Investigating the impact of afforestation on the magnitude of peak flow levels in the River Cober, Helston

Fig i: View of the Cober Valley towards Helston (Rossiter, 2014)

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"I certify that this dissertation is entirely my own work and no part of it has been submitted for a degree or other qualification in this or another institution. I also certify that I have not collected data nor shared data with another candidate at Exeter University or elsewhere without specific authorization"

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Abstract

The main aim of this study is to investigate whether there is a correlation between the increase in tree cover area in the Cober valley, and a decrease in the size of peak flow levels in the river Cober over time. This aim was investigated through looking at the growth of the Cober valley woodland by analysing satellite imagery and historical maps. Furthermore, changes in peak flow levels were investigated by using Peak Over Threshold data, for two gauge stations on the river Cober, in its upper and lower middle course (Trenear and County Bridge). Precipitation change was also investigated as a possible cause for any changes in peak flow. Results showed that tree cover increased over time, although peak flow did not increase or decrease. However, a small decrease in peak flow was observed in the upper course. Precipitation influenced peak flow at both stations, although more so in the lower middle course. This paper concludes that overall, tree cover increase is not significantly correlated with peak flow levels in the river Cober, although a weak correlation was observed in the upper course, suggesting afforestation is more effective at reducing peak flow levels in the upper course.

Chapter 1: Research Introduction

1.1. Introduction

Climate change is likely to lead to an increase in the frequency of high magnitude precipitation events over the UK in the future (Wilby *et al,* 2007). Furthermore, many river catchments in the UK will see an increase in surface run off, resulting from urbanisation, and changes in rural land management (DEFRA, 2004). A combination of these factors is likely to lead to flood risk in the UK, and the resulting damage, increasing (DEFRA, 2004). Therefore, the amount of funding allocated towards flood management in the UK will have to increase in order to prevent damage from flooding becoming more severe (Environment Agency, 2009). As of 2010, the total government spending allocated towards flood defences in England was £2.17bn, and the annual costs of flood damage is estimated at £1.1bn (Bennett and Hartwell-Naguib, 2014). However, with the frequency and magnitude of flood events becoming more severe, it has been suggested that if existing flood defences are to be maintained, then flood defence spending must increase by £1bn per year until at least 2035 (Bennett and Hartwell-Naguib, 2014). Over recent decades the UK have used engineered defences to control rivers and prevent flooding, however this is costly and therefore recently, a shift towards adapting to flooding, instead of trying to control it, has begun (Wilby *et al,* 2007). This approach involves working with natural processes by mitigating the impacts of flooding through changes in land use and cover, and should be a more sustainable option to cope with the threat of increasing flood risk resulting from future climate change (Wilby *et al,* 2007).

1.2. Aims

- To investigate whether there has been an increase or decrease in tree cover in the Cober valley over time
- To examine whether peak flow levels in the River Cober have increased or decreased over time
- To find out whether there is any relationship between tree cover area and peak flow levels in the River Cober

1.3. Hypothesis

- There is a significant correlation between the increase in the area of land, in the River Cober Valley, covered by woodland, and the decrease in peak flow levels in the River Cober.

1.4. Study site

This study takes place in and around the town of Helston, West Cornwall (Figure 1.4.1), as well as in the upper middle to lower middle course of the River Cober, between two river gauge stations at Trenear, in the upper middle course, and at County Bridge, in the lower middle course (Figure 1.4.2.).

Figure 1.4.1. Location of Helston and the Cober Valley in Cornwall, SW England (Google Earth, 2016a)

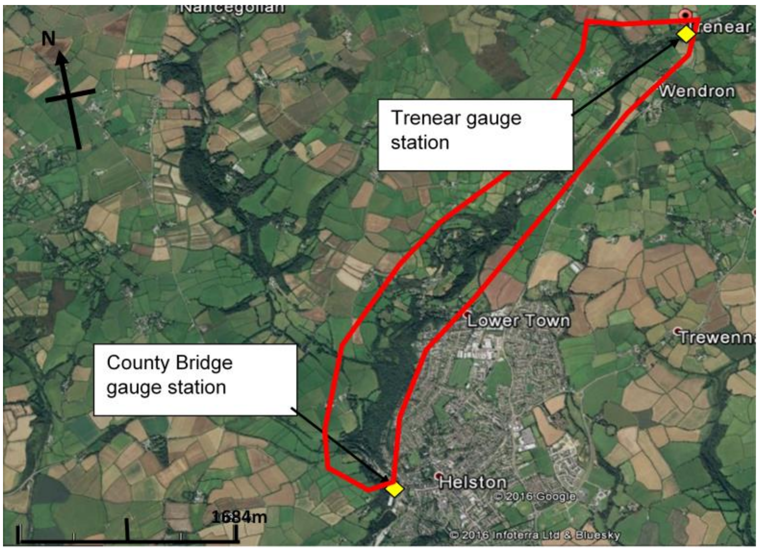

Figure 1.4.2. Study site in the Cober Valley and Helston showing the two gauging stations (Google Earth, 2016b)

The River Cober is 46km long from its source in the upland area of Carthew, near Four Lanes, to its mouth at Loe Bar, below Helston (Environment Agency, 2008). Carthew is located in one Cornwall's main upland areas and therefore receives an average of 400mm more rainfall than in Cornish lowland areas (Environment Agency, 2008). The river Cober flows through mainly rural areas consisting of a mixture of arable and pasture farmland. Urbanised areas mainly consist of small villages; Helston is the only town the river Cober passes through, and therefore is the largest urban area to be impacted by the Cober when it floods. Furthermore, much of the Cober Valley in the middle course of the Cober, is covered in extensive woodland, which has grown up over the past few decades. Before this, much of the mid Cober Valley was not covered by large trees, and was known locally as 'the moors' (Helston History, 2017a).

Helston is a small town in West Cornwall, with a population of 11,900 as of 2013 (Cornwall Guide, 2017). Most of Helston is located above the river Cober. However, over recent centuries the lower parts of Helston have become more developed, leading to regular damage from flooding occurring downstream from St John's Bridge, in St John's Road (Figure 1.4.3.) (Helston History, 2017a).

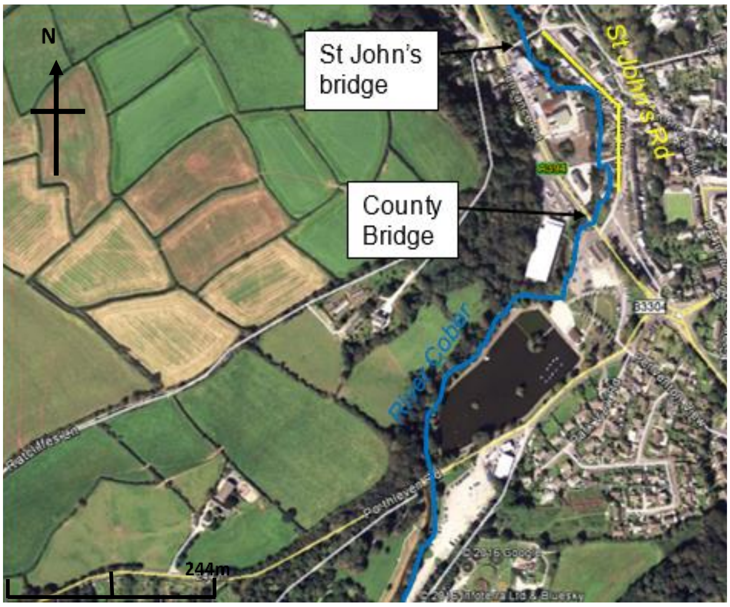

Figure 1.4.3. Map of lower Helston showing the area that is at most risk from the River Cober in flood (Google Earth, 2016c)

Chapter 2: Literature Review

2.1. Overview of UK flood risk

The increase in global mean surface temperatures (GMSTs), due to climate change, is becoming more severe with ten of the warmest years having occurred since 1997 (Hartmann *et al,* 2013). This is likely to have an impact on the global hydrological cycle, resulting in some areas of the world receiving higher amounts of precipitation than before (Wilby *et al,* 2007). Furthermore, it is also likely that some areas will have more frequent severe storm events (Wilby *et al,* 2007). This is going to become the case for precipitation and storm events in the UK, as an increase in the average annual temperatures of 2-3.5°C, by the 2080s, will contribute to higher levels of winter precipitation and more frequent heavy precipitation events (DEFRA, 2004). Changes in temperatures over the next century influence changes in peak flows in the UK's rivers (Sayers *et al,* 2015). For example, in South West England a 2°C rise in global mean temperatures (GMTs) would lead to a 5% change in peak flows in the 2020s, which could increase to a 18% change in peak flows by the 2080s (Sayers *et al,* 2015). Therefore, as the impacts of climate change become more severe, more people will become at risk of flooding in the UK. It is estimated that the number of people living in high flood risk areas could increase to between 2 and 3.3 million, from 1.4 million currently (DEFRA, 2004). Alongside this, annual economic damages to residential and commercial properties has the potential to rise to £1.5-20 billion from £0.9 billion currently (DEFRA, 2004). Therefore, costs related to trying to reduce the damage caused by flooding in the UK will increase, with an estimated £22-75 billion worth of engineering defences needed by the 2080s (DEFRA, 2004).

In the UK, the current situation surrounding flooding involves the increasing number of properties at risk, due to the increasing pressure for floodplains to be developed to meet housing demands, along with the increasing levels of winter precipitation, which is a result of climate change (Nisbet and Thomas, 2006). Over recent decades, the focus for flood management has evolved around hard engineering techniques (Dixon, 2013). However, hard engineering is becoming increasingly expensive (Nisbet and Thomas, 2006). For example, the Environment Agency are responsible for the installation and maintenance of a huge number of engineered defences in England, with the cost of replacing all of the Environment Agency's defences totalling £20 million (Environment Agency, 2009). Furthermore, with the current situation relating to climate change, hard engineering is an unrealistic solution for long term management (Dixon *et al,* 2016). Therefore, soft engineering management solutions are increasing in popularity, as they have the potential to involve the whole catchment through rural land use management, such as creating wetlands and planting wooded areas in the upper part of a small catchment (Nisbet and Thomas, 2006). Due to its longevity, soft engineering techniques are seen as the more sustainable approach to flood management (Nisbet and Thomas, 2006); and as a result, could become the focus of flood management in the future (Dixon *et al,* 2016).

Moreover, when considering flooding in smaller and more localised catchments, an increase in the magnitude and frequency of floods has been found, when compared to observations of current conditions (Prudhomme *et al,*2003). Also, larger floods will increase in magnitude and flood events of any size will become more frequent (Prudhomme *et al,* 2003). This change in the variability of small catchment flood regimes could result in unexpectedly large flood events occurring in catchments where such events are rare (Prudhomme *et al,* 2003). Therefore, flood management for small catchments must consider protecting against much larger flood events in the future and flood management solutions should be designed to last for the long term (Prudhomme *et al,* 2003).

2.2. Afforestation and flooding

2.2.1. Introduction to afforestation

Afforestation refers to woodland or forest being planted on land that previously, has not been forested (Thomas and Goudie, 2006). Afforestation is often thought of as having an ability to lessen the impact of flood events, although due to the complex set of factors that influence this, the subject is still highly debated (Nisbet, 2015). Afforestation can reduce the impact of flood events through improving factors such as interception, infiltration and reducing soil erosion (Nisbet, 2015). Afforestation is a soft engineering solution to flooding and works with natural processes to reduce the magnitude of flood events, and with costs of hard engineering defences on the rise, soft engineering offers a cheaper solution to flooding (Rewilding Britain, 2015).

Afforestation can reduce the volume of water that enters a river through greater interception of rainfall (Nisbet, 2015). Interception occurs when rain is partly or completely restricted by leaves in the tree canopy, from hitting the ground below (Nisbet and Thomas, 2006). Evergreen trees, such as conifers, are the most effective at intercepting rainfall as they can maintain a high level of interception throughout the year; whereas broadleaves are less effective as they lose their leaves in the winter, meaning broadleaf woodland are less able to intercept winter rainfall (Nisbet and Thomas, 2006). Calder *et al* (2003), found that conifers are able to intercept 25-45% of rainfall per year compared to 10-25% being intercepted by broadleaves. This is one of the major restrictions of afforestation as a method of flood mitigation, as many areas of woodland in the UK, such as the woodland in the Cober Valley, consist of broadleaves. Therefore, the amount of rainfall intercepted by broadleaves in the winter, when rainfall and chances of flooding are higher, is low (Nisbet and Thomas, 2006).

Furthermore, infiltration can be increased through afforestation, as trees can reduce the amount of physical disturbance to soils, meaning the soils are less compact, allowing for higher amounts of water to be stored in the pore spaces amongst the soil particles (Nisbet, 2015). When compared to agricultural land, where infiltration will be reduced through livestock grazing; land covered by woodland has much higher rates of infiltration, and this could reduce the chances of rapid surface runoff into rivers, which could lessen the chances of flash floods in small catchments (Nisbet, 2015). This could also reduce the volume of water entering a river, reducing flood levels downstream (Nisbet, 2015).

Afforestation can also help to reduce soil erosion as well as prevent too much sediment from entering a river via surface runoff (Nisbet, 2015).

Trees near a river bank can help to bind the sediment in the banks together, increasing the strength of river banks and therefore reducing the chances of erosion (Nisbet, 2015). Woodland can also block excess sediment from entering a river, through retaining the sediment amongst tree roots before it enters the river (Nisbet, 2015). Therefore, afforestation is able to reduce the magnitude and frequency of flooding through helping a river to maintain a channel capacity that is sufficient to carry a higher volume of water in an event of a flood (Nisbet, 2015).

Afforestation is most effective in catchments that are generally smaller than 100km^2 in area (Nisbet, 2015). This is because larger catchments are more likely to be influenced by a wider range of land use change than smaller catchments, as well as the fact that larger catchments tend to have more in the way of river engineering as a method of flood management (Nisbet, 2015). Therefore, afforestation would not be able to protect larger urban areas from flooding and so, for large urban areas, at the moment, the most effective method of flood management is hard engineering defences (Nisbet, 2015). Furthermore, woodland is most effective at reducing smaller floods and the effectiveness of this is dependant on the age of the woodland and on whether any other infrastructure, such as roads or drainage, are already in existence (McCulloch and Robinson, 1993).

2.2.2. Previous studies

There has been a wide range of research into the impact of afforestation on flooding downstream. One such study took place at Pontbren, in Wales, which looked at whether upland afforestation and changes in land management could reduce flooding downstream (Marshall *et al,* 2014). The study involved several sites in the upper catchment, such as one where sheep were removed from the land and another where grazing sheep were removed and broadleaf trees were planted (Marshall *et al,* 2014). The results showed that moving the land use away from sheep grazing reduced runoff by 48%, and that when trees were planted runoff reduced by 78% (Marshall *et al,* 2014). Therefore, these results suggest that afforestation in the upper catchment can reduce flooding, at a local scale, downstream (Marshall *et al,* 2014).

Furthermore, several other studies have found that afforestation can reduce peak flows and slow down flood peaks, such as a study by Robinson *et al* (2003), which found that when a forest was able to establish a well-developed canopy peak flow levels downstream were reduced by 10-20%. Also, Ghavasieh *et al* (2006) found that roughened vegetated strips on a floodplain were capable of delaying a flood peak over a 20km distance by between 2.4% and 5.6%. Finally, Thomas and Nisbet (2006), found that woodland on a floodplain was able to increase flood storage by between 15% and 71%, and therefore it is possible to use afforestation to reduce flooding downstream.

2.3. Helston Flooding

2.3.1. History of flooding in Helston

Helston has had a long history of being flooded by the River Cober, which flows through lower Helston before entering Loe Pool towards the Cober's mouth, with records of major floods affecting Helston dating back to the early 20th century (Environment Agency, 2008). However, according to local history, the Cober has been flooding Helston long before that. The Cober also used to be a lot wider and deeper in its lower course, has been said to have had characteristics similar to an estuary

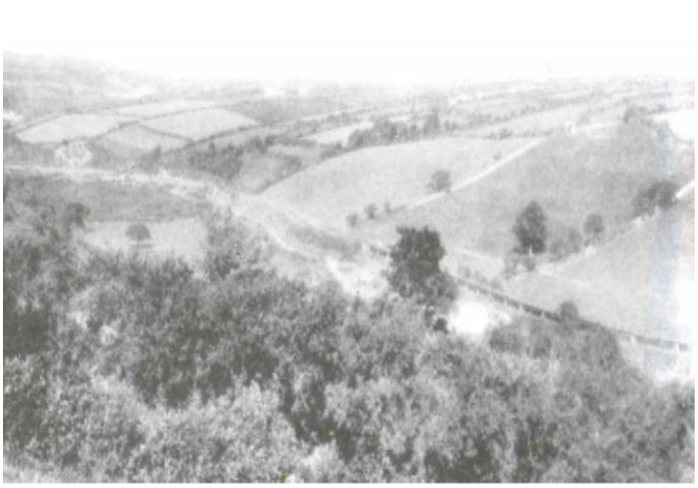

Fig. 2.3.1.1. Cober Valley before the growth of the woodland (date/author unknown) (Treloar, 1995)

Fig 2.3.1.2. Present day woodland in the Cober Valley (Rossiter, 2017)

as it was possible to sail into Helston up until the early 1300's (Helston History, 2017b). The area of St John's Road, which is the part of Helston that is most frequently flooded, lies on the Cober floodplain, and upstream from this is the Cober Valley woodland, which was dominated by surface mining and mills, during a time when the valley was sparsely vegetated (Fig 2.3.1.1), but since then the Cober Valley woodland has grown up relatively quickly, over the last 50 years (Fig 2.3.1.2.) (Helston History, 2017b). Helston itself, has increased in size recently, with major developments of residential housing on the eastern side of the Cober valley beginning in the late 1960's to mid-1970's.

Fig 2.3.1.3. Calamity in St. John's Road (author/date unknown) (Helston History, date unknown)

Helston has experienced several major floods since records began in the early 1900's (Fig 2.3.1.3.). Three of the most extreme floods occurred in December 1979, January 1988 and December 2012 (Cornwall Council, 2011; Ferguson and Fountain, 2012). Firstly, a flood that occurred during mid December 1979, resulted in damage to at least 15 properties in Helston (Cornwall Council, 2011). Another major flood occurred during late January 1988, which also resulted in the flooding of 15 properties in Helston, and was associated with several severe thunderstorms in the days before, which left ground saturated (Cornwall Council, 2011). Finally, the most recent severe flood event in Helston, occurred between the 22nd and 24th December 2012 (Fig 2.3.1.4.) following a long period of severe storms, which resulted in most properties in St John's Road, as well as surrounding roads and the park further downstream, being flooded (Ferguson and Fountain, 2012).

Fig 2.3.1.4. Flooding in St John's Helston December 2012 (Thomas, 2012)

2.3.2. Reasons for Helston's flooding

There are several factors which contribute to Helston's history of frequent flooding such as the catchment topography, as the upper catchment is located on some of the highest ground in Cornwall (Environment Agency, 2008). This has a strong influence on the amount of precipitation that eventually enters the Cober, as rainfall in the upland areas around the source at Cathew, is higher than in lowland areas (Environment Agency, 2008). Therefore, the higher volume of water in the upper course could make chances of flooding in Helston, further downstream, more likely (Environment Agency, 2008).

Furthermore, when the Cober enters Helston, its flow becomes more restricted through obstacles in the river, such as bridges (Environment Agency, 2008). St. Johns bridge, is the first major obstacle within the Cober channel before entering Helston itself. The bridge used to consist of one arch which restricted the flow during flood events, causing the water to back up behind the bridge and encouraging the Cober to overtop (Taylor, undated). Although a second arch has now been added, debris in the channel during floods often becomes trapped by these arches, meaning flood water still backs up behind this bridge (Taylor, undated).

Finally, much of the lower Helston area of St. Johns is built on the Cober's floodplain. Floodplains, when left in their natural state are able to store excess water levels until levels in the main channel drop again (Environment Agency, 2008). However, when a floodplain becomes urbanized, the natural process of flooding onto a floodplain, instead causes damage to any infrastructure on that floodplain (Environment Agency, 2008). Much of the Cober floodplain is urbanized and therefore this area is put at higher risk when the Cober floods.

2.3.3. Current management plans

Previous flood management of the river Cober has mainly concentrated on a hard engineering approach centred around the section of the Cober that floods the area of St. Johns, in the lower part of Helston. This approach involved shuttering, dredging, levees and channel straightening (Taylor, undated). Shuttering aimed to reduce bank erosion through lining the river banks with wooden planks, although the effectiveness of this method was low as the planks didn't line the whole river bank, and as a result, when the river levels were high, the planks were overtopped and erosion occurred anyway (Taylor, undated). Dredging occurred in the section of the Cober below Helston in the Penrose amenity park, in order to restrict the amount of water that backed up into the town during floods, through increasing the capacity of the channel by removing sediment (Taylor, undated). Furthermore, levees were created alongside the dredged section of the river Cober, from the removed sediment, in order to increase the channel capacity further, preventing flooding from occurring beyond the levees (Taylor, undated). Finally, channel straightening occurred in the Cober at the Penrose amenity park (Taylor, undated). Before this took place, the Cober meandered through the Penrose amenity park and its natural floodplain (Taylor, undated). The artificially straightened channel also prevents flood water from backing up into Helston, as a straight channel is able to move flood water through at quicker rates (Taylor, undated).

More recently, plans by Cornwall Council (2014), have been put in place to reduce flooding in several major Cornish towns, including Helston. This involves a combination of land management in the upper course, along with improvements to the engineered flood defences within Helston itself (Cornwall Council, 2014). This project will reduce flood risk for 200 properties (150 residential, 50 commercial) in Helston (Cornwall Council, 2014). Furthermore, Cornwall Council aim to reduce flood risk through a 'catchment approach' which aims to enhance the natural environment, in order to reduce surface runoff and flood risk (Cornwall Council, 2014). This approach will involve supporting the planting of trees and habitat improvement within the Cober catchment (Cornwall Council, 2014).

Furthermore, following the flood of December 2012, £1.8 million was made available to reduce the level of flood damage Helston receives, and to further protect 40 properties in Helston, through the Environment Agency's Helston Flood Alleviation Scheme (Wilkinson, 2015). This scheme involved protecting and clearing the river banks during 2015 (Wilkinson, 2015).

2.3.4. Future of Helston flooding

Flood risk throughout west Cornwall is likely to increase over the next century as a result of climate change (Environment Agency, 2008). Flood extent is likely to either remain the same or increase, and flood depths are likely to increase over the next 100 years (Environment Agency, 2008). As a result, the amount of people affected by flooding in West Cornwall will increase (Environment Agency, 2008). Climate change will lead to wetter winters and more frequent heavy rain, with annual precipitation increasing by 15% over the next 75 years (Environment Agency, 2008). This will increase river flows, as well as putting extra pressure on drainage networks and the Cober could experience a 20% increase in flows as a result of climate change (Environment Agency, 2008).

2.4. Summary

Flood risk in the UK is increasing as a result of impacts associated with climate change (DEFRA, 2004). This is leading to an increase in the costs associated with flooding, and as well as this, further funding will be needed to cope with the increasing flood risk (DEFRA, 2004). Therefore, there is a need for a shift towards a soft engineering approach which can be effective in the long term, as well as being cheaper (Nisbet and Thomas, 2006). Afforestation has been shown to lessen the impact of floods (Nisbet, 2015), with several studies finding that it can reduce surface runoff and flows, such as Marshall *et al's* (2014) study which found planting trees in the upper course of a river can reduce runoff and flooding downstream. Helston has had a long history of flooding and has experienced several major flood events (Cornwall Council, 2011) but despite this, has only limited defences (Taylor, undated). Helston's flooding is made worse by the Cober originating in an area of high precipitation, obstacles in the main channel and Helston's location on a floodplain (Environment Agency, 2008). Flooding in Helston is likely to become more severe and frequent in the future, with the Cober seeing a 20% increase in flow due to climate change (Environment Agency, 2008).

Chapter 3: Methodology

3.1. Introduction

This study is centred around a hypothesis testing approach, with the aim of testing the possibility of a correlation between a change in tree cover area in the river Cober valley and peak flow levels over time. Data collection took place in the form of a desk study and required the use of quantitative data. There have been a wide range of methods for investigating the effectiveness of afforestation, such as a modelling approach used by Dixon *et al* (2016), and the field plot experiments used by Marshall *et al* (2014) in order to investigate surface runoff. However, a desk study was most appropriate due to the size of the study site and the time and resources available to complete this investigation. In order to meet the aims of this study (see Chapter 1: Research Introduction, for more details), data was needed in the form of satellite images of the Cober valley, from a series of different years; as well as historical and present day maps of the Cober valley area. Furthermore, raw Peak Over Threshold (POT) data, dating back to the 1970’s, was required to investigate changes in peak flow in the Cober. Also, raw monthly precipitation data was needed to factor in changes in precipitation over time into the investigation as a possible cause for any increase or reduction in peak flow levels.

3.2. Tree cover area calculation

In order to investigate whether tree cover in the Cober valley has increased or decreased over time, the area of the Cober valley covered in trees was calculated for several years (1960, 1970, 2001, 2004, 2005, 2009, 2016). The years chosen were determined by the availability of satellite images and maps, and also by the fact that local knowledge tends to indicate that tree cover in the Cober valley began to increase around the middle of the 20th Century. Tree cover area was calculated through using a combination of satellite imagery, historical maps and *ImageJ* software. Satellite images of the Cober valley, for 2001, 2004, 2005 and 2009, were obtained from *Google Earth,* and the location of trees in each image were digitised, before being ran through *ImageJ* software, which gave the area of trees for that year in m^2. The same process occurred with the historical maps, which were obtained from *Digimap,* for the years 1960,1970 and 2016. Historical maps were used for some years, instead of satellite imagery, due to no satellite imagery of the Cober valley being available during those years.

3.3. Peak flow data

Peak flow data was required to investigate the possible increase or decrease in flow levels over time. Peak Over Threshold (POT) data was chosen for this research, as a threshold is set to only include larger flow events (NRFA and CEH, undated). Therefore, smaller flows, which are less likely to cause floods, are excluded from the data (NRFA and CEH, undated).

3.3.1. Sourcing peak flow data and the need to calculate threshold

Peak Over Threshold data was obtained from the *National River Flow Archive (NRFA)* website for stations at Trenear, in the upper middle course of the Cober, and at County Bridge, in the lower middle course of the Cober. However, one problem with these data sets was that the threshold already set, included too many smaller flows which were unlikely to result in flooding. This research only needed flows that were very likely to be responsible for floods. Therefore, it was necessary to calculate a new threshold for both data sets, which only included flows which resulted in flooding.

3.3.2. Calculating a new threshold

In order to filter the data set, so only flows responsible for flooding were shown, it was necessary to use evidence of past flood events in and around Helston and the Cober, to determine on which dates flows capable of causing flooding, occurred. Evidence of past floods in Helston were obtained through archived online newspaper reports, reports from Cornwall Council and historical photographs viewed in *Helston Museum's* photography archives. Once all the flows that were responsible for flooding in Helston had been determined, then a new threshold for that data set was calculated. This was the lowest flow causing a flood in that data set. This enabled data to be filtered to only include flows above this new threshold. This process to calculate a new threshold was completed for both the POT data at Trenear and at County Bridge. Furthermore, a side effect of calculating a new threshold for both Trenear and County Bridge was that it created a summary of the impacts of flooding in Helston alongside the magnitude of the peak flow levels. This allowed links between the magnitude of peak flows and the severity of flood damage to be made.

3.4. Precipitation data

Precipitation data was obtained from the *Met Office,* in order to account for the influence precipitation changes may have had on flow levels. This will make any relationship between changes in flow levels and afforestation clearer. The data set was filtered to only include values for dates relevant to the research. This was necessary as including all data values would make the data appear too busy.

3.5. Data analysis

Much of the data was analysed using time series plots as this was an effective method of visualising any changes in flow, precipitation and tree cover that may have occurred.

Precipitation data was plotted as several time series graphs in order to show any changes in flow levels over time, in relation to precipitation levels. There is a need to account for precipitation when analysing changes in flow, due to predictions that UK rainfall is likely to increase into the future, due to climate change, especially during the winter months (DEFRA, 2004). To demonstrate any changes in flow, time series graphs were plotted for dates at the beginning and end of each data set for Trenear and County Bridge.

Tree cover area was plotted as a time series graph in order to allow an increase or decrease in tree cover area to be seen. This, along with the flow and precipitation graphs, can demonstrate whether there is any link between afforestation and flow levels.

Gumbel probability was calculated for both data sets to demonstrate how larger flow events are less likely to occur again, than smaller flow events. As a result, suggestions relating to flood management and working to reduce the magnitude of events, instead of preventing them altogether, can be made. As afforestation has been shown to reduce the magnitude of flood events (Nisbet, 2015), the results from the Gumbel probability analysis demonstrate how afforestation, and similar natural flood management methods, can reduce the damage flooding causes, due to lower magnitude floods resulting in a lower level of damage, than more severe floods.

3.6. Summary

In summary, the relationship between tree cover area change and peak flow change in the river Cober valley, was investigated through the use of a desk study. Tree cover area change was investigated through analysing satellite images and historical maps of the Cober valley, for changes in area of the valley covered by woodland, over a series of years from 1960 to 2016. Peak Over Threshold data was collected from the *National River Flow Archive* for two gauge stations at Trenear and County Bridge. A new threshold was calculated so only flows that were very likely to have resulted in flooding were included in the data set. This was achieved through assessing which flows occurred alongside archived reports of flooding in Helston and the surrounding area. Precipitation data was also sourced to account for its influence on flow levels in the river Cober. Data was analysed through the use of several time series graphs, which analysed relationships between peak flow and precipitation at Trenear and County Bridge. Tree cover change was visualised through the use of a time series graph from 1960 to 2016. Gumbel's probability was calculated for flows at both Trenear and County Bridge, in order to look for patterns relating to the likelihood of large and small flow events from happening again in the future.

Chapter 4: Results

4.1. Tree cover area change

Results from the analysis of tree cover area change through the use of *ImageJ,* satellite images and historical maps of the Cober valley, indicate an overall increase in the area of the Cober valley that is covered by woodland from 1960 to 2016 (Fig. 4.1.1). Growth of the woodland was slow between 1960 and 2001, with an increase in the area of land covered by woodland of around 350,000m^2. In comparison, growth in the Cober valley woodland increased at a much quicker rate at the start of the 21st century, where an increase of 270,000m^2 occurs in less than a decade.

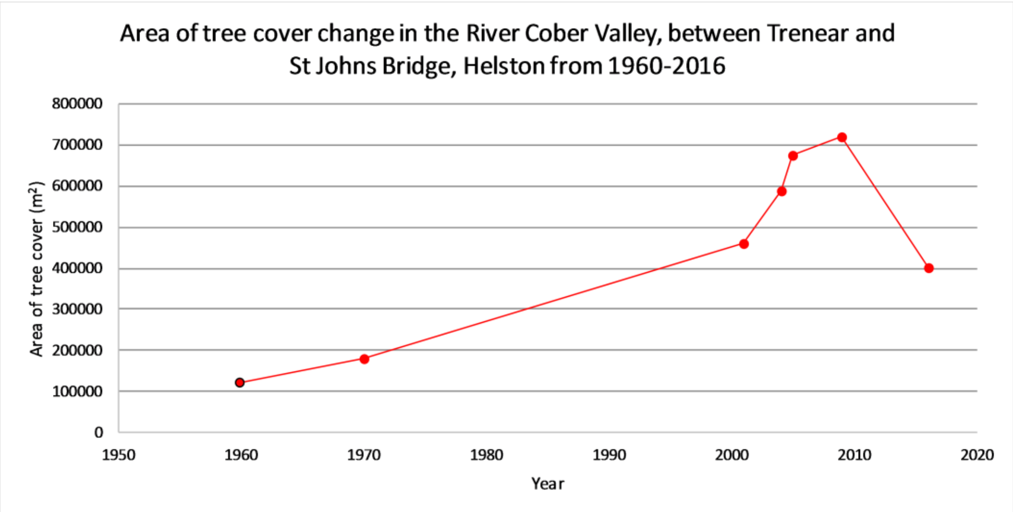

Fig 4.1.1. Time series plot of change in tree cover area in the Cober valley from 1960-2016

4.2. Peak flow change

Overall, there has been very little change in peak flow rates for both stations at Trenear and County Bridge. At Trenear, there is a weak decreasing trend for peak flow rates between 1988-2012 (Fig 4.2.1.). Most flows recorded at Trenear range from around 1.8m^3/s to 3.5m^3/s, with the largest flow occurring early on in the data set in 1988 and measured around 7.4m^3/s. Peak flows also appear to be clustered together at fairly regular intervals, such as those recorded between 1992-1994, 1999-2003 and later between 2008-2012.

In comparison, peak flow rates recorded at County Bridge, Helston show no obvious increase or decrease over time from 1974-2012 (Fig 4.2.2.). Most flows recorded at County Bridge have rates between 5m^3/s and 6.7m^3/s. The largest flows occurred in 1979, measuring around 11.9m^3/s and again in 2012, measuring around 12.5m^3/s. Peak flows at County Bridge also appear to show a clustering pattern around certain years, like at Trenear. However, large gaps in the data set between 1990 and 2000 mean it is hard to tell whether these clusters were regular like those observed at Trenear.

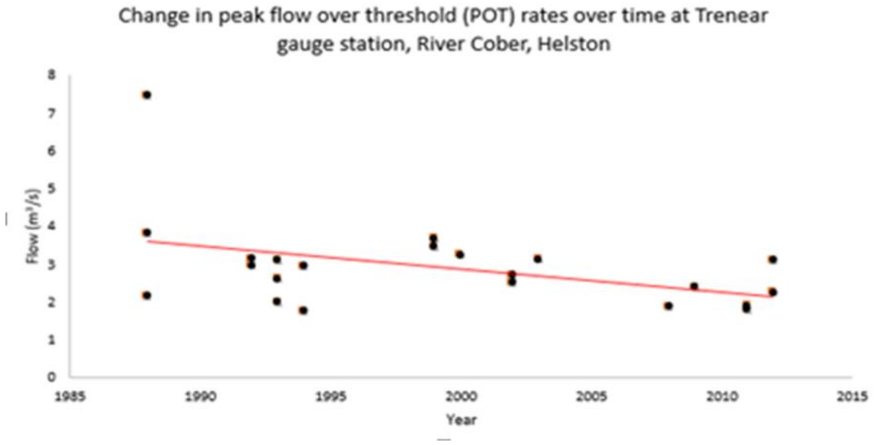

Fig 4.2.1. Time series plot showing change in peak flow at Trenear from 1988-2012. (Flow data: Cober at Trenear, NRFA and CEH)

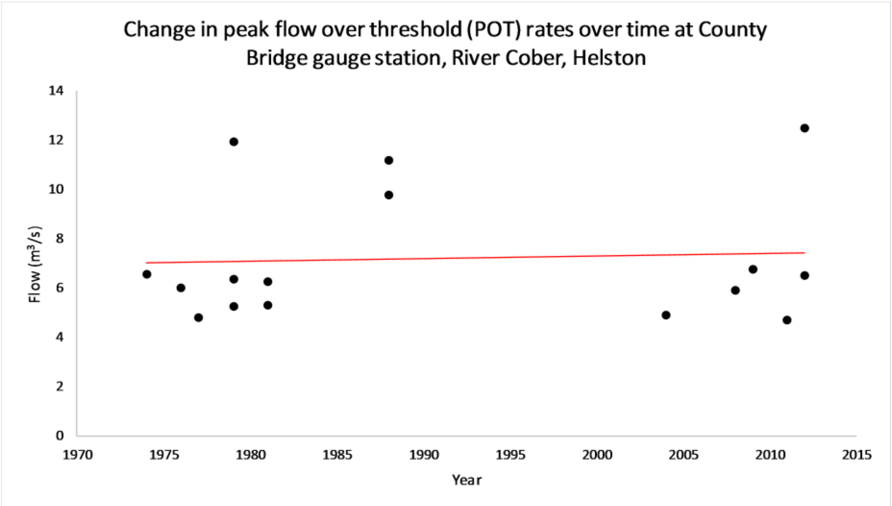

Fig 4.2.2. Time series plot showing change in peak flow at County Bridge from 1974-2012 (Flow data: Cober at Helston, NRFA and CEH)

4.3. Peak flow and precipitation

Precipitation appears to increase slightly over time between 1979 and 2012 (Fig 4.3.1, 4.3.2, 4.3.3, 4.3.4), with fluctuations occurring between summer and winter months.

At Trenear, flow rates between 1988 and 1994 range from around $2m^3/s$ to $7.4m^3/s$ (fig 4.3.1.). In relation to precipitation, some flows occur when precipitation is highest, such as a flow recorded in October 1988, which measured $3.8m^3/s$ alongside a precipitation level of around 145mm. However, the highest flow rate was recorded at $7.4m^3/s$ in February 1988, but this occurred when precipitation for that month was not especially high (95mm), which suggests another influence on flow rates occurred that month, possibly relating to a very high precipitation level in the month before, measuring about 230mm. In comparison, flow rates between 2008-2012 range from around $1.8m^3/s$ to $3m^3/s$, indicating little change in flow rates over time at Trenear (fig 4.3.2.). However, between 2008-2012 flow is more closely associated with precipitation levels with the majority of flows occurring with a higher level of precipitation, such as in January 2011, where the flow rate was recorded as $1.9m^3/s$ alongside a higher precipitation level of about 125mm.

At County Bridge between 1979-1981, flow rates range from around $5m^3/s$ to $12m^3/s$, with most flows having rates between $5m^3/s$ and $7m^3/s$ (fig 4.3.3.). Most flow rates appear to be influenced by precipitation levels, although this is more obvious with the highest flows during this time, such as in December 1979 when a flow of around $12m^3/s$ was recorded alongside the highest precipitation level for this period of around 215mm. In comparison, flow rates between 2008-2012 at County Bridge are still mostly associated with periods of higher precipitation levels. Again, this is more notable with the highest flows, such as a flow of around $12.5m^3/s$, recorded in December 2012, alongside a high precipitation level of around 200mm (fig 4.3.4.). However, flow rates don’t appear to have decreased much between 1979-1981 and 2008-2012, as most flows have rates measuring around $5m^3/s$ and $7m^3/s$.

Overall, flows at Trenear show more of a reduction between the earlier year in the 20th century and the later years in the 21st century than flows at County Bridge, which show very little change in flow rates. Furthermore, neither site show evidence to suggest another variable is alleviating the influence that precipitation has on flow rates, as the association between high flow and high precipitation tends to increase over time at both Trenear and County Bridge.

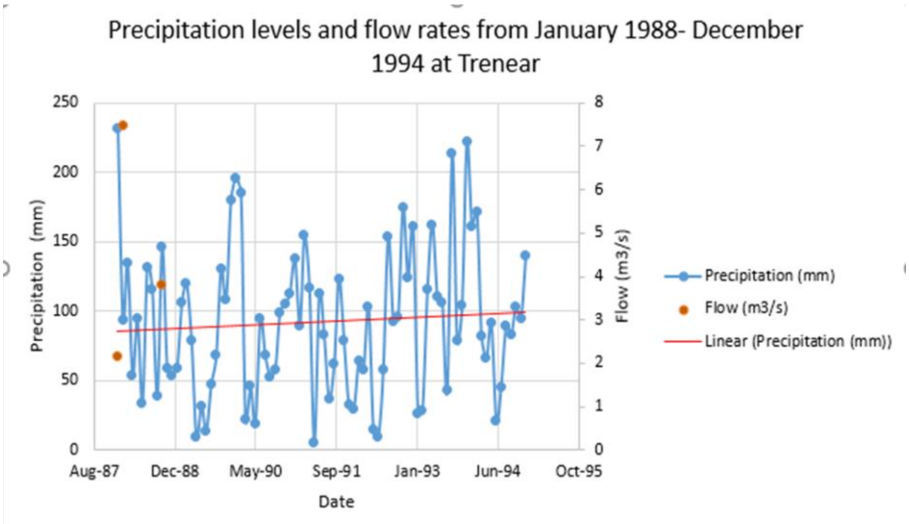

Fig. 4.3.1. Trenear precipitation and flow January 1988- December 1994 (Precipitation data: Met Office) (Flow data: Cober at Trenear, NRFA and CEH)

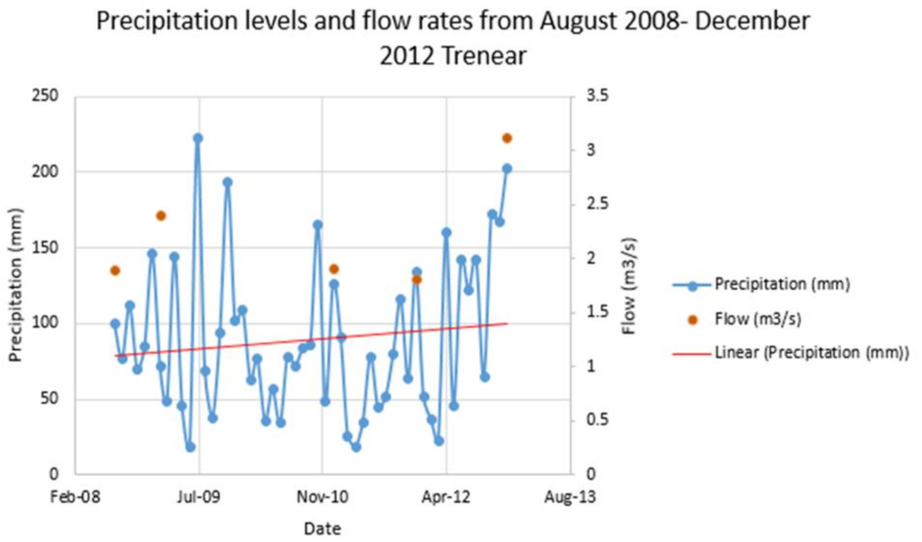

Fig 4.3.2. Trenear precipitation and flow August 2008- December 2012 (Precipitation data: Met Office) (Flow data: Cober at Trenear, NRFA and CEH)

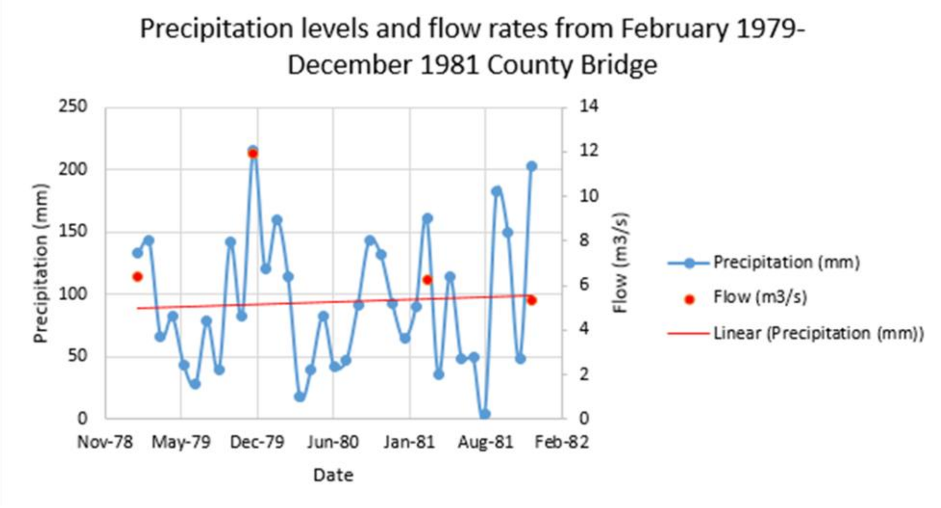

Fig 4.3.3. County Bridge precipitation and flow February 1979-December 1981 (Precipitation data: Met Office) (Flow data: Cober at Helston, NRFA and CEH)

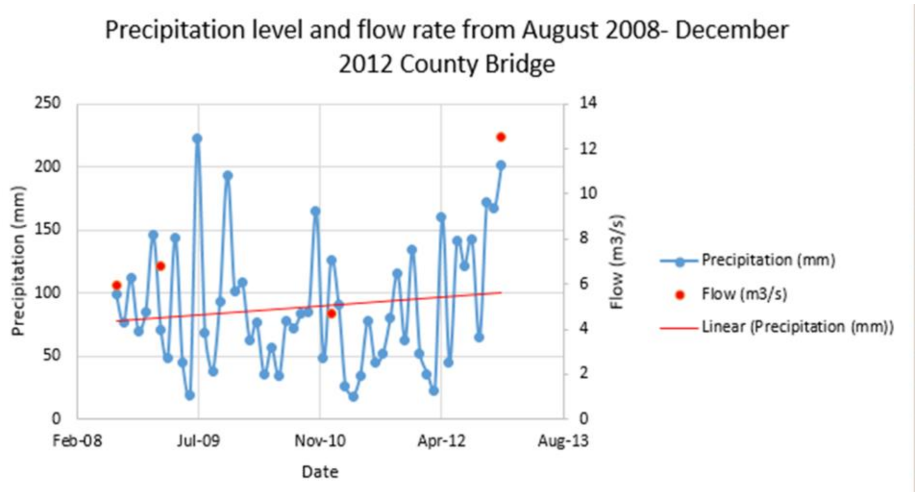

Fig 4.3.4. County Bridge precipitation and flow August 2008-December 2012 (Precipitation data: Met Office) (Flow data: Cober at Helston, NRFA and CEH)

4.4. Gumbel's probability and flood impacts

For flow rates recorded at Trenear, Gumbel's probability indicates that the lower the discharge or flow is, the higher the chances are of that flow rate from happening again. For example, a flow rate of around 2m^3/s has about a 78% chance of occurring again at Trenear (Fig 4.4.1.). Flows with a higher discharge or flow tend to have the lowest chance of occurring again, such as a flow measuring around 7.4m^3/s, which has almost a 0% chance of occurring again at Trenear. High magnitude and low frequency floods tend to result in the most damage. At Trenear, an assessment of flood impacts for each flow that occurred above a set threshold, found that the majority of the higher magnitude flows resulted in the highest amounts of damage (Table 4.4.1.). For example, a flow that measured 7.477m^3/s on 28/01/1988, resulted in 15 properties being flooded in Helston (Cornwall Council, 2011). Also, a flow measuring 2.611m^3/s on 09/06/1993, resulted in major flooding occurring in and around the river Cober (Cornwall Council, 2011). In comparison, the lower magnitude, but more frequent flows recorded at Trenear, resulted in less severe impacts, such as a flow that measured 1.813m^3/s on 13/12/2011, where only an environment agency flood alert was issued, the lowest of the three environment agency flood warnings (The Packet, 2011b).

For flow rates recorded at County Bridge, Helston, Gumbel's probability indicates that higher flows are less likely to occur again than lower flows. For example, a flow measuring around 12.5m^3/s has less than a 5% chance of occurring again, when compared to a flow with a rate of around 4.5m^3/s, which has an 85% chance of happening again (Fig 4.4.2.). Again the higher magnitude floods are the most likely to lead to higher levels of flood damage. As with Trenear, an assessment of flood damage relating to flows over a set threshold was carried out for flows at County Bridge (Table 4.4.2.). Again, this assessment found that more damage occurred with the less frequent but higher magnitude flows, such as on the 22^{nd} December 2012, when a flow rate of 12.53m^3/s was recorded, which lead to severe and extensive flood damage to parts of lower Helston, with St. John's road and its residential and commercial properties being damaged by flood waters (Ferguson and Fountain, 2012). The park and boating lake further downstream were also flooded and a severe environment agency flood warning was issued for Helston (Ferguson and Fountain, 2012). In comparison, the lowest flow recorded measuring 4.728m^3/s on 17/01/2011, only resulted in small scale flooding (The Packet, 2011a). In general, floods in which properties are damaged, have the highest flow rates, and floods where little damage is done to property or infrastructure, tend to have the lowest flow rates.

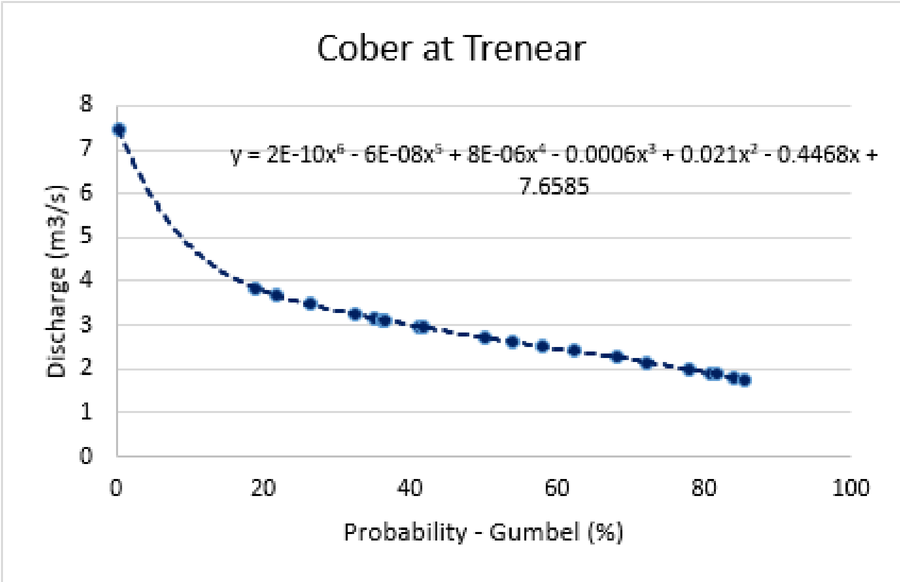

Fig 4.4.1. Gumbel's probability for flows at Trenear (Flow data: Cober at Trenear, NRFA and CEH)

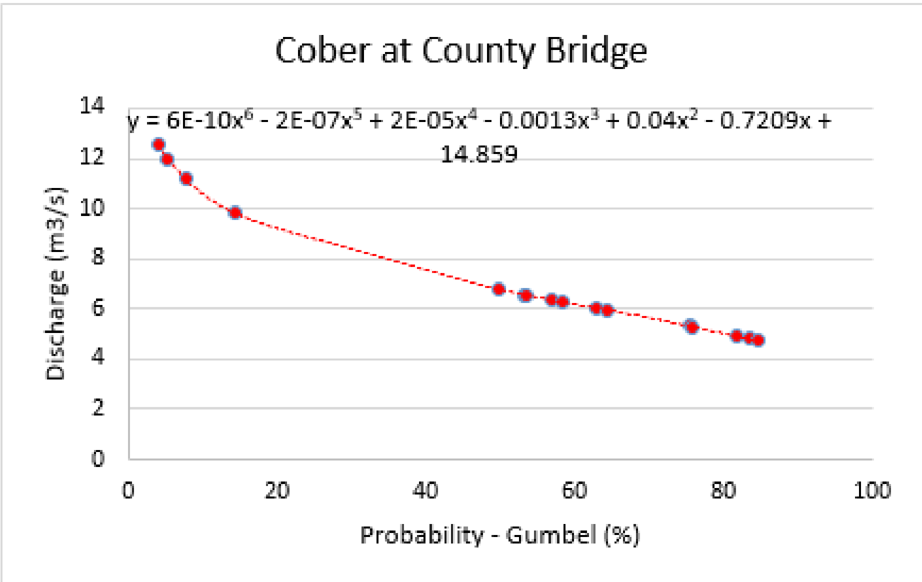

Fig 4.4.2. Gumbel's probability for flows at County Bridge (Flow data: Cober at Helston, NRFA and CEH)

Table 4.4.1. Trenear flow levels and impacts of the resulting flooding in Helston, Cober valley and the surrounding area (Flow data: Cober at Trenear, NRFA and CEH)

Flow levels at Trenear and impacts from the resulting flooding in Helston, Cober valley and the surrounding area			
Date	Stage (m)	Flow (m3/s)	Impact details (comments)
08/01/1988	0.813	2.154	st johns street flooded (Helston Museum, 1988)
28/01/1988	1.365	7.477	severe thunderstorm previous day (27th Jan) 15 properties flooded (Cornwall Council, 2011)
11/10/1988	1.034	3.831	severe thunderstorm (Cornwall Council, 2011)
30/11/1992	0.735	2.97	heavy rain- widespread flooding (Cornwall Council, 2011)
02/12/1992	0.769	3.158	heavy rain- widespread flooding (Cornwall Council, 2011)
09/06/1993	0.67	2.618	major flooding, 125mm in 9 hours- 92mm of this rain fell in 2 hours (Cornwall Council, 2011)
16/06/1993	0.55	1.997	50 properties flooded (Cornwall Council, 2011)
30/12/1993	0.762	3.119	very heavy rainfall, fluvial and surface flooding (Cornwall Council, 2011)
02/01/1994	0.731	2.948	very heavy rainfall, 200 properties effected no reports of property floods in helston (Cornwall Council, 2011)
28/12/1994	0.503	1.765	fluvial and surface flooding due to heavy rain (Cornwall Council, 2011)
19/12/1999	1.131	3.683	substantial fluvial flooding due to sustained rainfall between 17th-25th December 1999 (Cornwall Council, 2011)
25/12/1999	1.098	3.475	substantial fluvial flooding due to sustained rainfall between 17th-26th December 1999 (Cornwall Council, 2011)
08/11/2000	1.061	3.246	fluvial and surface flooding no reports of property floods in Helston (Cornwall Council, 2011)
14/11/2002	1.087	2.509	no reports of property floods in Helston but likely river over topped in places (Cornwall Council, 2011)
27/11/2002	1.163	2.716	heavy rain fluvial flooding- Porkellis effected, village located in Cober upper course (Cornwall Council, 2011)
01/01/2003	1.319	3.125	heavy rainfall Helston- 20 properties effected, villages in the upper course of the Cober also (Cornwall Council, 2011)
12/08/2008	0.87	1.888	no reports of property floods in Helston but likely river over topped in places (Cornwall Council, 2011)
10/02/2009	1.049	2.404	EA flood warning for cober at helston and cober between wendron (The Packet, 2009)
18/01/2011	0.878	1.912	small scale flooding (The Packet, 2011a)
13/12/2011	0.845	1.813	EA flood alert issued (The Packet, 2011b)
22/12/2012	1.313	3.11	river cober burst banks in several locations resulting in flooding downstream, riverside footpaths inaccessible (Ferguson and Fountain, 2012)
24/12/2012	0.996	2.255	river cober levels still high following flooding two days previous, riverside footpaths inaccessible (Fergusion and Fountain, 2012)

Table 4.4.2. County Bridge flow levels and impacts of the resulting flooding in Helston, Cober valley and the surrounding area (Flow data: Cober at Helston, NRFA and CEH)

Flow impacts at County Bridge and the impacts from the resulting flooding in Helston, Cober valley and the surrounding area			
Date	**Stage (m)**	**Flow (m3/s)**	**Impact details (comments)**
15/Feb/1974	1.482	6.563	reports of flooding elsewhere around cornwall so higher flow levels possible (Cornwall Council, 2011)
22/Mar/1976	1.265	6.031	reports of flooding elsewhere around cornwall so higher flow levels possible (Cornwall Council, 2011)
6/Oct/1977	0.64	4.805	fluvial flooding (Cornwall Council, 2011)
14/Feb/1979	0.781	6.364	fluvial flooding, homes in st johns flooded and damaged (Helston History, 2016)
28/Dec/1979	1.221	11.955	fluvial flooding 15 properties affected (Cornwall Council, 2011)
29/Dec/1979	0.685	5.289	fluvial flooding 15 properties affected (Cornwall Council, 2011)
11/Mar/1981	0.774	6.283	reports of flooding elsewhere around cornwall so higher flow levels possible (Cornwall Council, 2011)
13/Dec/1981	0.687	5.31	reports of flooding elsewhere around cornwall (fluvial and tidal) so higher flow levels possible (Cornwall Council, 2011)
28/Jan/1988	1.165	11.189	severe thunderstorm west cornwall, 15 properties effected in helston (Cornwall Council, 2011)
1/Feb/1988	1.062	9.819	severe thunderstorm west cornwall, 15 properties effected in helston (Cornwall Council, 2011)
17/Aug/2004	null	4.923	cober overtopped flooding roads though quick emergancy response prevented flooding at st johns (The Packet, 2004)
12/Aug/2008	null	5.937	reports of flooding in nearby areas so possible cober could have overtopped in places (Cornwall Council, 2011)
9/Feb/2009	null	6.772	flood warning issued for cober at Helston and between wendron and loe pool (The Packet, 2009)
17/Jan/2011	1.188	4.728	small scale flooding (The Packet, 2011a'hy)
22/Dec/2012	2.436	12.53	severe fluvial flooding, St Johns street , boating lake, park flooded, EA severe flood warning issued (Ferguson and Fountain, 2012)
24/Dec/2012	1.499	6.554	fluvial flooding levels beginning to reduce, st. johns street no longer flooded (Ferguson and Fountain, 2012)

Chapter 5: Discussion

5.1. Overview

Results from the analysis of tree cover area change and peak flow level change, have suggested that there is no strong relationship between an increase in the area of tree cover in the Cober valley, and a decrease in peak flow levels over time. In fact, generally peak flow levels have not reduced significantly at all. An exception to this is that peak flows at Trenear have showed a weak decreasing trend. Tree cover in the Cober valley has increased over time, as was expected.

5.2. Tree cover area change

The area of the Cober valley covered by woodland increased overtime as expected. However, there was a decrease in the area of tree cover in 2016. This decrease was not likely due to any deforestation that may have taken place, as no deforestation on a large enough scale to cause such as significant decrease, has taken place in the Cober valley recently. Therefore, the most likely cause of this decrease in tree cover is an error in tree cover area data collection. This is likely, as 2016 tree cover area data was collected from a map instead of from satellite images, as no satellite image for 2016 was available. Due to the fact that tree cover on maps is not as clear to read as tree cover from satellite images, the area of tree cover for 2016 may have been underestimated.

5.3. Peak flow

Results from the analysis of peak flow levels has found that generally there has been no reduction in peak flow levels. This is especially clear from the Peak Over Threshold data collected from the County Bridge station in Helston, where flow rates were measured to be mostly between $5m^3/s$ and $7m^3/s$ between 1979-1981, and were relatively the same for flows measured between 2008-2012, indicating little change in peak flow levels over time at this site. Peak flows measured at the Trenear station, in the upper course of the Cober, did however show a slight decreasing trend between 1988 and 2012.

Reasons for the minimal amount of change in peak flow levels over time, over the two sites, is likely to surround the idea that the increase in Cober valley tree cover has not been effective at reducing peak flow. This could be due to a number of factors, such as the type of woodland, location of the woodland in the Cober catchment, rural land use surrounding the Cober valley, precipitation levels in the upper course and increases in urban land use.

Type of woodland: The type of trees that grow in a woodland can influence the effectiveness a particular woodland has at intercepting rainfall and reducing flow levels downstream (Thomas and Nisbet, 2006). Previous research has suggested that broadleaf woodland, like the woodland in the Cober valley, is less effective at intercepting rainfall as broadleaf trees don’t maintain their leaves throughout the year (Thomas and Nisbet, 2006). Conifer trees do maintain their leaves throughout the year and therefore they are able to intercept more rainfall than broadleaves, and can do so throughout the year (Thomas and Nisbet, 2006). Broadleaves are only able to intercept higher levels of rainfall in the summer, when they have leaves (Thomas and Nisbet, 2006). Furthermore, research by Calder *et al* (2003), suggests that broadleaf woodland is less effective than conifer woodland at intercepting rainfall, as broadleaves were found to have intercepted 10-25% of annual rainfall, compared to conifers which intercepted 25-45% of annual rainfall. Therefore, this may be a reason for the very small amount of change in peak flow levels in the Cober, as most of the higher flows have occurred in the winter months, when the broadleaf woodland has been least effective at intercepting rainfall; meaning the Cober valley woodland would not have been able to reduce peak flow levels significantly enough, during winter months, to make much of a difference to peak flow levels.

Cober catchment woodland location: The location of woodland within a river catchment can influence its effectiveness in reducing surface runoff and therefore contributing to a decrease in peak flow levels (Marshall *et al,* 2014). Previous studies have suggested that woodland, that is located in the upper reaches of a catchment, is most effective at reducing surface runoff, with research conducted by Marshall et al (2014) concluding that upper catchment afforestation can reduce surface runoff and local scale flooding. Dixon *et al,* (2016), also found that reforested headwater locations in a river catchment can result in a 10% reduction in peak discharge. In terms of the river Cober, most of the Cober's woodland is located in the Cober's middle course and therefore could be less effective at reducing peak flow levels, than if it was located in the upper catchment, closer to the source. However, a reason why a small reduction in peak flow levels has been measured over time at Trenear, could be due to its location being closer to the upper catchment and the source, than the station at County Bridge. Therefore, woodland surrounding Trenear may be slightly more effective at reducing surface runoff, than the woodland downstream in the middle course of the Cober.

Rural land use: The majority of the entire Cober catchment consists of rural land cover, with much of the Cober valley being surrounded by pasture and arable agricultural land, especially on the western side of the valley, opposite Helston. Types of rural land use can influence the amount of surface runoff and the effectiveness of the infiltration of rainfall through soils, and with the introduction of the Common Agricultural Policy (CAP), came new agricultural practices which have led to factors that contribute to an increase in surface runoff (O'Connell *et al,* 2007). An example of such a factor is increased soil compaction, which can result in a reduction of infiltration of rainfall into soil, due to the ground becoming increasingly compacted through trampling from grazing animals, farm tracks from vehicles and machinery, and plough lines (O'Connell *et al,* 2007). Therefore, peak flow levels in the river Cober may be increased by agricultural practices to such a degree that woodland is not enough to significantly reduce peak flow levels in the Cober.

Upper course precipitation levels: Peak flow levels are influenced by high levels of annual precipitation, particularly in the upper course of the Cober, around its source at Carthew, located on one of Cornwall's upland areas, which receives an annual average of 400mm more precipitation than in the lowland areas (Environment Agency, 2008).

Cornwall receives a higher level of precipitation (1400mm in upland areas, 1000mm in lowland areas), than the annual average for England and Wales (920mm) (Environment Agency, 2008). These continually high levels of precipitation mean that any woodland in the Cober valley may not be significant enough to reduce peak flow levels, especially when storm events occur.

Urban land use: Urban areas can lead to a high percentage of precipitation becoming surface runoff, due to the vast increase in impermeable surfaces, such as concrete and tarmac on roads and pavements, with research finding that 53-75% of precipitation from rainstorm events becomes runoff in urban areas (Pauleit *et al,* 2005). On the eastern side of the Cober valley, during the 1960's and 1970's a major residential housing development began, significantly increasing the size of Helston as an urban area. This development began at relatively the same time as woodland in the Cober valley started to increase in area. Therefore, the significant increase in urban land use could have led to significant increases in surface runoff from the town, which may have been too much for woodland in the Cober valley to mitigate against, especially during storm events. Moreover, Helston is still increasing in area, meaning that surface runoff is likely to be a main cause of flooding in Helston in the near future.

5.4. Peak flow and precipitation

Precipitation levels in Cornwall have increased slightly overtime from 1979-2012, and therefore they could influence flow levels in the river Cober. This increase is expected due to climate change leading to an increase in the amount of rainfall the UK receives (DEFRA, 2004).

Precipitation is closely associated with peak flow levels at Trenear between 2008 and 2012. For example, flow levels in January 2011 measured 1.9m^3/s, alongside relatively high precipitation levels of approximately 120mm. Precipitation may be the primary factor influencing the magnitude of peak flow levels at this point in the river Cober, and not afforestation. Despite the fact that tree cover area is greatest between 2008-2012, peak flow levels were still high, suggesting tree cover was not effective in reducing peak flow levels at Trenear. Furthermore, between 1988 and 1994 at Trenear, only some flows occurred with precipitation levels were at their highest, suggesting precipitation had less of an influence on flow levels earlier on in the data set. For example, the highest flow level between 1988-1994 occurred when precipitation levels were not especially high, with a flow level in February 1988 measuring 7.4m^3/s, alongside a precipitation level for the same month which only measured 95mm. However, a possible explanation for this is that the flow level was still being influenced by the very high precipitation level from the previous month which measured at around 230mm. Therefore, it is hard to be sure of the influence precipitation had on flow levels between 1988 and 1994.

Peak flow levels at County Bridge in Helston, are more closely associated with precipitation levels than peak flows at Trenear. This is because most flows measured between 1979-1981 and 2008-2012, occurred at relatively the same time as high levels of precipitation were recorded for Cornwall. For example, in December 1979 precipitation levels measured at 215mm and a high peak flow was recorded as 12m^3/s. Also, in December 2012, a high flow of 12.5m^3/s was recorded alongside a precipitation level of 200mm, one of the highest levels of precipitation recorded for this period. The close relationship between peak flow and precipitation therefore suggests that middle course afforestation is not as effective at reducing flow levels, than afforestation in the upper course, as only some flows were associated with high precipitation at Trenear, compared to the majority being linked to high precipitation levels at County Bridge.

5.5. Summary

This study found no strong correlation between changes in tree cover area and peak flow levels. Overall, tree cover area increased overtime, with the exception of a decrease by 2016, which was likely due to an error that occurred during data collection. There was generally no reduction in peak flow levels, and this was more evident at County Bridge than at Trenear, as peak flows at Trenear showed a slight decrease. There are several possible reasons for such little change in peak flow levels, despite an overall increase in tree cover area, such as the type of woodland in the Cober valley consisting of broadleaves and not conifers; as the type of trees in a woodland can influence how effective that woodland is at intercepting precipitation (Thomas and Nisbet, 2006). Another reason included the location of the woodland in the Cober valley catchment, as the woodland is located in the middle course of the river Cober. Upper course afforestation has been shown to be the most affective at reducing surface runoff and downstream flooding (Marshall *et al,* 2014). Furthermore, an increase in peak flows in the river Cober could relate to the high amount of rural land in the Cober catchment, as agricultural land use can lead to an increase in surface runoff, as well as reduced levels of infiltration (O'Connell *et al,* 2007). Also, precipitation levels in the Cober's upper course are much higher due to Cornwall's upland areas, such as around the Cober's source at Carthew, having above average precipitation levels (Environment Agency, 2008). Moreover, urban land use can result in greater amounts of surface runoff, leading to higher volumes of water entering rivers (Pauleit *et al,* 2005). A combination of these factors, can lead to the possibility that tree cover in the Cober valley is not significant enough to mitigate against the high peak flow levels, in order to reduce flow significantly downstream. Finally, peak flow was found to be closely linked to precipitation levels, especially downstream at County Bridge.

Chapter 6: Conclusion

This study has used data from satellite imagery, maps, peak flow data and precipitation data in order to determine whether there is a link between an increase in tree cover area, and a decrease in peak flow levels in the river Cober valley. An overall increase in tree cover area in the Cober valley has been found since 1960. Also, overall the magnitude of peak flow levels in the river Cober has neither increased or decreased over time since the mid 1970's, although a small decrease in peak flow levels was found for the gauge station in the upper middle course of the river Cober at Trenear. Also, as a by-product of the investigation into changes in peak flow, the assessment of past flood events in Helston, highlighted the link between high magnitude flood events and greater levels of damage to property from flooding. Furthermore, there seems to be very little relationship between tree cover area and peak flow levels in the river Cober valley, although again a weak relationship between an increase in tree cover area and a decrease in peak flow levels was suggested at Trenear. Therefore, this study concludes that there is no significant correlation between an increase in woodland area, and a decrease in peak flow levels in the river Cober valley; although the research findings do suggest some weak correlations for sites in the upper course of the Cober.

6.1. Implications, recommendations and future research

Although this investigation has found that the growth of woodland in the Cober valley hasn't led to an overall decrease in peak flow levels over time, there was some evidence for woodland surrounding Trenear, in the upper course, that the growth of woodland in this area may have had a slight impact on decreasing peak flow levels in the upper course of the river Cober. Therefore, a recommendation made as a result of this investigation would be that the 'catchment approach' proposed by Cornwall Council, should concentrate any afforestation efforts in the upper Cober catchment, especially closer to the source at Carthew (Cornwall Council, 2014). This is supported by research by Marshall *et al* (2014), which found upland afforestation could decrease surface runoff and downstream flooding.

Furthermore, since previous research has suggested that the type of trees used in afforestation of a river catchment can be influential in determining the effectiveness of trees at intercepting rainfall (Calder *et al,* 2013); any future afforestation that occurs in the upper catchment of the Cober, would be more effective at reducing peak flow levels and downstream flooding, if the use of conifer trees was considered instead of broadleaf trees, as conifers will be able to protect against the impacts of high precipitation events, which occur in the winter as well as those which occur in the summer (Thomas and Nisbet, 2006).

Future research should aim to focus on the factors affecting surface runoff in the Cober valley and the wider Cober catchment, due to surface runoff significantly impacting peak flow levels. This research should look into the degree to which factors, such as rural land use and urban land use, are going to change in the future, as the town of Helston and the surrounding rural area develops and evolves. This is likely to impact the amount of rainfall entering the river Cober as surface runoff, which could result in an increase in the magnitude and frequency of flood events in Helston in the future. Therefore, research into this area could influence how land is used and managed in the Cober catchment to try and reduce any increases in future flooding in Helston.

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