4. RIVER APPLICATIONS

Summary guidance tables

Table 4.1 Rainfall

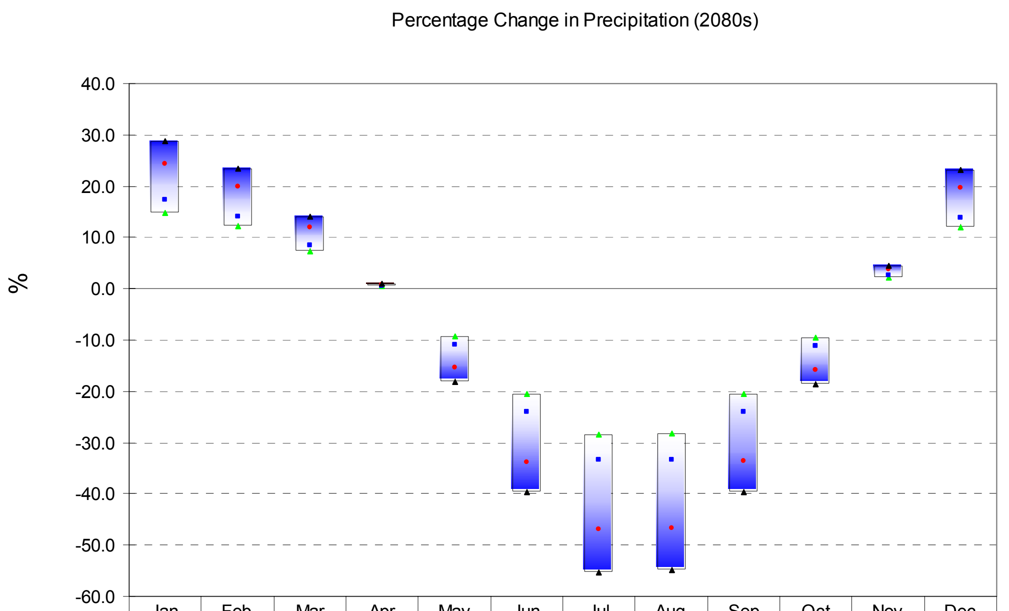
Importance of climate change to this task	High
Input variables in UKCIP02 or this report	Mean seasonal and extreme daily rainfall
Relevant sections in UKCIP02 or this report	Chapters 4 and 5 of UKCIP02, particularly percentage changes in extreme daily averaged rainfall in Figure 55 (Page 59) and annually averaged rainfall in Figures 35-38 (Page 33-36)
Confidence in climate change information	High (Increased winter rainfall depths and intensity) Medium (Decreased summer rainfall)
Appropriate level(s) of climate change assessment	A national contingency allowance plus sensitivity testing is appropriate and consistent, but scenario testing may provide greater insight into the range of possibilities in major projects.
National allowance plus sensitivity test	Add the established percentage increase allowance to present-day levels. At present, the 20% allowance (MAFF, 2000) for river flow is probably best applied to all rainfall durations, but refined recommendations may be developed in the near future.
Modelling	Apply scenario modelling using information from Chapters 4 and 5 of UKCIP02 for the four different scenarios to assess the range of outcomes which may occur under future climate change. The scenarios provide information only on daily, monthly and seasonal rainfall, and for the moment, there is no additional information for other rainfall durations. The typical approach to rainfall in climate impacts models involves applying monthly rainfall change factors to historic daily rainfall series. A rainfall change factor is the climate scenario rainfall depth (for a defined period) divided by the 1961-1990 rainfall depth. For any study the factors may be derived from the most appropriate UKCIP 50km^2 grid square. Alternatively the climate scenario data may be interpolated but this may give a false impression of precision. The simple approach of interpolating between UKCIP grid squares has some shortcomings, and in some cases it may be appropriate to use a statistical downscaling model such as the SDSM developed by Wilby *et al*. (1998, http://www.sdsm.org.uk/).

Derived loading variables	Rainfall depths
Derived structure variables	
Derived economic variables	
Investment decisions	

Demonstration calculations

The percentage change in rainfall for all four climate scenarios for the Ouse catchment is shown below.

Change in average monthly rainfall for the 2080s for the Sussex Ouse catchment



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Low Emissions	14.9	12.1	7.3	0.5	-9.3	-20.5	-28.6	-28.3	-20.5	-9.6	2.3	11.9
Med-Low Emissions	17.4	14.2	8.5	0.5	-10.9	-24.0	-33.4	-33.4	-23.9	-11.2	2.7	13.9
Med-High Emissions	24.4	19.9	12.0	0.7	-15.3	-33.7	-47.0	-46.6	-33.6	-15.8	3.7	19.6
High Emissions	28.8	23.5	14.1	0.9	-18.1	-39.8	-55.4	-55.0	-39.7	-18.6	4.4	23.1

Source (Atkins, 2002b, forthcoming)

NB: Daily averaged rainfall is directly useful only for large catchments but, pending further research, the percentage changes for daily averaged rainfall probably represent best estimates for other durations as well. When planning a study, it should be remembered that there are many uncertainties about the structure and sequencing of rainfall that limit the predictability of changes in extremes, no matter how much modelling is undertaken.

Table 4.2 Catchment wetness

Importance of climate change to this task	Medium
Input variables in UKCIP02 or this report	Soil moisture
Relevant sections in UKCIP02 or this report	Soil moisture section of Chapter 4 of UKCIP02, particularly Table 50 (Page 50)
Confidence in climate change information	High (decreases in summer and autumn in the south east) Medium (increases in winter and spring in the north west) Low (if used for individual catchment studies)
Appropriate level(s) of climate change assessment	Qualitative consideration only. The impact of soil moisture contents on flood risk is covered elsewhere (Table 4.5). The catchment scale or local impacts of changing soil moisture contents can only be estimated using appropriate modelling techniques. In flood defence design studies that use FSR / FEH rainfall-runoff modelling, sensitivity analysis of the impact of catchment wetness on peak flow should be completed irrespective of any climate impacts assessment.
National allowance plus sensitivity test	None
Modelling	Catchment soil moisture contents can be modelled using rainfall-runoff models (Table 4.5).
Derived loading variables	Catchment wetness
Derived structure variables	
Derived economic variables	
Investment decisions	
Demonstration calculations	

Table 4.3 Urban drainage volume

Importance of climate change to this task	High
Input variables in UKCIP02 or this report	Chapter 5 of UKCIP02, particularly percentage changes in extreme daily averaged rainfall in Figure 55 (Page 59)
Relevant sections in UKCIP02 or this report	Table 4.1 of this report
Confidence in climate change information	Medium/Low

Appropriate level(s) of climate change assessment	The general national allowance for rainfall plus sensitivity testing is probably the best that can be done for the moment. Scenario testing may provide greater insight into the range of possibilities in major projects.
National allowance plus sensitivity test	Add the standard national precautionary allowance to present-day volumes. For the moment the 20% allowance for river flow can be applied to all rainfall durations, but refined recommendations may be developed for the much shorter duration relevant to urban drainage.
Modelling	Apply scenario modelling using results from Chapter 5 of UKCIP02 for the four different scenarios to assess the range of outcomes which may occur under future climate change. The scenarios provide information only on daily, monthly and seasonal rainfall and, for the moment, there is no additional information for other rainfall durations. The use of weather generators to derive sub-daily rainfall series is now widespread amongst drainage engineers. Climate change could be built into these software tools but further research is required in this area before any definitive guidance can be given. UK Water Industry Research Ltd has funded a major project into changes in daily and sub-daily rainfall intensities but this research is not in the public domain.

Derived loading variables	Rainfall intensity and drainage volume
Derived structure variables	
Derived economic variables	
Investment decisions	

Demonstration calculations

NB: Daily averaged rainfall may provide a poor representation of high intensity (short duration) rainfall but, pending further research, the percentage changes for daily averaged rainfall probably represent best estimates for other durations as well.

Table 4.4 Pumped drainage volume

Importance of climate change to this task	High
Input variables in UKCIP02 or this report	Chapter 5 of UKCIP02, particularly percentage changes in extreme daily averaged rainfall in Figure 55 (Page 59)
Relevant sections in UKCIP02 or this report	Table 4.1 of this report
Confidence in climate change information	High for mean sea level (Table 3.1) High for winter rainfall increase (Table 4.1) Medium for summer rainfall decrease (Table 4.1)
Appropriate level(s) of climate change assessment	The general national allowances for rainfall and mean sea level rise, plus sensitivity testing is probably the best that can be done for the moment. Scenario testing may provide greater insight into the range of possibilities in major projects.
National allowance plus sensitivity test	Add the standard national precautionary allowance to present-day levels. For the moment the 20% allowance for river flow can be applied to all rainfall durations, but refined recommendations may be developed for the shorter duration relevant to pumped drainage.
Modelling	Apply scenario modelling using results from Chapter 5 of UKCIP02 for the four different scenarios to assess the range of outcomes which may occur under future climate change. The scenarios provide information only on daily and seasonal rainfall, and for the moment, there is no additional information for other rainfall durations. However, the typical slow response of pump drained fenland catchments means that percentage changes to daily rainfall is probably sufficiently refined for initial analysis of impacts.
Derived loading variables	Rainfall volume
Derived structure variables	Pump sizing and operational cost changes over time
Derived economic variables	Frequency of flood damage through capacity exceedence
Investment decisions	Pump operational procedures, renewal and replacement cycles
Demonstration calculations	
NB: Daily averaged rainfall may provide a poor representation of shorter duration rainfall but, pending further research, the percentage changes for daily averaged rainfall probably represent best estimates for other durations as well.	

Table 4.5 River flow

Importance of climate change to this task	Medium
Input variables in UKCIP02 or this report	Rainfall intensity
Relevant sections in UKCIP02 or this report	Chapters 4 and 5 of UKCIP02, particularly extreme daily rainfall in Figure 55 (Page 59)
Confidence in climate change information	Medium

Appropriate level(s) of climate change assessment	National contingency allowance for possible river flow increase plus sensitivity testing may be adequate, but modelling is probably justified for assessment of new defence schemes.
National allowance plus sensitivity test	Add established 20% allowance to present-day winter river flow rates (but ongoing Defra /Agency research at CEH may provide a refinement to this allowance).
Modelling	Use catchment or site-specific rainfall and evapotranspiration scenarios as input to continuous simulation river modelling (see detailed technical statement in Section 4.2.3).

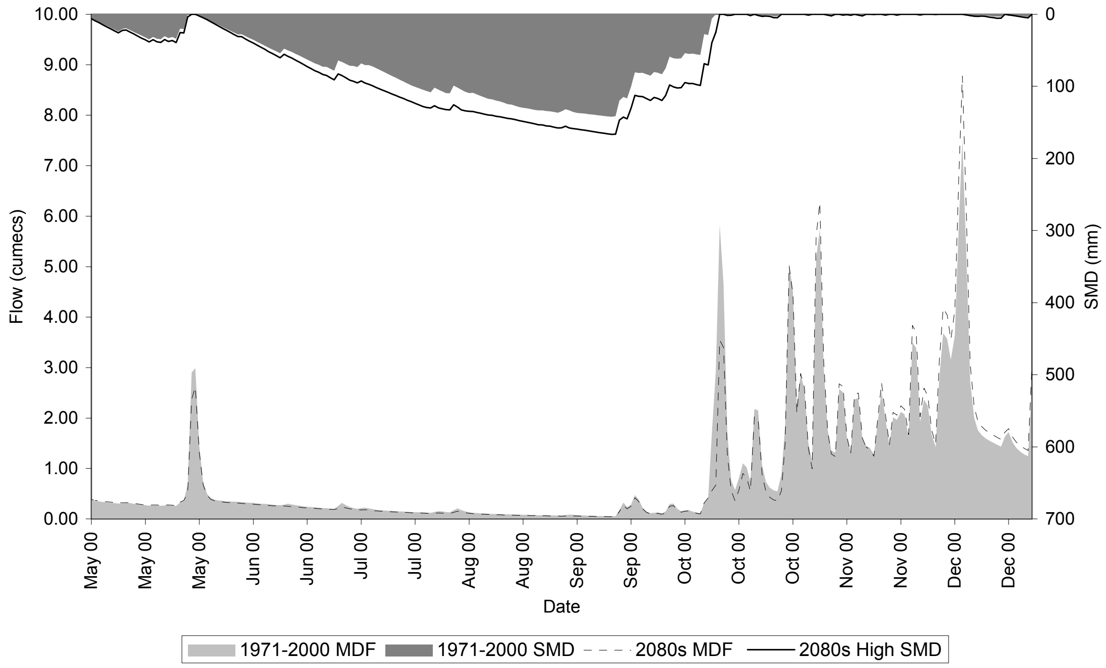
Derived loading variables	River flow
Derived structure variables	
Derived economic variables	
Investment decisions	

Demonstration calculations

The Ouse at Ardingly was modelled from 1971-2000 and for the UKCIP98 2080s High climate change scenario. Rainfall and evaporation were considered in the model using the approach described in Table 4.1.

The graph below shows the Mean Daily Flow (MDF) and Soil Moisture Deficit (SMD) for the catchment between May 2000 and January 2001. This period covers the peak flows during the Autumn 2000 floods.

In this example the average increase in annual maximum of MDFs between the 2080s and the 1971-2000 period was 7% and the increase in the Autumn 2000 flow was 17%. Soil moisture deficits were larger during the summer due to increased evaporation and reduced rainfall. Peak flows in the summer months were reduced.



Mean Daily Flow and Soil Moisture Deficit: Upper Ouse, Sussex

Table 4.6 Extreme river flow and level

Importance of climate change to this task	Medium/High
Input variables in UKCIP02 or this report	Rainfall intensity and river flow
Relevant sections in UKCIP02 or this report	Chapters 5 of UKCIP02, particularly extreme daily rainfall in Figure 55 (Page 59) and Table 4.5 of this report
Confidence in climate change information	Medium

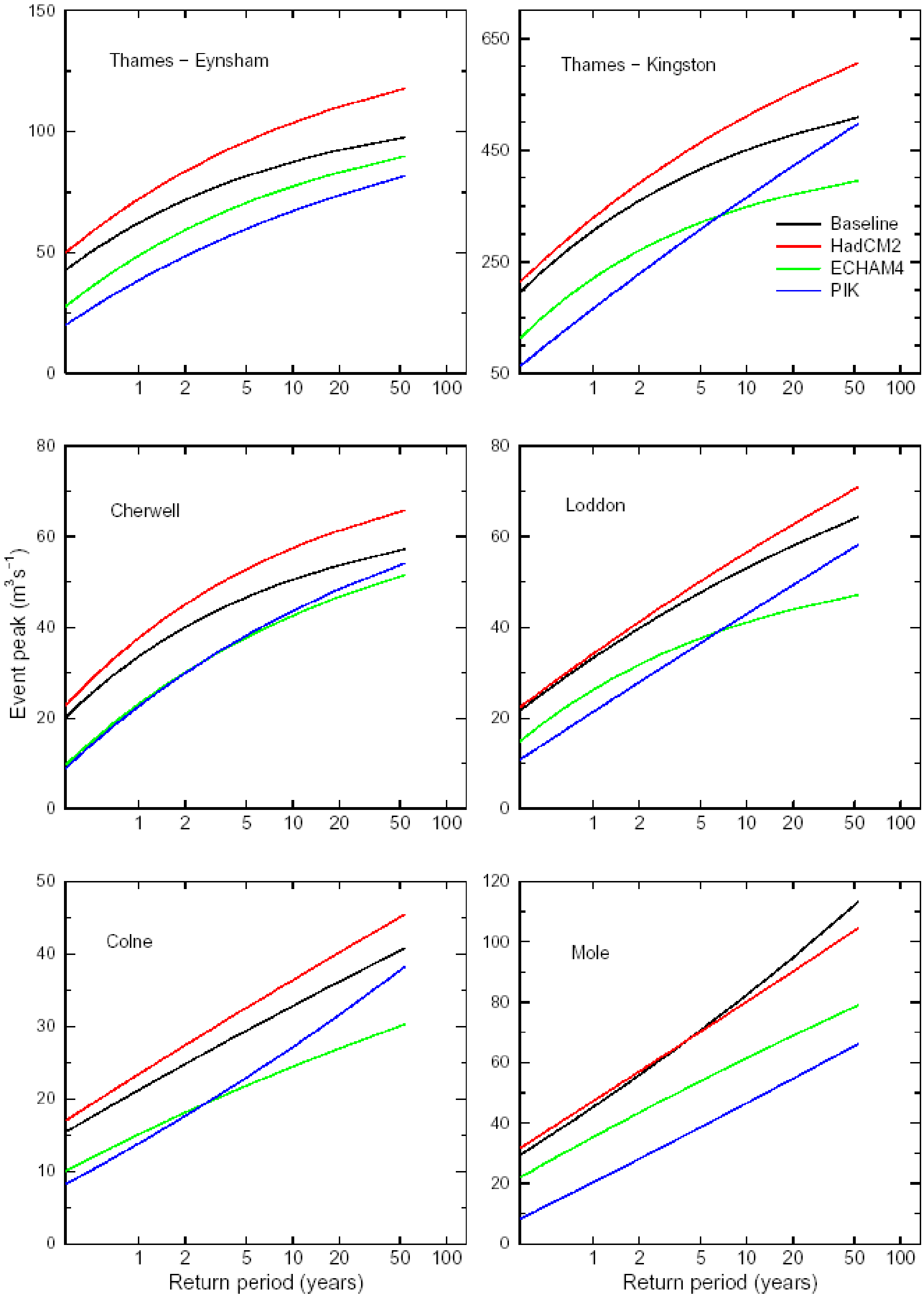
Appropriate level(s) of climate change assessment	National allowance plus sensitivity testing may be adequate, but modelling and economic impact are probably justified for assessment of new defence schemes.
National allowance plus sensitivity test	Add established 20% allowance to present-day river flow rates and extremes (but ongoing Defra /Agency research may provide a refinement to this allowance).
Modelling	Use site-specific rainfall predictions as input to continuous simulation river modelling and/or FEH analysis to predict change in river flow (see detailed technical statement in Section 4.2).

Derived loading variables	Extreme river flow
Derived structure variables	Extreme river level, defence crest level
Derived economic variables	
Investment decisions	

Demonstration calculations

1 Thames catchment example

The following example from the EUROTAS project Task 3 on the River Thames Catchment (Samuels, 2001, http://www.hrwallingford.co.uk/projects/EUROTAS) shows the sensitivity of the flood frequency estimates to the climate change model (HadCM2 and ECHAM4) and the method of downscaling adopted. The PIK scenario uses expanded statistical downscaling on the ECHAM4 scenario data, which produces a change in character of the flood frequency distribution for the Thames at Kingston. All results were produced using the CLASSIC continuous simulation model by CEH Wallingford.

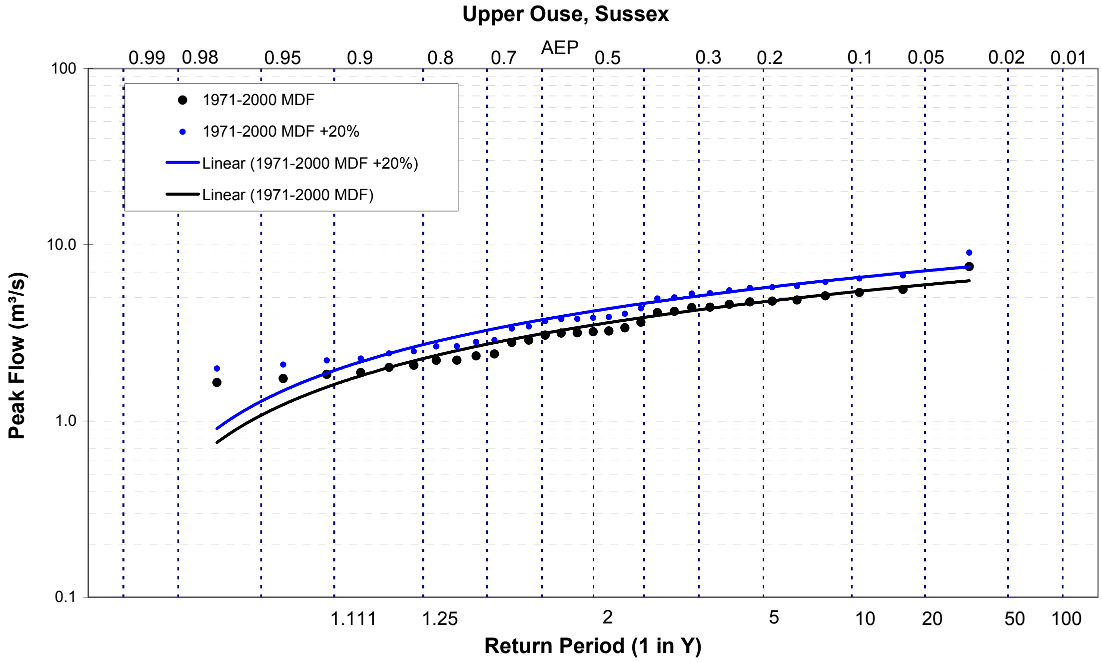


Flood frequency curves for the baseline period (1961-1990) and with three climate change scenarios for 2041-2070

2 National allowance example

The statistical approach to flood estimation involves fitting curves to annual maximum flow data. The example below shows a flood frequency curve fitted to a 30-year record from Ardingly gauge in the headwaters of the Sussex Ouse.

The national allowance of 20% was added to the annual maxima data and a new curve was fitted to the adjusted data.



3 Use of the national allowance in the River Aire Section 105 Study

As part of the River Aire Section 105 Study, flows were increased by 20% at the inflows to an ISIS hydraulic model. This increase was equivalent to using a 200 year return period flood rather than a 100 year return period flood and amounted to an average increase of 0.25m in water levels after the increased flows had been run through the hydraulic model.

4 Analysis of outputs from continuous simulation

The graph below plots the annual maxima produced by continuous simulation. In this example there is no significant change in the Mean Annual Flood and there is a smaller increase in the 1 in 20 year and above flood events. In statistical terms, there is no increase in the average flood but there is an increase in the variance of the flood frequency curve.

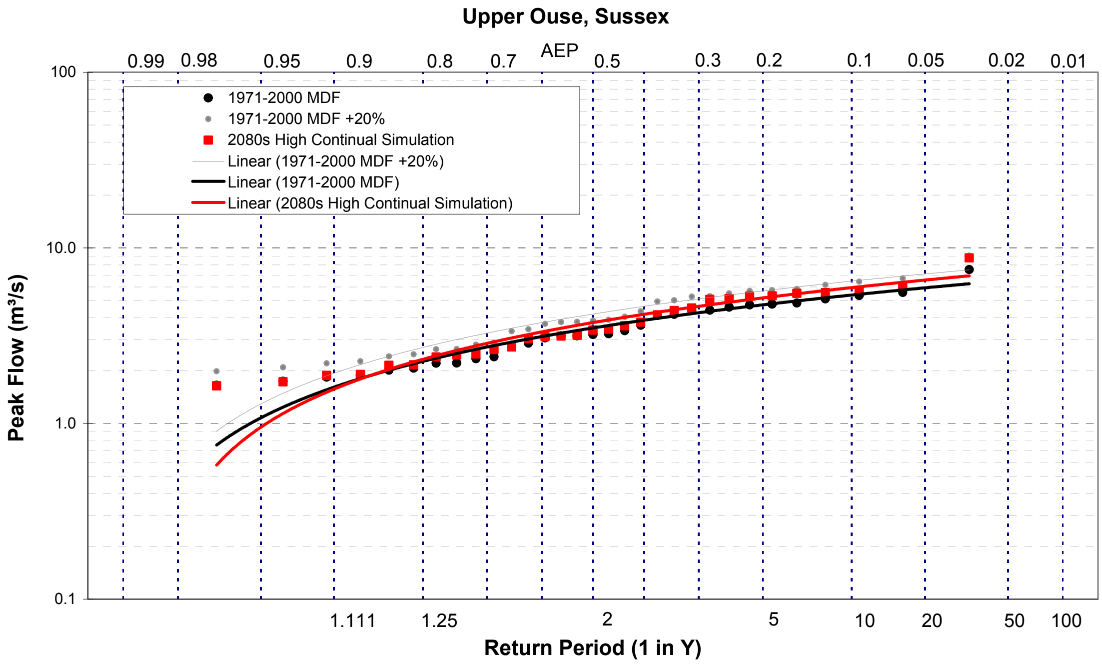


Table 4.7 Area of river flooding

Importance of climate change to this task	Medium
Input variables in UKCIP02 or this report	River flows and high water levels
Relevant sections in UKCIP02 or this report	Tables 3.1, 3.2, 4.5 and 4.6 of this report
Confidence in climate change information	Medium
Appropriate level(s) of climate change assessment	Application of national allowances for river flow and water level may be sufficient for sensitivity testing, to determine the change in extreme river level, the volume of water over the banks and the consequent increase in flooded area. However, full re-calculation of river level, and flood propagation and mapping will often be necessary, and scenario testing may be helpful in understanding the uncertainties involved.
National allowance plus sensitivity test	For each flood condition of interest, add the established mm/year allowance to the present-day water level (if in an area of tidal influence) and the established percentage allowance to river flow. Due to topography, the plan extent of flooding may not be significantly affected by marginal changes in flow/level unless these cross thresholds of overtopping of either primary or secondary defences. A preliminary desk assessment may be sufficient to demonstrate little change in flood area.
Modelling	If the desk assessment suggests a significant change in flood area, move on to model several aspects of the processes involved, including sea level, river flow change and flood propagation, possibly for the four alternative scenarios and/or different periods into the future (see detailed technical statement in Section 4.2).
Derived loading variables	
Derived structure variables	Flood area
Derived economic variables	Value of damage due to flood
Investment decisions	
Demonstration calculations	

Table 4.8 Probability of river flood

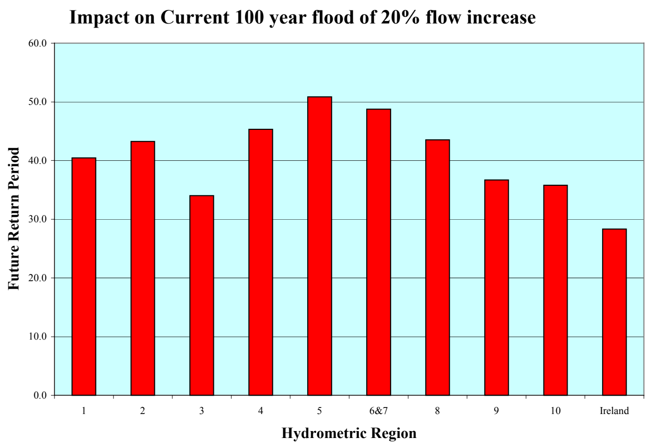
Importance of climate change to this task	Medium
Input variables in UKCIP02 or this report	River flows and high water levels
Relevant sections in UKCIP02 or this report	Tables 3.1, 3.2, 4.6 and 4.7 of this report
Confidence in climate change information	Medium

Appropriate level(s) of climate change assessment	Application of national allowances for river flow and water level may be sufficient for sensitivity testing, to determine the new probability at which the threshold for flooding is reached. However, full re-calculation of river level may be necessary, and scenario testing may be helpful in understanding the uncertainties involved.
National allowance plus sensitivity test	For a range of high loading conditions with estimated probabilities of occurrence, add the established mm/year allowance to the present-day water level (if in an area of tidal influence) and the established percentage allowance to river flow. Then estimate the new probabilities of occurrence of the same loading conditions after climate change.
Modelling	Model several aspects of the processes involved, including sea level and river flow change, possibly for the four alternative scenarios and for different periods into the future, allowing for the fact that flood events could be of different types following climate change. (See detailed technical statement in Section 4.2).

Derived loading variables	
Derived structure variables	
Derived economic variables	Cost of flood, flood frequency, cost of upgrading to new defence crest level
Investment decisions	Whether or not to upgrade defence level

Demonstration calculations

A sensitivity analysis was undertaken in the second phase study of the national assets at risk of flooding and coastal erosion (Defra, 2001). The approach was based upon applying a percentage increase to the river flows at all return periods to the dimensionless regional growth curves of the FSR and interpreting the result as a change in annual frequency for the given value of peak discharge. The underlying growth curve was assumed to be unchanged (this assumption amongst others is open to question). The results given below are for the future return period of the current 100 year flood estimate of the FSR by FSR region.



1.1 Rainfall-runoff modelling techniques

1.1.1 Comments on guidance for river applications

Tables 4.1 to 4.8 outline some simple sensitivity tests and modelling approaches that can be used to estimate the possible impacts of climate change on fluvial flooding. There are two levels of assessment; firstly, the application of the national allowance of an increase of 20% on rainfall or peak river flow. In terms of the physical processes of rainfall-runoff and hydraulics, this appears to be inconsistent because any increase in rainfall will be stored within catchment vegetation and soils and attenuated in headwater floodplains. However, the application of a clear simple rule has clear advantages.

The ongoing Defra / Agency research at CEH Wallingford (Project W5B-01-050) into climate change and continuous simulation may result in a revision of the simple 20% rule.

Prior to the publication of the CEH research, some flood studies may require more detailed modelling as described in Tables 4.5 and 4.6. The section below provides some further information on standard flood studies modelling techniques and the linkages between runoff and climate variables.

1.1.2 The Flood Studies Report (FSR) and Flood Estimation Handbook (FEH)

It is widely recognised that the FSR / FEH rainfall-runoff approach requires updating as it is still based on the original FSR dataset extending only to the 1970s. The use of the statistical method (Table 4.5) and continuous simulation are also far more robust approaches for flood estimation than the FSR rainfall-runoff method. Nevertheless it is useful to understand the linkages between climate variables and predicted flood flows developed as part of the original FSR losses model.

If the FSR model is to be used for sensitivity analysis or climate impacts assessment the following are required:

- Control and scenario rainfall storm duration, depth, profiles – direct from Regional Climate Model rainfall statistics. (Before RCM rainfall statistics are used they require validation against observed records for either the 1961-1990 or 2071-2100 period.)

- Control design Tp, BF and SPR for control period (1961-1990) and either scenario values/factors or *pdfs* for BF and SPR and the correlation between them.

Table 4.9 below summarises some of the key variables. The level column indicates the level of complexity in terms of testing the sensitivity of runoff to changes in climate variables.

Table 4.9 Key variables in rainfall-runoff modelling techniques

Level	FEH Variable	UKCIP02 Variable	Notes
1	SAAR	Annual average rainfall	Basic FEH parameter. Catchment SAAR could be derived directly from UKCIP02 scenarios.
1	The Median Flood Flow QMED	None	Historically a 0.5 correlation between SAAR and QMED
2	Standard Percentage Runoff SPR	Historic SPR plus dynamic components derived from rainfall? RCM Runoff is not directly comparable.	Most sensitive component of FSR losses model to climate change. SPR is an event based statistic.
2	Percentage Runoff PR_{rural}	Runoff (see above)	*FEH Vol.4. 2.3* See comments relating to SPR $PR_{rural} = SPR + DPR_{CWI} + DPR_{RAIN}$ $DPR_{CWI} = 0.25\ (CWI - 125)$ If P <= 40 mm, $DPR_{RAIN} = 0$, Else $DPR_{RAIN} = 0.45(P\text{-}40)^{0.7}$
3	Catchment Wetness Index CWI	Derived from daily rainfall or Daily SMD	FEH CWI = 125 + API5 – SMD Note that FSR/FEH guidance of design CWI based on SAAR
3	Soil Moisture Deficit SMD	SMD from UKCIP02 is not directly comparable because it is based on $50km^2$ grid squares	The UKCIP02 RCM SMD data have not been validated against more detailed rainfall-runoff models. The probability of flooding increases when SMD is 6mm or less. It would be useful to present the RCM SMD data in the form of the number of days that the soil is "wet" i.e. the PROPWET variable. This may be a useful flood risk indicator.
3	Antecedent Precipitation Index API5	Derived from daily rainfall	$API5 = 0.5^* [P_{d-1}+0.5\text{^}2^*P_{d-2}+0.5\text{^}3^*P_{d-3+}0.5\text{^}4^*P_{d-4}+0.5\text{^}5^*P_{d-5}]$
2	PROPWET	SMD	The fraction of time that the catchment is wet.
2	Tp	None	Time to peak - climate change should have no significant effects.
2	BF	None	Baseflows are relevant in permeable catchments – likely to increase on average with climate change. Can be estimated as f(CWI, SAAR and AREA) – $BF = \{33(CWI\text{-}125)+3.0.SAAR + 5.5\}10^{-5}.\ AREA$
By comparison			
4	None	Continuous simulation using a rainfall-runoff model	While much of the research has used PDM a simpler model, such as a Penman model may be more appropriate. The Environment Agency, CEH and NEECA consultants between them have a good selection of models and databases of model parameters. **Far too complex for general use so the models need to be run for a range of catchments and the results presented for particular types of catchment.**

1.1.3 Continuous simulation modelling

A number of rainfall-runoff models that can be used to estimate the impacts of the UKCIP02 climate change scenarios on peak river flow are outlined in Table 4.10.

Table 4.10 Rainfall-runoff model summary

Model	**Model Type**	**Description**	**Comments on use of continuous simulation of flood peaks**
HYSIM	Conceptual (Mass balance)	Seven store conceptual model coupled to a simple hydraulic routing model.	Physically based model but with a large number of parameters. Generally used for water resources studies rather than flood studies.
CATCHMOD (TCM)	Conceptual (Mass balance)	Penman 3 parameter model, requiring division of the catchment into different response zones, representing areas with different runoff characteristics.	A simple model developed within Thames Region of the Environment Agency. It has been used for estimating the impacts of climate change on river flows in both Thames and Southern Region of the Environment Agency (e.g. Atkins, 2002b).
IHACRES	Transfer Function/UH	A systems type model based on the Unit Hydrograph. It has two modules: the first calculates effective rainfall (ER) from rainfall and temperature and the second converts ER to stream flow.	A simple model but not used widely within the Environment Agency.
Probability Distributed Model (PDM)	Conceptual	A mass balance model that uses a probability density function rather than single parameter to represent storage within a catchment.	This model is being used by CEH for evaluating the impacts of the UKCIP02 scenarios on peak flows. It is used in flow forecasting systems in England. This model is now available as part of HR Wallingford's ISIS suite of models.
NAM	Conceptual	A mass balance model based on the relationship between storage, process thresholds and flow routing through several non-linear reservoirs.	This model forms part of the Danish Hydraulic Institute's MIKE11 suite of models. It has been used for flood forecasting systems in East Anglia and Section 105 flood studies in Wales.

2. DECISIONS

2.1 Summary guidance tables

Table 5.1 Standard of service

Standard of service is defined as the adequacy of a defence, measured in terms of the annual probability of the event which causes a critical condition (e.g. breaching, overtopping) to be reached.	
Importance of climate change to this task	Medium
Input variables in UKCIP02 or this report	River flows, high water levels, waves, probabilities of damage and/or flooding
Relevant sections in UKCIP02 or this report	Tables 3.2, 3.4-3.8, 3.11, 4.6 and 4.8 of this report
Confidence in climate change information	Medium
Appropriate level(s) of climate change assessment	Determine the most important failure mode(s). Application of national allowances for relevant loading parameters may be sufficient for sensitivity testing. Full re-evaluation of all loading variables and failure probabilities will usually be necessary, for example for cost-benefit assessment. Scenario testing may be helpful in understanding the uncertainties involved.
National allowance plus sensitivity test	Apply national allowances to the variables involved, re-work the failure calculations and estimate the increased probability of occurrence of loading conditions causing failure. The standard of service, expressed as an annual probability, then follows from the probability of failure.
Modelling	Model several aspects of the processes involved, including all loading variables and their combined probability of occurrence. Determine the probability of the failure mode(s). Assessment of these rare combined probabilities would be assisted by long-term simulation coupled with joint probability analysis. Scenario modelling would be helpful in understanding the uncertainties involved. Although the absolute accuracy of the derived standards of service may be low, any comparisons between present-day and future scenario values should be valid.

Derived loading variables	
Derived structure variables	
Derived economic variables	Standard of service for a defence, expressed as the annual probability of an event which it would protect against, and the way in which this is likely to change over time
Investment decisions	Whether to do nothing, repair the defence, upgrade an existing defence, or construct a new defence, and appropriate timing of investment in relation to changing risks

Demonstration calculations

1) Sea level above an estuary wall

Consider a hypothetical estuary wall on the south coast of England, assumed to have failed in its service if the sea level, unaffected by waves or flow, exceeds the wall level.

> Let the present-day extreme water levels be 2.14, 2.26, 2.34, 2.42, 2.60, 2.72 and 2.90mCD for return periods of 1, 2.5, 5, 10, 25, 50 and 100 years, and the wall level be 2.90mOD. The annual probability of the event that the wall would protect against is 0.01. Increasing all sea levels by 6mm/yr to represent conditions in 25, 50 and 100 years time would increase the extreme water levels by 0.15, 0.30 and 0.60m, respectively, and hence the annual probability of failure to about 0.02, 0.04 and 0.3, respectively.

2) Overtopping of a sea wall

Consider a hypothetical sea wall on the east coast of England, assumed to have failed in its service if the overtopping rate exceeds 40 litres/metre/second.

> Consider overtopping of a smooth sloped seawall, toe elevation at 0.0mOD, crest elevation at 8.0mOD. Consider wave conditions of H_s = 4.0m, T_m = 8.0s occurring in conjunction with a sea level of 3.7mOD (1 year joint return period), 4.0mOD (10 years), 4.3mOD (100 years) and 4.6mOD (1000 years). Assuming that H_s at the toe is limited to 55% of the toe depth, the depth-limited heights for the four cases are 2.04, 2.20, 2.37 and 2.53m. The overtopping rates, calculated using the Owen formula for the four cases, are 7.5, 15, 29 and 56 l/m/s. The annual probability of the event that the wall would protect against is about 0.003.
>
> Now add allowances for future climate change over 80 years, adding 0.4m to sea level (and therefore toe depth, with corresponding increase in depth-limited wave height), 10% to wave height and 5% to wave period. The revised overtopping rates are 26, 47, 83 and 148 l/m/s, increasing the annual probability of failure to about 0.2, ie fifty to one hundred times greater.

3) Breaching of a shingle bank

See example calculations in Table 3.7.

Table 5.2 Cost benefit assessment

The 'cost' is the present value of whole life costs involved in any defence options considered, including maintaining the present position, and any proposed improvements. The 'benefit' is the reduction in present value of economic losses due to flooding etc. over the whole period of the evaluation, relative to the do-nothing position, attributable to the proposed option.	
Importance of climate change to this task	Medium
Input variables in UKCIP02 or this report	River flows, high water levels, waves, probabilities and cost of damage and/or flooding
Relevant sections in UKCIP02 or this report	Tables 3.2, 3.4-3.7, 3.10, 3.11, 4.3, 4.4, and 4.6-4.8 of this report
Confidence in climate change information	Medium
Appropriate level(s) of climate change assessment	For each option determine the most important condition(s) in which various levels of flooding would occur and the economic value of the associated losses at the present time. Apply national allowances to relevant loading parameters for future time steps (e.g. 10 year intervals) over the evaluation period and use the results to sum the economic value of losses using agreed discount factors. Determine the whole life costs of each option and use these to derive benefit/cost ratios and incremental benefits and costs for each option.
National allowance plus sensitivity test	As above, apply national allowances to the variables involved, re-work the flooding calculations and estimate the increased probability of occurrence of loading conditions causing flooding. The benefit/cost ratio for each combination of defence strategy and scenario can then be calculated using normal calculation methods. Appropriate scenario testing around the recommended allowances may be helpful in understanding the uncertainties involved.
Modelling	Model several aspects of the processes involved, including all loading variables and their combined probability of occurrence. Determine the probabilities of the various flooding events. The benefit/cost ratio for each combination of defence strategy and scenario can then be calculated using normal calculation methods. Assessment of these rare combined probabilities would be assisted by long-term simulation coupled with joint probability analysis. Such scenario modelling would be helpful in understanding the uncertainties involved for large or significant investment projects (but see note below).

Derived loading variables	
Derived structure variables	
Derived economic variables	The changes in costs and benefits of different investment options over specified period(s) of time in the life of an existing or proposed defence
Investment decisions	Whether to do nothing, or repair / replace / construct the defence; appropriate timing of investment in relation to changing risks

Demonstration calculations

As both costs and benefits may be different under different climate scenarios, it cannot be assumed without doing full calculations that the benefit/cost ratio will necessarily increase or decrease, or that the preferred option will remain the same under climate change. The two sets of illustrative results below are based on a recent study in England, where climate change was represented by the appropriate precautionary allowance for sea levels, with the consequent increase in depth-limited wave heights.

Location 1 has a promenade and low shingle beach, protected in parts by rock armour and in parts by groynes. The potential threat is high overtopping and consequent damage to infrastructure, but the present standard of defence is 100-300 years, varying slightly through the defence length. The *do nothing* option would allow continued erosion of the shingle and a rapid increase in the frequency of overtopping. The *maintain* option assumes repair of groynes and renourishment of shingle beaches to hold their present state. The *sustain* option would involve minor additions to the maintain option to bring the entire length up to the 200 year standard of defence and sustain that position under climate change. The *improve* option would involve more significant new works to bring the standard of defence above 300 years for the whole defence length. All benefits increase slightly under climate change and *maintain* remains the preferred option.

Option	Benefit (£M)		Cost (£M)		B/C ratio		Comments on defences
	Now	After	Now	After	Now	After	
Do nothing	200 year defence but potentially rapid deterioration						
Maintain	10.31	10.37	2.81	2.81	3.7	3.7	Maintain 200 year standard
Sustain	10.58	11.06	3.27	3.27	3.2	3.4	Sustain 200 year standard
Improve	11.33	11.09	3.52	3.52	3.2	3.2	Improve to over 300 years

Location 2 has a coastal defence protected by a nourished shingle beach and breakwaters, apart from one small area where continued erosion between two breakwaters would begin to allow larger waves to pass. The potential threat is breaching in the lee of the erosion, but at present the whole area has a high standard of defence of over 200 years, although under the *do nothing* option this would drop rapidly in the small area affected by erosion. The cost of the maintain option increases under climate change, reducing the B/C ratio, and changing the preferred option from *maintain* (Now) to *sustain* (After).

Option	Benefit (£M)		Cost (£M)		B/C ratio		Comments on defences
	Now	After	Now	After	Now	After	
Do nothing	200 year defence but potentially rapid deterioration in one area						
Maintain	6.56	7.38	0.89	1.39	7.4	5.3	Maintain 200 year standard
Sustain	6.56	7.80	1.39	1.39	4.7	5.6	Sustain 200 year standard

NB: For national investment programmes an important aspect is that different projects competing for funds are appraised on a consistent basis. Therefore, whilst decisions on option choice should take full account of the potential impacts and uncertainties, it is generally preferable that the final results are reported in relation to agreed allowances that are designed to provide an appropriate precautionary response.

Table 5.3 Planning assessment

Importance of climate change to this task		Low/Medium
Input variables in UKCIP02 or this report		River flows, high water levels, probability of flooding
Relevant sections in UKCIP02 or this report		Tables 3.2, 3.10, 3.11, 4.7 and 4.8 of this report
Confidence in climate change information		Medium
Appropriate level(s) of climate change assessment	Application of national allowances for river flow and/or water level may be sufficient for sensitivity testing, to estimate present-day and future probabilities of flooding. Modelling of river / water level, and flood propagation and mapping will only be necessary for major developments and/or where new building may affect flood propagation. As established planning policy is more important than precise calculation of risk, scenario modelling is unlikely to be helpful (except perhaps in developing new policy).	
National allowance plus sensitivity test	Application of national allowances for river flow and/or water level to estimate present-day and future probabilities of flooding.	
Modelling	Modelling of river / water level, and flood propagation and mapping where a major development is proposed and/or where new building may affect flood propagation.	
Derived loading variables		
Derived structure variables		Changes in probability of flooding over the life of the development
Derived economic variables		Cost of flood damage or of mitigation measures required and their potential impacts elsewhere
Investment decisions		Whether or not to allow development as a sustainable option
Demonstration calculations		

2.2 National policy and national assets at risk

Guidance on development of national policy and assessment of national assets at risk in the context of climate change is not given in this report, as these tasks would not be undertaken by non-specialists. Defra and the Environment Agency have funded a number of recent studies of the national value of assets at risk from river and coastal flooding, how that risk might increase following climate change, and the investment needed to maintain the current level of risk. The most recent publication on assets at risk is Defra (2001), but National Flood Risk Assessment 2002 is due to report soon.

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