CLIMATE CHANGE AND FLOOD FREQUENCY IN THE UK

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ABSTRACT
Global warming is predicted to cause significant changes to the world's climate, but uncertainties remain about the precise nature of these changes. This is particularly true with regard to possible changes at a regional or local level and to changes in the climate extremes that produce catchment flooding. Such changes might include more frequent short-duration, high-intensity rainfall or more frequent periods of long-duration, sustained rainfall of the type responsible for the Autumn 2000 floods. To address the uncertainty surrounding this issue, Defra guidance on flood defence scheme appraisal currently suggests sensitivity allowances for climate change, for example a 20% increase in peak flows over the next 50 years.

The need to further develop this policy and guidance on climate change impacts is being informed by improved modelling capabilities and climate change scenarios. For example, statistical rainfall models and fine resolution regional climate model data are now available to drive the hydrological models used to investigate the potential impacts of climate change on flood flows. CEH-Wallingford has been commissioned by Defra and the Environment Agency to use these data sets and models to assess the impacts and this paper describes the final project results for a range of catchments across the UK.

The results from this research show a wide range of impacts on peak flows, showing both increases and decreases, depending on the location and the characteristics of the catchments. However, all but the most extreme increases are within the 20% range of sensitivity testing currently recommended by Defra. Until more specific regionalised guidance, or guidance based on responses due to catchment characteristic can be provided this appears to remain an appropriate response to the uncertainty in climate change impacts on peak flows over the next 50 years.

INTRODUCTION
This paper describes the potential impacts on flood flows in ten catchments across Britain under a range of climate change scenarios. The results presented are from the project "Impact of climate change on flood flows in river catchments", which is in Risk and Uncertainty Theme of the joint Defra/ EA Flood and Coastal Defence R&D programme (within the Climate Change sub-theme). The work represents a broadening of the scientific basis for the Defra Project Appraisal Guidance (PAG) on climate change saying that "sensitivity analyses of river flood alleviation schemes should take account of potential increases of up to 20% in peak flows over the next 50 years" (MAFF, 2001).

The study catchments were selected to provide a range of catchment type and location. The UK Climate Impacts Programme (UKCIP) climate change scenarios (UKCIP02; Hulme and Jenkins, 2002) have been used, as well as scenarios developed by statistical downscaling and the application of output from the Hadley Centre Regional Climate Model (RCM). Downscaling is a term used to describe the translation of changes in climate variables from one resolution to another, to better suit the application for which they are being constructed.

STUDY CATCHMENTS
The 10 catchments were selected to have a good geographical spread (Figure 1), and to incorporate different catchment areas, permeabilities and land uses. Table 1 summarises some of the catchment characteristics. Two of the selected catchments are located within catchments used for the Catchment Flood Management Plan trials. These are the Beult at Stile Bridge (40005), within the Medway catchment, and the Severn at Haw Bridge (54057). The Severn and the similar-sized Thames at Kingston (39001) are included because they were used in earlier studies (Reynard *et al.* 1998, 2001; 2003). The Anton at Fullerton (42012) provides an example of a highly permeable chalk catchment, whereas the upland Duddon at Duddon Hall (74001) in the Cumbrian Mountains has a low permeability. The Rea at Calthorpe Park (28039) is a highly urbanised catchment, contrasted with the rural Lymn at Partney Mill (30004). The Halladale at Halladale (96001) in northern Scotland was

included for comparison with catchments having a more southern climate. Two middle-sized catchments were selected; the Ouse at Skelton (27009) in northern England and the Severn at Bewdley (54001) in the west.

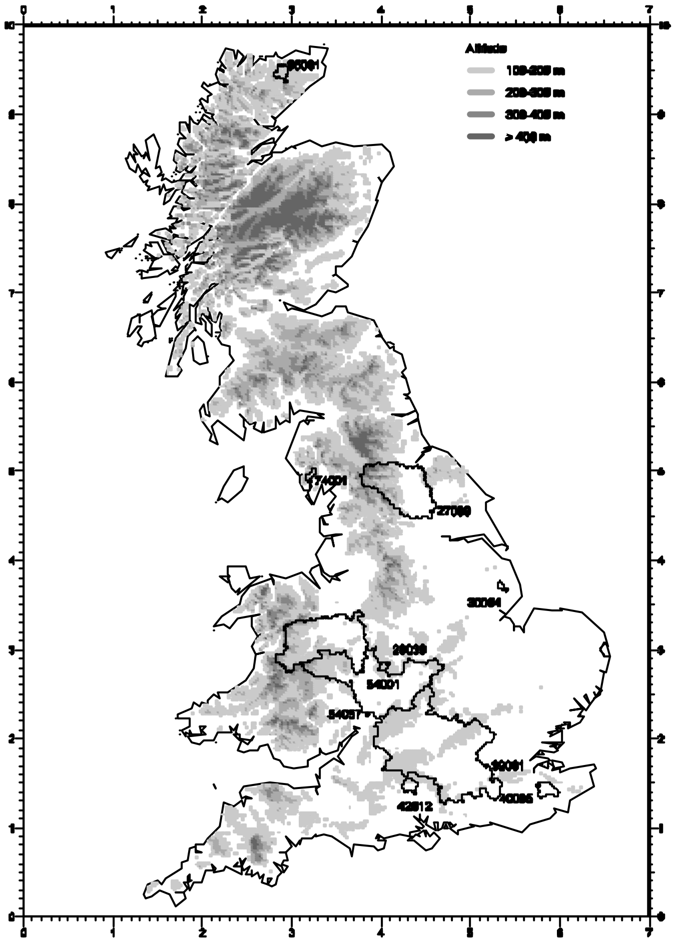

Figure 1 Topography and location of the 10 study catchments

HYDROLOGICAL MODELS

Due to the different nature and size of the study catchments two types of hydrological model have been used. Full descriptions of the models, the calibration and validation procedures for these study catchments, and a discussion of hydrological model uncertainty may be found in the final project report (Reynard *et al*, 2004).

The CLASSIC (Climate and Land-use Scenario Simulation In Catchments) model was developed for estimating the impacts of climate and land use change in large catchments and was initially tested on the Thames, Severn and Trent drainage basins (Crooks *et al.* 1996). It has been further developed and used in the earlier climate change impact studies (Reynard *et al.* 1998, 2001, 2003). This semi-distributed model comprises three component modules (models for the soil water balance, the hydrological response and the channel routing). It is applied on a grid square framework with climatic inputs of rainfall and potential evapotranspiration (PE) to each grid square. For the smaller catchments the Probability Distributed Model (PDM; Moore 1985, 1999) is used. This is a conceptually-based catchment model that attempts to represent non-linearity in the transformation from rainfall to runoff by using a probability distribution of soil moisture storage. This determines the time-varying proportion of the catchment that contributes to runoff, through either ‘fast’ or ‘slow’ pathways

Table 1 Catchment characteristics for the 10 study catchments

Number	Catchment name	Area (km^2)	Location of river flow gauge (m)		Base flow index	Mean flow (m^3s^{-1})	SAAR 1961-1990 (mm)
			Easting (km)	Northing (km)			
27009	Ouse at Skelton	3315	456.8	455.4	0.43	49.03	900
28039	Rea at Calthorpe Park	74	407.1	284.7	0.48	0.83	781
30004	Lymn at Partney Mill	62	540.2	367.6	0.66	0.52	685
39001	Thames at Kingston	9948	517.7	169.8	0.64	66.64	706
40005	Beult at Stile Bridge	277	575.8	147.8	0.24	2.07	690
42012	Anton at Fullerton	185	437.9	139.3	0.96	1.85	773
54001	Severn at Bewdley	4325	378.2	276.2	0.53	61.88	913
54057	Severn at Haw Bridge	9895	384.4	227.9	0.57	105.31	792
74001	Duddon at Duddon Hall	86	319.6	489.6	0.28	4.97	2265
96001	Halladale at Halladale	205	289.1	956.1	0.25	4.97	1102

CLIMATE CHANGE SCENARIOS

The scenarios applied in this study can be split into three groups; those derived from the UKCIP02 data, those from statistical downscaling and those from dynamic downscaling. These are described in more detail below.

UKCIP02 scenarios

The UKCIP02 scenarios (Hulme *et al.* 2002) comprise a set of four alternative future climates spanning a range of global emissions, namely the low, medium-low, medium-high and high emissions scenarios, for three future 30-year time slices centred on the 2020s, 2050s and 2080s. The scenarios are presented as monthly changes, compared with the 1961-90 baseline, for 15 climate variables, for a 50 x 50km grid across the UK. For hydrological modelling purposes, changes in rainfall and potential evapotranspiration (PE) are required. Changes in PE have been calculated using the Penman-Monteith equations with climatic variables of temperature, wind speed, relative humidity and net radiation.

The UKCIP02 scenarios have been applied to the daily rainfall baseline time series in such a way as to also reproduce the changes in seasonal daily rainfall frequency described in the UKCIP02 Technical Report (Hulme *et al.* 2002). The method developed to combine these various sources of information is described in Reynard *et al* (2004). This scenario has been termed the "combined" scenario. The monthly percentage changes in potential evaporation (PE) have been applied in a simple proportional way to the daily time step of PE used to drive the models.

Statistical downscaling

The Statistical Downscaling Model (SDSM), developed by Wilby (1998, 2002), has been used to provide daily time series of rainfall to drive the hydrological model CLASSIC. Rainfall time series were developed for each of the model grid boxes for each catchment. One set of results was produced using the multi-site, spatially correlated, version of SDSM (Wilby *et al*. 2003) and one with a single site model that does not account for the spatial dependence between grids (McSweeney, 2003).

This downscaling method was used to derive a continuous time series of daily rainfall data for the 20 km grid squares used for the Severn at Bewdley and the 10 km grid squares for the Ouse at Skelton from 1961 to 2099 for the A2 and B2 emissions scenarios (IPCC, 2000).

Dynamic downscaling – use of Regional Climate Model output
For dynamic downscaling, links with a Defra-funded Hadley Centre Annex 15 project "Change in Flood Prediction using a RCM", reported fully in Kay (2003) have allowed the use of hourly output from the ~25 km RCM directly to drive both the PDM and CLASSIC models.

Whereas the UKCIP02 scenarios are implemented by perturbing a baseline (1961-1990) climatology, both the statistically and dynamically downscaled scenarios produce alternative baselines.

Figure 2 shows the flood frequency curves (relating average return period (in years) to peak flow) for the observed flows (dotted line) for the Severn at Bewdley (54001), the flows modelled from the observed rainfall (solid line), the SDSM A2 control period (long-dashed line), the SDSM B2 control period (short-dashed line) and the RCM baseline (dot-dashed line). For this catchment there is good agreement between the observed and modelled curves, and, indeed, the flood frequency curves generated using the SDSM for both the A2 and B2 control periods. The curve from the RCM rainfall appears considerably more extreme, and this is the case for five of the ten study catchments. For other catchments however, notably the Thames, the correspondence is better.

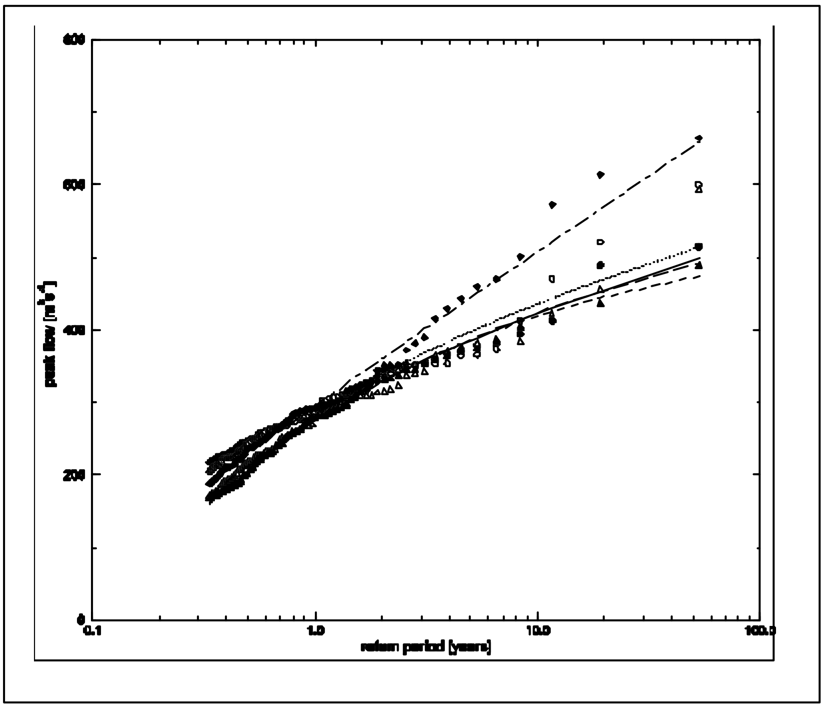

Figure 2 Comparison of baseline (1961-1990) flood frequency curves for the Severn at Bewdley, observed flows (dotted line, open circle), modelled from observed rainfall (solid, filled circle), SDSM A2 (long-dashed, open triangle), SDSM B2 (short-dashed, filled triangle), RCM (dot-dashed, filled diamond)

FLOOD FREQUENCY ANALYSIS UNDER CLIMATE CHANGE
The partial duration, or peaks-over-threshold (POT), method (Naden, 1993) was used to fit frequency distributions to the modelled baseline and scenario 30-year flow series. An average rate of three events per year was used for the frequency analyses with standard rules employed to ensure that extracted flood peaks were independent events. The magnitudes of the POT were fitted using the generalised Pareto distribution, with the peak arrival times assumed to correspond to a Poisson distribution. Fitting was carried out using the method of probability-weighted moments (Hosking and Wallis, 1987).

UKCIP02 scenarios
The percentage change in flood flows for the ten catchments under the UKCIP02 scenarios are summarised in Table 2 for two selected return period flows (5-year and 50-year) for the 2050s and the 2080s under the Medium-High emissions scenario. The results show quite different changes under these scenarios for the Thames (39001) and the (large) Severn (54057) compared with the results under the UKCIP98 scenarios, reflecting the warmer and drier nature of the more recent Hadley

Centre modelling results. Across all catchments the impacts vary in both size and direction with change in excess of 20% occurring only for the Duddon (74001) at the higher return period flows in the 2080s. This is also the only catchment to show an increase in flows under all scenarios for all return periods. The over-riding factor appears to be the location (in terms of the climate change, rather than the current climate). These factors out-weigh the potential patterns in the impacts due to either catchment size or geology. For example the Halladale (96001) in northern Scotland (relatively small, hydrologically-responsive) does not show the same impact as the Duddon despite their similar catchment characteristics, as the Halladale lies in an area where the UKCIP02 scenarios show less change in precipitation, particularly of winter averages, than for the north west of England.

Table 2 Summary of percentage changes in the 5 and 50-year return period peak flows under the UKCIP02 scenarios (Medium-High 2050s and 2080s). Decreases are shown in italics with increases of more than 20% in bold.

Catchment	2050s		2080s	
	5-year	50-year	5-year	50-year
27009	*-0.3*	*-3.9*	0.4	*-7.1*
28039	7.3	*-1.3*	2.8	*-7.6*
30004	*-4.0*	*-8.3*	*-4.5*	*-13.9*
39001	*-2.9*	*-1.2*	*-2.5*	0.6
40005	5.1	*-4.6*	9.8	*-11.2*
42012	*-1.8*	4.7	*-1.7*	8.5
54001	*-3.0*	*-0.9*	*-4.7*	*-6.7*
54057	*-1.6*	1.0	*-0.5*	4.2
74001	6.9	4.2	10.1	**21.9**
96001	*-2.1*	2.0	*-2.8*	*-2.9*

The results also show an overlap in impact between the 2050s and 2080s, with the high of the 2050s generally similar to the medium-low of the 2080s. For most catchments the percentage changes follow a similar pattern across the four emission scenarios and time slices. The main exception is the urban Rea at Calthorpe Park (28039) where the Medium-Low and Low scenarios for the 2050s and Low scenario for the 2080s show an increase at the 50-year return period, whereas the other scenarios show a decrease. In general the impact of the higher winter rainfall is offset by the increase in PE and the, on average, hotter, drier conditions during the summer and autumn.

Statistical downscaling – use of SDSM

Flood frequency curves were derived for the two emission scenarios, A2 and B2, and three time slices, the baseline period of 1961-1990, the 2050s and the 2080s. The flood frequency curves for the impacts of the SDSM data are given in Figure 3 for the Ouse (27009). In addition a flood frequency curve was also derived for the single-site (independent grid square) rainfall time series for the baseline period. The difference between the two dotted lines in Figure 3, and comparing these curves to the solid “observed” baseline, gives an indication of the positive contribution of using spatially correlated rainfall fields from SDSM in generating flood runoff. The single-site, uncorrelated, rainfall for the model grids greatly under-estimates the baseline flood frequencies as the large-scale rainfall events, which are more likely to produce floods in catchments as large as the Ouse, are not being simulated.

These results were produced for the Ouse and the Severn at Bewdley (54001) only. In summary the B2 scenario shows an increase in flood frequency for all return periods greater than five years and for the Ouse (27009) the two emissions scenarios have an opposite impact. The highest increase for both catchments is shown to be for the B2 scenario for the 2050s for return periods greater than 20 years. It should be noted that the B2 scenario used for the statistical downscaling is from a “real” B2 simulation, rather than from re-scaling A2, as was done for all other scenarios.

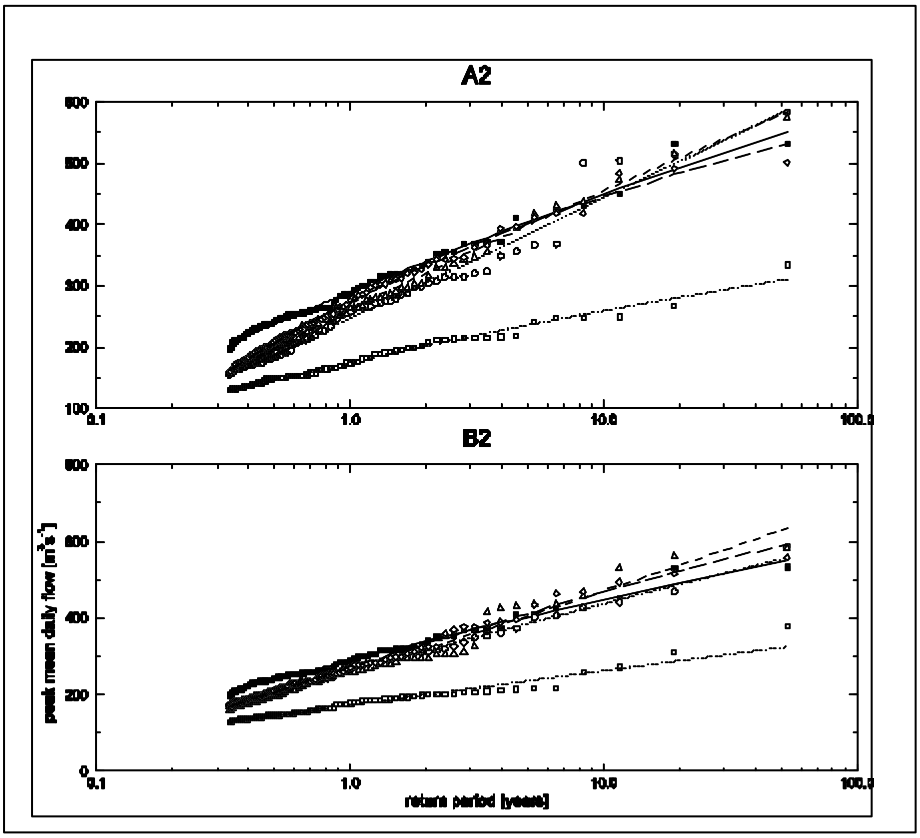

Figure 3 Flood frequency curves for the Ouse at Skelton under the A2 and B2 scenarios; modelled from observed rainfall baseline (solid line, filled square), SDSM multi-site baseline (dotted, open circle), SDSM 2050s (short dashed, open triangle), SDSM 2080s (long dashed, open diamond), SDSM single-site baseline (dotted, open square).

Dynamic downscaling – use of RCM data

The impacts due to the application of the hourly rainfall data from the Hadley Centre 25 km RCM are summarised in Table 3 for a range of return period flows, with decreases shown in italics.

The results show that for seven of the catchments the percentage change becomes increasingly negative with increasing return period, with three of these having a decrease of more than -20% in the 50-year return period flow. The results for the Lymn at Partney Mill (30004) are reproduced in Figure 4 to illustrate this change. Most catchments show an increase at 1 year return period. It should be noted that the results are for only one scenario for one time slice, so how the change for the 2080s relates to change in the intervening period, or the variability in the change had a number of RCM ensembles been analysed, cannot be identified.

Table 3 Summary of percentage changes under the RCM scenario for the 2080s for a range of return period peak flows.

Catchment	1-year	5-year	20-year	50-year
27009	5.0	8.7	10.7	11.7
28039	13.7	0.3	*-14.0*	*-23.4*
30004	6.1	*-2.7*	*-12.0*	*-18.4*
39001	7.0	14.2	16.7	17.7
40005	9.3	*-2.3*	*-13.8*	*-21.5*
42012	12.4	10.8	3.5	*-2.2*
54001	*-3.3*	*-12.1*	*-19.4*	*-23.8*
54057	*-4.0*	*-9.9*	*-14.5*	*-17.8*
74001	17.3	16.9	16.3	15.7
96001	14.5	5.0	*-6.9*	*-15.2*

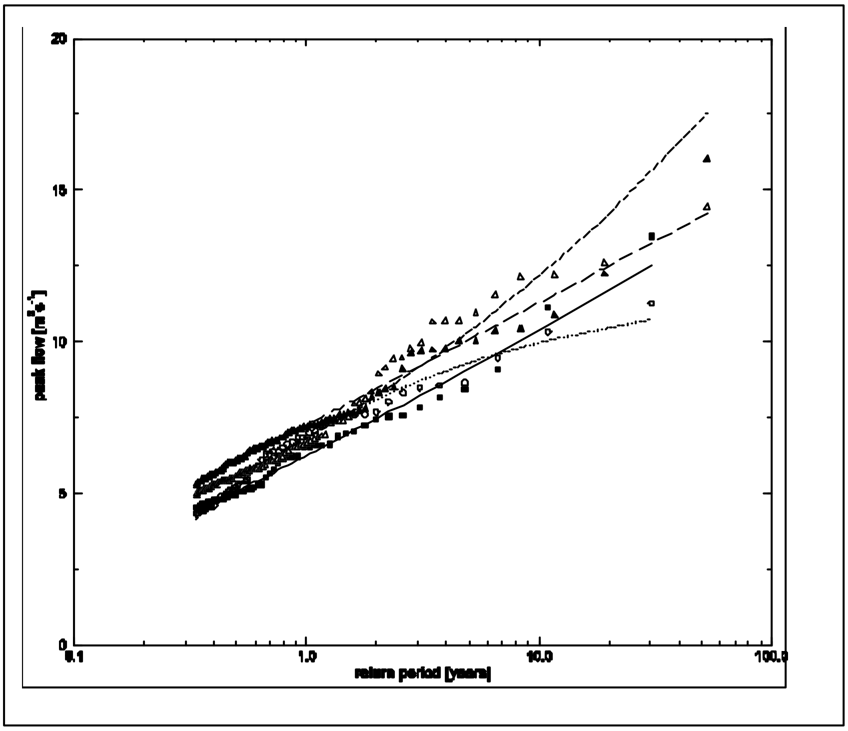

Figure 4 Flood frequency curves for the Lymn at Partney Mill (30004); observed flows (dotted line, open circles), modelled flows from observed rainfall (solid, filled squares), RCM baseline (short-dashed, open triangles), RCM data for the 2070-2100 period (long-dashed, filled triangles).

Rainfall resampling

To make some allowance for "natural variability" in the future rainfall series a method of resampling the rainfall was developed. This involved making a number of different time-series from the original rainfall series, by selecting the rainfall month-by-month, with replacement. That is, the rainfall for, say, "January 1961" of a series being constructed is taken from a randomly selected January of the original series; "February 1961" is taken from a randomly selected February, and so on. This method obviously does not change the sub-monthly variability (for example the hourly or daily intensities), but does allow changes in rainfall accumulations over a number of months. It is this that can result in quite different flood frequencies from the resampled series to those from the original series. For example, a wet winter, which was preceded by a dry autumn in the original series, could be preceded by a wet autumn in a resampled series, thus greatly increasing the chance of flooding during that winter period.

Three rainfall series were resampled. For the UKCIP02 scenarios, the rainfall series produced for the 2080s (by perturbing the baseline, 1961-1990, series according to the "combined scenario") was used and for the RCM both the 1961-1990 and 2071-2100 rainfall series were resampled.

Using this method to create a large number of resampled series, an equally large number of flood frequency curves can be produced and an average flood frequency can be calculated, along with uncertainty bounds. In this study 100 resampled rainfall series were generated. Note that this resampling method has only been applied to the six PDM catchments due to the complexity of applying this technique to the gridded rainfall required by CLASSIC, as opposed to the catchment rainfall required by the PDM.

Table 4 summarises the results from resampling the UKCIP02 data and gives the percentage changes in flood peaks at the 20-year return period. The mean of the change for the four single UKCIP scenarios is compared with the mean, minimum and maximum changes when using 100 resamples of the 2080s data.

Table 4 Percentage changes in the 20-year return period peak flows for the 2080s comparing the mean of the UKCIP02 four emissions scenarios with the mean, minimum and maximum of the 100 resamples. Increases in excess of 20% are shown in bold, with decreases in italics.

Catchment	Time slice	UKCIP02 mean	100 samples for UKCIP02		
			Minimum	Mean	Maximum
28039	2050s	5.1	*-21.5*	*-0.8*	**23.0**
	2080s	*-1.1*	*-28.1*	*-5.8*	**20.4**
30004	2050s	*-5.0*	*-24.8*	*-7.6*	9.1
	2080s	*-8.0*	*-27.7*	*-10.3*	7.7
40005	2050s	0.1	*-21.7*	*-4.9*	10.3
	2080s	*-2.4*	*-23.6*	*-5.4*	10.7
42012	2050s	2.1	*-9.0*	6.1	**24.3**
	2080s	3.8	*-9.0*	6.5	**28.3**
74001	2050s	5.8	*-14.4*	2.3	17.8
	2080s	13.2	*-12.5*	8.9	**31.4**
96001	2050s	*-0.1*	*-20.4*	*-2.9*	15.8
	2080s	*-2.1*	*-21.5*	*-5.1*	15.6

These results demonstrate that it would only take a slightly different sequencing of events to push some catchments into rather higher percentage changes in flood frequency (note, though, that resampling the observed rainfall time-series could also result in quite a range of flood frequencies). The maxima suggest that highly urbanised catchments (e.g. 28039), groundwater catchments (e.g. 42012), and catchments in the north west (e.g. 74001) may be generally more susceptible to changes in climate of this nature. Figure 5 shows the median, maximum and minimum flood frequency curves generated from the resampled rainfall series for the 2050s under the four emissions scenarios for the Rea at Calthorpe Park (28039).

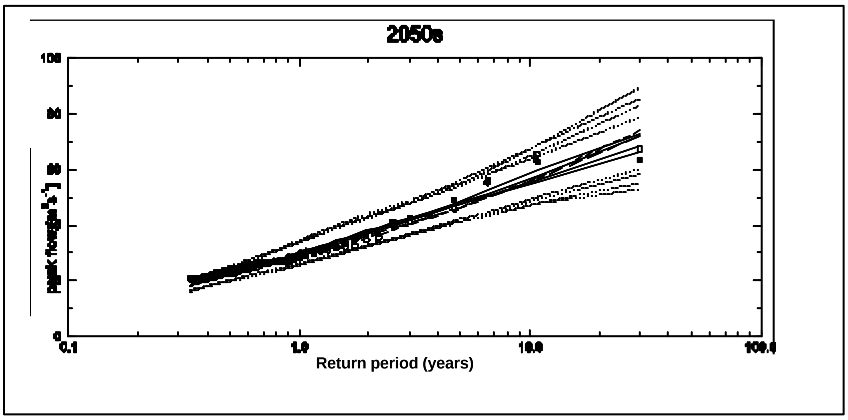

Figure 5 Flood frequency curves for the Rea at Calthorpe Park (28039) for median, maximum and minimum changes from the 101 resampled rainfall series for the 2050s under the four UKCIP02 emissions scenarios (full explanation of the lines is in the text box below).

Short-dashed line and open circles — from observed flows.
Long-dashed line and filled squares — modelled using observed rainfall.
Solid lines — median modelled, using 100 resamples under each of the four UKCIP02 emissions scenarios.
Dotted lines — 90% upper and lower uncertainty bounds, using 100 resamples under each of the four UKCIP02 emissions scenarios.

DISCUSSION

The percentage changes in flood frequency are noticeably different from those given in the earlier reports (Reynard *et al.* 1998, 2001) where changes in flood frequency under all scenarios were positive. The differences from previous estimates are the direct result of the scenarios developed from the more recent version of the GCM.

Given these warmer and drier scenarios, any flood peaks occurring in September and October are automatically reduced due to the lower effective rainfall during these seasons, and for the larger less-responsive catchments many peaks in November and December and even January are also reduced through the replenishment of large soil moisture deficits. This is further supported by the fact that the Duddon (74001) shows increases under nearly all scenarios due to its more responsive nature and because it lies in an area of significant rainfall increase in all seasons but the summer.

The pattern of changes across the time slices also shows that any impact is a fine balance between the seasonal changes in rainfall and the increases in PE, so that for the Halladale under the UKCIP02 scenarios there is a slight decrease by the 2050s, but an increase by the 2080s.

All the percentage changes in flows under all scenarios for the 2080s at the 20-year return period are summarised in Table 5. Decreases are shown in italics with increases in excess of 20% highlighted in bold. Only two catchments show increases under all scenarios (apart from the minimum change from the resampled data), these being the Duddon (74001) and the Anton (42012), and only the Duddon shows a change in excess of 20% for anything other than the maximum from the resampling. The large increases under the maximum change from the resampled RCM data reflect the fact that both the baseline rainfall series and the future (2080s) series were resampled for the RCM analysis. This means that this maximum change represents the change from the minimum baseline curve to the maximum future curve, whereas for the UKCIP02 data only the baseline rainfall was resampled.

Table 5 Percentage changes for the 20-year return period peaks for each of the study catchments for the 2080s.

Catchment	UKCIP02				Resampling UKCIP		SDSM		RCM	Resampling RCM	
	Low	Med Low	Med High	High	Min	Max	B2	A2	A2	Min	Max
27009	*-2.2*	*-3.6*	*-3.8*	*-4.2*			7.0	*-3.8*	10.7		
28039	6.4	*-2.5*	*-2.6*	*-5.5*	*-28.1*	**20.4**			*-14.0*	*-26.7*	**94.2**
30004	*-3.5*	*-5.6*	*-9.9*	*-13.1*	*-27.7*	7.7			*-12.0*	*-27.9*	13.1
39001	*-1.6*	*-1.6*	0.0	2.8					16.7		
40005	*-0.5*	*-1.5*	*-3.9*	*-3.7*	*-23.6*	10.7			*-13.8*	*-37.2*	**61.3**
42012	2.5	3.2	4.6	5.0	*-9.0*	**28.3**			3.5	*-72.9*	**474.9**
54001	*-2.1*	*-2.7*	*-5.4*	*-6.7*			10.4	6.8	*-19.4*		
54057	1.2	1.2	3.0	4.4					*-14.5*		
74001	6.6	8.3	16.1	**21.9**	*-12.5*	15.8			16.3	*-2.1*	**35.4**
96001	0.1	*-0.9*	*-3.1*	*-4.6*	*-21.5*	15.6			*-8.9*	*-18.5*	**31.8**

Only two catchments show decreases under all scenarios (apart from the maximum impact from resampling), these being the Lymn (30004) and the Beult (40005). Both these catchments are on the eastern side of the country where the current balance between rainfall and PE is already critical. The other six catchments show a range of positive and negative change.

The two CFMP catchments are the Beult, showing mainly decreases in flood flows, and the Severn to Haw Bridge (54057) with slight increases under the UKCIP02 scenarios but a more significant decrease using the RCM data.

UNCERTAINTY

The results presented should be seen in light of the uncertainty in a climate change impact study. These sources include:

- future emissions of greenhouse gasses;
- the representation of physical processes within the global climate model (GCM);
- natural climate variability;
- scenario development (downscaling);
- hydrological impact model (model structure and parameterisation).

Some of these sources of uncertainty have, to a degree, been addressed in the current study namely: two of the IPCC SRES emissions scenarios (IPCC, 2000) have been used in conjunction with the statistical downscaling method; rainfall resampling has considered an aspect of natural climate variability; various downscaling techniques, both statistical and dynamic, have been used; the hydrological model uncertainty due to calibration has been discussed and quantified (Reynard et al, 2004).

Other sources have not been addressed: the output from only one GCM has been used, and only the UKCIP02 scenarios represent any use of ensembles of results from an individual model. It is worth noting that Jenkins and Lowe (2003) suggest that the relative uncertainty due to the range of GCM simulations is greater than either emissions uncertainty or natural variability. Indeed the current estimate is that the range of change in global-mean precipitation is ±70% depending on the choice of GCM, compared with ±25% for the choice of emissions scenario (Jenkins and Lowe, 2003). Within this study, even those areas where some account of uncertainty has been taken, it cannot be said to have sampled from the entire range.

CONCLUSIONS

The results of this paper and the final project report (Reynard et al, 2004) show the impacts of climate change on flood frequency in the study catchments, under the selected scenarios, to be considerably lower than those previously determined for the 2050s. This is determined primarily by the fact that the version of the Hadley Centre GCM driving the climate changes produces significantly drier and warmer summers and autumns, so that, despite the wetter winters (on average), flood frequencies in many catchments decrease. This does not apply to those catchments that are more responsive, i.e. steep-sided, small or urban catchments, but even in these the precise response is determined by the spatial and temporal detail of the climate changes.

For each of the catchments a range of climate impacts has been shown. In only a few of these is there an obvious tendency towards either a decrease (30004 and 40005) or an increase (74001 and 42012). All other catchments present a range of change, both positive and negative.

A wider range of impact was presented using resampled rainfall data, but even with these data sources the maximum impact from UKCIP02 scenarios was rarely above 20%. These results suggest that the current 20% sensitivity band appears appropriate as a precautionary response to the uncertainty of future climate change impacts on flood flows. The range of impacts in this study is wide, across catchments, time slices and scenarios, but in general below the 20% increase. This has been determined by the dry and warm nature of the Hadley Centre model used to generate all the scenarios and using other GCMs will undoubtedly produce different results.

Finally, it is important to consider all the various sources of uncertainty involved in climate change impact studies, and how this uncertainty impacts on the decision that the research informs (Willows and Connell, 2003). Steps are being taken to understand, quantify and ultimately reduce these uncertainties, but they can never be eradicated completely.

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