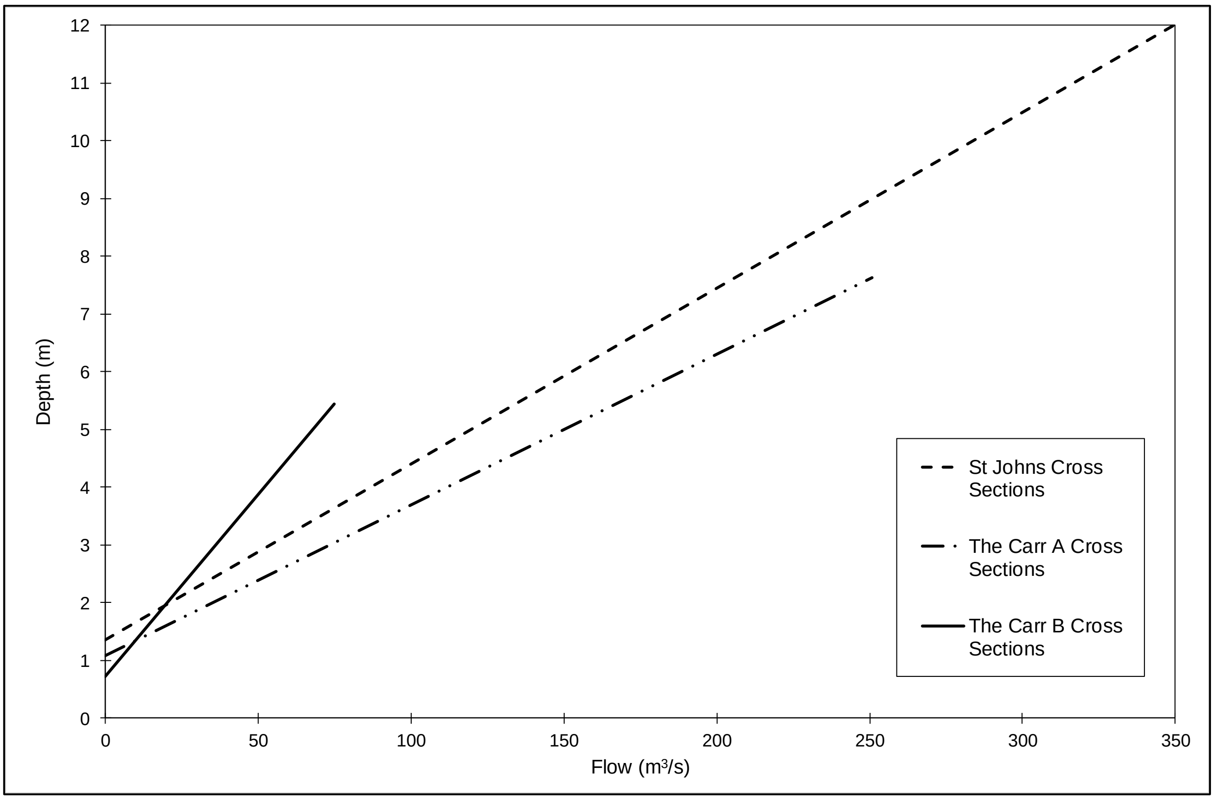

Figure 6:11- Average trend lines for flow (m^3/s) of the River Cober against depth based on cross section at three locations along the River Cober.

The data collected gave great variations of expected flow rate for the River Cober (Figure 6:11), trend lines provide an average flow rate, calculated from the data for the three areas cross sections surveyed (Figure 6:11).

Watershed GIS Work:

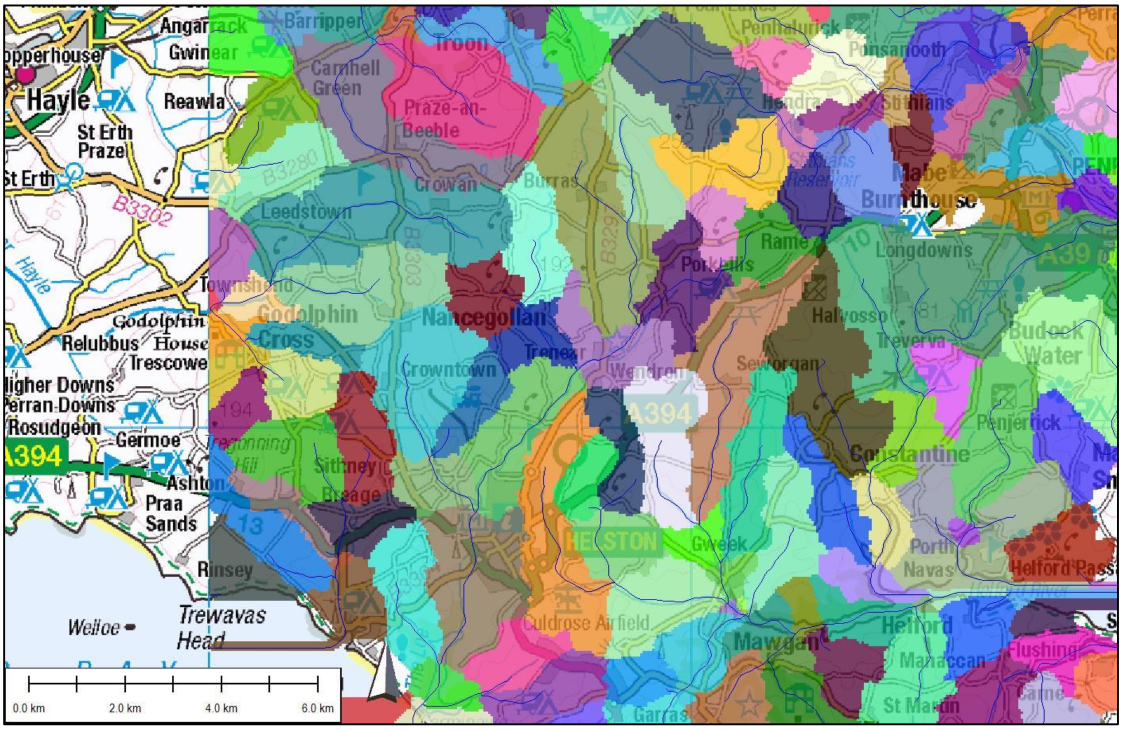

Figure 6:12- The catchment areas of the main stream network of the River Cober as well as surrounding river networks. The catchments are clearly shown by the varying coloured shapes.

The catchment area/ drainage basin is the area where precipitation can be collected from within for a specific river. Every drainage basin acts as an individual hydrological system receiving quantifiable inputs and outputs (Ward and Robinson, 2000). The drainage basin is a crucial aspect to river regime. The regime can be defined by the shape and size of the catchment. For example a round short catchment will mean that water will be able to join the main river channel quickly. The varying small catchments for each stream that make up the River Cober vary in shape (Figure 6:12). However by visual inspection the majority are long and elongated in shape, meaning that rain falling in the catchment area takes a long time to enter the river system. However some of the areas closer to the main river are shorter and rounder in shape; meaning that there will be a mixture of regime seen along the River Cober.

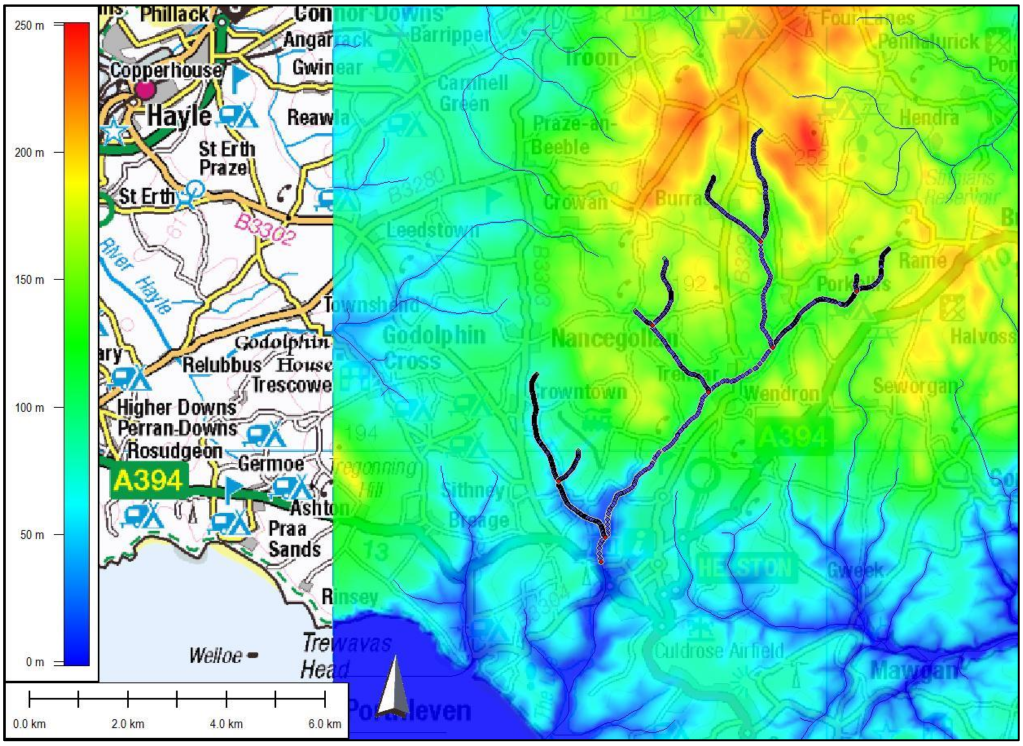

Figure 6:13- the rivers and streams highlighted in bold are considered to influence the River Cober before it reaches Helston, and therefore would be most important when considering the flooding effects on Helston.

This work concerns the flooding in Helston. Therefore, it is only necessary to consider the stream and river network of the River Cober that is above Helston. When considering catchment size the streams highlighted in Figure 6:13 are the tributaries that were taken into consideration.

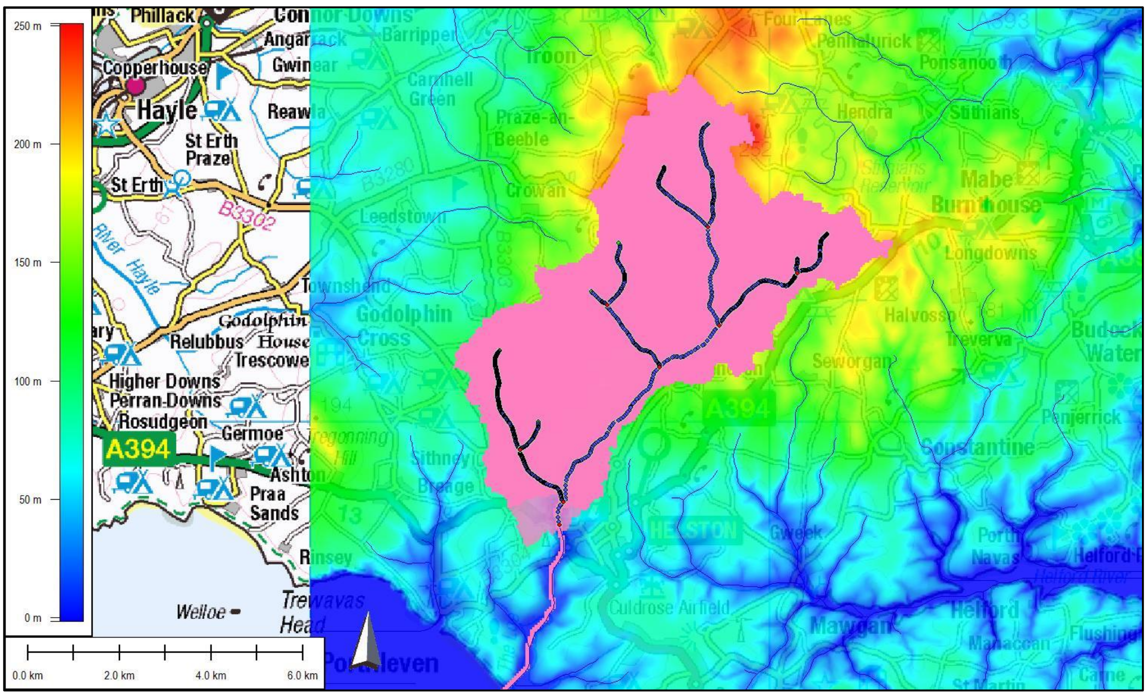

Figure 6:14- Highlighted in the large pink block is the whole of the area of the catchment of the River Cober that would influence the river regime in Helston.

The size and area of the catchment needs to be quantified in order to look at the potential river flow that will affect the river regime in Helston (Figure 6:14). The area highlighted in pink is suggested to be the size of the River Cober catchment effecting Helston and is 39.753 km^2. The shape of the catchment is elongated and tight to the river path particularly on the east side of the catchment.

Rainfall rates:

Rainfall rates can be deduced from historic weather data collected by the Met Office. The Wendron weather station is located in the North of the River Cober catchment near Camborne. Monthly rain data since 1978 has been averaged so the average rainfall per month from 1978 to 2015 is displayed (Table 6:2). Using the area of the catchment calculated in Figure 6:14 the volume of water that falls over the catchment can be calculated (Table 6:2).

Table 6:2- Rainfall and water volume data for the River Cober catchment and Wendron weather station (Source: Met Office, 2016).

Month	Catchment Area (m^2)	Rainfall per Month (mm)	Rainfall per Month (m)	Water Volume from Whole Catchment (m^3/month)	Seconds in the Month	Water Volume from Catchment (m^3/s)
January	39753000	123.3675676	0.123367568	4904230.914	2678400	1.83103006
February	39753000	91.51891892	0.091518919	3638151.584	2419200	1.503865569
March	39753000	78.58648649	0.078586486	3124048.597	2505600	1.246826547
April	39753000	70.48648649	0.070486486	2802049.297	2678400	1.046165359
May	39753000	64.18648649	0.064186486	2551605.397	2592000	0.984415663
June	39753000	60.64054054	0.060640541	2410643.408	2678400	0.900031141
July	39753000	65.02162162	0.065021622	2584804.524	2592000	0.997223968
August	39753000	73.59189189	0.073591892	2925498.478	2678400	1.092256003
September	39753000	72.50810811	0.072508108	2882414.822	2592000	1.112042755
October	39753000	116.8945946	0.116894595	4646910.819	2678400	1.734957743
November	39753000	120.6162162	0.120616216	4794856.443	2592000	1.849867455
December	39753000	131.7810811	0.131781081	5238693.316	2678400	1.955904016

St Johns Bridge:

The St Johns bridge is a significant feature on the River Cober. It has two distinct arches that allow water to pass through. Although the water is extremely slow moving in the left hand tunnel. It is approximately 6.592 m in width with the arches continuous through the whole bridge width (Figure 6:15).

Figure 6:15- Picture demonstrating the distinctive arches of the St Johns bridge Helston. (Source: Authors Own.)

These arches will undoubtly have an effect on the flow in the river as well as the capacity of the river at that point. The edge of the arches were recorded using reflectorless technology and on the Leica 1200 total station (Figure 6:16).

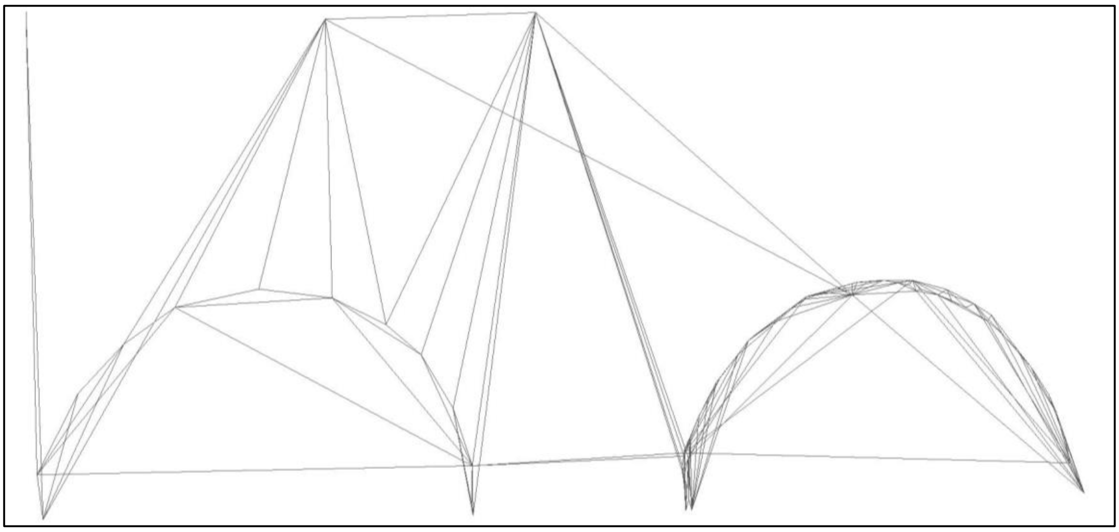

Figure 6:16 - Sketch AutoCAD drawing of the St Johns bridge, on the River Cober Helston.

By using the data collected reflectorlessly the area within the arches can be estimated. The size of the arches is assumed to be the same for the purpose of this work.

Area of the Arch: 3.910 m^2

Width of the Bridge: 6.592 m

Area of 1 Tunnel: 25.774 m^3

Area of both Tunnels: 51.548 m^3

CHAPTER 7: DISCUSSION:

The potential reason for flooding in Helston:

The secondary and historic data collection discussed in Chapters 4 and 6 clearly demonstrated an issue with flooding in Helston. The results section discussed in Chapter 6 demonstrates varying parameters relating to the flooding in Helston.

The CES software creates various different outputs, both the flow and conveyance outputs for this work are shown in Appendix 2. However the CES software only provides predictions based on certain parameters (cross section geometry, roughness, sinuosity and slope) so whether these predictions are correct is unclear. These predictions will be quantified and tested below.

The National River Flow Archive (NRFA) is the main source for hydrometric data in the United Kingdom (UK). It has 1500 gauging stations on rivers across the UK, and can therefore provide access to daily, monthly and flood river peak river flow data. There is a gauging station on the River Cober at Helston County Bridge which is located in between Area 1 and Area 2. The flow data from this station is from 01/09/2014 to 01/09/2015 is presented in Figure 7:1.

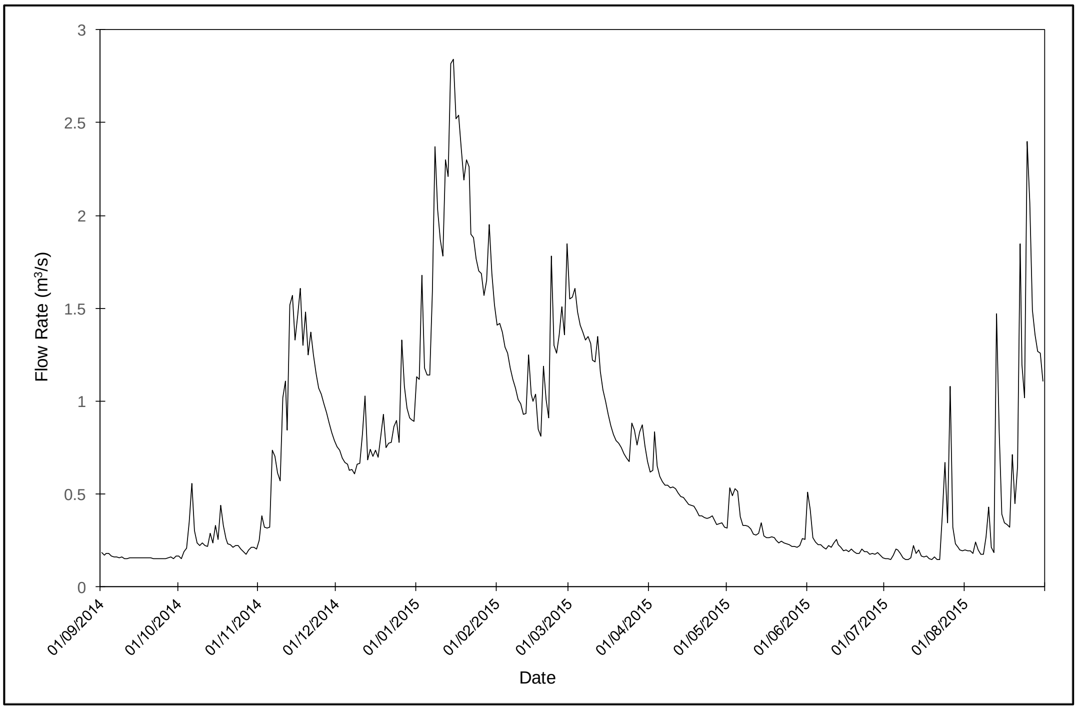

Figure 7:1- Flow rate data for one year from 1/09/2014 to 1/09/2015 for the River Cober at Helston County Bridge. (Source of Data: National River Flow Archive [17/07/2016]).

According to the NRFA data the flow along the River Cober flow rates vary between 0 and 3 m^3/s. With the highest flow rates in January, which is the same time period as the historic flooding in Helston. The NRFA record the mean flow rate along the River Cober as 1.004 m^3/s (NRFA, 2016). The typical depth level range of the River Cober at the Helston County Bridge is between 0.232 m and 1.400 m (Shoothill Gauge Map, 2016). Comparing these daily averages from gauge data there is no noticeable correlation to the work from the outputs calculated using the CES software (Figure 6:7, 6:8, 6:9 and 6:10). However the NRFA data also calculates the peak flow rates seen on the river, and is of more interest to this study in relation to flooding.

Table 7:1- Data for the two most recent records of peak flow rate (Source: National River Flow Archive, 2016).

Date Recorded	Depth (m)	Flow Rate (m^3/s)
22/12/2012	2.436	12.530
24/12/2013	1.837	8.635

It can be seen Figure 6:8iii definitely agrees and predicts a similar flow rate to peak flows recorded by the NRFA. For example when the River Cober is at a depth of 1.837 (Table 7:1) the CES software (Figure 6:8iii) would predict a flow along the River Cober of approximately 8 m^3/s. Agreeing with the data presented by the NRFA from a gauging station. However this agreement does not occur with the data collected in cross sections A-L. These areas predict much greater flow rates at the same depth. This variation in the prediction is most likely related to the areas the cross sections and what is most relative to the River Cober. This therefore suggests that the cross sections M to Q give the most accurate outputs when using the CES software.

The cross sections A to G predict a flow rate at 1.837 m of approximately 10 to 15 m^3/s (Figure 6:8i). This higher flow rate prediction from the cross section data input into the CES software is mainly because of the roughness values for this area. Cross section B and C are both predominately formed from a concrete ramp on the right bank. Cross sections D and E have a masonry wall on the right bank. Cross section F and G have tall masonry walls on both banks that are part of the supporting walls for the St Johns Bridge. These anthropogenic structure anomalies decreased the roughness values entered into the CES software. Hence there was a reduced amount of friction accounted for and therefore a higher flow rate is predicted.

In a similar manner cross sections H to L from Area 1 also seem to over predict the flow rate. At a depth of 1.837 m Figure 6:8ii predicts a flow rate of approximately 25 m^3/s, much higher than ever could be expected on the River Cober. The reasons as to why these flow predictions are so much greater than what would be expected is unclear. The cause is not as obvious as the over prediction from cross sections A to G. The area is similar to the cross sections M to Q, with similar topography and roughness values. The notable differences are a few inlets at approximately 1 m on the right bank. However initial thoughts are that this would reduce the flow rates not the increase seen. Therefore these predictions should be considered as an anomaly and discarded. These anomalies could be caused by inaccuracies in the topographical surveying.

Corrections of these anomalies could be completed by reducing the errors within the surveying. This could have been completed by setting the control network up to greater precision. The use of a static GPS survey using differential GPS would have allowed for an accuracy of ±0.1 to 5 mm. Due to the potential of anomalies in the cross section A to M; the cross section data M to Q is now going to be used for the rest of the analysis.

Shothill Gauge Map (2016) suggests that the River Cober can flood in Helston potentially at any depth level over approximately 1.4 m (Figure 7:2). This approximate depth can then be used to calculate the conveyance of the River Cober from the CES outputs.

Figure 7:2 Shothill Gauge suggested flooding level for the River Cober at Helston County Bridge (Source: Shothill Gauge Map, 2016 [17/07/2016]).

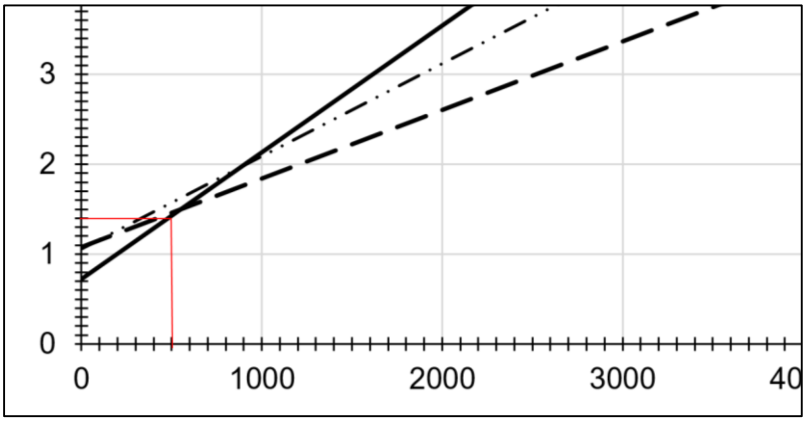

Figure 7:3 - suggestions of how the 1.4 m potential flood level from Shothill Gauge Map could affect the potential conveyance of the River Cober using the data collected for Cross Sections M to Q. (See Figure 6:9 for full scale graph).

By taking the expected flood potential depth (Figure 7:2) estimated by flood gauging the conveyance of the River Cober can be estimated (Figure 7:3). The expected conveyance (or discharge capacity of a water course) of the River Cober at flood level is estimated using the CES software to be 500 m^3/s. However the expected flow is only approximately 10 m^3/s (Figure 7:3). Hence it would be expected that the River cannot discharge at the rate and there will be an excess of water due to the slow flow rate. Potentially the cause of flooding within Helston.

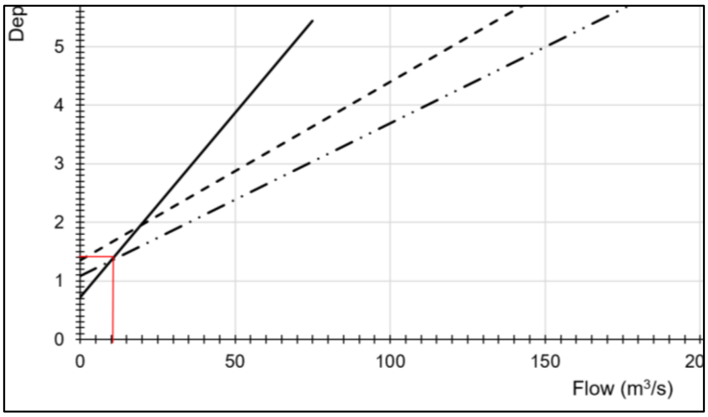

Figure 7:4- Expected flow rate at an potential flood level of 1.4 m from Shothill Gauge Map. Estimated using the data collected using the data collected for cross sections M to Q. (See Figure 6:10 for full scale graph).

Comprehensive meteorological data is recorded for the River Cober catchment (Table 6:2). Therefore the precipitation input can be compared to the River Cober output. Unsurprisingly the months with the greatest amount of average rainfall are the months where most flooding is recorded historically. This data (Table 6:2) is an average rainfall for each month from the years 1978-2015. It demonstrates a relatively low volume of water entering the catchment. For example in December (the month with the highest average rainfall) the water volume entering the catchment is 1.956 m^3/s. With a capacity of 500 m^3/s and a flow rate of up to 10 m^3/s this volume of water would not cause flooding along the River Cober. However flooding should not be expected as this an average rainfall, and the River Cober is not always in flood; in fact it is normally at a low level of between 0.19 m and 0.59 m in average weather conditions (River Levels, 2016).

In relation to precipitation rate what needs to be considered is the rate seen during large flood events. The Environment Agency (2016) record a flood in Helston (31/12/2002) where 49.8mm of rainfall was recorded from 19:00 on the 31/12/2002 until 9:00 on the 01/01/2003. Across the entire River Cober catchment (Figure 6:13) this has been calculated to be water volume of 39.280 m^3/s; significantly greater than then the 1.956 m^3/s water volume contribution from the catchment normally expected in December (Table 6:2).

Utilising the conveyance calculation of 500 m^3/s for the entirety of the River Cober this extra water does not exceed the conveyance. However the current water level at that point needs to be considered as well as the predicted flow rate. Taking into account the 10 m^3/s flow rate during potential flooding calculated previously using the CES software initial suggestions suggest it is not the capacity of the River Cober that is an issue but instead the apparent slow flow rate. The currently predicted flow rate suggests that there is 29.280 m^3/s of water that cannot flow into the river at a sufficient rate even with sufficient conveyance within the river. Therefore with a conveyance potential of 500 m^3/s and a flow of 10 m^3/s and an input of 39.280 m^3/s; 10 m^3/s can leave the river but 39.280 m^3/s is entering. Therefore there is a requirement for 529.280 m^3/s of conveyance (if the river was already at full capacity) so 29.280 m^3/s of water needs to be accounted for outside of the River Cober and hence it floods in Helston. The same is seen for other flood event scenarios.

The Environment Agency (2016) record of historic flooding also records problems with the capacity of the St Johns bridge in Helston. Flooding of the St Johns Road area (Figure 4:10) is recorded due to “St Johns Bridge obstructing flow” and “channel capacity exceeded” in 1973 (Environment Agency, 2006, p. 1). The St Johns Bridge is also recorded to have obstructed the flow and cause a flood in 1979 and 1988. This clearly suggests that the St Johns Bridge has a potential to be a further obstacle to flood causation on the River Cober. The small capacity of the arches is demonstrated in Figure 6:15. The capacity of one arch way is 25.744 m^3. Therefore the arches can only have capacity for 51.548 m^3/s. Hence the bank full river capacity of 500 m^3/s greatly exceeds what can pass under the bridge at one point. Consequently enlarging the small arches on the St Johns Bridge (Figure 6:16) would help to mitigate against overloading the capacity at the bridge.

The issue relating to conveyance and flow rate directly links in to the flood inundation demonstrated from using the DTM data (Figure 6:2). When in flood the flood will occur in the area shaded on the OS map. This DTM data compares well to the flood inundation modelled by the Environment Agency (Figure 7:5). The Environment Agency also shows that the main area of flood inundation is in the St Johns Bridge area. This agrees with the areas flooded historically. It also links into the issues surrounding the capacity of St Johns Bridge. Figure 7:6 demonstrates the flood inundation around Area 1; it clearly demonstrates that flooding in the area will be a problem, hemmed in by the steep contours of the Loe Valley on either side on the River Cober. Figure 7:7 further demonstrates evidence of flood inundation within Area 1 (Appendix 1a) with the markings on the tree suggesting flood water reached that point at some point recently.

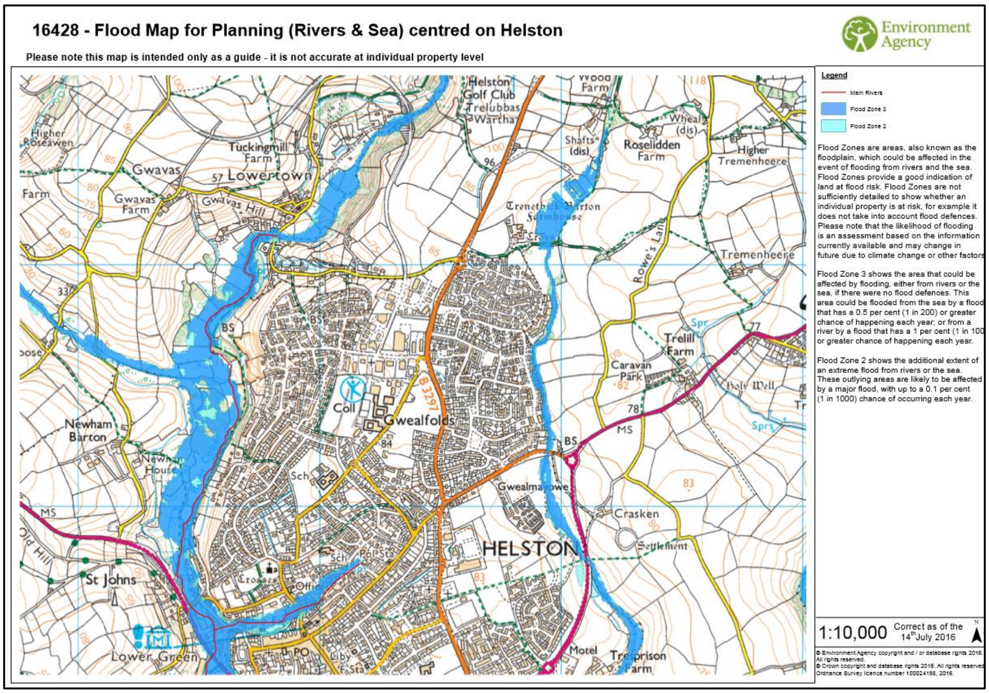

Figure 7:5- Environment Agency flood inundation map based on contour data. (Source: Environment Agency, 2016c)

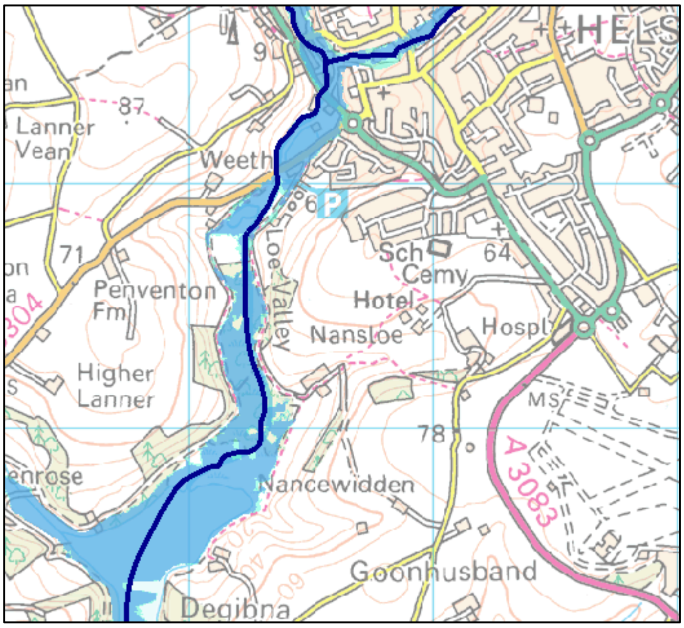

Figure 7:6- Flood inundation of including Area 1 (Source Environment Agency 2016d).

Figure 7:7- Evidence on flood inundation on a tree in the South West corner of Area 1 (Appendix 1a).

This work clearly demonstrates that for normal precipitation rate conditions the conveyance and flow rate of the River Cober is adequately contained within the conveyance of the river. However at peak precipitation rates (for example the 2002 flood rates) the flow and conveyance capacity of the river is not great enough. When this occurs flood inundation occurs in the areas suggested in Figure 6:2, 7:5 and 7:6. It seems essential to somehow mitigate against this potential flood inundation.

Mitigation techniques for the River Cober:

The current flood alleviation engineering in place that the Environment Agency maintain (the channelisation of the River Cober) agrees with the findings in this work. It allows the water in the channel to move quickly through Helston. The Environment Agency still maintain this with dredging. However as suggested by the Penny Anderson Associates (2014) this method is environmentally degrading to an already sensitive habitat. Also the evidence of flooding in Helston clearly demonstrates that these methods are not completely alleviating the flood risk within Helston.

It is not possible to completely reduce and protect the risk of flooding in Helston, however mitigation of certain aspects may reduce the damages experienced

(Heidari, 2009). Clearly these mitigation plans need to resolve the conveyance and flow issues previously discussed. The most obvious way to overcome these issues would be to further straighten the channel, increase the size and create a smooth engineered surface. This is a common methodology for flood alleviation with 8504 km of rivers in England and Wales subject to major or capital works in 1983 (Brookes and Gregory, 1983). This would increase the capacity and flow of the River Cober. However building large concrete structures is no longer considered the most effective defence against flooding (WWF Scotland, 2007); and are also extremely costly to design, build and maintain (WWF Scotland, 2007). Further to this straightening of rivers is no longer seen as acceptable due to the environmental degradation witnessed (Pepper and Rickard, 2009).

Pepper and Rickard (2009) suggest some further engineering methods that will increase the capacity to carry flood flows of the River Cober. One option is to complete further channel maintenance, which is essentially keeping the channel clear of any excessive vegetation, removing debris and obstructions and desilting where necessary (Pepper and Rickard, 2009). Allowing a channel to become heavily overgrown can greatly increase the likelihood of flooding from the channel. The objective is to maintain the channel capacity to ensure it is adequate for flood conveyance (Pepper and Rickard, 2009). However historically extreme channel maintenance was considered acceptable with environmental considerations secondary to the objective of increasing flood conveyance (Pepper and Rickard, 2009). It is now considered not acceptable to allow the clearance of long reaches of river channels, so channel maintenance as an engineering approach is not accepted. Channel modification has been an extremely controversial subject, and frequently disrupts and destroys aquatic life, promotes erosion and siltation and changes channel patterns (Keller, 1975).

Channel enlargement is also suggested by Pepper and Rickard (2009) as an obvious way to increase the capacity of a river channel and therefore overcome the flooding problem. However there are numerous drawbacks concerning channel enlargement, these include: environmental degradation due to loss of natural channel features, instability of the channel as the vegetation is removed therefore greater erosion, increased rates of sedimentation in the engineered channel and an unnatural visual appearance in the channel particularly at low flow conditions (Pepper and Rickard, 2009). Therefore channel modifications are becoming less favourable in flood mitigation.

In Helston where channel modifications have already taken place it is possible to improve the environmental issues surrounding such heavily engineered designs. Keller (1975) suggests that a reproduction of channel forms produced by natural fluvial processes will minimize some of the adverse effects seen through river engineering works. The main methodology to allow channel modifications to occur with reduce environmental effects is the design of distinct morphology such as regularly spaced pools and riffles (Keller, 1975). Designing pools and riffles into channel modifications means that: channel stability maybe increased, biological damage within the stream will be reduced and there will an increase in the visual aspect of the channel modification.

The location of the River Cober needs to be considered as within Helston such an extreme engineering scheme would most likely be fruitless; due to the rare hydrological conditions in place in relation to Loe Pool. Moving the water through at a quicker pace at this point would most likely mean that flood would simply peak later as it would back up in Helston due to Loe Pool. Further to this issue there is also the environmental degradation factors that need to be considered, considering the close proximity and location of the lower River Cober to the Loe Pool SSSI (Figure 4:9ii). Suggesting that neither channel maintenance or channel enlargement are suitable as flood mitigation measures within Helston. Soft engineering approaches are therefore more appropriate to try and mitigate against flooding in Helston.

The original Land Drainage Improvement Works (Assessment of Environmental Effects) Regulation 1988 (Tunstall et al., 2004) combined with the later European Water Framework Directive (WFD) as well as increased public awareness of environmental issues and concern about habitat and wildlife loss has meant there is growing use and interest in soft engineering approaches to flood alleviation schemes (Tunstall et al., 2004). The European Water Framework Directive is one of the most significant pieces of water legislations (Griffiths, 2002). The key objectives help with the further administration and implementation of soft engineering schemes. The objectives of WFD are: to prevent the further deterioration of the status of aquatic ecosystems and wetlands, promote sustainable use of water resources, enhancement of the aquatic environment, ensure the reduction of pollution of water and mitigate the effects of floods and droughts (Griffiths, 2002).

There are various approaches that can be utilised in the River Cober catchment, the key to effective success with these schemes is to implement sustainable management within the entire catchment that is fully integrated (WWF Scotland, 2007). With this in mind the WFD has recently moved to try and implement a whole river catchment process.

The main theme within soft engineering are runoff attenuation features (RAF's). "RAF's are soft engineered interventions designed to increase the storage capacity of the river catchment" (Nicholson et al., 2012, p. 464). They look to regulate runoff through temporary storage of flood water, disconnect and lengthen flow pathways as well increase the roughness of flood plain features (Nicholson et al., 2012).

One solution several areas of the literature discuss is utilising woody debris from the trees within the catchment. WWF Scotland (2007) suggest that natural dams should be restored in catchments. A building up of woody debris will create pools that will slow flood water down from entering the river system and also trap sediment (WWF Scotland, 2007). Nicholson et al., (2012) also suggest that a build up of large woody debris in a catchment may help to mitigate against flooding. The large woody debris (or natural dams) slows the propagation of the flood peak by creating a more tortuous route downstream for precipitation. As well as this there are other benefits to allowing a natural build up woody debris in the upper catchment for example nutrient cycling will be increased (Nicholson et al., 2012). The creation of natural dams is something that could be easily transferred into the River Cober catchment. The catchment already has potential for this as there are areas of natural woodland at Porkellis Moor and Burras these could be left with limited maintenance therefore allowing woody debris to build up. Although as the flow depth of runoff increases, the effect of woody debris or natural dam decreases (Nicholson et al., 2012) overall this could be an effective measure to reduce the inputs of precipitation into the River Cober. Therefore decreasing the requirement to increase the flood conveyance and flow rate within the channel.

The WWF Scotland (2007) suggest that reconnecting rivers with their floodplains is a further solution to flooding. This agrees with the plan that Penny Anderson Associates (2014) in partnership with the National Trust suggested for the River Cober. Where there is a proposal for lower short sections of the River Cober to be changed to allow flow to pass put into the floodplain for greater river floodplain interactions. This would also enhance the sensitive carr habitat formed in the lower reaches on the River Cober. Lowlands can be further developed so they can hold a large amount of water and can also be managed to divert peak flood water from the river and discharge out the storage water within a specific time period (Prajamwong and Suppataratarn, 2009). This management would be ideal with the carr habitat which thrives well when submerged ephemerally. Reconnecting the River Cober with its floodplain by the methods outlined in Chapter 4 by Penny Anderson Associates (2014) will allow the flood plain to store and hold significant volumes of water that can then be released as the River Cober returns to a normal depth (WWF Scotland, 2007).

A more significant alteration that could be made in the upper River Cober catchment is the use of retention ponds within the drainage network. This agrees with the Environment Agency plan to investigate the creation of upstream storage (Chapter 4). Natural depressions within the catchment could be modified to retain water (Faisal et al., 1999), which in turn would reduce the amount of water needing to be factored into the flood conveyance. Retention ponds can both reduce flood peaks and increase the lag time of the flood at a point lower down the river (Nicholson et al., 2012). This would work in a similar fashion to the commonly used method of controlled release from reservoirs used in some river catchments (WWF Scotland, 2007). This is a suitable solution in the River Cober catchment due to the topography demonstrated (Figure 6:1). In the upper catchment there is a limited amount of steep topography, henceforth there is a selection of relatively flat areas suitable for retention ponds. However this method does require good cooperation with landowners within the catchment.

Alternative sustainable management can also be completed within Helston itself. The WWF Scotland (2007) suggest that sustainable management can be achieved to increase the speed of flow through towns. This would be an ideal solution for the River Cober which has a slow flow speed effecting the flood conveyance. Blockages in urban channels are caused by a build up of sediment, fallen trees and human rubbish which dramatically slow the flow of the river. Sustainable management of this aims to increase the capacity of the channel and hence the speed of the flow of the water. Completed by removing sediment at key points in the catchment (WWF Scotland, 2007). Although this does not at first seem a sustainable solution, the WWF Scotland (2007) suggest it will eventually become a self-managing process. Therefore different to dredging which has been previously completed in the River Cober. This sustainable removal of sediment in the River Cober catchment above Helston would be a major source of flood mitigation on the River Cober, as it directly tackles the main problems surrounding the flooding; flow and capacity. However clarification into how it is sustainable would have to be sourced.

There are numerous methods to alleviate flooding all with different considerations and strategies to try and resolve the same issue. In the case of the River Cober some methods will work better than others. Before being able to consider which method or methods would be most suitable for the River Cober catchment further investigations need to be completed. Some sustainable soft engineering may occur almost by accident for example natural barriers, sponges and forest drains (WWF Scotland, 2007). These need to be taken into consideration before new plans can be finalised. Although this will not be completed in this work, a catchment wide study following an environmental site investigation methodology should be completed. This would allow the options outlined above to be assessed for feasibility within the Cober catchment.

CHAPTER 8: CONCLUSION:

This work has focused on flooding in Helston, using traditional surveying techniques to look at the capacity and flow of the River Cober. The use of the CES software allowed river conveyance and flow to be calculated. The GIS software has also allowed the topography to be considered when calculating catchment area.

Globalmapper identified the River Cober to have a long thin catchment of 39.753 km^2. It also has a relatively low elevation of under 250 m; with limited variation seen in topography. The majority of the catchment is used for agricultural land, with the only large urban settlement being Helston. Which this work has focused on.

Conveyance for the River Cober was calculated at an approximate flood depth to be 500 m^3/s. Suggesting that at full bank flow the River Cober can carry 500 m^3/s of water within the banks. At the same approximate flood depth the River Cober has been predicted from this work to be able to flow at 10 m^3/s. The flood scenario of a 2002/3 flood when 39.280 m^3/s of precipitation was entering the river from the outlined catchment demonstrates how the precipitation levels are too high for the speed of flow and the conveyance is exceeded. The issue of river conveyance within Helston is further exacerbated by the interruptions to river flow and capacity. In particular, with this example the St Johns Bridge.

These findings suggest that more needs to be completed for the flood alleviation scheme. Initial obvious suggestions are to increase the amount of hard engineering surrounding the river channel in Helston, in order to increase speed of flow through the town. This has been done historically through channelisation, which can be identified on the historic maps within the work. However it has not alleviated the flooding issues within Helston. This maybe because of the complex hydrological situation Loe Bar creates. Hard engineering solutions would have to take into consideration the effect of Loe Bar on the hydrological regime of the River Cober.

Negative issues surrounding hard engineering solutions and the inappropriate nature and lack of effectiveness of them in Helston mean soft engineering and sustainable approaches have been considered within the work. The soft engineering measure considered are: use of natural dams and woody debris, reconnecting the river with the floodplains, use of retention ponds and removing sediment and debris in key locations. From the methods researched the most suitable in Helston is likely to be the reconnection of the river with the floodplains. This agrees with the work completed for the National Trust by the Penny Anderson Associates (2014). This could be completed by removing the anthropogenic objects obstructing flow on the flood plain such as the gravel paths which are marked on the plan (Appendix 1a). This alleviation scheme would also enhance the rare willow carr habitat found on the flood plain area in the lower Loe Valley. This plan is also most likely to be the most economic efficient as there will be little requirement for intervention once the initial outlay had been completed.

This research is particularly important at highlighting issues with flooding around Helston, and trying to pinpoint exact reasons as to why Helston floods. This therefore allows more targeted solutions to the flood inundation within Helston.

However this research can be taken much further. The outputs of the CES software have been demonstrated to be useful. However the area where the surveying was too small and did not cover a large enough area of the River Cober. Cross sections M to Q allowed a good comparison and therefore some conclusions could be made. However the other two areas where cross sections were taken in places that were not realistic of the rest of the River Cober. If the work was to be taken further in the future cross sections should be completed the entire length of the River Cober. This would not only allow for more valid results but would allow different areas of the catchment to be compared. Further work could also include the flood inundation modelling; flood inundation could be modelled using the topographic data collected through the survey, although a suitable programme to model this through would have to be researched first.

Further work should also look into the effects and practicalities of each of the soft engineering solutions suggested. This work highlights that soft engineering could help to provide the long term solution for flooding in Helston. However further work needs to be carried out as to the feasibility of each solution within the catchment.

This work has demonstrated the use of the CES software and applied it in Helston. It demonstrates the need for soft engineering solutions in the catchment. Greater use of the CES software and traditional surveying techniques in the entire River Cober catchment could allow for better applications of alleviation schemes; and real chance to solve or reduce the flooding issue within Helston.

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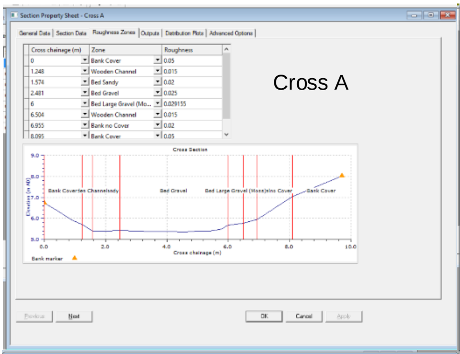
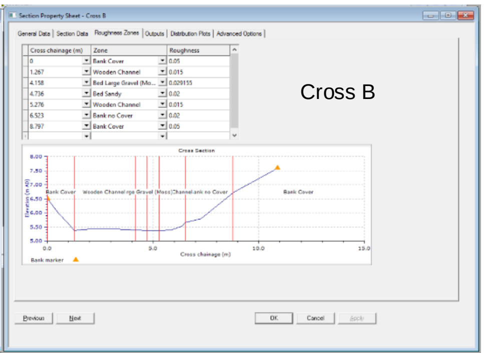
APPENDIX:

Appendix 1a The Carr Topographic Plan.

Appendix 1b- St Johns topographic plan.

Appendix 2- Cross Section Data


Cross A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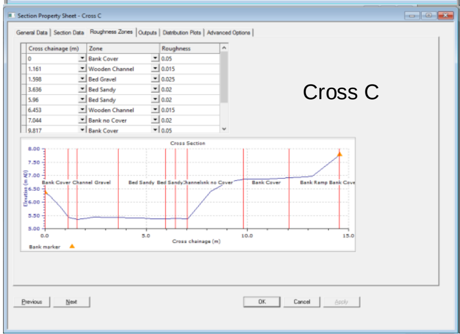
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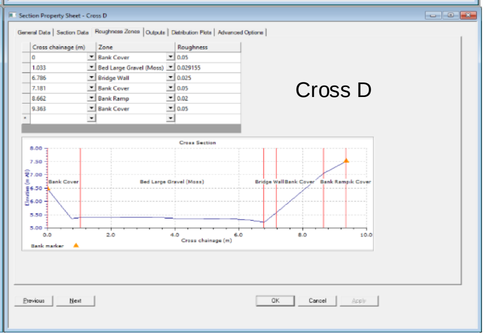
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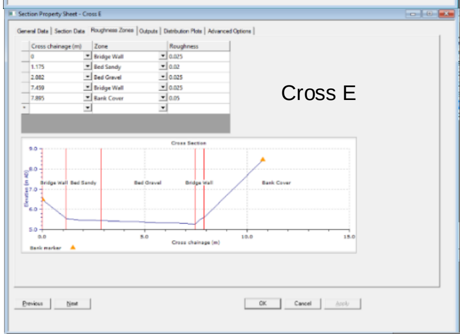
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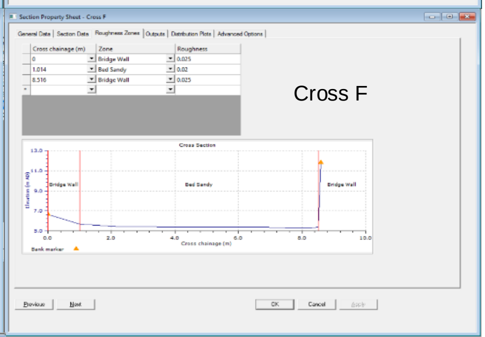
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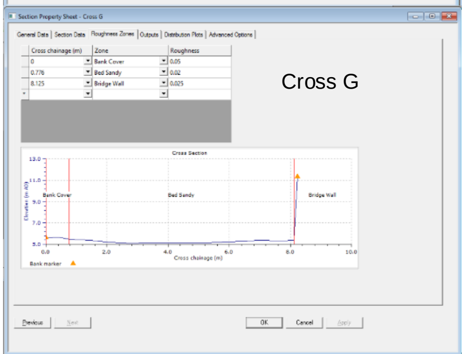
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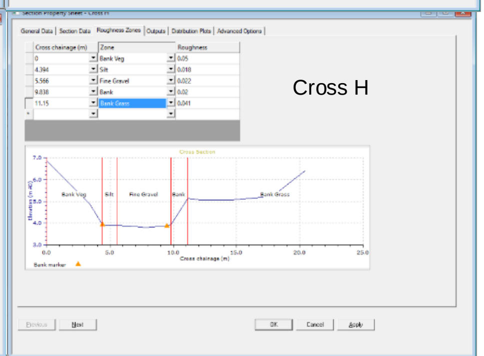
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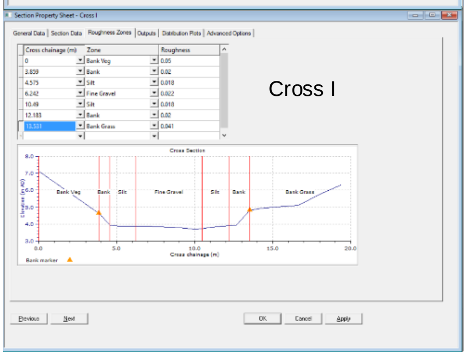
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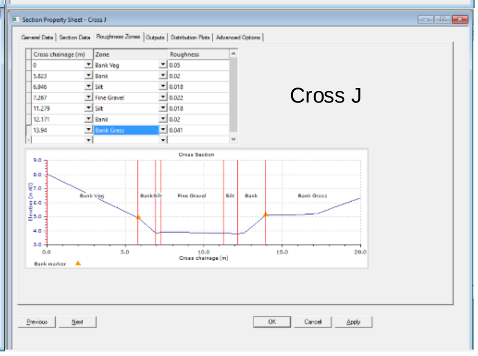
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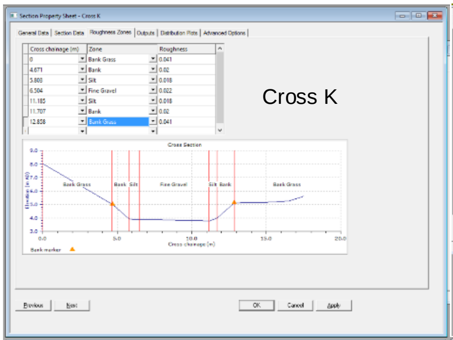

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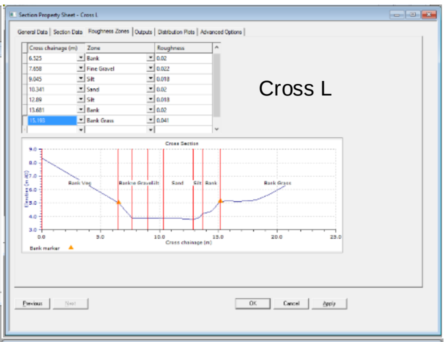

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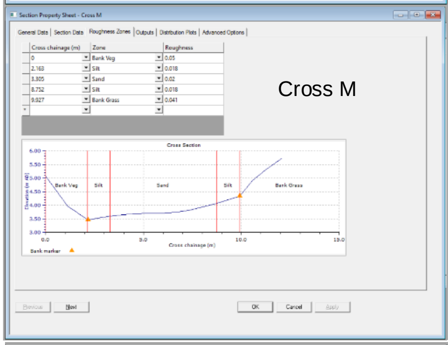

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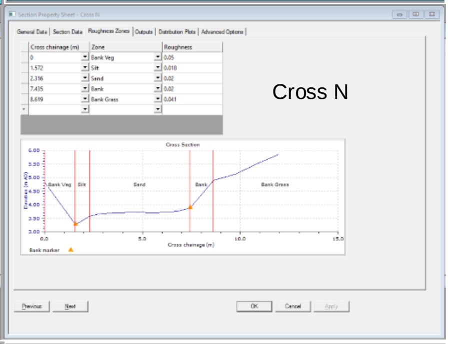

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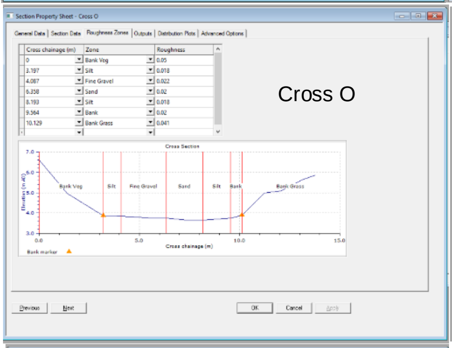
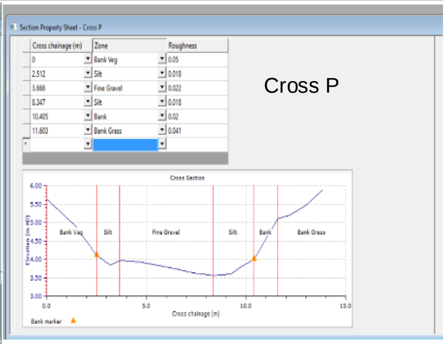


Cross O



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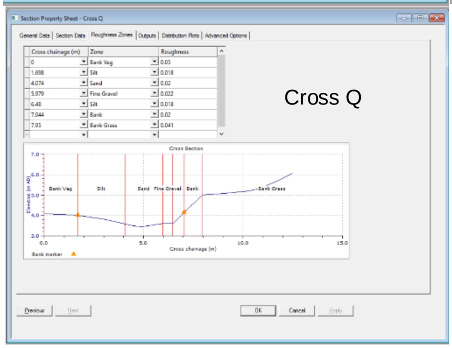

Cross Q

Appendix 3- Roughness Data

Cross Section	Point Number	Roughness Description/Notes
A	1	Top of Bank- trees and soil
	2	Soil with dense vegetation
	3	Soil with dense vegetation
	4	Large flat rocks
	5	Course sand at bottom of wooden panels
	6	Course sand
	7	Small rugged stones
	8	Small stones/pebbles
	9	Small stones/pebbles
	10	Large flat stones
	11	Larger stones with moss
	12	Very course sand
	13	Sand bottom of wooden panels
	14	Bare soil and rocks
	15	Loose soil
	16	Vegetation and soil
	17	Top of Bank- vegetation.
B	1	Top of Bank- Dense ferns and vegetation
	2	Dense ferns and vegetation
	3	Soil and pebbles
	4	Gravel/ sand- bottom of wooden panels
	5	Flat pebbles and gravel
	6	Medium pebbles and rocks
	7	Large flat pebbles
	8	Medium sized pebbles
	9	Medium sized pebbles
	10	Medium sized pebbles
	11	Small pebbles
	12	Large flat stones
	13	Course sand
	14	Course sand
	15	Concrete ramp
	16	Concrete ramp with debris
	17	Concrete ramp
	18	Low vegetation
	19	Top of Bank- Grass and soil
C	1	Top of Bank- Grassy vegetation
	2	Grassy vegetation
	3	Top of masonry wall
	4	Gravel and Sand
	5	Large flat stones and gravel
	6	Medium sized pebbles
	7	Medium sized pebbles
	8	Medium sized pebbles
	9	Large pebbles
	10	Large pebbles

	11	Large pebbles
	12	Medium sized pebbles
	13	Medium sized pebbles
	14	Course sand and gravel
	15	Edge of stone wall
	16	Soil and long grass
	17	Concrete
	18	Concrete
	19	Concrete
	20	Concrete
	22	Soil and vegetation
D	1	Top of wall
	2	Edge of wall
	3	Sand with gravel
	4	Sand with gravel
	5	Large to medium pebbles
	6	Large to medium pebbles
	7	Large to medium pebbles
	8	Medium pebbles
	9	Medium pebbles
	10	Medium pebbles
	11	Small pebbles
	12	Sand
	13	Stone wall
	14	Stone wall
	15	Grass
	16	Grass
E	1	Top of wall- vegetation
	2	Silt
	3	Sand/gravel
	4	Gravel
	5	Small round pebbles
	6	Small round pebbles
	7	Small and flat stones
	8	Small and flat stones
	9	Medium pebbles
	10	Medium pebbles
	11	Large pebbles
	12	Fine gravel
	13	Fine gravel
	14	Edge of stone wall
	15	Edge of stone wall
	16	Top of wall
F	1	Top of wall
	2	Silt
	3	Silt
	4	Sand
	5	Gravel

	6	Small round pebbles
	7	Small flat pebbles
	8	Small flat pebbles
	9	Small pebbles
	10	Small pebbles
	11	Course gravel
	12	Sand/gravel
	13	Sand- bottom of wall
	14	Top of Wall
G	1	Top of Wall
	2	Silt
	3	Silt
	4	Silt/mud
	5	Silt/mud
	6	Sand/silt
	7	Sand
	8	Sand
	9	Sand
	10	Sand
	11	Sand
	12	Sand
	13	Sand
	14	Course sand
	15	Sand and pebbles
	16	Course Sand
	17	Top of Wall
H	1	Top of bank
	2	Mud and vegetation
	3	Silt
	4	Silt
	5	Fine gravel
	6	Course gravel
	7	Course gravel
	8	Course gravel
	9	Fine gravel
	10	Fine gravel
	11	Silt/mud
	12	Soil and vegetation
	13	Soil and vegetation
	14	Soil and vegetation
	15	Soil and vegetation
	16	Soil and vegetation
	17	Soil and vegetation
I	1	Top of bank- dense vegetation
	2	Soil and ivy
	3	Silt
	4	Silt
	5	Silt

	6	Edge of gravel
	7	Gravel
	8	Course gravel
	9	Fine gravel
	10	Fine gravel
	11	Fine gravel
	12	Silt with gravel
	13	Sand and debris
	14	Sand and debris
	15	Silt/sand
	16	Silt
	17	Grass
	18	Grass
	19	Grass
	20	Grass
	21	Grass
	22	Grass
	23	Grass
J	1	Top of bank- vegetation
	2	Mud and vegetation
	3	Silt
	4	Silt
	5	Gravel/silt
	6	Gravel
	7	Gravel
	8	Gravel
	9	Gravel
	10	Gravel
	11	Gravel
	12	Sand and silt
	13	Silt
	14	Mud
	15	Grass
	16	Grass
	17	Grass
	18	Grass
	19	Grass
K	1	Top of Bank
	2	Mud and vegetation
	3	Silt
	4	Silt
	5	Edge of gravel
	6	Fine gravel
	7	Fine gravel
	8	Gravel
	9	Gravel
	10	Fine gravel
	11	Silt

	12	Silt
	13	Grass
	14	Grass
	15	Grass
	16	Grass
	17	Grass
	18	Grass
L	1	Top of Bank- trees
	2	Vegetation
	3	Silt
	4	Silt
	5	Gravel
	6	Gravel
	7	Coarse gravel
	8	Coarse gravel
	9	Fine gravel
	10	Fine gravel
	11	Gravel and pebbles
	12	Silt
	13	Fine mud
	14	Find mud
	15	Grass
	16	Grass
	17	Grass
	18	Grass
	19	Grass
	20	Grass
M	1	Top of Bank- soil and vegetation
	2	Soil and vegetation
	3	Silt
	4	Silt
	5	Sand
	6	Fine sand
	7	Fine sand
	8	Sand
	9	Sandy silt
	10	Sandy silt
	11	Sandy silt
	12	Sandy silt
	13	Silty mud
	14	Silt mud
	15	Grass and mud
	16	Soil
	17	Grass
N	1	Top of bank- trees
	2	Mud and vegetation
	3	Silt
	4	Sand

	5	Sand with gravel
	6	Sand with gravel
	7	Sand with gravel
	8	Sand
	9	Sand
	10	Fine sand
	11	Grass
	12	Grass
	13	Mud
	14	Grass
O	1	Top of bank- vegetation
	2	Vegetation
	3	Silt
	4	Silt
	5	Gravel
	6	Gravel
	7	Gravel
	8	Fine gravel
	9	Sand
	10	Sand
	11	Silt
	12	Silt
	13	Silt
	14	Grass
	15	Grass
	16	Grass
	17	Grass
P	1	Dense vegetation
	2	Vegetation
	3	Silt
	4	Silt
	5	Gravel
	6	Gravel
	7	Gravel
	8	Fine gravel
	9	Silt with small pebbles
	10	Silt
	11	Silt
	12	Silt
	13	Grass
	14	Grass
	15	Grass
	16	Grass
Q	1	Dense vegetation
	2	Vegetation
	3	Silt
	4	Silt
	5	Silt

	6	Sand
	7	Sand
	8	Corse sand
	9	Gravel
	10	Gravel
	11	Silt
	12	Silt
	13	Silt
	14	Grass
	15	Grass
	16	Grass
	17	Grass
	18	Grass
	19	Grass