Environment Agency

Adapting to Climate Change:

Advice for Flood and Coastal Erosion Risk Management Authorities

We are the Environment Agency. We protect and improve the environment and make it **a better place** for people and wildlife.

We operate at the place where environmental change has its greatest impact on people's lives. We reduce the risks to people and properties from flooding; make sure there is enough water for people and wildlife; protect and improve air, land and water quality and apply the environmental standards within which industry can operate.

Acting to reduce climate change and helping people and wildlife adapt to its consequences are at the heart of all that we do.

We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

Published by:

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1 Introduction

This part describes Defra's policy statement and its relation to this advice

This advice replaces Defra's Supplementary Note to Operating Authorities – Climate Change Impacts, October 2006. It is provided as supplementary information to Defra's policy statement on Appraisal of Flood and Coastal Erosion Risk Management (2009) and the Environment Agency's Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG), as well as supporting the FCERM National Strategy for England.

This advice builds Government's policy for climate change adaptation, and is specifically intended for projects or strategies seeking Government Flood Defence Grant in Aid (FDGiA). However, Risk Management Authorities (RMA) in England may also find this information useful in developing plans and making FCERM investment decisions even if there is no intention of applying for central government funding. Guidance for Wales is still provided by the Defra 2006 supplementary note - Treatment of climate change impacts.

The purpose of this advice is to ensure that an economically credible appraisal, taking account of the uncertainties associated with climate change, can be made to support Government investment decisions. This is necessary to ensure that a fair comparison can be made between investment in projects in different locations which compete for central government grant, as well as ensuring that the most appropriate means of reducing risk is investigated in any one place.

With the anticipated long term changes to our climate over the coming century and the threats this brings, we need to continue to adapt our management of flood and coastal erosion risk to reduce the impacts. Given the long lifetime and high cost of the built environment and many flood and coastal erosion management measures, it is imperative that we plan for, and invest in, projects that are appropriate for the changing risks we face. This includes designing for adaptation where appropriate.

Defra's appraisal policy statement recommends a "managed adaptive approach" where possible and sets out some broad principles that should be considered. The managed adaptive approach contrasts with a precautionary approach, which may be appropriate in some circumstances.

A managed adaptive approach allows for adaptation in the future, and is most likely to be appropriate in cases where ongoing responsibility can be assigned to tracking the change in risk, and managing that risk through multiple interventions. This provides flexibility to manage future uncertainties associated with climate change.

In some circumstances, future adaptation may not be technically feasible or too complex to administer. For example, it may not be possible to manage multiple interventions or it may be economically more efficient to build in a precautionary element at the outset. In these cases, a precautionary approach, with a one-off intervention, may be the only feasible or best option. However, considering only precautionary options would lead to greater levels of investment at fewer locations. Whereas a managed adaptive approach would ensure a fairer and more flexible spread of public investment and therefore should be preferred where possible.

2 Transitional arrangements

This part describes the transitional arrangements for this advice

This advice should be applied to all future appraisals that are started (new) from July 2011 or are to be submitted for approval after 1st January 2012. Work already in progress should, as a minimum, be assessed ensuring that this advice would not lead to different decisions.

However, even for substantially complete work, or that submitted for approval before 1 January 2012, if the new advice can be factored in, or the plan or investment decision tested against them without slowing completion or adding significantly to the cost, then this should be done.

For existing approved plans and strategies we would not normally expect this advice to be applied until the next review, unless specific investment projects within them are planned before this. In these cases, project appraisals should adopt the new advice (subject to the first paragraph above).

3 Provision of change factors

This part describes climate change factors for RMAs to apply to investment planning decisions.

What is the change factor?

To assess the potential impacts that climate change may have on extreme rainfall, river flood flows, sea level rise and storm surges, change factors are provided in Annex 1. The change factors quantify the potential change (as either mm or percentage increase, depending on the variable) to the baseline. It is recommended that options are developed planning for the change factor covering the whole of the decision lifetime. However, rather than base options solely on the change factor, the upper and lower end estimates can be used to refine the options to prepare for a wider range of future change.

The change factors are based on UKCP09 or research using UKCP09 data. UKCP09 provides a large toolkit of information and data. The change factors have been developed to help RMAs use the UKCP09 information in a timely and cost-effective way and to provide a consistent approach. Change factors for river flood flows, extreme rainfall, mean relative sea level rise and storm surges are provided in the tables in Annex 1, an example of their presentation is provided in Table a, below.

Upper and lower end estimates of change are provided to help represent the range of the future risks. Government recommends that when considering climate change a full appreciation of emission scenario and climate uncertainty is undertaken. The upper and lower end estimates are designed to achieve this within flood and coastal erosion risk management applications.

Although, it is anticipated that the eventual change in river flows and sea level rise to lie somewhere within the range of lower to upper end estimates, more extreme change cannot be discounted. To help represent this extreme change "H++ scenarios" have been included in line with the UKCP09 approach. This can be used to represent more severe climate change impacts and help identify the options that would be required.

An example of the contents of Annex 1 is provided here,

	Total potential change anticipated for the 2020s	**Total potential change anticipated for the 2050s**	**Total potential change anticipated for the 2080s**
Northumbria			
Upper end estimate	25%	30%	50%
Change factor	10%	15%	20%
Lower end estimate	0%	0%	5%
Northumbria H++	35%	45%	75%

Table a, showing potential changes in peak river flow for Northumbria River Basin District.

Those circumstances involving events of extremely high probabilities or where the consequences of rare events could be extreme. i.e. large tidal barriers, then the upper end of the full range may be better informed through use of the H++ limits.

In addition to the provision of change factors, Annex 2 provides a methodology to help RMAs make full use of the numbers from Annex 1.

What is the H++ scenario?

The H++ scenario provides RMAs with estimates of sea level rise and river flood flow change beyond the likely range but within physical plausibility. It is useful for contingency planning to understand what might be required if climate change were to happen much more rapidly than expected. It is not possible to say exactly how likely the H++ scenario is.

4 Limitations and Managing Exceptions

This part describes locations where the climate change factors need to be applied with caution.

The change factors provided have been derived from national scale research. There may be cases where local evidence supports the use of other local change factors. In such cases decision makers may use alternative change factors where robust science supports this. Where national grant in aid is being sought, the Environment Agency will need to be satisfied that the science is indeed sufficiently robust to support such an exception.

It will be up to the RMA to consider the most appropriate local evidence and justify exceptions on a case-by-case basis. The rationale for using any alternative and the implications should be transparent and recorded within the plan or investment decision documentation.

5 Supporting Science

This part briefly describes where the supporting science for this advice can be found.

An extensive summary of the science that has led to the development of this advice and the change factors and lower and upper end estimates of change is provided in Annex 3. This is to ensure complete transparency of the approach and to widen the knowledge base between RMAs and their consultants. Understanding the science is vital for RMAs in their decisions.

Annex 1 Provision of change factors

This annex provides climate change factors for RMAs to apply to investment planning decisions

1. Changes to river flood flows by river basin district

Understanding of the potential changes to river flood flows has increased significantly following a major joint Defra/Environment Agency research project. It is now considered that there is sufficient confidence in the projected changes that regionalised information can be provided.

The Defra/Environment Agency research was undertaken to understand how different catchments across England and Wales respond to changes in climate. UKCP09 projections of rainfall and temperature were then used to develop river flood flows projections through the century. These are presented in Table 1 for a standard catchment within each river basin district.

The information provided in Table 1 is derived for change to river flow likelihood of a 1 in 50 (2%) chance of occurring in any year. For extrapolation of these projections to higher return periods the research suggested that the regional allowances are likely to remain relatively constant with increasing return period.

The change factor corresponds to the central estimate of change from the research. The upper and lower estimates are provided to represent the full range of potential change in river flow for use in most circumstances. The projections are percentage change to a 1961-90 baseline.

	Total potential change anticipated for the 2020s.	**Total potential change anticipated for the 2050s**	**Total potential change anticipated for the 2080s**
Northumbria			
Upper end estimate	25%	30%	50%
Change factor	10%	15%	20%
Lower end estimate	0%	0%	5%
Humber			
Upper end estimate	25%	30%	50%
Change factor	10%	15%	20%
Lower end estimate	-5%	0%	5%
Anglian			
Upper end estimate	30%	40%	70%
Change factor	10%	15%	25%
Lower end estimate	-15%	-10%	-5%
Thames			
Upper end estimate	30%	40%	70%
Change factor	10%	15%	25%
Lower end estimate	-15%	-10%	-5%
SE England			
Upper end estimate	30%	55%	100%
Change factor	10%	20%	30%
Lower end estimate	-15%	-5%	0%

	Total potential change anticipated for the 2020s.	Total potential change anticipated for the 2050s	Total potential change anticipated for the 2080s
SW England			
Upper end estimate	30%	40%	75%
Change factor	15%	20%	30%
Lower end estimate	-5%	0%	5%
Severn			
Upper end estimate	25%	40%	70%
Change factor	10%	20%	25%
Lower end estimate	-10%	-5%	0%
Dee			
Upper end estimate	20%	30%	45%
Change factor	10%	15%	20%
Lower end estimate	0%	0%	5%
NW England			
Upper end estimate	25%	35%	65%
Change factor	15%	20%	30%
Lower end estimate	5%	10%	10%
Solway			
Upper end estimate	25%	35%	65%
Change factor	15%	20%	25%
Lower end estimate	5%	15%	10%
Tweed			
Upper end estimate	25%	35%	35%
Change factor	15%	20%	30%
Lower end estimate	0%	5%	15%

Table 1: Changes to river flood flows by river basin district compared to a 1961-90 baseline.

For changes beyond the 2080s, it is recommended that the 2080s changes are used. The 2020s covers the period 2015 to 2039, the 2050s the period 2040 to 2069, and the 2080s the period 2070 and 2099.

The illustration below, Figure 1, shows how the projections for changes in river flow may be plotted and used in typical assessments.

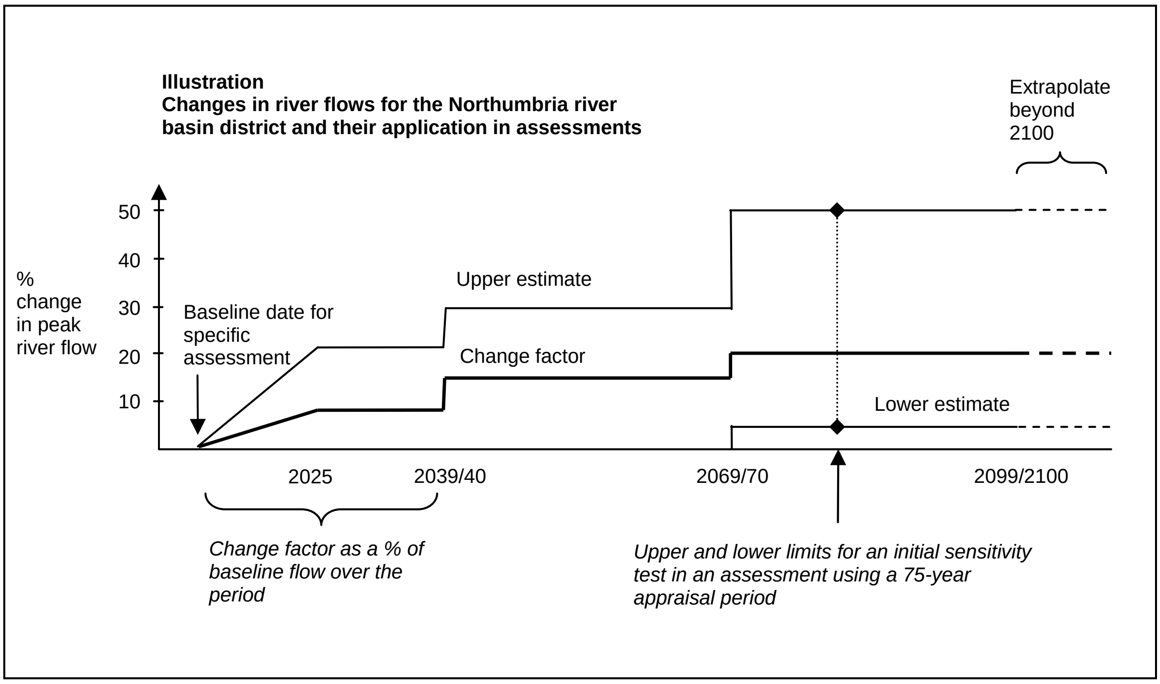

Figure 1. Changes in river flows for the Northumbria river basin district and their application in assessments.

H++ limits

The research showed that a small number of modelled catchments, within each river basin district, showed significantly greater increases to river flood flows than the standard catchment. We are not able to provide guidance yet to help RMAs determine whether they may be managing one of these non-standard catchment. But a H++ scenario is provided that represents the upper end estimate of these non-standard catchments, see Table 1a. For circumstances where the consequences of rare events could be extreme, RMAs may wish to test their decisions against the H++ scenario. This would help illustrate the risks such changes could present. If the study area falls outside the grey shaded area on the map in Figure 2, there is no need to investigate the H++ scenario as one of these non-standard catchments are not in these locations.

	Total potential change anticipated for the 2020s.	Total potential change anticipated for the 2050s	Total potential change anticipated for the 2080s
Northumbria	35%	45%	75%
Hull	35%	45%	75%
Anglian	35%	55%	90%
Thames	40%	55%	90%
SE England	40%	70%	125%
SW England	40%	60%	110%
Severn	40%	55%	100%
Dee	30%	45%	70%
NW England	40%	60%	105%
Solway	40%	55%	105%
Tweed	35%	50%	65%

Table 1a. H++ river flood flow scenarios for each river basin district.

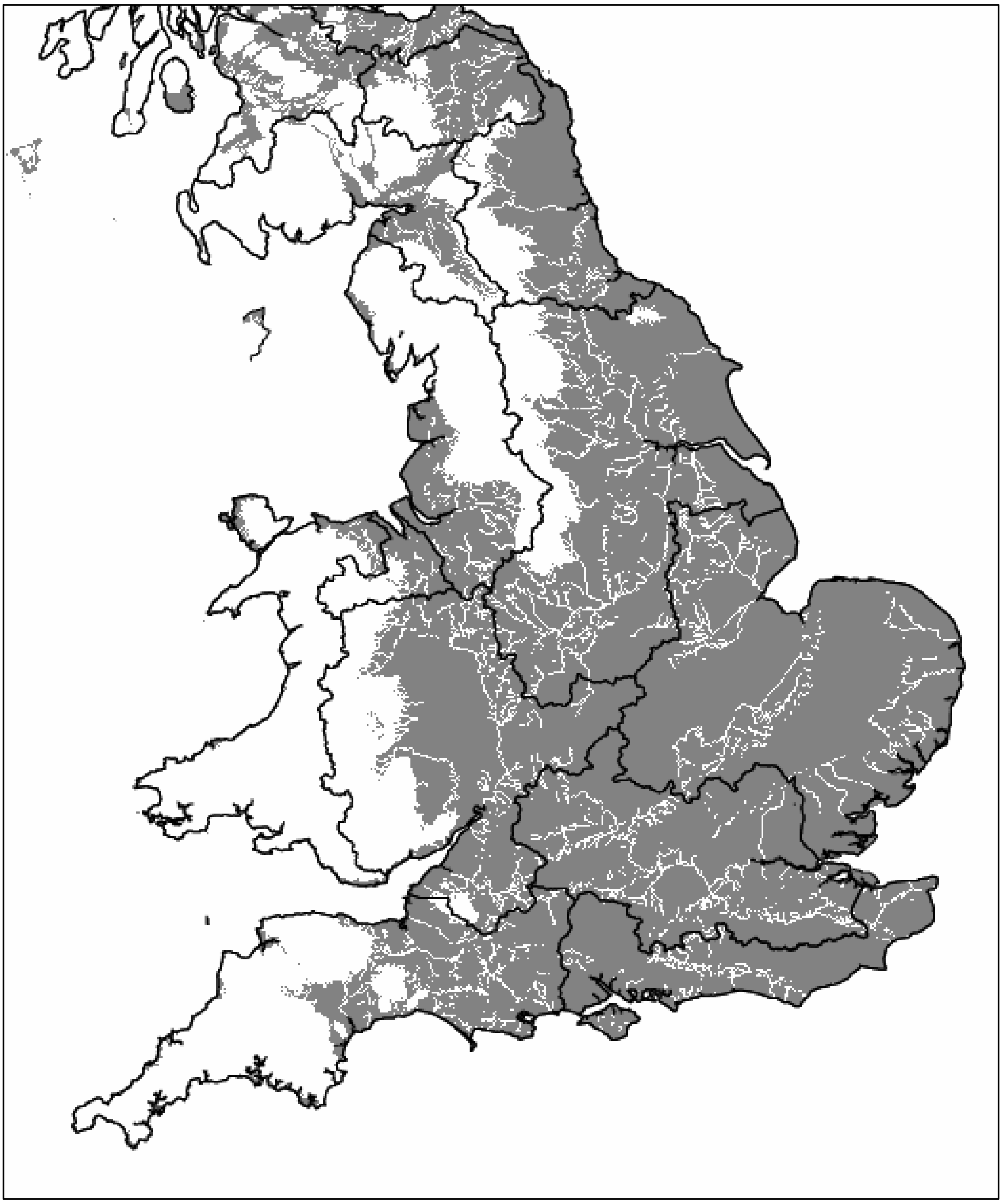

Figure 2. Map showing areas (grey) where the above non-standard catchment type is possible.

A map of river basin district for England is available here

2. Change to extreme rainfall

Although we are able to make qualitative statements as to whether extreme rainfall is likely to increase or decrease over the UK in the future, there is still considerable uncertainty regarding the magnitude of these changes locally. UKCP09 provides useful information on change to rainfall across the UK accessible through the user interface. This information is most robust for more common events such as changes to the wettest day of a season. Typically, for flood management purposes the concern is much rarer events such as those that have a 1 in 20 year chance of occurring or rarer. Developing quantitative predictions of future changes for such extreme rainfall at the local scale remains a key challenge for climate scientists. This is discussed further in Annex 3.

It is recommended that where projection of future rainfall is required for events more frequent that those with a 1 in 5 year chance of occurrence, information is taken from the UKCP09. Where rarer events are being considered, it is recommended that changes to rainfall presented in Table 2 are used.

Only maximum daily total rainfall data have been considered from the climate model projections, and so it is not possible to provide any guidance on how rainfall at hourly timescales may change.

Applies across all of England	**Total potential change anticipated for 2020s**	**Total potential change anticipated for 2050s**	**Total potential change anticipated for 2080s**
Upper end estimate	10%	20%	40%
Change factor	5%	10%	20%
Lower end estimate	0	5%	10%

Table 2: Change to extreme rainfall intensity compared to a 1961-90 baseline.

As with river flows, it is recommended that the 2080s changes are used beyond 2100. The 2020s covers the period 2010 to 2039, the 2050s the period 2040 to 2069, and the 2080s the period 2070 and 2099. Use of these ranges in assessments also follows the illustration set out for river flows.

The peak rainfall intensity ranges should be used for small catchments and urban/local drainage sites. For river catchments over, say $5km^2$, the peak flow ranges should be used.

No H++ scenario is provided for change to extreme rainfall.

3. Change to relative mean sea levels

Projections of relative mean sea levels for any location around the whole UK coast are provided within UKCP09. They are summarised and explained within the marine report, and available through the user interface.

UKCP09 relative sea level rise projections account for future land level movements. They also, for the first time, account for regional oceanographic effects. These regional effects arise from the difference in change in sea level for the region immediately surrounding the UK compared to the global mean.

UKCP09 relative sea level rise projections are available for three emission scenarios through the user interface as change relative to 1990 for any year up to 2100. They are presented as central estimates of change for each emission scenario with upper and lower confidence bands.

The projections are based on the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report. Since that was published the possible magnitude of sea level rise has attracted renewed attention, and a number of researchers have suggested that the IPCC numbers underestimate the range of potential sea level rise during the 21st century. For this reason, it is recommended that RMAs do not use the central estimates of relative sea level rise from UKCP09 as the change factor for their investment decisions. Instead, it is recommended that the upper confidence band (95 percentile) medium emission projection is used, see Table 3. The scientific basis for this recommendation is provided in detail in annex 3.

A low probability high end scenario is also presented within the UKCP09 (UKCP09 H++ scenario) marine report to provide users with estimates of sea level rise increase beyond the likely range but within physical plausibility. The UKCP09 H++ scenario is presented as a range for the whole of the UK, from 93cm up to 1.9m increase for 2100 compared to 1990. The UKCP09 H++ scenario range has been used to develop an upper end estimate and H++ scenario within this advice presented in Table 3 below. It is envisaged that only those circumstances involving events of extremely high probabilities or where the consequences of rare events could be extreme would be required to consider the H++ limits within assessments covering the period to 2115.

Because only the total sea level increase for 2100 is provided for UKCP09 H++ scenario rates of changes for different time-slices through the century are provided in Table 3.

The change factor and the lower end estimate can be taken direct from UKCP09 user interface for the relevant location. The user interface provides change for any year through the century compared to 1990. When taking projections from UKCP09, change up to 2115 should be derived by extrapolating beyond 2100.

	Sea level rise mm/yr up to 2025	Sea level rise mm/yr 2026 to 2050	Sea level rise mm/yr 2051 to 2080	Sea level rise mm/yr 2081 to 2115
H++ scenario	6	12.5	24	33
Upper end estimate	4	7	11	15
Change factor	Use UKCP09 relative sea level rise medium emission 95% projection for the project location available from the User Interface.			
Lower end estimate	Use UKCP09 relative sea level rise low emission 50% projection for the project location available from the User Interface.			

Table 3. Change to relative mean sea level.

4. Change to storm surge

The latest research into the future storm-surge climate presented in UKCP09 marine report is based on the Met Office Hadley Centre/Proudman Oceanographic Laboratory (POL) models. The Hadley Centre/POL models suggests that change to storm surge (defined as skew surge in UKCP09) around the UK, with a 1 in 50 chance of occurring in any given year, is projected to increase by less than 0.9 mm/yr (not including relative mean sea level change) over the 21st century. In most locations this trend could not be clearly distinguished from natural variability. The largest changes were found in the Bristol Channel and Severn Estuary.

There is a long-period natural variability known to affect European storminess (longer than a few decades). Over the century-scale, change has been reported to be of the order of 50cm. Accounting for this long-period variability would also account for the projected change to storm surge from UKCP09 over the century. Where coastal extreme water levels are derived from very long tide gauge records, the order of 100 years, the full range of natural variability will be accounted for.

It is anticipated that further advice will be provided in time to account for the full range of natural variability. It is recommended that a full and rigorous analysis of the current extreme coastal water levels is undertaken us the “national coastal flood boundary data for the coasts of England and Wales”, reports can be downloaded from http://publications.environment-agency.gov.uk/?lang=_e by searching on the title 'Coastal boundary'.

There is significant uncertainty in the projected change to the storm track over the UK, the primary driver of storm surge intensity and frequency. Other plausible international climate models were used in UKCP09 to evaluate alternative projections of storm surge over the century. This is presented in UKCP09 as a H++ scenario for storm surge. As with the H++ sea level rise scenario it is not possible to estimate how likely this is to occur, but the H++ storm surge scenario is not considered to be as unlikely as the upper end of the H++ sea level rise range. In this advice the UKCP09 H++ storm surge scenario is presented as the upper end estimate.

	Total potential change anticipated up to the year 2020s	Total potential change anticipated 2050s	Total potential change anticipated 2080s.
Upper end estimate	20cm	35cm	70cm
Change Factor	Ensure a rigorous assessment of the current coastal extreme water level has been undertaken	Ensure a rigorous assessment of the current coastal extreme water level has been undertaken	Ensure a rigorous assessment of the current coastal extreme water level has been undertaken
Lower end estimate	n/a	n/a	n/a

Table 4. Change to storm surge

Surge and mean sea level changes can be taken to be additive and change to extreme coastal water levels can be evaluated by adding the mean relative sea level change to the current extreme coastal water level. The base date of the EA national coastal flood boundary data estimates are from 2008, and any climate change projections into the future must use this as a start date for the calculations. The projections translate into assessments similar to the diagram for rivers with a fixed baseline date of 2008.

5. Change to wave climate

Change to wave climate is presented within UKCP09. There are large uncertainties especially with the projected extreme values. Changes in the annual maxima are projected to be between –1.5 m and +1 m. Projections of longer return period wave heights will reflect the same pattern but with larger error bars. Changes in wave period and direction are rather small and more difficult to interpret.

Given the significant uncertainty both to the future position of the storm track over the UK and the projections of wave climate within UKCP09, it is recommended that RMAs employ a sensitivity analysis to understand the impact on flood risk and coastal change, and the form of any feasible options. The sensitivity analysis can be used as part of the scenario neutral approach presented in Annex 2.

It is anticipated that over the next 12 months, wave climate projections will become available covering significant wave height, period and direction. When these are published this advice note will be updated to include that evidence.

Annex 2: Methodology

This annex provides advice for applying climate change projections in FCERM

The quantified information provided in Annex 1 of this advice note sets out the climate change factors to use when assessing future flood or coastal risks and uncertainty arising from climate change. The following methodology is provided to support Annex 1 and the wider principles set out in the introduction in section one of this note.

Previous guidance provided single estimates of change to evaluate risk at certain future epochs. There are weaknesses to this approach.

- It does not provide a full understanding of the inter-relation between change in climate and change in risk,
- no insight into what might occur if something happens other than the exact climate change prediction and, correspondingly,
- adaptation decisions may be tied to a narrow assumption of what might occur,
- when new scenarios are released, new impact studies have to be performed with additional cost.

An alternative approach, and the one presented here, is to undertake a sensitivity analysis across the range of plausible change over the life of the assessment and identify the adaptation responses that may be required. This is described here as a “scenario neutral approach” and does not rely on specific climate model results to predict change.

Once the sensitivity analysis has been done, this methodology recommends the development of adaptation options planning for the degree of change represented by the change factor, presented in Annex 1. However, rather than base options solely on the change factor, the analysis from the scenario neutral approach can be used to refine the options for a higher degree of preparedness for a wider range of future change. It may be necessary to undertake the ‘scenario neutral approach’ for interim periods within the overall assessment to inform options development, however, the amount of assessment should be kept to a proportionate minimum.

This should deliver adaptation options to take forward that are not tied to a single assumption of what may happen in the future and are therefore more able to cope with a wider range of possible future scenarios. This will help address the significant uncertainty in current climate projections, both at the scale and the timeframe of typical FCERM decisions.

This annex is designed to complement the activities normally undertaken in the development of FCERM plans and investment appraisals, such as risk assessment, option development and appraisal. Adaptation should not be considered as a separate exercise, but integrated into all activities to support wider objectives and outcomes.

The steps in this section are:

Steps	Question to address
a. Build on the assessment of current risks	What drives flood or coastal erosion risk today? What is the vulnerability to current climate? Is there information on areas that could be susceptible to change?
b. Assess potential future sensitivities	What is the sensitivity to future changes? Where is adaptation required and for what level of change?
c. Identify feasible options	What adaptation options are available across the range of possible future changes? Are there opportunities to sequence options or build in flexibility?
d. Refine Options	Is additional information or modelling necessary? What are the best options? What should be implemented and when?
e. Implement plans	Will future generations understand the decisions made?
f. Monitor, evaluate and review	Have the objectives been met? Does additional adaptation need to be undertaken or planned?

a. Build on the assessment of current risks

Risk assessment is central to FCERM planning and provides information that will help evaluate the impact of future change. Understanding flooding and coastal processes and vulnerability to the current climate can help identify:

- areas particularly sensitive to change,
- useful options, particularly no or low regret options
- help set priorities.
- and identify thresholds that if exceeded may lead to significant increase in impact.

Understanding historic vulnerability to other drivers, such as land-use change can also be helpful in identifying potential future sensitivities. An understanding of wider catchment or coastal processes will ensure adaptation is strategic and does not increase flood or erosion risk elsewhere.

b. Assess potential future sensitivities

The aim of this step is to assess the sensitivity to future change of the baseline option and identify where adaptation may be required. The baseline is often the ‘do nothing’ option in many applications but this should be established by reference to the substantive guidance for the relevant plans or investment appraisals.

This step sets out an approach to undertake a sensitivity analysis across the appropriate range of change. This is described as a “scenario neutral approach” — i.e. not relying on specific climate model predictions. This approach uses the tables in Annex 1 and will identify:

- areas very sensitive to change,
- areas tolerant to change
- potential adaptation options that may be required for different degrees of change

For high level plans the upper and lower estimates would be used to give an indication of the range that might occur over the lifetime of the plan and be used in the primary consideration of different policy options. Projections based upon the central change factor are largely of secondary use as a planning guide.

For investment appraisals the central change factor will provide the focus for options consideration with the upper and lower estimates providing a range to test the extent to which options can adapt.

The component of this step are:

Scenario Neutral Approach

Understand the range of possible future changes	Evaluate the potential range of change	Using the lower and upper estimates from Annex 1, what is the range of change that might occur over the appraisal period?
	Develop test scenarios	Based on the potential range of changes, identify a set of test scenarios to explore any sensitivities in the decisions being made
Broadly evaluate future sensitivity	Undertake broad risk assessment	Model future risks using test scenarios Is there significant change compared to the current risks?
	Identify areas sensitive to change	What areas are susceptible to change? Are some areas very sensitive to small degrees of change? Are some areas tolerant of large ranges of change?
Refine assessment of future sensitivity	Undertake more detailed assessment in areas susceptible to change	What additional information would improve the assessment? What impacts would more severe change have? Would some level of change present risks that would be very hard to mitigate?
	Iterate	Iterate stages 2-5 and consider what adaptation options are available

It is important that proportionate effort is taken. The test scenarios used initially should be designed to provide the broadest assessment of sensitivity to change and the development of the initial 'long list' of potential options. If there is significant sensitivity to change, then the test scenarios could be complemented by increments between the lower and upper end estimates. For instance, if the lower and upper end estimates for changes to river flows range from +5% to +30% and simply interpolating between increments is not considered a realistic option then, an assessment to change could be undertaken moving incrementally from +5%, +10%, +20% and +30%. It is best to use a risk based approach, initially assessing the broad scale, later focusing if necessary on those areas that are at highest risk and/or most vulnerable to change.

The lower and upper end estimates can help in representing the range of risks. But, there is still the likelihood, although low, that change could be outside this range. To further support the analysis the H++ scenario for sea level rise and change to river flows can be used. Additionally, the test scenarios can be extended by using, for example, a historic worst case, a hypothetical worst case scenario or by targeted sensitivity testing.

The important thing is not to limit the analysis to an overly narrow assumption of what degree of climate change may occur while overall keeping the effort involved proportionate to the implications for decision-making.

c. Identify feasible options

The aim of this step is to identify options that can ideally adapt to cater for the sensitivity to change shown by the assessment in step b. It may be that some options are not able to provide this degree of adaptation but it may still be appropriate for them to be included in the list for consideration in the remaining development stages of the plan or appraisal. Options should be developed in-line with the overall objectives and constraints of the project. This work should be done at a scale commensurate with the needs of the plan or appraisal

Developing adaptation options to cover the range of change from section b will help identify the full range of what may be required in the future. Options can be developed to respond to change from the lower through to the upper end estimates. There are a number of approaches that can be applied to develop feasible options.

Identify options that could deal with a range of change.	One approach is to develop options that reduce risk over the range of change or could be designed from the outset to cope with the upper end estimate of climate change.
Build in flexibility	Another approach is to build in the ability to adjust an option should it be required; i.e. build in flexibility. Examples include purchasing an area behind a flood wall to enable the wall to be raised if necessary.
Delay decisions that would be difficult to change — Adaptive Management	A complementary approach is to build flexibility into the decision process itself over time through waiting and learning. For example, sequencing options so that no or low regret options are taken earlier and more inflexible measures are delayed in anticipation of better information.

d. Refining options

The preceding steps will have provided an understanding of the sensitivity of the system to future change and may have enabled options to be developed sufficiently to inform the final decision-making processes. Where this is not the case then some refinement will be necessary which is likely to involve considering change over interim periods of the overall plan or appraisal period.

We recommend that options are refined using the change factor presented within Annex 1. However, rather than base options solely on the change factor, the analysis from section c can also be used to refine the options so that they better reflect the wider range of future change. Only in exceptional circumstances would it be necessary to use the upper and lower estimates at the interim level.

For instance, an option could be developed to manage the change factor over the whole life of the plan, but have flexibility built-in to cater for the different changes suggested by the upper and lower limits. A decision will be required in the future whether to use this additional response. The timing of that decision will be dependent on the lead time to mobilise the additional response and the actual rate of climate change. It may be that an assessment over interim periods is therefore necessary where such refinement would be cost effective and necessary to adequately inform options definition and decisions.

There may be a number of feasible options. The options will need to be critically assessed using the wider required objectives or outcomes of the appraisal. At this stage it is worth considering the following questions:

- How flexible should the option be?
- How robust should the option be?

It may be useful to consider the following criteria in more depth to refine the options

Criteria	**Description**	**Considerations**
Flexibility	An option's ability to be adjusted to new information or circumstances in the future	Could require additional work (and cost) now to build in flexibility, but may be better than retrofitting later.
		Generally, flexibility may be a good option where the cost of a precautionary approach is high, and options can be designed for cost-effective modification at a later stage
		Risk that the future adjustment won’t be implemented — enforcement may be problematic
Robustness	A decision is robust if it is unaffected by a wide range of possible future scenarios	Greater resource use (and potentially cost) now against the benefits of decreased vulnerability to a wide range of possible future climatic changes
		Risk that additional capacity may be redundant if climate change is not so severe
		Less requirement to revisit decisions in the future, no risk that later adjustments won’t be implemented
		Generally, robustness is a good option where the cost difference of adapting to different futures is small, e.g. minor level raising of upstream storage reservoir – or where the cost (or risk) of flexibility is prohibitive – e.g. the cost of deepening a flood relief channel at a future date
Flexible and Robust		Sequencing interventions and/or making them flexible may allow for more severe climate change to be managed. Delaying additional work until there is greater certainty may save costs.

We recommend that where possible opportunities are sought to sequence the investment over time, rather than implement a robust (precautionary) design from the outset. This should provide a more responsive design to adjust for changes in our climate change knowledge in the future, and so be more cost-effective.

It may not be possible to identify a series of actions to cover the whole of the decision period now. The best outcome may be actions that take us part way through the period where there is most confidence of the magnitude of climate change or of what actions must be taken. For the remainder, where uncertainty is greater, a number of conditional options may have been identified that could all be relevant, i.e. 'if X occurs by date Y, then do Z'. This requires the identification of 'triggers' to indicate when a decision must be made to implement the action. These 'trigger' levels will need to be identifiable and capable of being monitored. The focus now should be keeping the preferred later options open. It can be decided through periodic review if they will be required ultimately.

The ability to enforce later actions is vital if flexibility is to be designed into the options. Enforcement may not happen because the plan's legacy is not understood by future generations, later interventions by others act to limit the ability to deliver the planned action, or because other flood or coastal needs in the future take priority. These risks will need to be identified and mitigated if flexibility is to be pursued,

It will be necessary to decide whether to implement an action within the option(s) straightaway. Generally, there are a number of things to consider to decide what should be done now:

- Action is needed where the current risk is considered unacceptable
- Action is needed in areas where any delay could lock-in irreversible impacts or limit flexibility to cope with future climate change
- Take opportunities to incorporate adaptation into planned maintenance or regeneration activities
- Take opportunity to implement adaptations that will have immediate or multiple benefits or are low cost

Note. Real options analysis, described in HM Treasury supplementary guidance on adaptation, can help in determining the cost-effectiveness of building flexibility into the option. However, it requires a view of the likelihood of different climate change outcomes. There is still considerable uncertainty in the understanding of climate change on flood and coastal erosion and confidence in probabilistic projections of climate change at the local scale and at longer timescales is low. The principles of real options can certainly be useful to develop options for appraisal, but the use of the full method to optimise adaptation options may not be cost-effective for many FCERM projects.

e. Implementation

FCERM decisions typically cover long lifetimes. The future contains considerable uncertainty, it is vital that the assumptions and actions taken are fully recorded. It is likely that later generations will have to reconsider our plans and determine whether planned interventions should be made or that additional actions are required.

A record of the actions and assumptions should be made secure for the lifetime of the plan and all information clear and accessible to later generations. If the future begins to emerge differently, it should be clear how the timing, form and degree of the later interventions would change and how this is to be monitored using the triggers identified in step c or d. The plan should also record the estimated intervention lead times and how these may change under different rates of climate change. The mechanism to enforce later actions should be identified and recorded. If responsibility lies with others they will need to take ownership.

In line with the FCERM National Strategy for England adaptation should be delivered consistently within a catchment or coastal cell. Consideration should be given to adjacent plans and higher level plans.

Adaptation to climate change may affect flood or coastal erosion risk elsewhere, and the ability of others to adapt, now or in the future. This should be considered in the option development and subsequent implementation plan. Well planned actions to better manage flood or erosion risks should not result in consequential impacts on third parties.

f. Monitoring, evaluation and review

Planning is only the first step. Adaptation is an iterative process of planning, implementation and review. It will be important to monitor, evaluate and periodically review the performance of adaptation within FCERM decisions.

Where there is some flexibility in a project, either in terms of sequencing of options or possible adjustments in interventions, plans should be responsive to new information; for example, a given level of impact might trigger implementation of an additional measure. Plans may require monitoring strategies to collect information on change both within the physical system and climate change projections for evaluation and review. This information can be used to inform the periodic review of FCERM plans and strategies.

Links to the FCERM Appraisal Guidance

Flood and Coastal Erosion Risk Management Appraisal Guidance sets out how to put the Defra Policy Statement: Appraisal of Flood and Coastal Erosion Risk Management, June 2009, into practice. The appraisal guidance is used for all projects applying for grant funding. The advice given here on climate change adaptation supports the appraisal guidance replacing the supplementary note, October, 2006.

The principles set out within the FCERM appraisal guidance regarding uncertainty, adaptable management, flexibility in design and sensitivity analysis are very relevant for climate change adaptation. This advice further promotes these principles, additionally setting out an approach aimed to develop measures that will be successful given the future risks we face and the uncertainty in the magnitude of change.

Schemes involving Flood Defence Grant in Aid (FDGiA)

An RMA may decide to recommend an investment decision that is not based on the change factor in this advice. However where FDGiA is involved in its implementation, the investment appraisal supporting the application for grant must develop at least one option based on the advised change factor so that it is possible, during the grant application process, to understand the implications of any alternative factor which may influence the outcome of the application. This approach also ensures that the implications of alternative interpretations on how risk is assessed and managed can be more consistently compared and communicated.

We recommend that RMAs making FCERM investment decisions not attracting grant funding also follow this approach.

Annex 3 Supporting Science

This annex provides background information to the development of changes provided in annex 1. It also provides useful links to other sources of information.

Projections of sea level rise

Information on projected change to the marine environment is provided by UKCP09 marine and coastal projections chapter. The Marine Climate Change Impacts Programme Annual Report Card 2010/11 provides an update on scientific understanding of climate change impacts on our seas.

Sea Level Rise	Current trends	Future Projections
	Global sea level has risen at a mean rate of 1.8mm per year since 1955. From 1992 onwards a higher mean rate of 3mm per year has been observed.	An increase in global sea level rise below 1m is still considered more likely than a rise of above 1m by the end of the century
	Sea-level rise measured over the UK is consistent with the observed global mean	Projections of change from UKCP09 for the UK suggest a rise of between 12 and 76cm by 2095, compared to a 1980-1999 baseline, not including vertical land movement. This approximately equates to rates of between 1.2 and 7.6 mm per year respectively.
		Considering projected land movements, a greater rise in southern regions of the UK is likely relative to the north.
		Faster melting of Antarctic and Greenland ice sheets could result in sea level rise greater than the UKCP09 projections above. Although, it cannot yet be predicted how fast this will occur estimates of its likely maximum size based on observations of the past, and plausible constraints on ice sheet dynamics are provided in UKCP09 as a H++ scenario ranging from 93cm to 1.9m globally by 2100.

Table 5. Summary of latest research findings on sea level rise for the UK.

UKCP09 sea level rise projections are based on the IPCC's fourth assessment report[i], 2007.

Some components of future sea level rise are thought to be well understood such as the contribution from thermal expansion of the oceans. However, what is not well understood is the stability of the Greenland and Antarctic ice sheets and their contribution to sea level rise through the flow of the outlet glaciers and ice streams that drain these ice sheets[ii]. Numerous processes contribute to the rate of flow, but these processes cannot yet be properly modelled. Observations suggest that they have contributed 0 – 0.7 mm/year to sea level rise during the period 1993-2003. The projections in the fourth assessment report assume that this contribution (1993-2003) simply remains constant until the end of this century. A number of authors have suggested that this approach underestimates the possible magnitude of sea level rise during the twentieth century[iii].

Observations, largely from satellites, show that both ice sheets are losing mass overall[iv]. There was an acceleration in the rate of ice flow especially since 2003, due to the speed–up of many outlet glaciers on the Greenland and ice streams in the West Antarctic Ice Sheet. This recent acceleration may be due in part to natural variability, and might not continue[v]. Observations show that a number of the outlet glaciers that accelerated have since started to slow. Research on-going under the ICE2SEA program[vi] will improve projections of the contribution of ice to future sea-level rise. Some of these results may be available for the IPCC fifth assessment report in 2013.

It is also worth noting that the IPCC fourth assessment report models used for the sea level rise projections do not include uncertainties in climate-carbon cycle feedback and so do not cover the full range of projected global mean temperature change reducing the potential upper end estimate of sea level rise.

There have been a number of papers that have commented on the sea level rise projections from IPCC fourth assessment report and some have tried to derive a better estimate of rise through the century[vii]. There have been a number of approaches to this. Some have used a semi-empirical method[viii], others consider the eventual contribution from different glacier flow velocities[ix], others proxy records from the last interglacial period[x], and others have used expert opinion[xi].

In the Netherlands, expert judgement was used to derive sea level rise scenarios for coastal management. That concluded that plausible global sea level rise scenarios were 0.55m to 1.1m in 2100. In UKCP09, reported work published by Pfeffer et al, 2008[xii]. They concluded that an increase of up to 2m of sea level rise for the twenty-first century cannot be excluded. But a rise of 0.8m is more likely.

Given the research since the IPCC fourth assessment report it seems clear that considerable uncertainty in sea level rise projections remains. This implies the need for coastal managers to keep open a range of adaptation options and to be able to change the approach as the predictions become more robust. It also leads to the recommendation in annex 1 to use the upper end of the medium emissions scenario from UKCP09 as the change factor, especially where coastal managers are not able to pursue a managed adaptive approach.

Land levels are changing across the UK as a result of the earth's crust responding to the loss of the ice sheets following the end of the last ice age. These vertical land movements' trends are well understood and expected to remain constant over the 21st century[xiii].

Projections of storm surge and wave climate

Storm surge and waves	Natural variability in wave climate is large and the role of anthropogenic influence is unclear.	There is no consensus on the future storm and wave climate for north-western Europe, since projected future storm track behaviour varies among atmospheric models.
	Increases in monthly mean and maximum wave height in the north-eastern Atlantic occurred between 1960 and 1990; however, this rise in wave height may be part of long-term natural variability. There has been no clear pattern since 1990.	Predictions of storm behaviour used by the UKCP09 wave model show storm tracks moving south, resulting in lower wave heights to the north of the UK and slightly larger wave heights in some southern regions, especially the south-west.
	There is no significant evidence for any recent observed trend in storm surge frequency or magnitude.	Changes to storm surge driven extreme water levels appears to be less important than changes in global mean sea level over the next 100 years.

Table 6. Summary of latest research findings on changes to storm surge for the UK.

The main driver of future risk on the coast is predicted to be sea level rise, rather than change to storm surge intensity, although there is no consensus on the future storm and wave climate for north-western Europe.

Projections of change to river flood flows

Significant positive trends were observed in all high-flows indicators over the 30–40 years prior to 2003, primarily in maritime-influenced, upland catchments in the north and west of the UK. But, there is little compelling evidence for high-flow trends in lowland river flows. Long river flow records (>55 years) provide little compelling evidence for long-term trends but show evidence of pronounced multi-decadal fluctuations. Trends are thought to be linked to changes in winter precipitation arising from changes in atmospheric circulation patterns (North Atlantic Oscillation); it is not clear if this is natural variability or the mark of a changing change[xiv].

Defra and the Environment Agency have funded substantial research to consider future change to river flood flows in England and Wales, reports available here.

The summary findings are:

- Results for the 2080s show that for the catchments modelled (155 in total) the Defra 2006 20% allowance no longer encompasses the majority of catchment changes in flood flows using the UKCP09 climate projections. Current guidance is likely underestimating the changes to future river flows for a significant number of catchments tested with UKCP09 and other climate models.
- This challenges the degree to which the current guidance provides precautionary factors for river flows.
- Some 15% of catchments modelled showed changes in the central estimate of river flow greater than 30% for the 2080s using UKCP09 projections.

- There is strong evidence from our research that catchment response to climate change is dependent on catchment properties. This implies that a single national factor for climate change may be inappropriate and that more ‘regionalised’ allowances, based on catchment type, should be developed.
- By continuing with a single national factor we would be under-representing the future risk for certain types of catchments for certain locations in the country.
- We are now much better able to understand how different catchment properties influence river flow changes from climate change, potentially allowing us to provide regionalised projections of change by catchment types and location.
- We have developed a technique to determine catchment response to climate change for the whole of the river network in England and Wales.
- UKCP09 does not provide us with a full understanding of changes to extreme, e.g. convective rainfall at the scales we need to manage, so there is a high degree of uncertainty associated with changes to river flows for small, rapidly responding catchments — typically heavily urbanised catchments

This research formed the basis for the change factors provided in annex 1 together with a methodology to determine catchment type.

Projections of change to Extreme Rainfall

There has been significantly increased precipitation over northern Europe (an area which includes the UK) between 1900 and 2005; particularly noticeable since about 1979. These changes are likely to be the result of human activity[xv]. There have been more frequent spells of very wet weather and an increase in total precipitation, at least during the last 40 years. Over the past 100 years the intensity of UK precipitation has increased during winter and to a lesser extent also during spring and autumn. All regions of the UK have experienced an increase over the past 45 years in the contribution to winter rainfall from heavy precipitation events[xvi].

- UKCP09 does not provide us with a full understanding of changes to extreme, convective rainfall at the scales we need to manage for surface water flooding
- Met Office research[xvii] carried out for the Pitt Review in 2008 suggested that the 1:20 year rainfall event could increase by up to 40% at the local scale.
- Compared to the Defra 2006 guidance (+20% for the 2080s) this means we could be under-representing changes to extreme rainfall for some regions of England and Wales
- The UKCP09 toolkit does not provide adequate resource to allow for future flood risk assessments for low probability rainfall events (rarer than 1:5 annual probability) without additional guidance
- The Met Office research for the Pitt review has been used as the basis for the numbers provided in annex 1.

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