



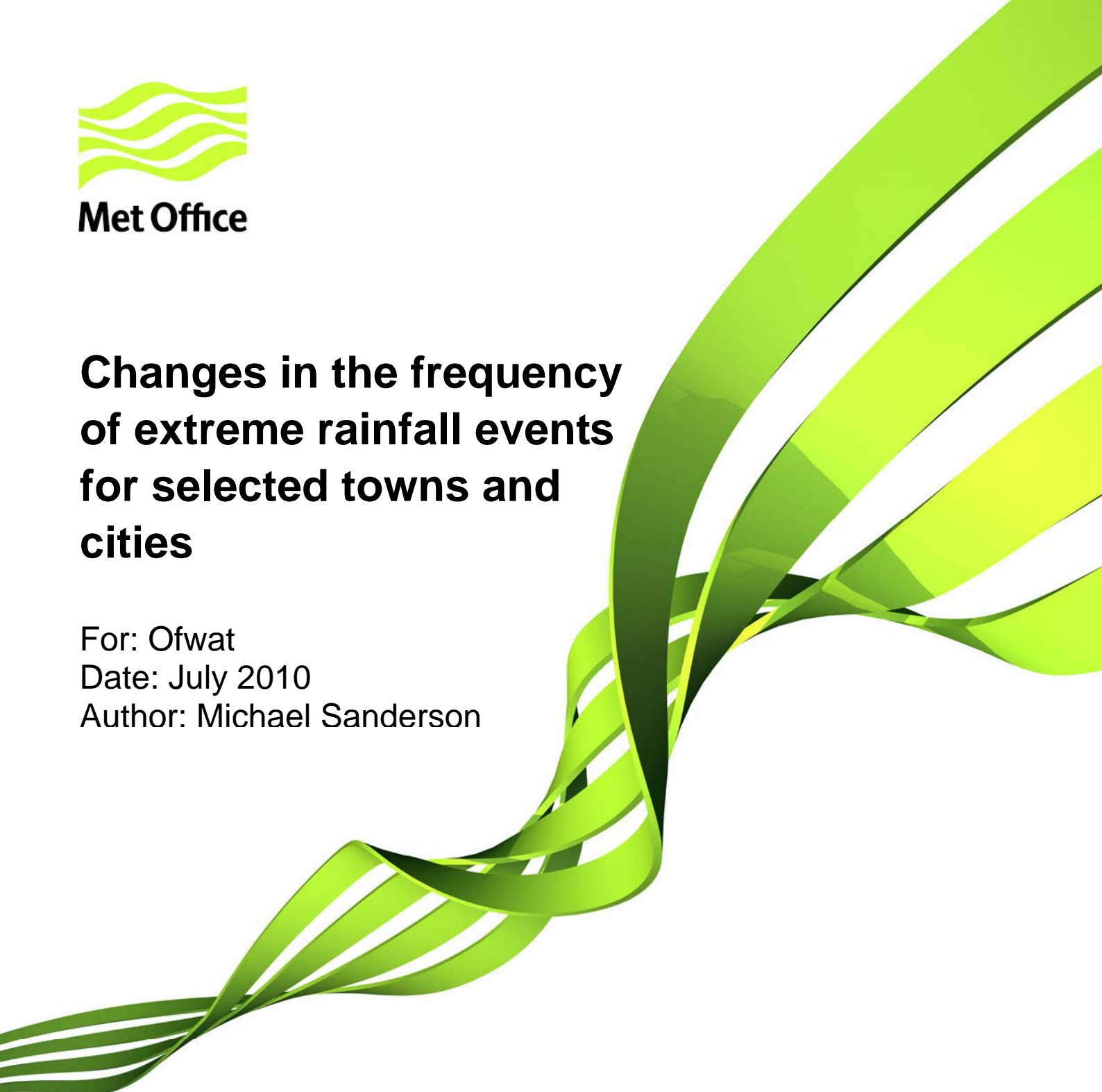
Met Office

Changes in the frequency of extreme rainfall events for selected towns and cities

For: Ofwat

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Executive Summary

- Magnitudes of daily rainfall events (called return levels) for events with return periods of 1 in 5, 10, 20, 30, 50 and 100 years have been calculated from observed rainfall amounts for winter (December, January and February) and summer (June, July and August) for 40 towns and cities across the UK. Additionally, the locations where the largest changes occur were also identified.
- The frequency of the events with the same magnitudes for the 2040s, 2060s and 2080s have been calculated using an 11 member ensemble of regional climate projections released alongside the UKCP09 climate projections. The spread of possible changes was also calculated.
- The uncertainty in the frequency of the future daily rainfall events was largest for the 1 in 100 year events, and smallest for the 1 in 5 year events in both seasons. The uncertainty also increased in the order 2040s, 2060s, 2080s.
- All winter rainfall events are projected to become more frequent.
- There is no clear signal for the change in frequency of summer rainfall events. The range of possible changes means that summer rainfall events could become much less frequent, or that they might be much more frequent.
- There is a large spread in the projected extreme rainfall amounts in the 11 member model ensemble, and so these results (particularly those for summer) should be used with caution. They have been generated using the latest science available for extreme value analysis, but some of this science is still being developed and evaluated.
- During winter, the biggest increases in frequency of 5 and 10 year events are projected to occur over Essex, Sussex and Kent. For the 20, 30, 50 and 100 year events, the biggest increases occur over Suffolk. There is greater uncertainty in the locations where the minimum changes occur in winter, as the locations identified are in different parts of England and Wales. For 5 and 10 year events, the smallest changes occur in South Yorkshire. For the 20, 30, 50 and 100 year events, the smallest changes occur over Herefordshire and

Worcestershire. Small changes are also projected over Southend-on-Sea in Essex.

- During summer, the biggest increases in frequency of 5 and 10 year events are projected to occur over central southern England (Berkshire, Hampshire and Surrey). For the 20, 30, 50 and 100 year events, the biggest increases are projected to occur over both Dorset and north-west England (Cumbria and Lancashire). The smallest changes (where the frequency of summer rainfall events does not change or decreases slightly) occur over Norfolk.

Introduction

Ofwat have asked the Met Office to provide guidance on future daily rainfall return periods (i.e., the frequency of the event) for England and Wales. Return periods have been calculated for 40 towns and cities. The locations where the biggest and smallest changes in return periods occur have also been identified.

An analysis of the trends in measured rainfall amounts has been performed by Jenkins et al. (2008). Annual mean rainfall over England and Wales has not changed significantly since records began in 1766. However, the proportion of winter rainfall falling in heavy rainfall events has increased over all regions of the UK over the past 45 years. In summer, rainfall has decreased in all regions except north-east England and northern Scotland. The UKCP09 climate projections (Murphy et al., 2009) suggest that UK rainfall is likely to continue to become more polarised in the future – winters are projected to become wetter and summers are projected to become drier but with less confidence. Some climate projections (other than UKCP09) suggest that, although total summer rainfall may decrease, it could be concentrated into a number of intense downpours from storms.

In this report, the term *return level* refers to the magnitude of the daily rainfall event, and the *return period* is the frequency of the event. For example, if 100 years of daily rainfall data were available, an event with a 1 in 20 year return period would be expected to occur 5 times in that dataset, and on average once every 20 years. Alternatively, in any year, such an event has a probability of occurring equal to 1 in 20 (i.e. a 5 % chance). In this report, return levels for events with a return period of 1 in 5, 10, 20, 30, 50 and 100 years have been calculated from observed and modelled daily rainfall amounts for winter (December, January and February) and summer (June, July and August), using data for the end of the 20th century. In this report, these events will be referred to as *extreme events*. It is likely that the magnitude of daily rainfall events with a given return period will change by different amounts in each season in the future. Alternatively, the return periods of rainfall events with a given return level are likely to change (i.e., become more or less frequent in the future). Only daily total rainfall data are available from the climate model projections used in this study, and so it is not possible to provide any guidance on how rainfall on, for example, hourly timescales may change.

In this report, the calculation of the change in return period of a rainfall event with a given magnitude (return level) is described. For example, an event which currently has a return period of 1 in 20 years might have a return period of 1 in 15 years by the 2080s. The data used to calculate the changes in return period for a given return level is described in the next section. Next, the methodology is briefly outlined. The return periods for a number of locations are then presented, with a discussion of the results.

Data Sources

Two different sources of rainfall data have been analysed. Daily rainfall amounts have been calculated for the period 1960 – 2006 for every land point in the UK at a resolution of 5 km using measured rainfall amounts from the UK rain gauge network. This dataset was created by interpolation of the rain gauge data to the 5 km grid using statistical relationships between rainfall amounts and many topographical parameters. Further details are given by Perry et al. (2009). The 5 km data have also been interpolated to the 25 km grid of the regional climate model which was used as part of the process to create the UKCP09 climate projections, and it is the 25 km resolution rainfall data which have been analysed in this project.

Secondly, daily rainfall amounts from an 11-member ensemble of regional climate models (RCM) were analysed. The 11-member ensemble data have been released alongside the UKCP09 climate projections (Murphy et al., 2009). The 11-member RCM data provide projections of daily climate for a continuous time period from 1950 to 2099 under the SRES A1B emissions scenario (which is classed as a medium emissions scenario in the UKCP09 climate projections). This scenario was developed by the IPCC and is described in detail elsewhere (Nakićenović and Swart, 2000). Briefly, this scenario assumes rapid economic growth and the introduction of new and efficient technologies, with a mixture of fossil fuel and renewable energy sources. The UKCP09 climate projections are also available for high and low emissions scenarios. However, similar climate model data to the 11-member ensemble are not available for these two other scenarios. The UKCP09 projections for the high and low emissions scenarios were generated in the following way. Statistical relationships between the regional and global climate model projections were established for the medium emissions scenario. These relationships were then used with global climate model projections for the high and low emissions scenarios to emulate RCM projections for the high and low emissions scenarios. This procedure is described in detail by Murphy et al. (2009), Chapter 3.

Methodology

Extreme value analysis (EVA) was used to calculate the return levels of daily rainfall events with return periods of 5, 10, 20, 30, 50 and 100 years. Extreme value analysis is a statistical method that may be used to characterise the probability and magnitude (return level) of events that are more extreme than any that exist in a given data series (Coles, 2001). For example, a 20 year observation record could be used to estimate the return level of an event with a return period of 1 in 100 years. EVA provides a method which enables extrapolations of this type. It also allows estimation of a suitable threshold for the identification of extreme events and their return periods. It is important to remember that the uncertainty in the projected extreme events will increase with larger return periods. For example, the uncertainty in the return level of a 1 in 100 year event will be larger than the return level of a 1 in 20 year event. The uncertainty will also be smaller for longer data series, as a long data series is likely to contain more extreme events. The derivation and methods used to fit the extreme value curve to data are described in detail by Coles (2001) and Brown et al. (2008b). The EVA curve was fitted to the observed rainfall data (for the period 1960 – 2006) and all 150 years worth of data from each of the 11 member ensemble of RCM simulations. This curve fitting was done for each 25 km grid square containing the locations listed in Table 1. Additionally, the locations where the largest changes in return periods occur will also be identified.

Table 1. Locations for which changes in return periods have been calculated. The Water and Sewerage Company regions in which each location lies are arranged north to south.

Northumbrian: Darlington Newcastle-Upon-Tyne	Anglian: Cambridge Ipswich	Welsh: Aberystwyth Bangor Cardiff Hereford Swansea Wrexham	Southern: Bournemouth Brighton Canterbury Portsmouth
United Utilities: Carlisle Lancaster Liverpool Manchester	Lincoln Northampton Norwich Peterborough Southend-on-Sea	Thames: Basingstoke London Oxford Swindon	Wessex: Bristol Yeovil
Yorkshire: Hull Leeds Scarborough Sheffield	Severn Trent: Birmingham Nottingham Shrewsbury Stoke-on-Trent		South West: Exeter Penzance Plymouth

The generation of the return levels and how their return periods could change in the future was calculated in the following steps:

1. Work out current (1980-2006) return levels of all rainfall events with return periods between 2 and 400 years from 25 km gridded rainfall data using extreme value analysis (EVA).
2. Identify current return levels for 6 return periods (1 in 5, 10, 20, 30, 50 and 100 year events) from step 1.
3. Repeat step 1 using climate model data for the period 1961-1990 (control period) from the 11-member RCM ensemble.
4. Repeat step 3 using climate model data for the periods 2030-2059 (2040s), 2050-2089 (2060s) and 2070-2099 (2080s).
5. Calculate climate scaling factors by dividing the return level for each of the future periods (step 4) by the return level for the control period (step 3), again for all of the return periods (2 – 400 years).
6. Using probabilistic data from UKCP09, calculate the distribution of scaling factors for each return period for all time periods (2040s, 2060s and 2080s) from each RCM ensemble member. Next, combine the results from all RCM members to calculate a single distribution of scaling factors for each time period and each return period. Then, multiply these scaling factors by the return levels calculated from the observed data in step 1 to calculate the future return levels for all return periods.
7. Use data from step 6 to calculate 10th, 50th and 90th percentile return levels for all return periods (2 – 400 years). Identify which future return periods (using the 50th percentile, the “central estimate”) have the closest return levels to those identified in step 2.
8. Plot the data from step 7 to show how the return period of rainfall events (with a present-day return period of 1 in 5, 10, 20, 30, 50 and 100 years) could change during the 21st century. An example is shown in Figure 1, and data for all locations are listed in the Appendix.

Results

Projected changes in return periods for rainfall events which currently have return periods of 1 in 5, 10, 20, 30, 50 and 100 years were calculated for all locations listed in Table 1, using the 10th, 50th and 90th percentiles of future rainfall distributions, for both winter (DJF) and summer (JJA) rainfall for the 2040s (2030-2059), 2060s (2050-2089) and 2080s (2070-2099). An example of these changes is shown for Newcastle-upon-Tyne in Figure 1. Equivalent figures for all locations are given in the Appendix. The return periods are shown on the y-axis, and the data are plotted at the four time periods on the x-axis, where their relative positions are correct. The present day data analysed were recorded over the period 1960-2006, and are centred on (about) 1980 – this point is labelled as “Present” in Figure 1. The other three points are shown at 2040, 2060 and 2080. Results for DJF are shown in the top row and for JJA in the bottom row.

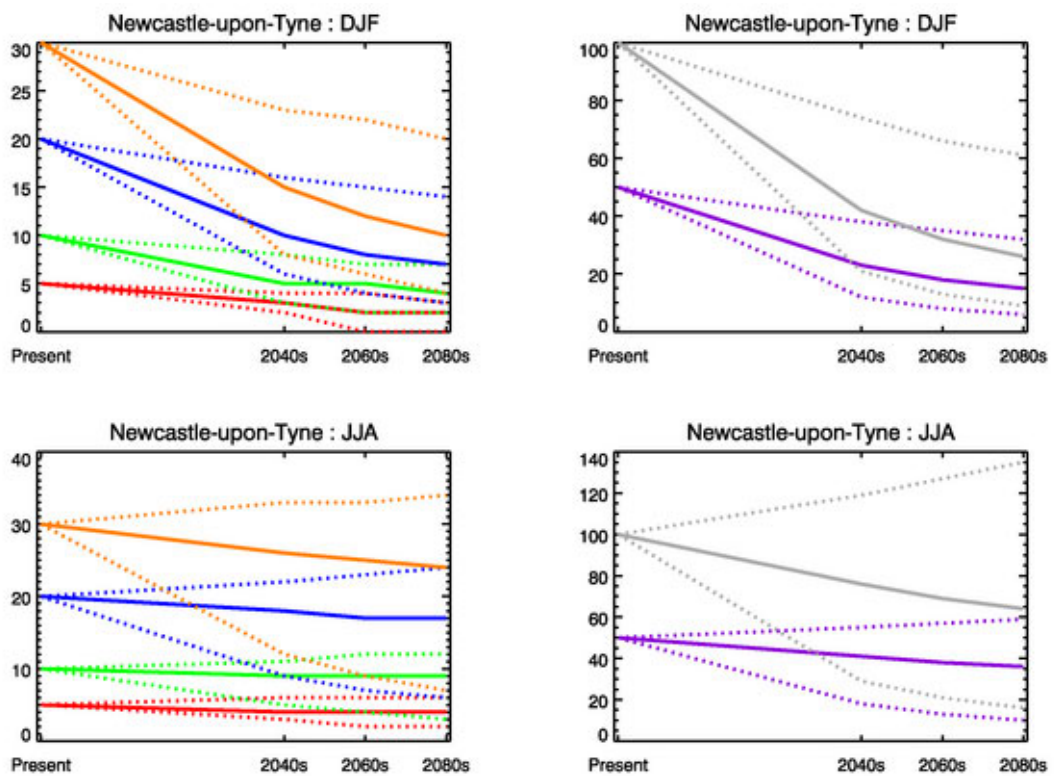


Figure 1. Change in return period for rainfall events with present-day return periods of 1 in 5 (red), 1 in 10 (green), 1 in 20 (blue), 1 in 30 (orange) [left-hand panels] and 1 in 50 (purple) and 1 in 100 years (grey) [right-hand panels]. The return periods are shown on the y-axis. The central estimate (50th percentile) is indicated by a solid line, and the 10th and 90th percentiles, calculated using the full range of probabilistic projections from UKCP09, illustrate the possible range of return periods and are shown by dotted lines. The present-day return periods are positioned at 1980 on the x-axis (marked as ‘Present’). Changes for winter (DJF, top row) and summer (JJA, bottom row) have been calculated separately. Note that the scale of the y-axis is different for each panel

The results for Newcastle-upon-Tyne are broadly representative of those for the other towns and cities considered (see Appendix). In winter the rainfall events become more frequent (i.e. the future return period is smaller than the present day return period) and the biggest change is projected to occur between the present day and the 2040s. This could be because the extreme rainfall events, especially those for the higher return periods (which have larger return levels) are already near to their maximum possible return levels. There will be a maximum amount of precipitable water in the atmosphere, which can fall to the ground as rain. The extreme events with longer return periods may be close to this value. Although the atmosphere can hold more water vapour as it warms, the incremental change in these extreme events as the climate warms could become progressively smaller.

For Hull, Peterborough and Swindon the uncertainty in changes in winter rainfall is large, and there is a suggestion that winter return levels for some return periods might decrease in frequency. For Carlisle, Cardiff, Southend-on-Sea and Basingstoke, the 10th percentile changes for winter rainfall in the 2040s are very large. For these locations, the extreme value curve is fairly flat, in that the difference in return levels between a 1 in 100 and a 1 in 200 year event is small. Hence, a small increase in the return level produces a very large change in the return period. Owing to the uncertainty in these results (discussed in more detail below), some of these features could be caused by 'noise' or natural variability.

In summer the changes in future return periods of the rainfall events is much less clear. The central estimate (solid lines in Figure 1 and figures in the Appendix) projects summer extremes to become slightly more frequent (i.e., the return period decreases in the future). However, the 10th percentile projects summer extremes to decrease in frequency (the future return periods are larger than the present-day return periods). For the 1 in 100 year event, the uncertainty means that by the 2080s such an event could occur with a return period between 1 in 20 years and 1 in 140 years. The uncertainty in the change in summer rainfall is generally larger than that for winter rainfall. For most locations, there is no clear signal. Summer rainfall extremes could either increase in frequency or decrease. The uncertainty in summer rainfall is very large for locations in the south and south-east; Norwich, Cambridge, Ipswich, London, Canterbury, Brighton, Portsmouth, Bournemouth, Southend-on-Sea and Basingstoke. For some cities (e.g., London, Sheffield, Southend-on-Sea) the central estimate suggests almost no change in summer rainfall. For Norwich, the central estimate of the summer rainfall extremes

suggests that they will be less frequent. For all other cities, the central estimate indicates that summer rainfall extremes will become slightly more frequent.

The results shown in the Appendix suggest that, for winter, the return periods for a given rainfall event (i.e., a given return level) decrease with time (those events become more frequent). For summer, the changes are less clear. The central estimate (50th percentile) suggests that summer extremes may become slightly more frequent in the future, but the uncertainty is very large. The 10th percentile changes for summer suggest that the rainfall events will become much less frequent (i.e. the future return periods are larger than those for the present day). If there were no trend in the extreme rainfall amounts, the lines in the figures in the Appendix would be horizontal.

The changes in extremes found for the UK towns and cities in this report are consistent with those from the study by Fowler and Wilby (2010). These authors have estimated detection times for changes in seasonal rainfall extremes as a result of climate change for several regions of the UK. They found that changes in winter extremes could be detected by the middle of the 21st century, but changes in summer extremes were highly uncertain, and no detection was possible. Similar conclusions were reached by Fowler et al. (2010), who examined extreme rainfall changes over the UK from the *climateprediction.net* project. These authors found that changes in winter extreme rainfall, as a result of climate change, could be detected as early as 2010, but any changes in summer extremes were not detectable even by 2080.

The location where largest changes in the frequency of extreme rainfall events take place depends on the return period and season. During winter, the biggest increases in the frequency of 5 and 10 year events are projected to occur over Essex, Sussex and Kent. For the 20, 30, 50 and 100 year events, the biggest increases are projected to occur over Suffolk. There is a suggestion that large changes might occur over north-east and north-west England as well, but only at single locations, meaning this result is uncertain. There is greater uncertainty in the locations where the minimum changes occur in winter, as the locations identified are in different parts of England and Wales. For 5 and 10 year events, the majority of the smallest changes occur in South Yorkshire. For the 20, 30, 50 and 100 year events, the smallest changes occur over Herefordshire and Worcestershire, and small changes are also projected over Southend in Essex.

The locations experiencing the largest changes in the frequency of summer rainfall events also depend on the return period. For 5 and 10 year events, the biggest

increases in frequency are projected to occur over central southern England (Berkshire, Hampshire and Surrey). For the 20, 30, 50 and 100 year events, the biggest increases are projected to occur over both Dorset and north-west England (Cumbria and Lancashire). The smallest changes (where the frequency of summer rainfall events does no change or decreases slightly) all occur over Norfolk.

Caveats

There are a number of caveats that need to be considered when using the results in the Appendix. Despite these caveats, the results presented in this report are believed to be the best estimates that current statistical techniques allow. The data analysed (both observed and modelled rainfall) have a resolution of 25 km, and so represent an average over an area of size 25 km by 25 km = 625 km². Extreme rainfall events, particularly those occurring in summer, occur on small spatial scales (areas of a few km²). Some of these events could be missed by the rain gauge network. Similarly, some parts of the UK have better coverage of rain gauges than others.

Almost all of the towns and cities for which the changes in extreme events have been calculated have areas much smaller than 625 km². There may be local topographical or other effects on rainfall in that city which have not been captured by the regional climate model. Many important processes which can affect rainfall, such as the flow of air upwards and over hills, convection and cloud formation, take place at spatial scales smaller than the model resolution. These processes cannot be modelled explicitly, and so they must be estimated using relationships with variables such as wind, temperature and humidity calculated at the scale of the model (here, 25 km). These relationships are called parameterisations. Previous work by the Met Office and Reading University has shown significant improvements in the representation of extreme rainfall using very high resolution climate models, with better representation of the diurnal cycle and of internal cloud dynamics (essential for capturing the development and persistence of convective events such as the storm which caused the flooding of Boscastle in 2004).

An analysis of annual, summer and winter rainfall observations by Jenkins et al. (2008) shows that annual mean precipitation over England and Wales has not changed significantly since 1766 when the records began. The rainfall in both summer and winter is highly variable, but appears to have increased in winter and decreased in summer since 1961. The actual change varies widely with location. It is possible that the use of

rainfall for the period 1960 – 2006 could bias the results, owing to the trends in summer and winter rainfall. However, the use of a shorter period of data (e.g., 1980-2006) would mean fewer extremes would be available for the EVA and greater uncertainty in the results. The EVA may not work if too few extremes are available (i.e., if the data series is too short).

The gridded rainfall observations analysed for this report come from a comparatively short period (roughly 50 years). It is possible that, by chance, the observations do not contain a representative sample of extreme events. There are no techniques currently available that allow an assessment of how representative a small period of data are of the “true” precipitation climatology without having access to that climatology.

The climate projections analysed in this report assume that there will not be any major volcanic activity during the 21st century (comparable to the eruption of Mt Pinatubo), and no major change in or collapse of the thermohaline circulation. These events would lead to major disruption of the UK climate. The climate projections have been generated with a single climate model. Other models may simulate different responses of UK precipitation to climate change.

In this report, climate model projections which were generated using a medium emissions scenario (SRES A1B) have been analysed. The UKCP09 projections also considered a low and high emissions scenario. Maps showing the percentage changes in rainfall for the wettest days in winter and summer are available for all three scenarios for the 2020s, 2050s and 2080s from UKCIP, and may be used to provide some guidance on how the extreme rainfall events in different parts of the country could change under the low and high emissions scenarios. Generally, there are similarities in the patterns of change in rainfall in the low, medium and high emissions scenario, but the magnitudes of change are smallest under the low emissions scenario and greatest under the high emissions scenario. The uncertainty in the changes (the difference between the 10th and 90th percentile changes) is also greater under the high emissions scenario than the low emissions scenario.

Overall, for winter, the extreme rainfall events considered in this report could become more frequent under both the low and high emissions scenarios (when compared with the present-day) as well as the medium emissions scenario analysed in detail here. However, the increase in frequency is likely to be smaller under the low emissions scenario, and greater under the high emissions scenario. For summer, the changes are

less clear, with both increases and decreases in frequency possible. The range of possible changes is likely to be greatest under the high emissions scenario, and smallest under the low emissions scenario. Other work has shown that extreme events may change at different rates to seasonal mean rainfall.

The extreme value analysis methodology used here ensures that the same proportion of rainfall events is classed as extreme for each time period. However, the absolute magnitudes of the extreme events in each period will be different. Ideally, the threshold used to define an extreme event (i.e. all rainfall amounts above some threshold are classed as extreme) would be determined separately for each location, optimising the number of data points being selected whilst ensuring they are extreme events. However, for the large amount of data analysed here this is not practical so a threshold representing the 98th percentile was adopted for daily rainfall events. The exact threshold used is, to some extent, arbitrary, but previous work has shown that the 98th percentile is a reasonable one to use.

The projected changes in return periods should be used with caution. There is still a large spread in the return levels between the 11 models analysed here, and it is likely that the “true” distribution is poorly sampled. Despite best efforts, the large spread may still be caused by a significant component of natural variability or, in addition, the spread may be due to the ensemble design to sample climate modelling uncertainty. The changes in return periods have been generated using the latest science available for extreme value analysis, but some of this science is still being developed and evaluated.

Summary

Changes in the frequency of extreme daily rainfall amounts for winter and summer have been estimated for 40 towns and cities using modelled rainfall amounts. Modelled daily rainfall amounts from an 11 member regional climate model ensemble, which were released alongside the UKCP09 climate projections, have been analysed using extreme value analysis (EVA). The formulation of the EVA curve has been modified to incorporate climate change, i.e., the fact that there is a trend in the modelled rainfall data. This was necessary to ensure that the same proportion of rainfall events is classed as extreme in the present day as in the future. Otherwise, if the same threshold was used for all time periods, too few or too many events would be used for the EVA

and the fit to the data would be poor. We believe that the results that we have obtained are the best estimates that current statistical techniques allow.

Rainfall amounts with return periods of 1 in 5, 10, 20, 30, 50 and 100 years were calculated using EVA on observed rainfall data which had been interpolated to the same 25 km grid used by the regional climate model. Next, rainfall amounts for the same return periods were calculated from the 11 member regional climate model ensemble for the present day, 2040s, 2060s and 2080s. Scaling factors were calculated by dividing the future return levels by the modelled present day return levels with the same return period. Rainfall amounts calculated from observed rainfall data were multiplied by the scaling factors to obtain future return levels. Scaling factors are used because climate models contain biases. Using scaling factors helps to reduce the impact of biases on the results. Other work has shown that percentage changes in modelled rainfall from different models are more consistent than absolute changes, and agree more closely with observed percentage changes. A distribution of future rainfall changes was calculated using probabilistic information from UKCP09, from which the 10th, 50th and 90th percentile changes were calculated. The 50th percentile is the central estimate, and the return periods of future events are unlikely to be smaller than the 90th percentile value or greater than the 10th percentile value (Murphy et al., 2009).

The change in return period of extreme rainfall events was then calculated for 40 towns and cities. For winter, all extremes were projected to become more frequent in the future (their return periods are smaller than present-day return periods). However, the change in summer extremes is much less certain. The 50th percentile change projects that summer extremes will become slightly more frequent in most locations, but the 10th percentile changes project that summer extremes will be much less frequent.

Future Work

Figures illustrating how the return periods of rainfall events with a return period of 1 in 5, 10, 20, 30, 50 and 100 years could change under the A1B scenario during the 21st century have been produced. Similar figures showing the same changes under the B1 (low emissions) and A1FI (high emissions) scenarios could also be produced. The changes in extreme rainfall events have been calculated for 40 locations in England and Wales. The analysis could be extended to cover the whole of the UK, and the results aggregated for each water company's region. These aggregated results would provide

useful information for planning of future adaptation strategies, such as drainage design and flood protection infrastructure.

Much of the rainfall in the UK is produced by frontal processes, which have a typical duration of 5 days (Brown et al., 2008a). This analysis could therefore be repeated using 5 day accumulated rainfall, which would show how extreme rainfall from weather fronts could change during the 21st century.

Only 11 regional climate model simulations were available for analysis. Future work in this area at the Met Office will attempt to use the UKCP09 methodology to produce probability distributions of changes in extreme weather utilising a statistical emulator to sample all the relevant uncertainties. These new data will allow a much improved estimation of the “true” distribution of rainfall extremes to be obtained thereby allowing a refining of the 10th, 50th and 90th percentile values derived in this study and providing a more robust level of confidence in the results.

A very high resolution climate model (1.5 km) is currently being used to simulate the climate over the UK south of the Wash for two 20 year periods, one representing the present day and the other the mid-21st century. This model can explicitly simulate convection, cloud formation and evolution, and the resulting rainfall, which is especially important for modelling of summer extreme rainfall events. Results from these simulations will be analysed to understand the processes which trigger extreme rainfall events, and how the return levels and frequency of future extremes could change from the present day. The rainfall data could be analysed using extreme value analysis to create improved estimates of how extreme rainfall events (particularly summer events) might change in the future.

Little work has been done on verifying modelled precipitation on sub-daily timescales. If the diurnal cycle of modelled precipitation was found to be satisfactory, the EVA method could be applied to modelled hourly rainfall. The evolution of summer and winter extreme rainfall events from the model could also be analysed. The total amount of rain from a storm might not change, but the temporal characteristics could change – for example, a typical 1 in 5 year storm might last for 3 hours during the present day but could only last 2 hours (with more intense rainfall) in the future. Any change in temporal characteristics could impact on results from sewerage and drainage models.

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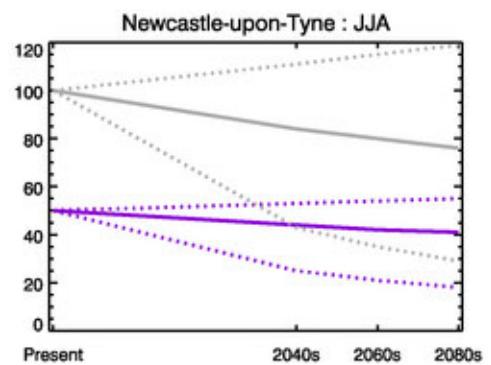
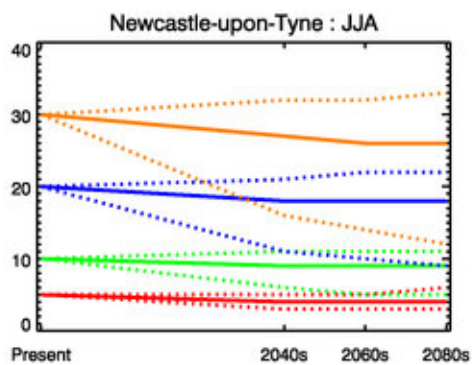
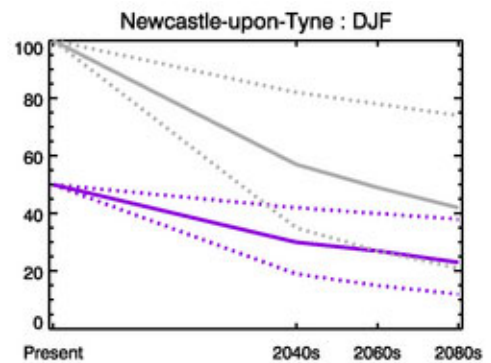
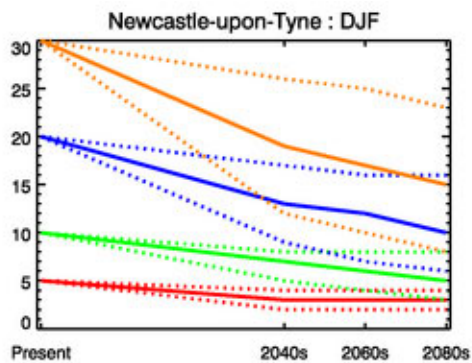
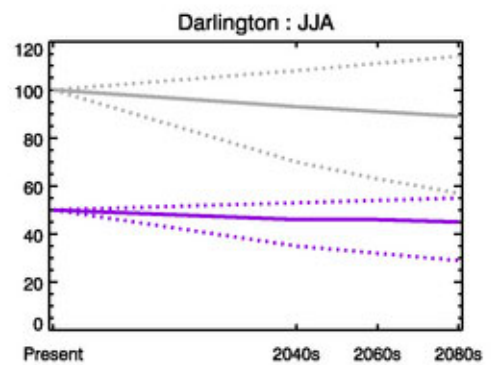
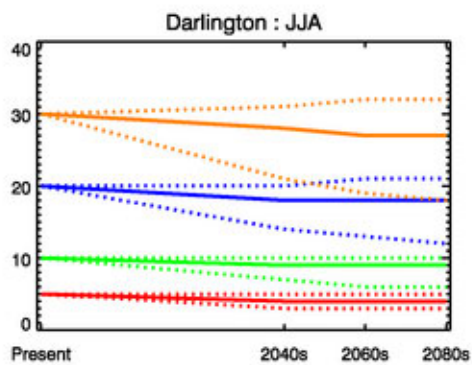
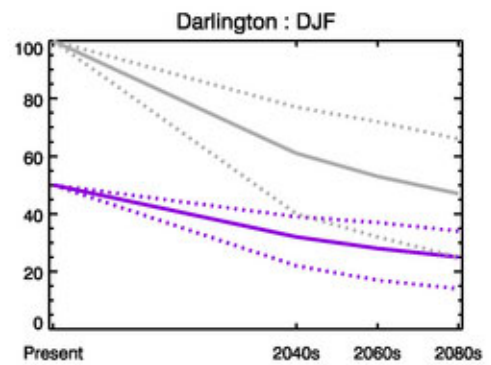
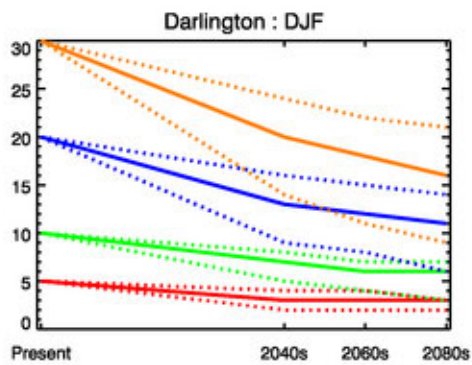
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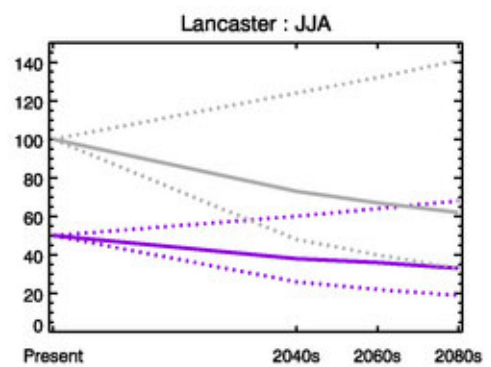
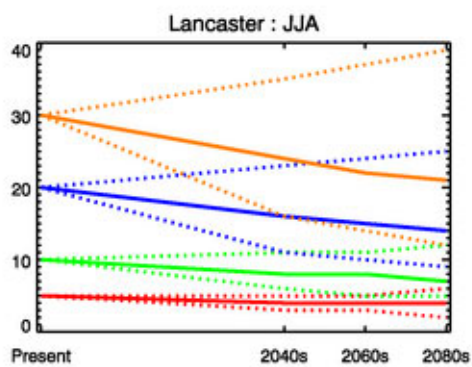
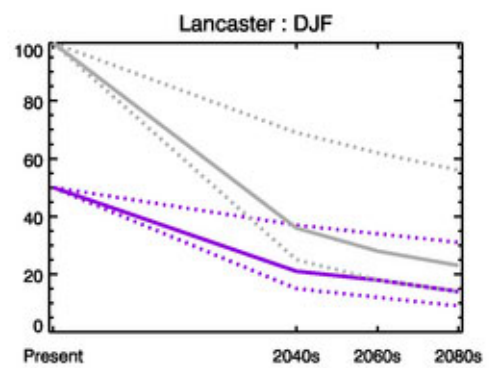
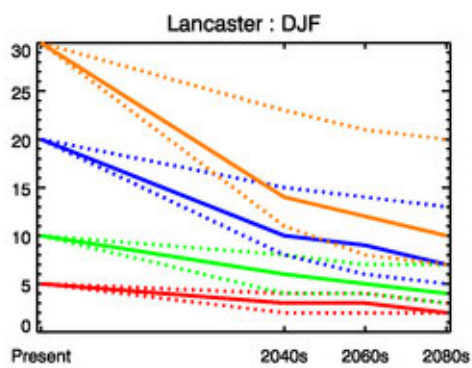
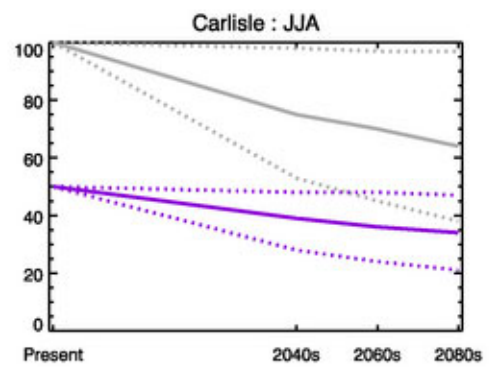
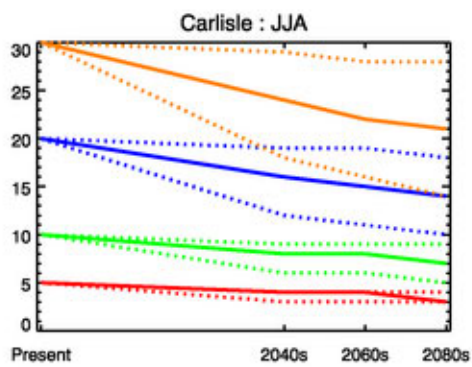
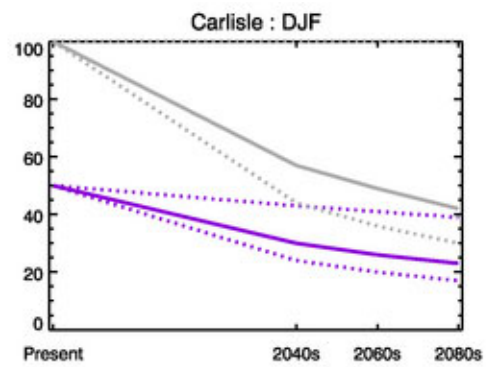
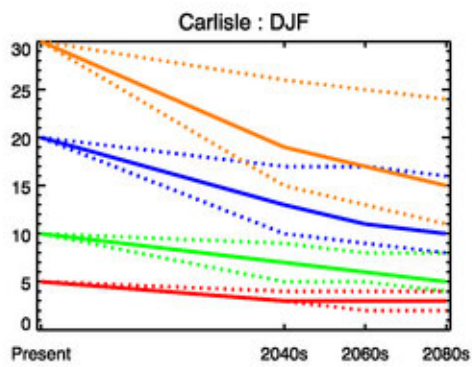
Appendix

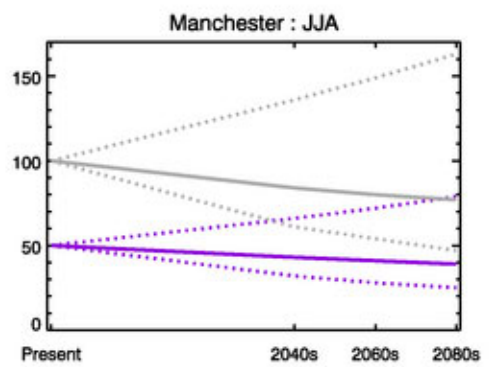
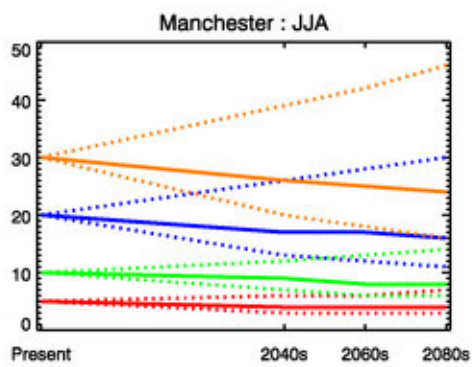
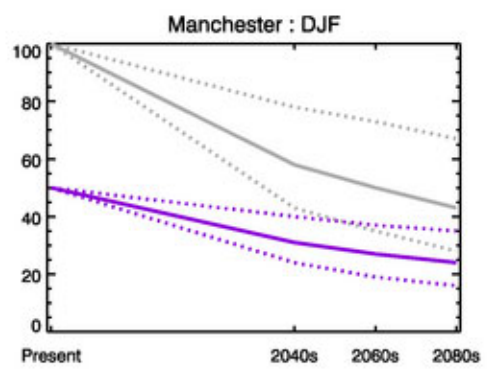
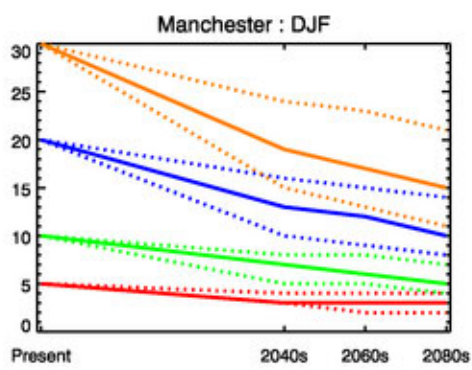
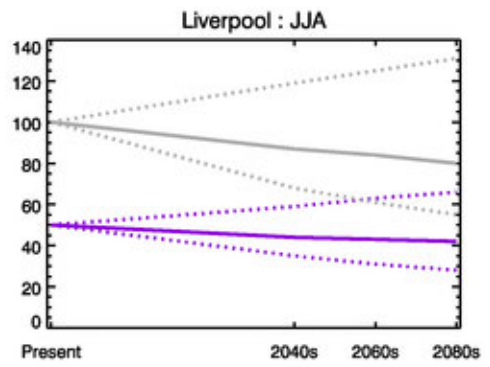
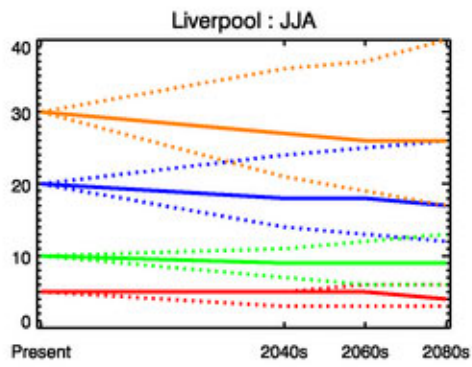
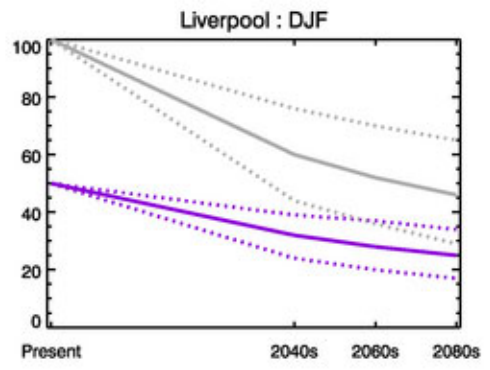
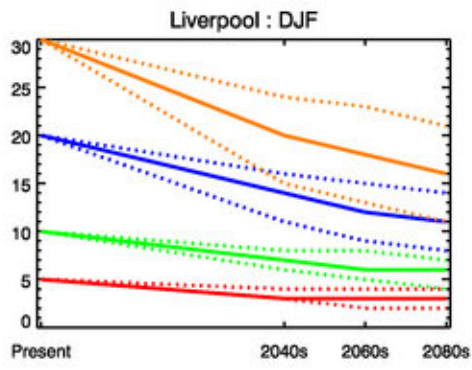
Graphs showing the changes in return period for rainfall events with present-day return periods of 5, 10, 20, 30, 50 and 100 years are shown here for all locations listed in Table 1. The graphs are shown in the same order. The horizontal scale ranges from 1980 (the present-day data are centred on 1980) to 2080. The return period is given on the y-axis. The left-hand panels show results for return periods between 1 in 5 and 1 in 30 years, and the results for return periods of 1 in 50 and 1 in 100 years are shown in the right-hand panels. For some locations (e.g., Basingstoke, Cambridge and Ipswich), the uncertainty in the return periods is very large. If the return period exceeds 400 years, it is set to 400 years.

Water and Sewerage Company region: Northumbrian

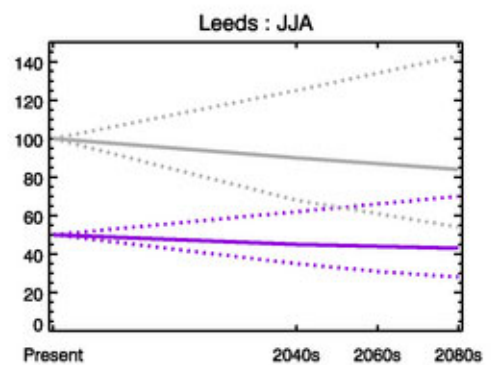
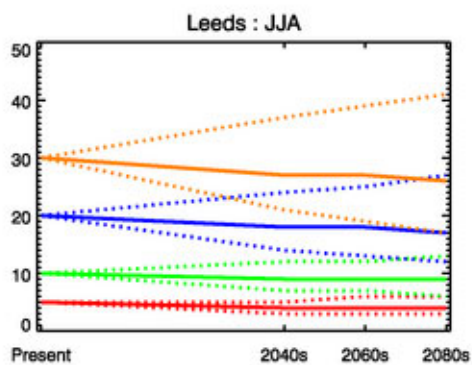
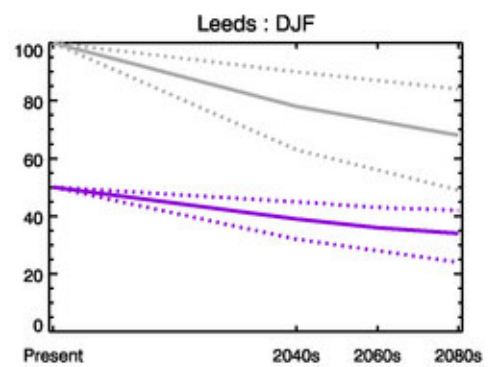
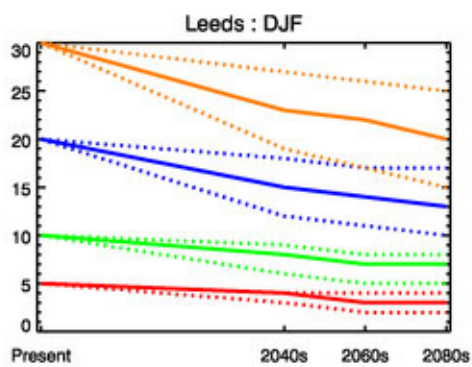
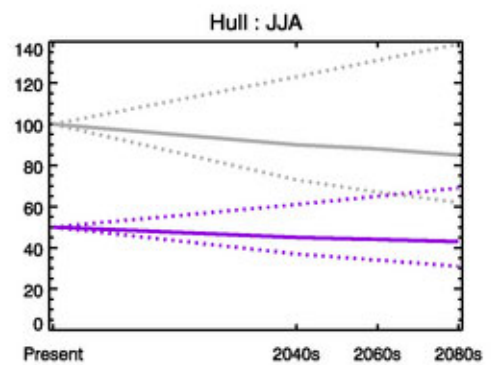
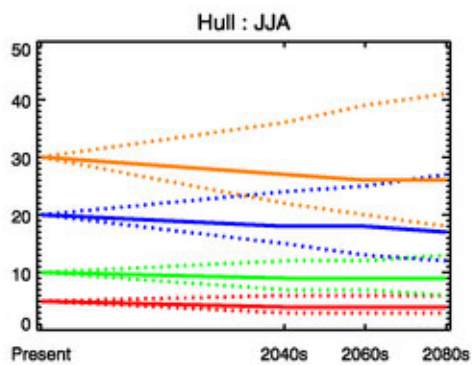
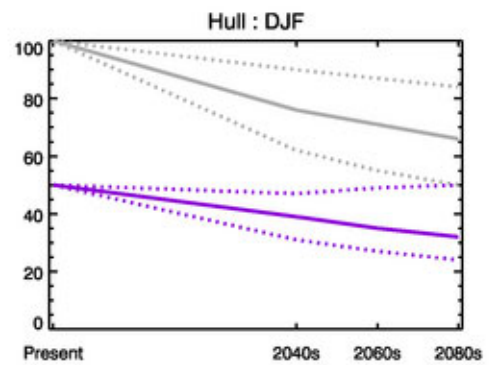
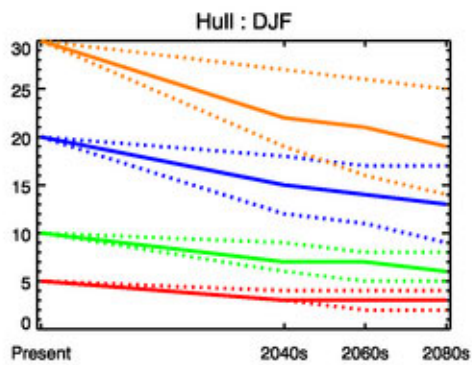


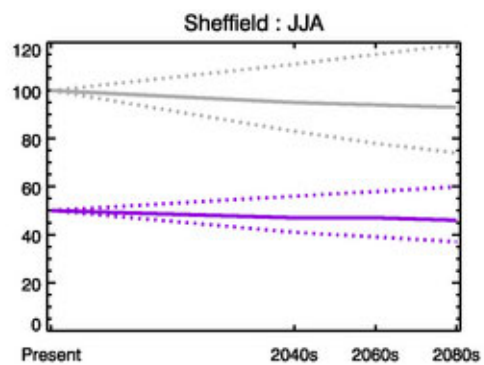
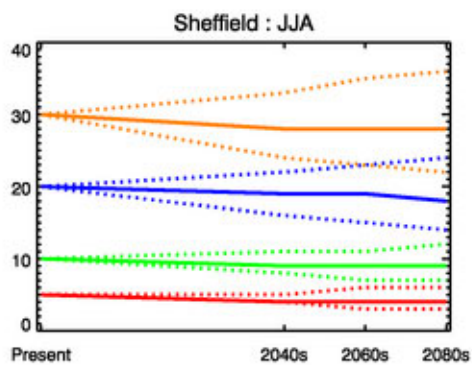
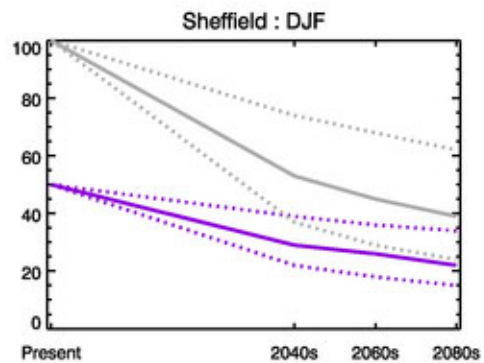
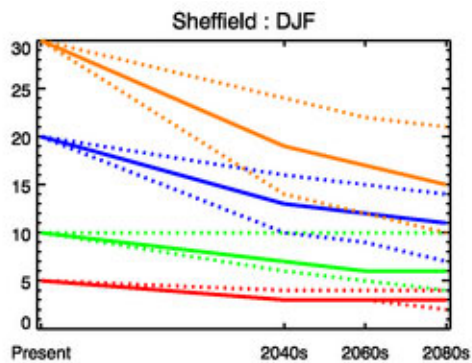
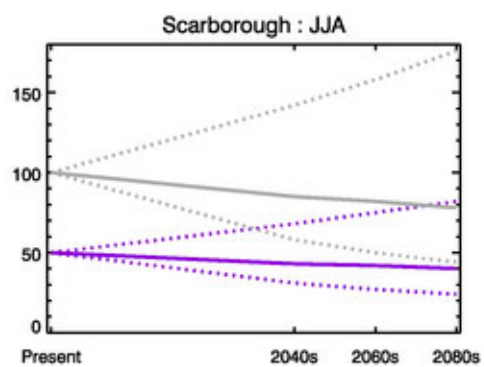
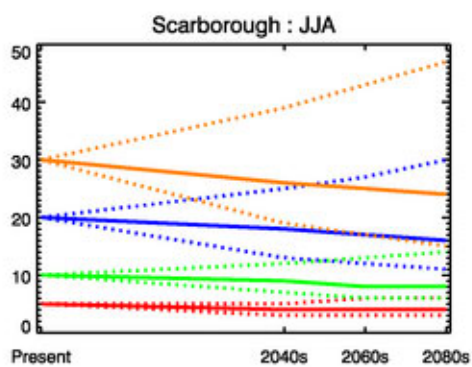
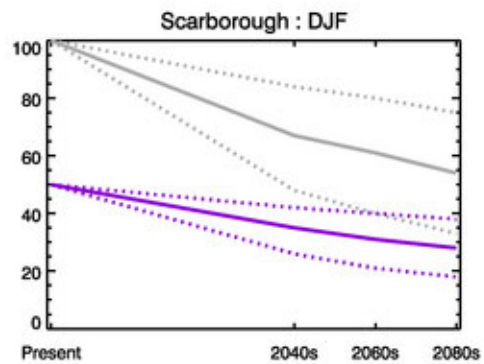
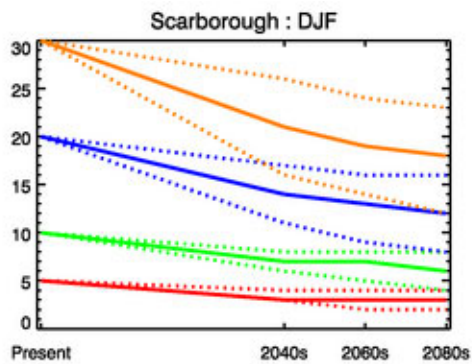
Water and Sewerage Company region: United Utilities



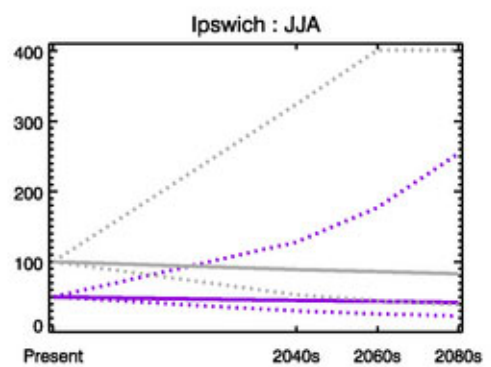
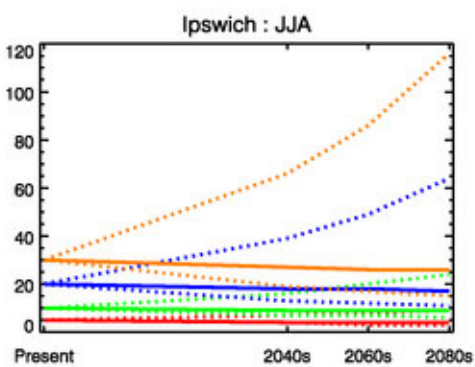
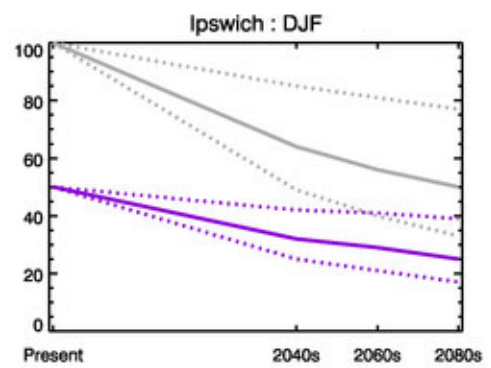
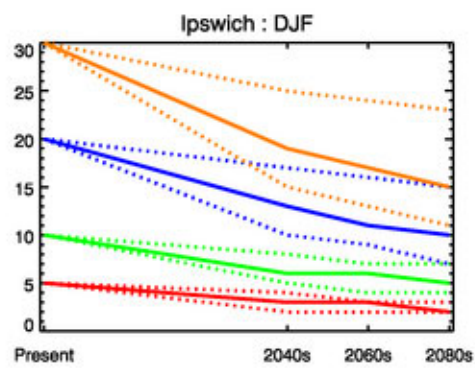
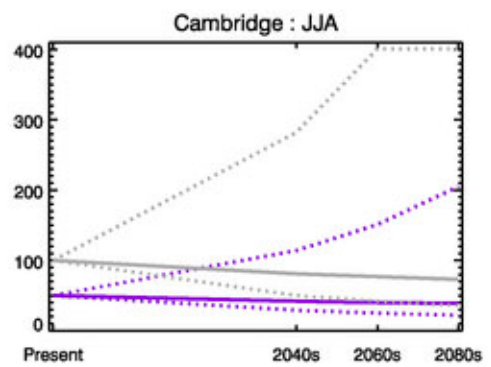
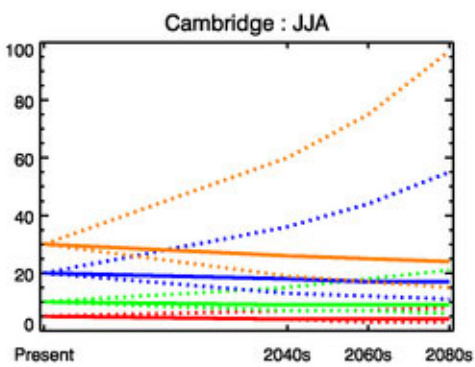
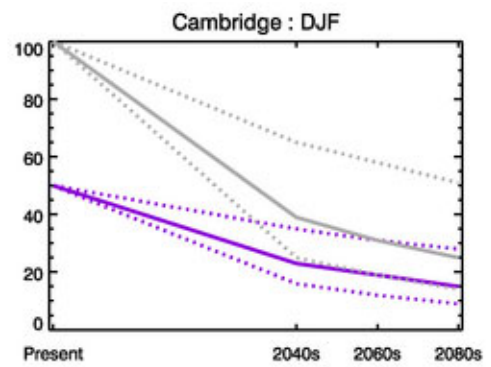
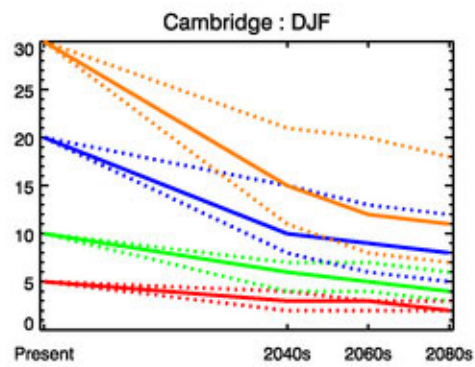


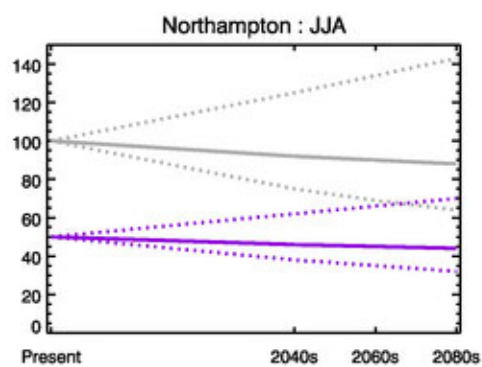
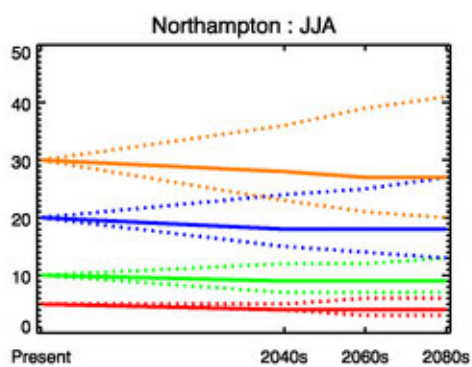
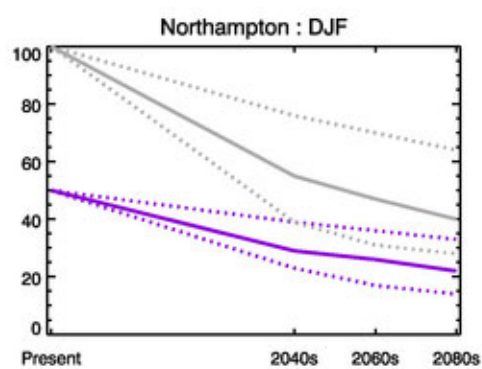
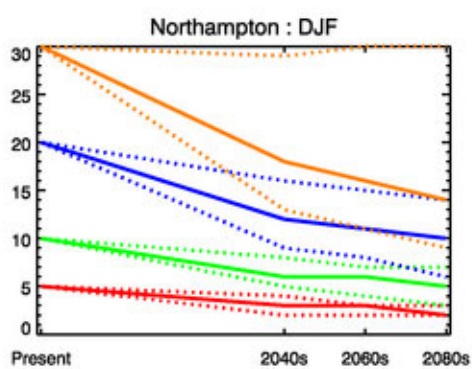
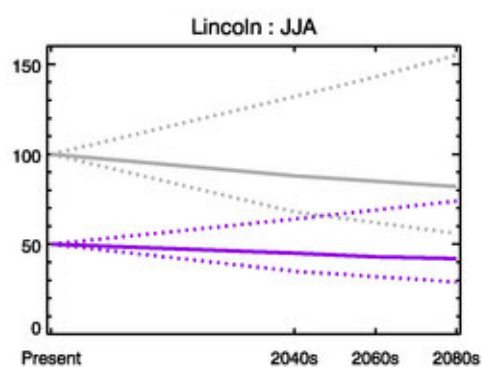
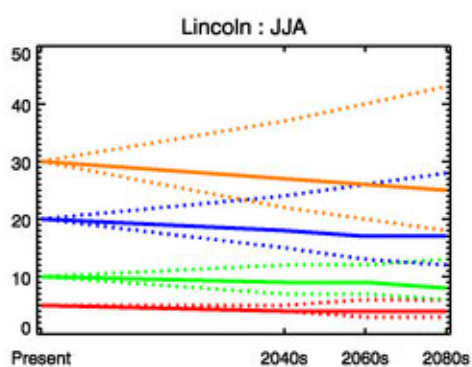
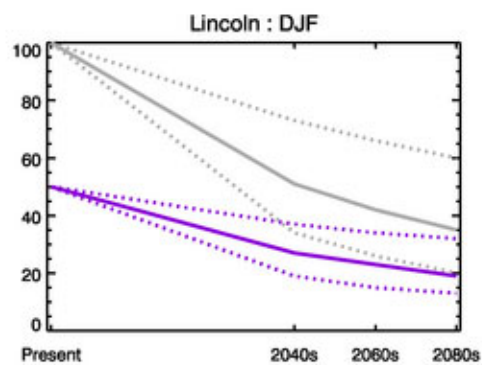
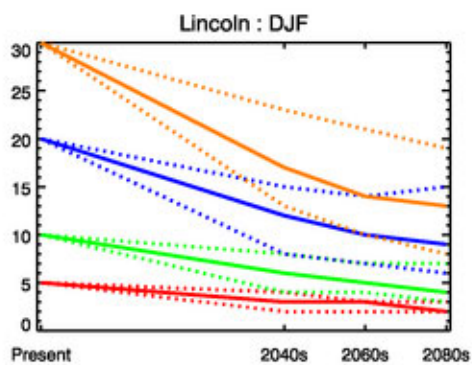
Water and Sewerage Company region: Yorkshire

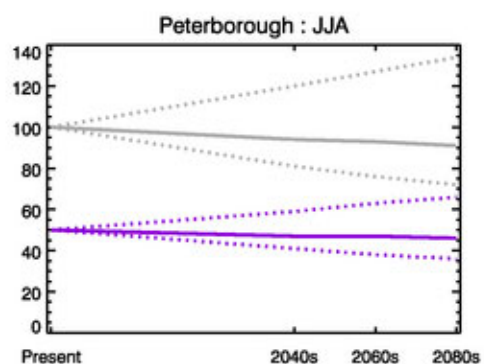
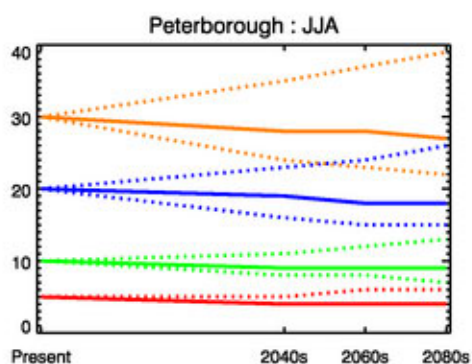
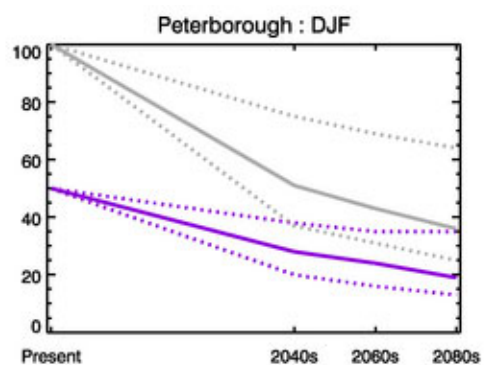
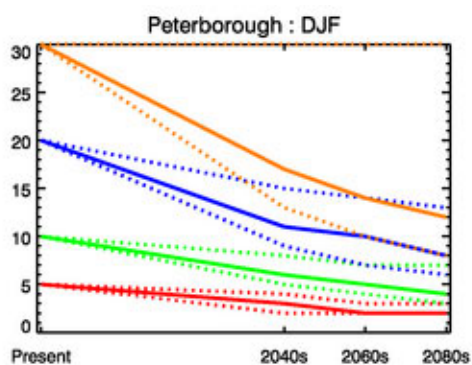
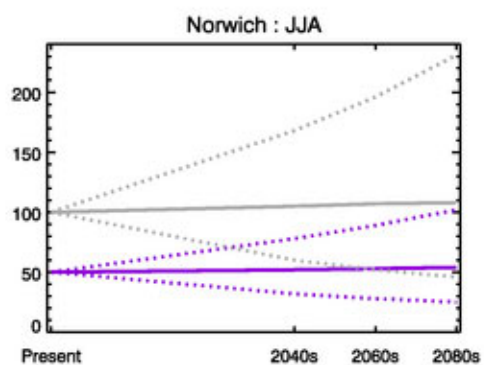
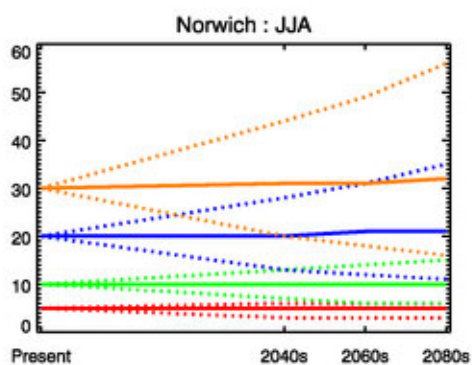
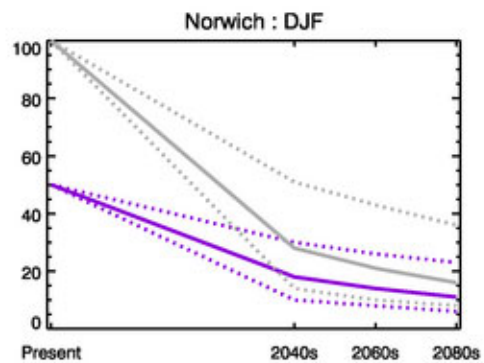
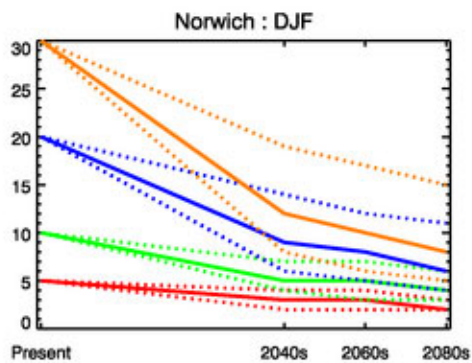


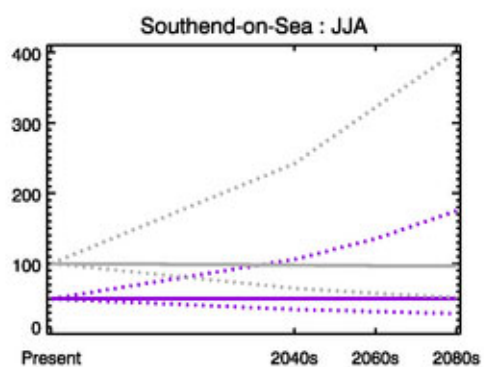
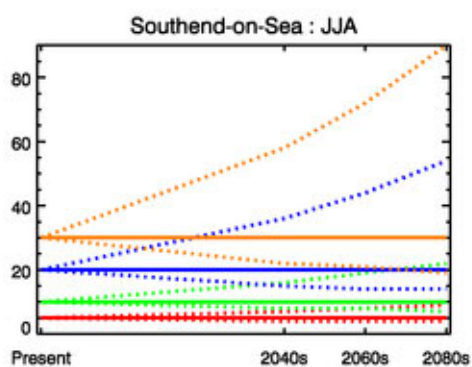
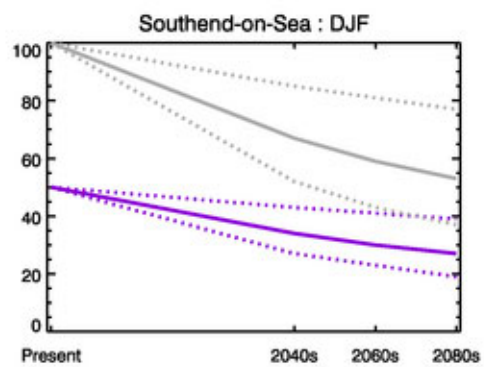
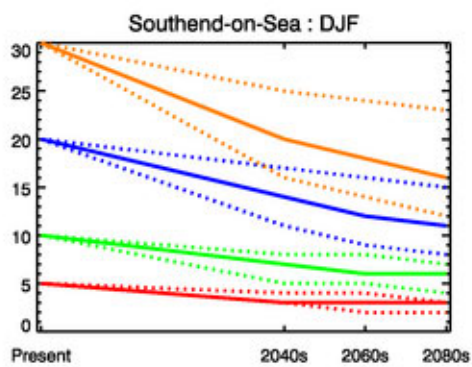


Water and Sewerage Company region: Anglian

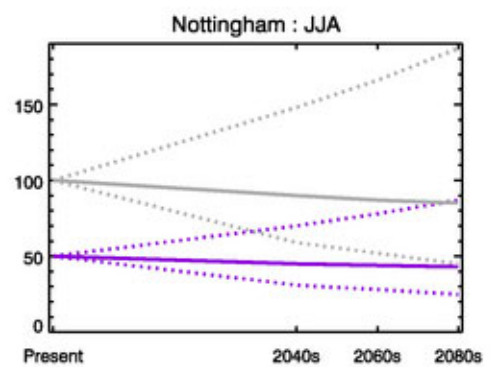
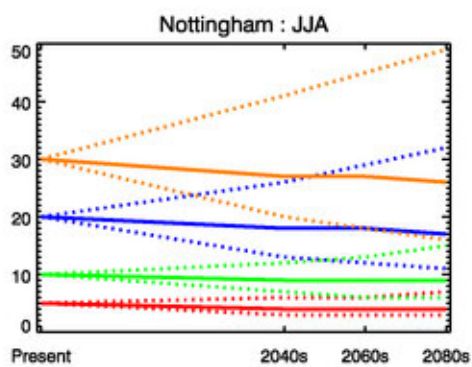
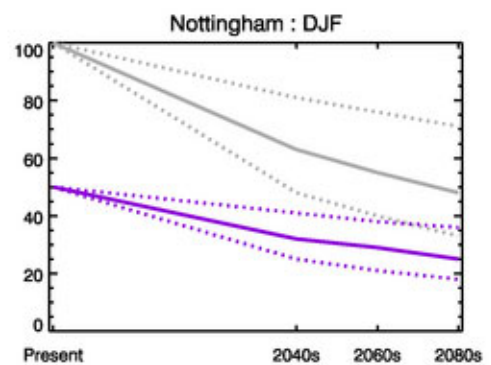
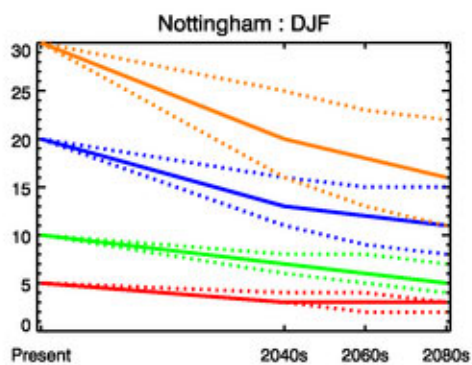
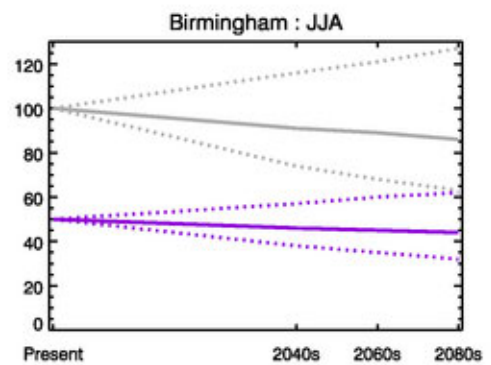
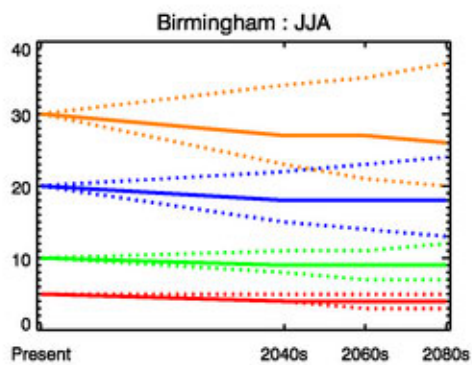
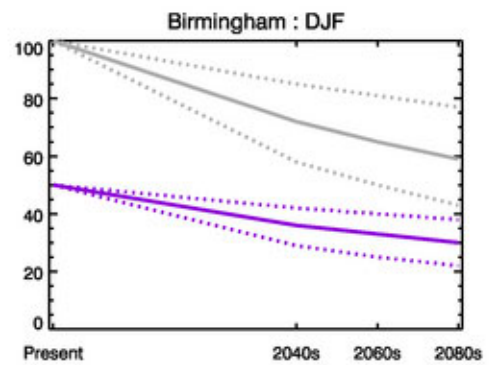
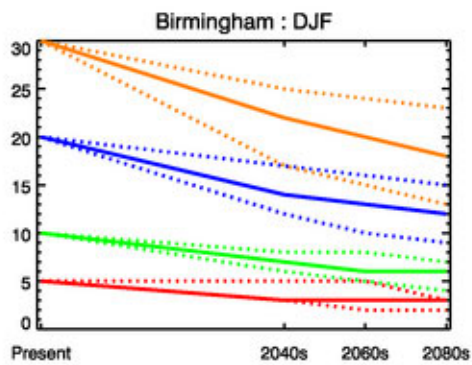


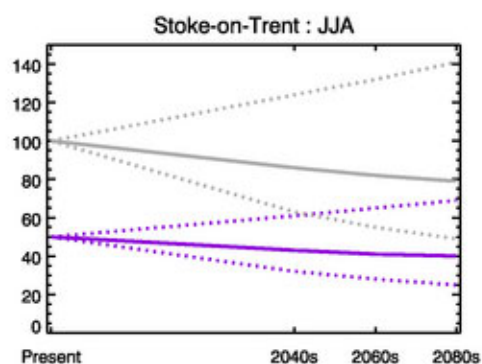
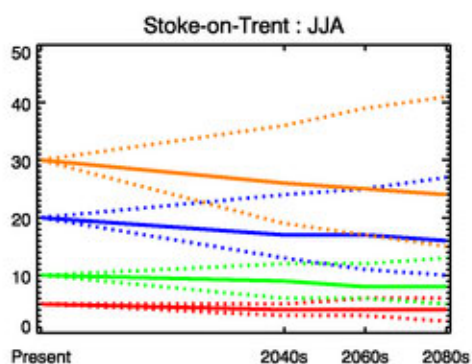
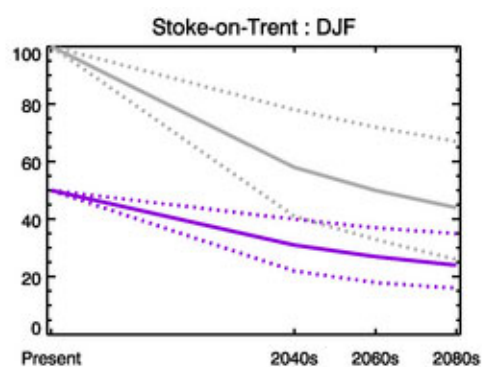
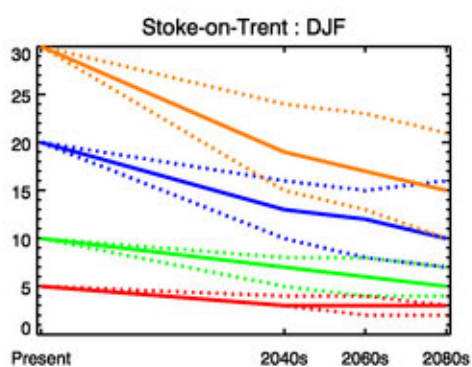
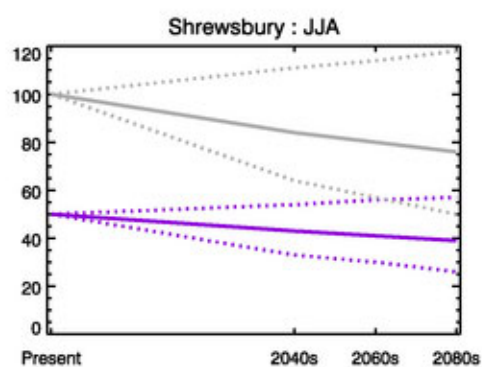
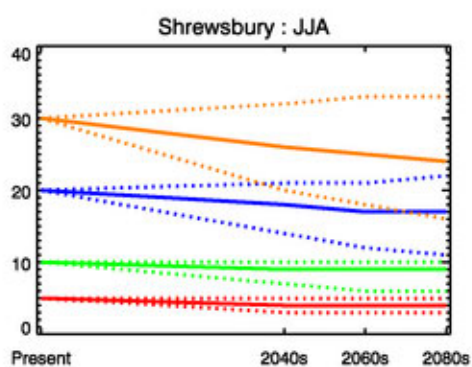
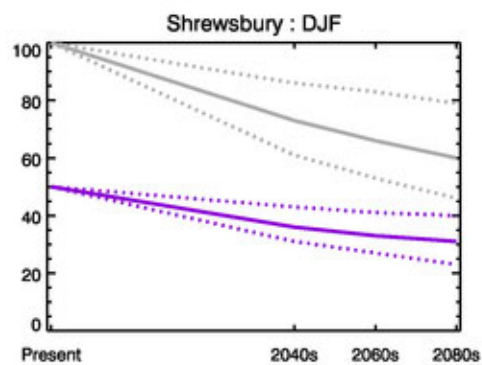
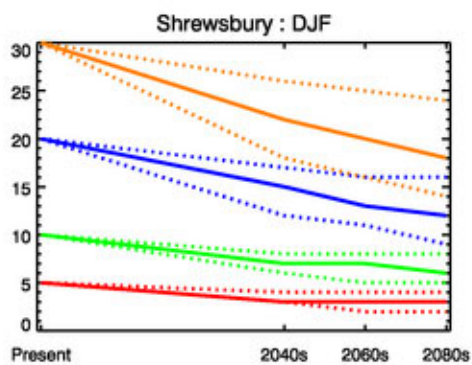




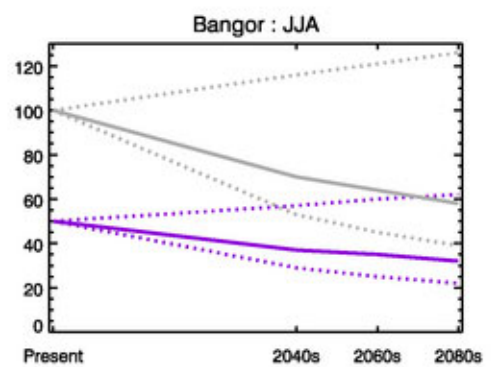
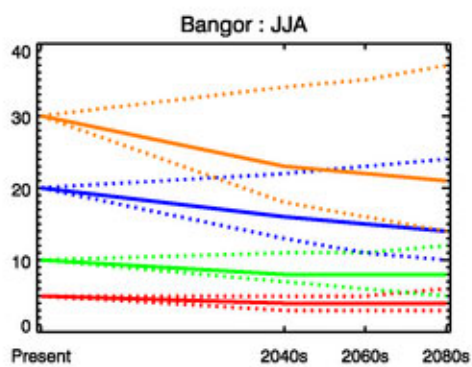
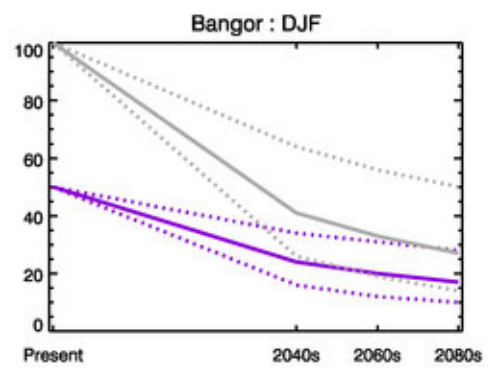
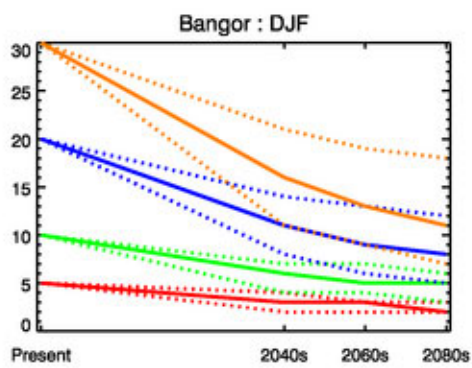
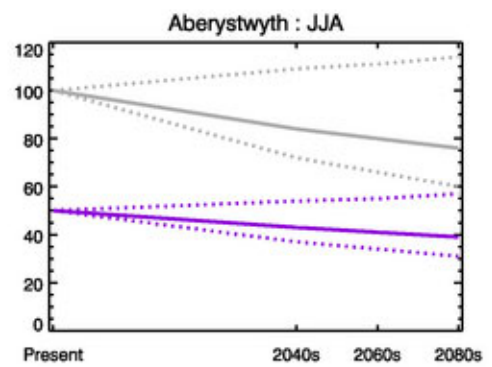
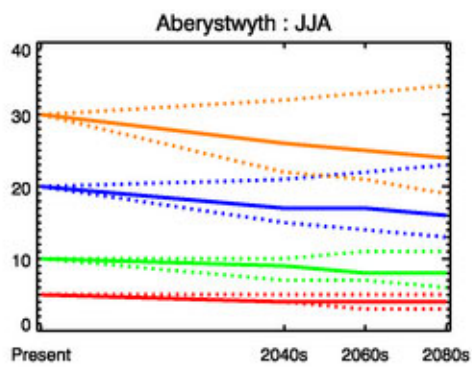
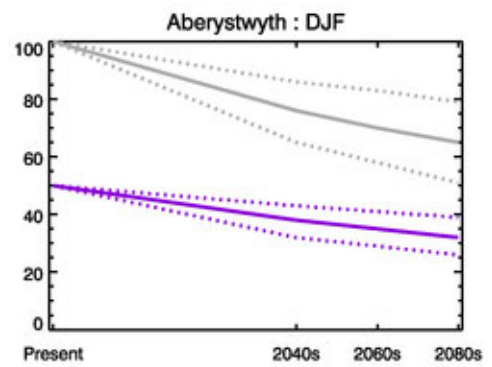
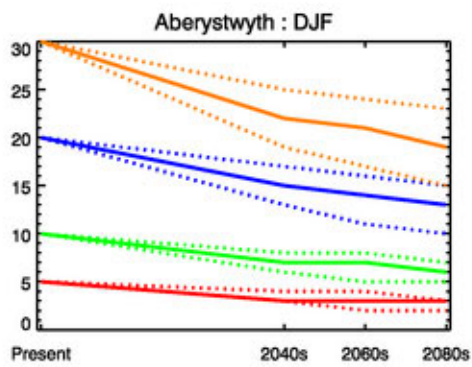


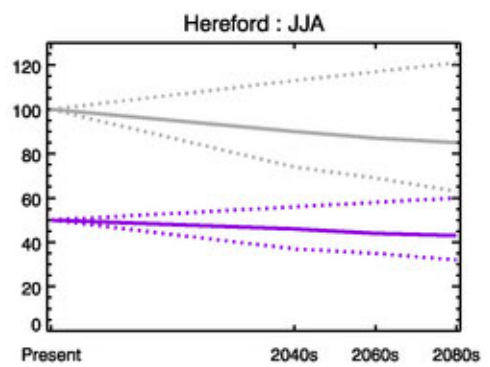
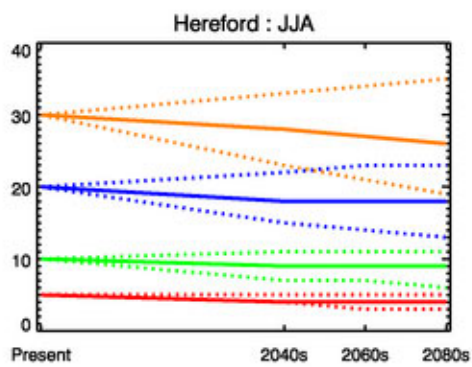
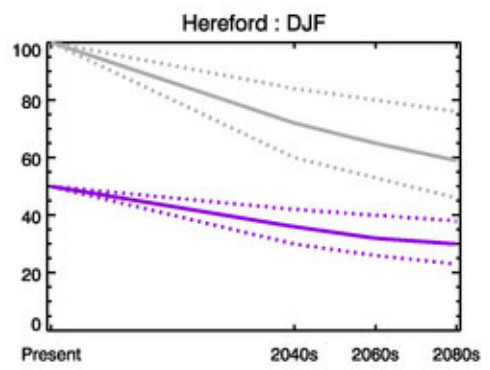
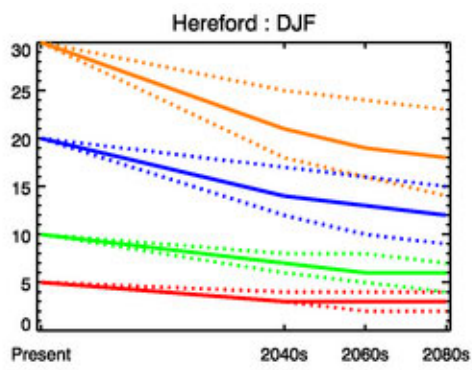
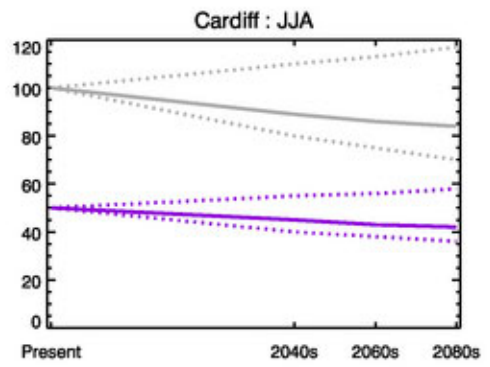
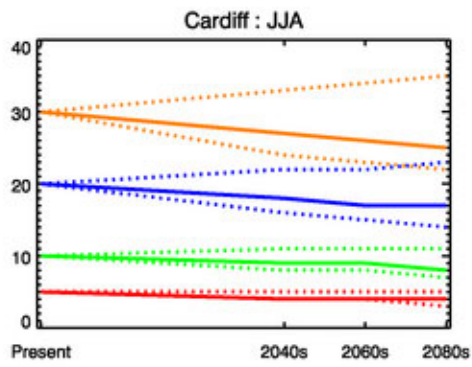
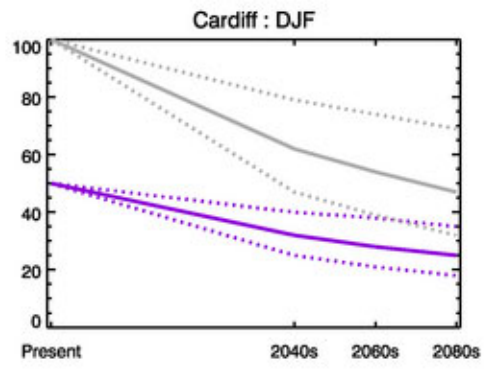
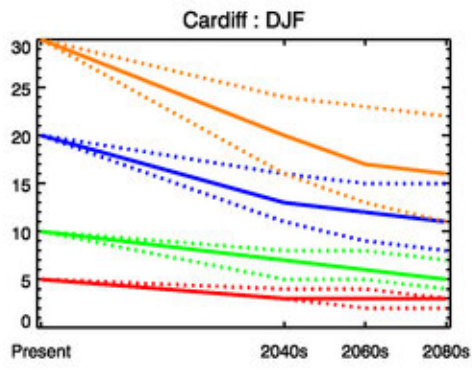
Water and Sewerage Company region: Severn Trent

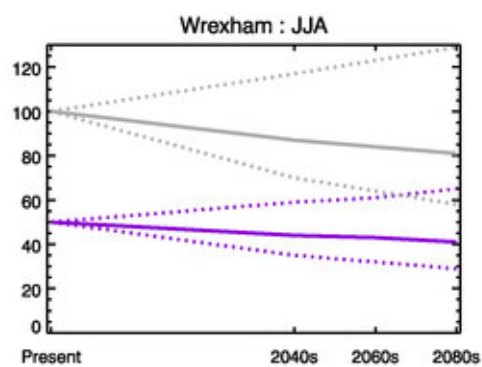
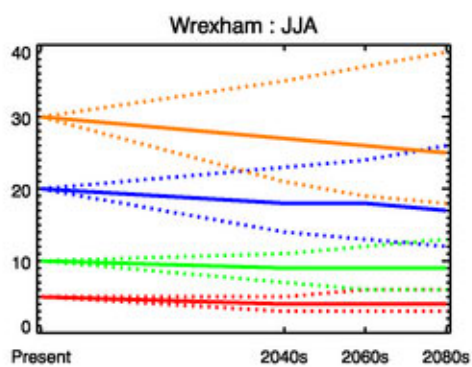
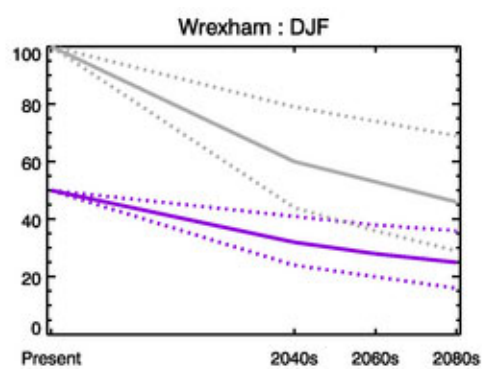
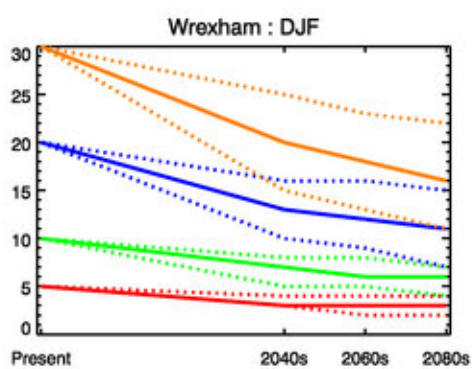
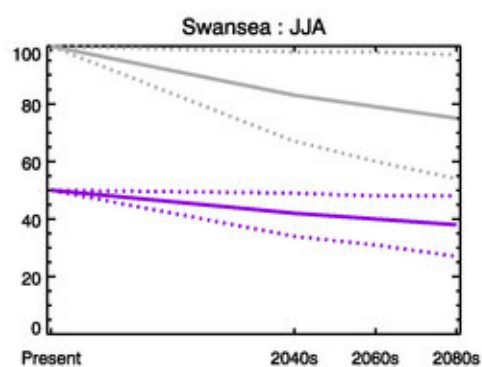
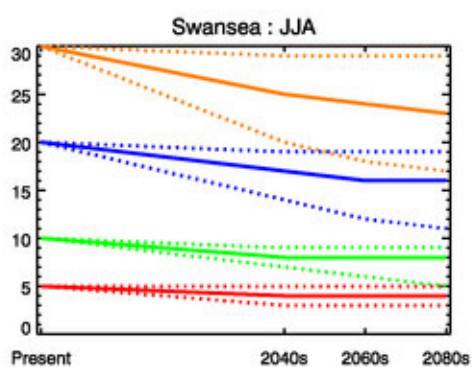
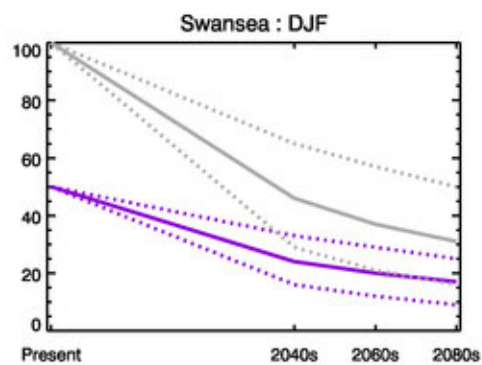
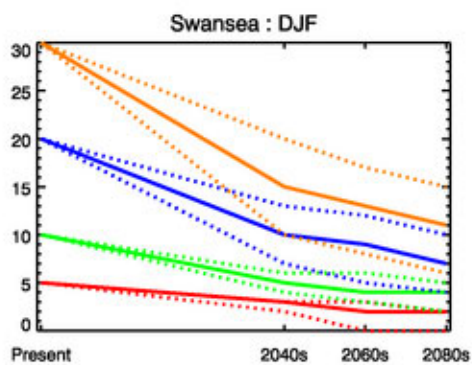




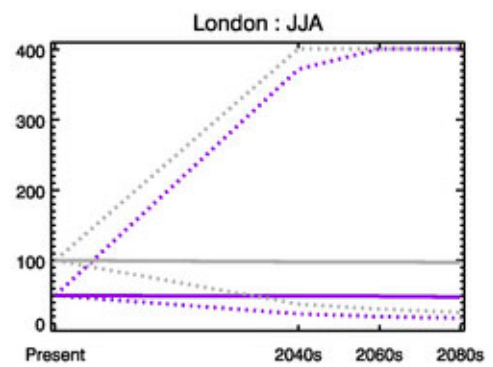
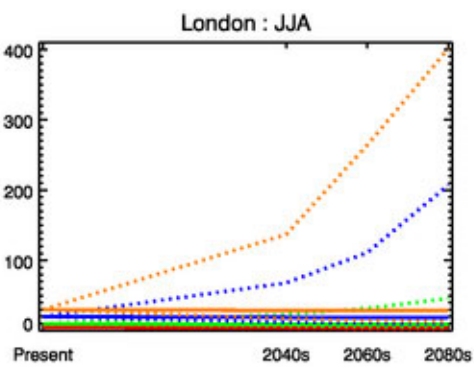
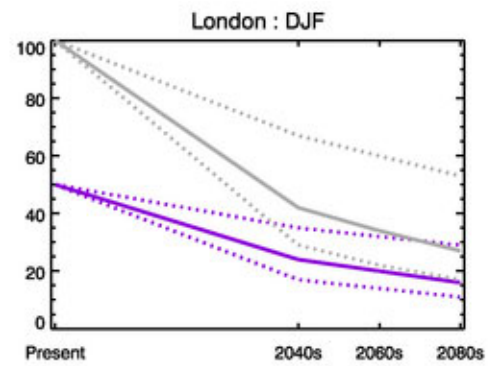
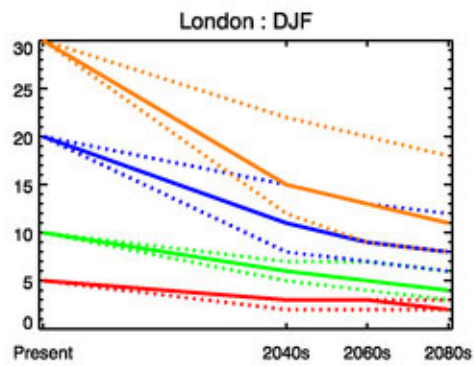
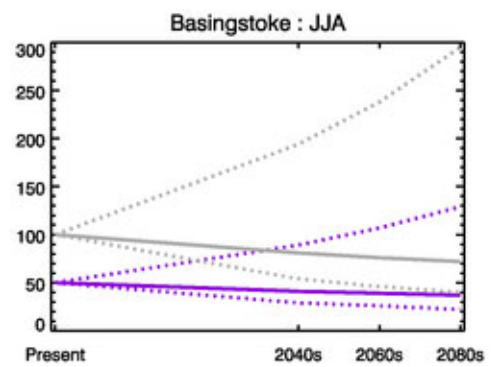
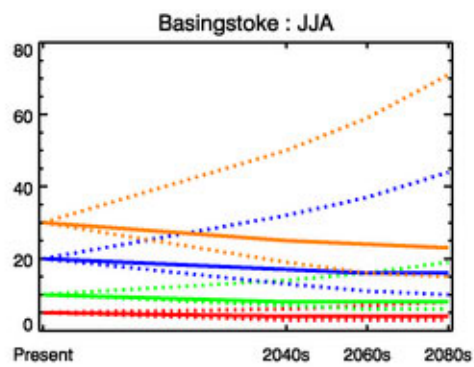
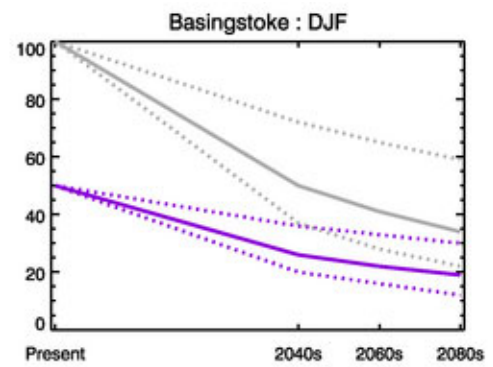
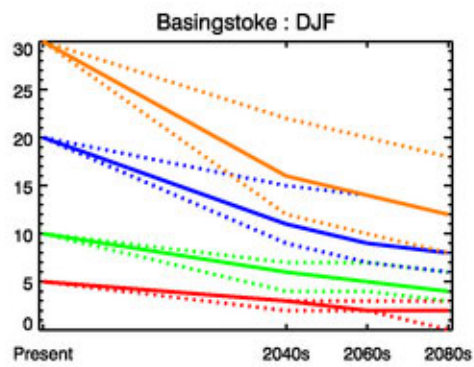
Water and Sewerage Company region: Welsh

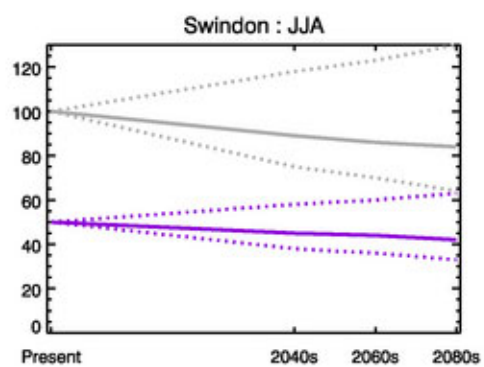
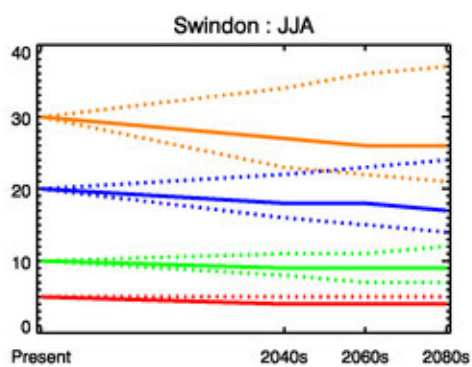
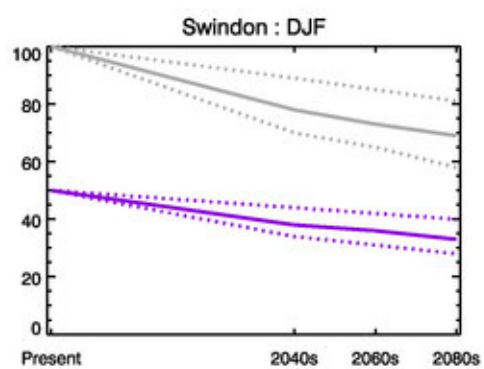
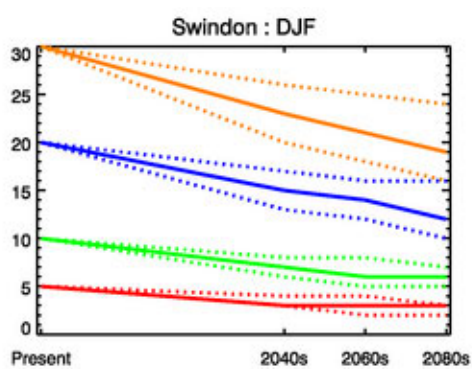
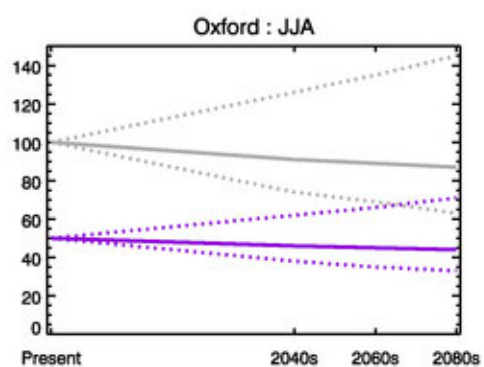
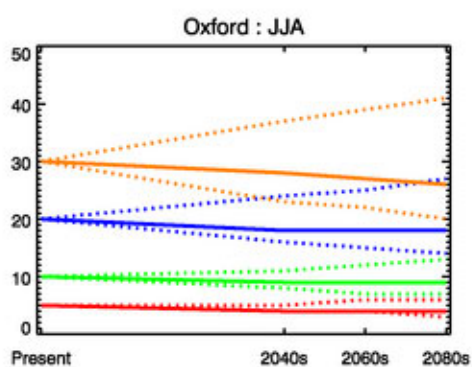
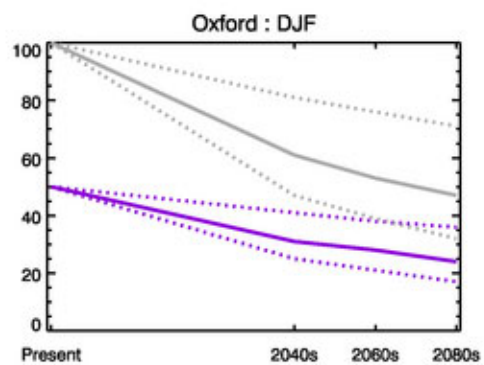
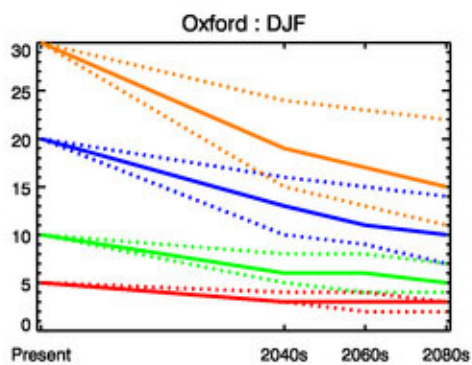




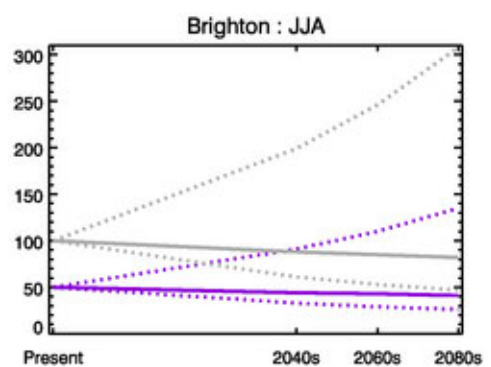
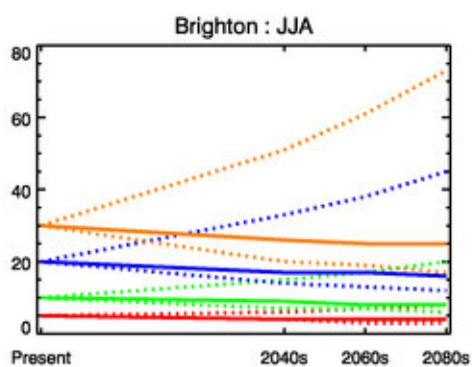
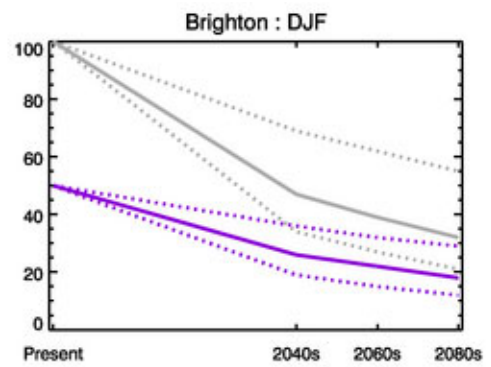
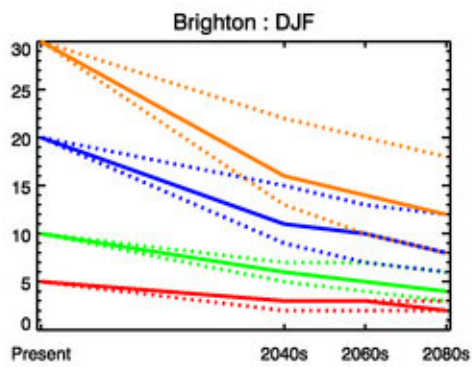
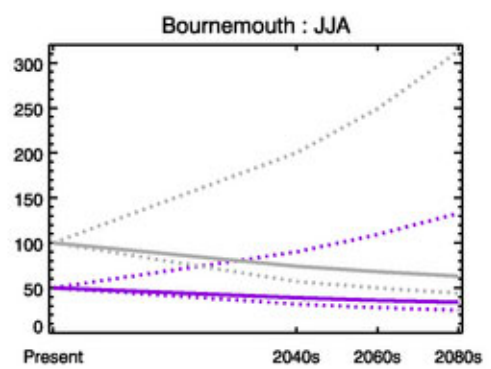
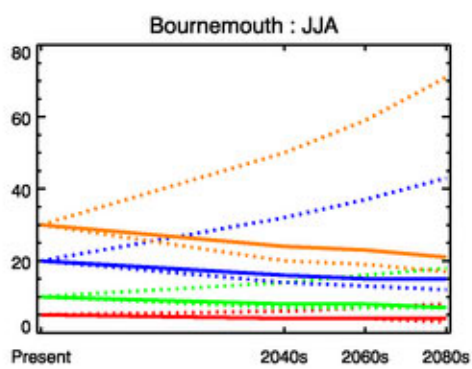
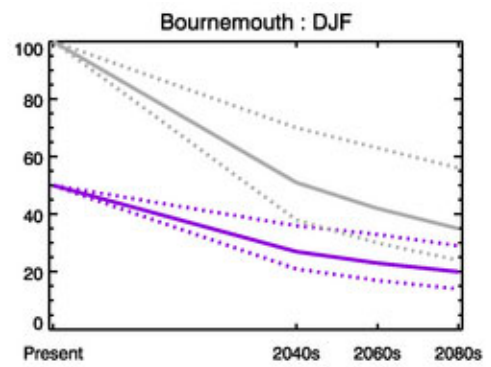
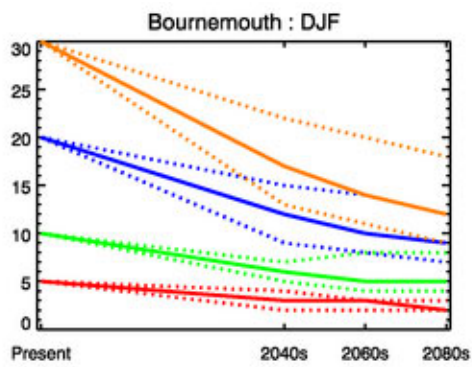


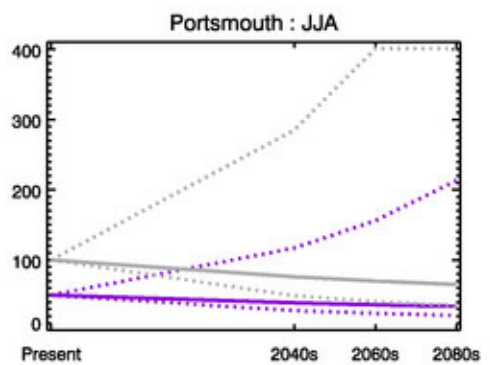
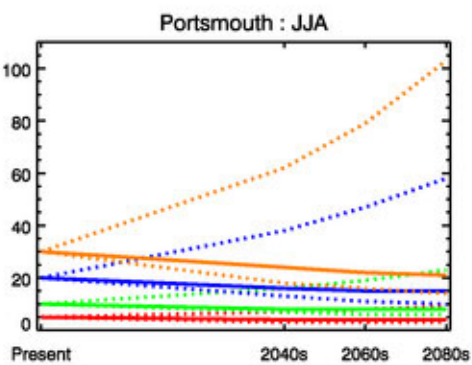
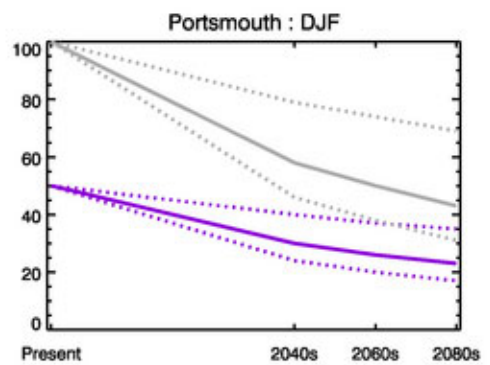
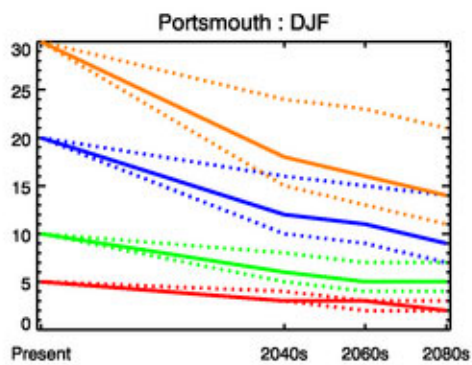
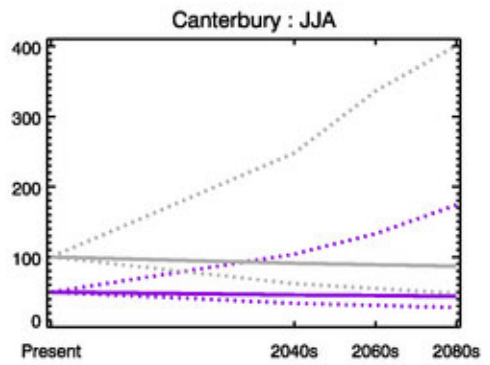
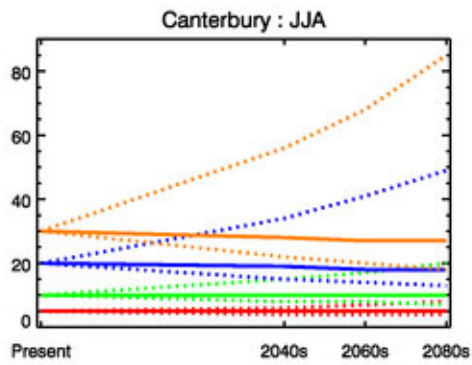
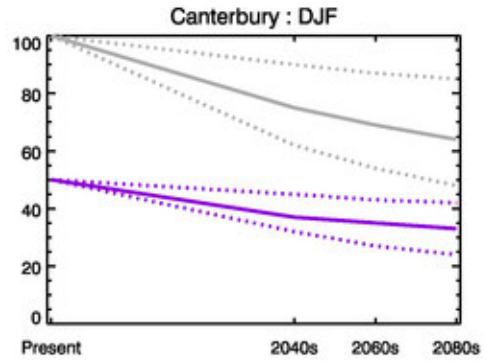
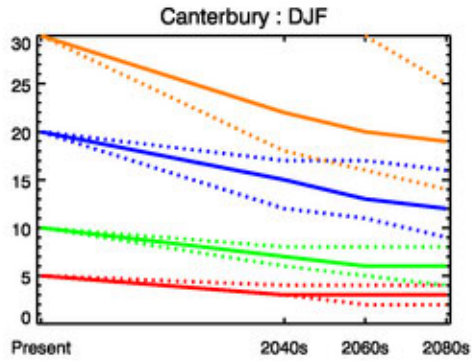
Water and Sewerage Company region: Thames



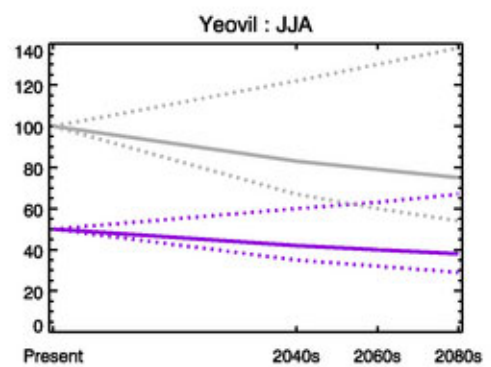
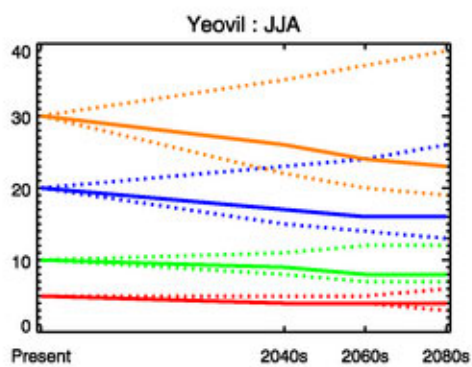
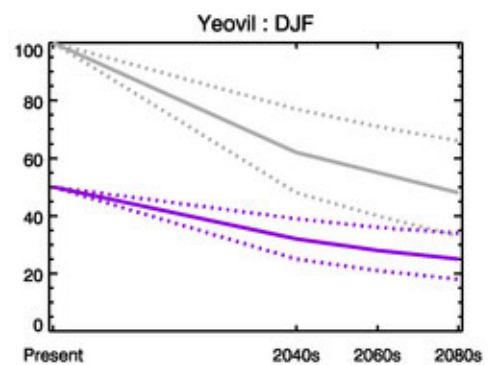
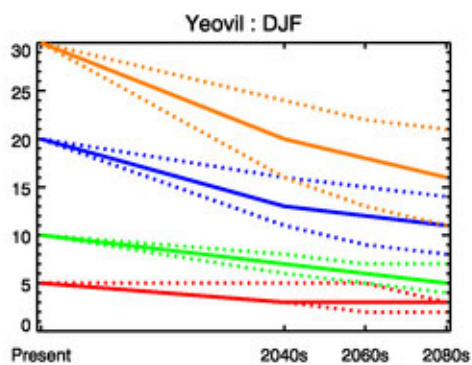
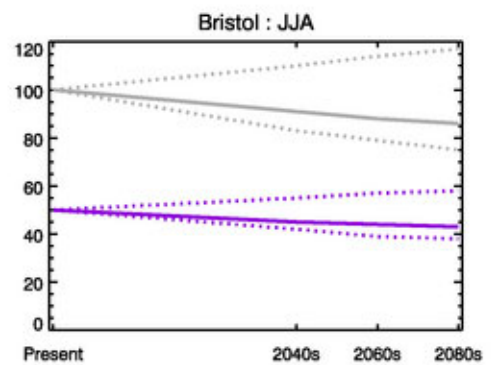
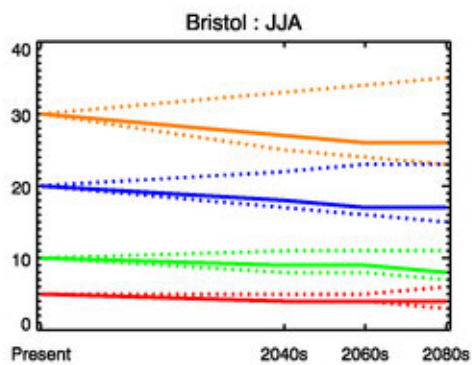
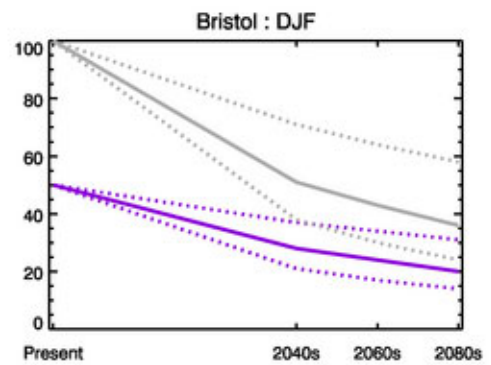
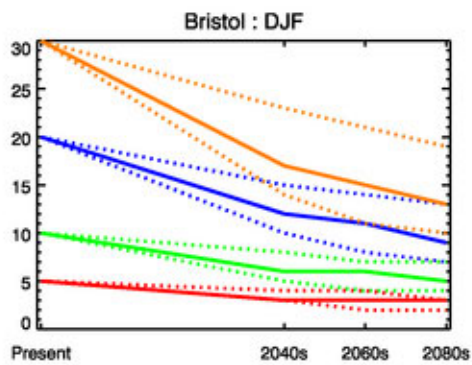


Water and Sewerage Company region: Southern

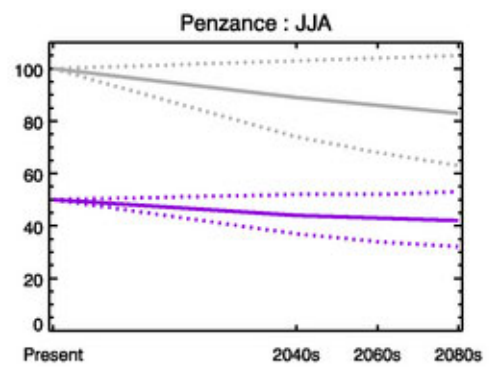
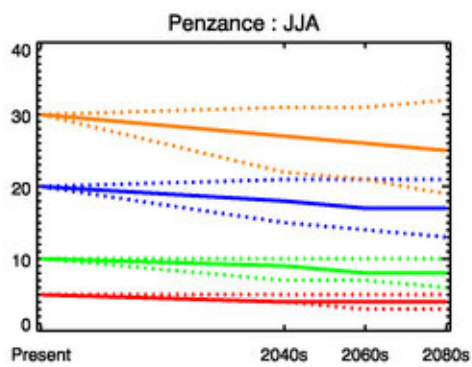
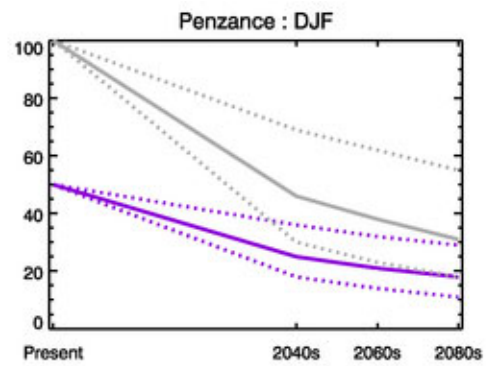
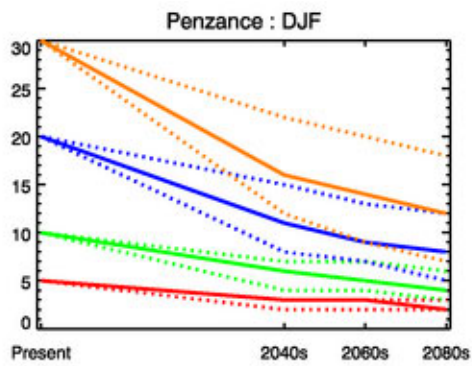
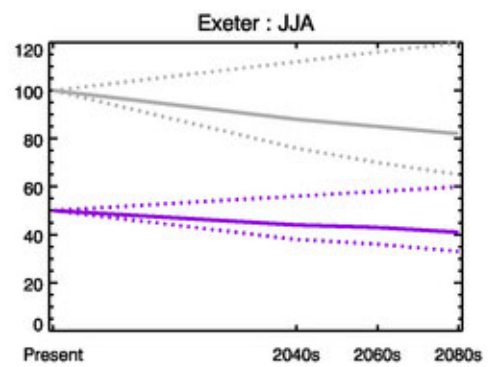
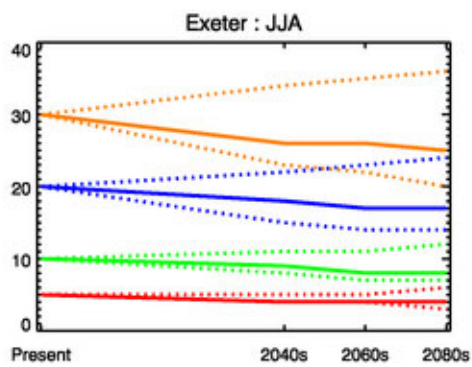
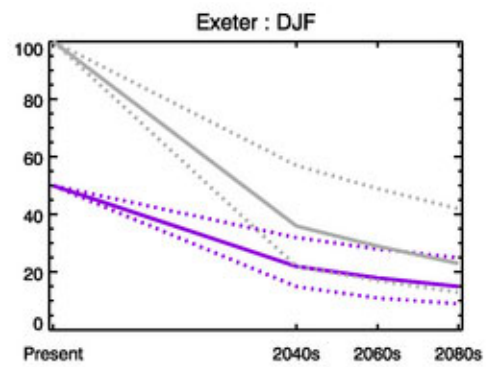
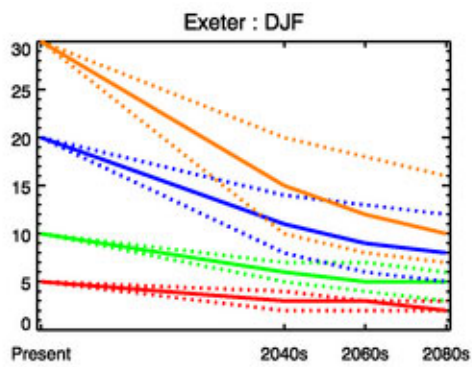


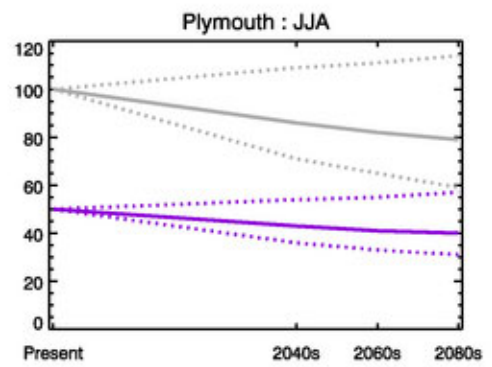
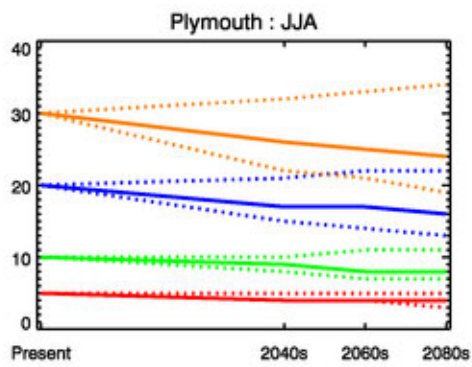
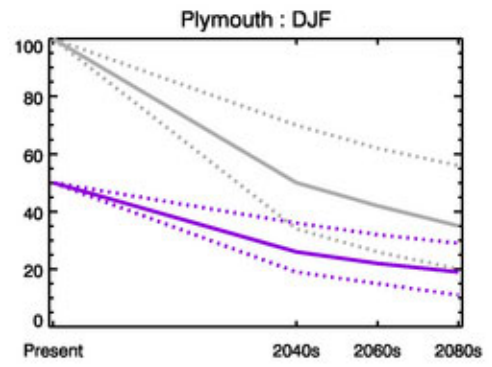
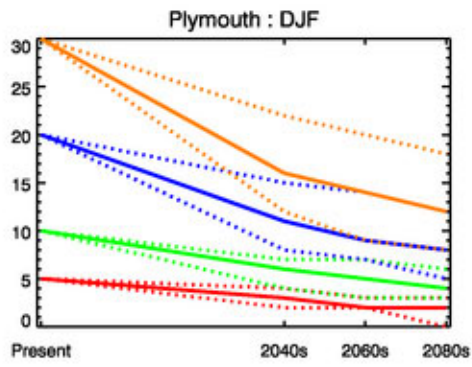


Water and Sewerage Company region: Wessex



Water and Sewerage Company region: South West





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