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.

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1 Introduction

This advice is an update to the 2011 version of '*Adapting to Climate Change: Advice to Flood & Coastal Risk Management Authorities*'. 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 (FCERM) appraisal guidance for projects, which can be found on Gov.uk.

This version of the document reflects an assessment completed by the Environment Agency between 2013 and 2015 using UKCP09 data, to produce more representative climate change allowances for England. There have been no changes to the climate change allowances for wind speed, wave height, storm surge, mean sea level or peak rainfall intensity. There have been small changes to peak river flow allowances in many of the River Basin Districts. The 10th (Lower), 50th (Central), 70th (Higher Central) and 90th (Upper) percentiles are presented. The 50th (Central) percentile was previously referred to as the 'change factor' in earlier versions of this document.

This advice is based on Government's policy for climate change adaptation, and is specifically intended for projects or strategies seeking Government Flood & Coastal Erosion Risk Management Grant in Aid (FCERM FCERM GiA). 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.

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 that compete for central government grant, as well as ensuring that the most appropriate means of reducing risk is investigated in any one place.

Given the long lifetime and high cost of the built environment and many flood and coastal erosion management measures, it is imperative that plans and investment projects take into account, in an appropriate way, the changing risks over the coming century. This includes designing for adaptation to a changing climate where appropriate.

Defra's appraisal policy statement recommends a "managed adaptive approach" where possible and sets out some broad principles that should be considered. A managed adaptive approach is based on taking action when particular trigger points are observed. It 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 pre-determined interventions. This provides flexibility to manage future uncertainties associated with climate change.

In some circumstances, a managed adaptive approach may not be technically feasible. 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. Considering only precautionary options would lead to greater levels of investment at fewer locations. 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 advice should be applied to all future appraisals that are started (new) from March 2016 or are to be submitted for approval after 1st September 2016. 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 September 2016, if the new advice can be factored in, or the plan or investment decision tested against it 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 climate change allowances

What are the climate change allowances?

To assess the potential impacts that climate change may have on extreme rainfall, river flood flows, sea level rise and storm surges, climate change allowances are provided in Annex 1. The climate change allowances quantify the potential change (as either mm or percentage increase, depending on the variable) to the baseline. The climate change allowances are based on the best available, credible, peer-reviewed scientific evidence from UKCP09, but given the complexity of the science around climatic projections, there are significant uncertainties attributed to the climate change allowances. This is why the climate change allowances are presented as a range of possibilities (Lower, Central, Higher Central and Upper), to reflect the potential variation in climate change impacts over three epochs from the present day to 2115. It is recommended that the performance of flood risk management options are assessed against all of the change allowances covering the whole of the decision lifetime.

The climate change allowances are based on UKCP09 or research using UKCP09 data. UKCP09 provides a large toolkit of information and data. The climate change allowances have been developed to help RMAs use the UKCP09 information in a timely and cost-effective way and to provide a consistent approach. Climate change allowances 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 1, below.

Lower (10th percentile), Central (50th percentile), Higher Central (70th percentile) and Upper (90th percentile) climate change allowances are provided to help represent the range of the future risks. The focus of this document is to inform the design and resilience of flood and coastal erosion risk management schemes, which should consider credible and reasonable climate change impacts. For example, most FCERM schemes are designed to the Central allowance (formerly referred to as the ‘change factor’ in previous versions of this document), with sensitivity testing completed against the Upper allowance to understand potential impacts and any ‘cliff-edge’ effects, where the flooding consequences of the Upper allowance may shift and become extremely severe. The Upper allowance should be used in scheme design to consider the longer term sensitivity to future climate change impacts. Mitigation measures should be determined and planned for in the scheme (e.g. through a strategy for managed adaptation) up to the Higher Central allowance – thereby encouraging the use of managed adaptation. Government recommends that when considering climate change a full appreciation of emission scenario and climate uncertainty is taken into account. The Central, Higher Central and Upper allowances are designed to achieve this within flood and coastal erosion risk management applications.

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

Table 1 Potential changes in peak river flow for Northumbria River Basin District

	Total potential change anticipated for '2020s' (2015-39)	Total potential change anticipated for '2050s' (2040-2069)	Total potential change anticipated for the '2080s' (2070-2115)
Northumbria			
Upper (90th percentile)	20%	30%	50%
Higher Central (70th percentile)	15%	20%	25%
Central (50% percentile)	10%	15%	20%
Lower (10th percentile)	5%	5%	10%

Although we have a reasonable level of certainty that the future impacts of climate change will lie somewhere between the Central and Upper allowances, more extreme change cannot be discounted. To help represent this extreme change "H++ scenarios" have been included in line with the UKCP09 approach. These can be used to represent more severe climate change impacts and help identify the options that would be required.

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

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

4 Limitations and Managing Exceptions

The climate change allowances provided have been derived from national scale research. There may be cases where local evidence supports the use of other local climate change allowances. In such cases decision makers may use alternative climate change allowances where robust science supports this. Where national flood and coastal erosion risk management grant-in-aid (FCERM GiA) is being sought, the Environment Agency will need to be satisfied that more recent, credible, peer-reviewed scientific evidence has been used in the assessment which is sufficiently robust to consider 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 other data and the implications should be transparent and recorded within the plan or investment decision documentation.

Annex 1 Provision of climate change allowances

1. Changes to river flood flows by river basin district

Understanding of the potential changes to river flood flows from climate change was significantly improved following the completion of the joint Defra/ Environment Agency research project *FD2020 – Regionalised impacts of climate change on flood flows* (2009). 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.

Defra and the EA undertook a further research study in 2010 ('FD2648') that looked at the range of responses from 155 catchments across England and Wales under the UKCP09 probabilistic scenarios (medium and high emissions only). They suggested that the level of risk can vary quite substantially between river-basin regions, so setting regional allowances would be preferable to a single nationwide allowance of peak flows. Towards the end of 2011 the Environment Agency published the first version of '*Adapting to climate change – Advice for flood and coastal risk management authorities*'. This provided a range of allowances for each river basin district that reflected the findings of FD2648.

The revised climate change allowances provided in Table 2 are based on the same approach (by river basin district) as used in the 2011 version of '*Adapting to climate change: Guidance for flood risk management authorities'* but with some differences:

- A 'Higher Central' allowance has been added based on the 70th percentile as an option between Central and Upper allowances, as it will be helpful as an intermediary step to understand where potential 'cliff-edge' effects are experienced between the Central and Upper allowances. Furthermore, it is envisaged that schemes will consider planning for adaptive mitigation for future climate change by considering the potential effects under the higher Central allowance.
- The Upper is based on 90th percentile rather than the 80th percentile plus one standard deviation used in the 2011 document.

Finally, the allowances are based on UK analysis of the UK Climate Projections, not the England and Wales Climate Projections that were used in the 2011 analysis.

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

The climate change allowances correspond to the Central estimate of change from the research. The projections are percentage changes to a 1961-90 baseline.

Table 2 Peak river flood flow allowances by river basin district (use 1961-90 baseline)

Climate Change estimate (percentile)	Total potential change anticipated for 2020s (2015-39)	Total potential change anticipated for 2050s (2040-2069)	Total potential change anticipated for the 2080s (2070-2115)
Northumbria			
Upper (90th)	20%	30%	50%
Higher Central (70th)	15%	20%	25%
Central (50th)	10%	15%	20%
Lower (10th)	5%	5%	10%
Humber			
Upper (90th)	20%	30%	50%
Higher Central (70th)	15%	20%	30%
Central (50th)	10%	15%	20%
Lower (10th)	5%	5%	10%
Anglian			
Upper (90th)	25%	35%	65%
Higher Central (70th)	15%	20%	35%
Central (50th)	10%	15%	25%
Lower (10th)	0%	0%	5%
SE England			
Upper (90th)	25%	50%	105%
Higher Central (70th)	15%	30%	45%
Central (50th)	10%	20%	35%
Lower (10th)	-5%	0%	5%
Thames			
Upper (90th)	25%	35%	70%
Higher Central (70th)	15%	25%	35%
Central (50th)	10%	15%	25%
Lower (10th)	-5%	0%	5%
SW England			
Upper (90th)	25%	40%	85%
Higher Central (70th)	20%	30%	40%
Central (50th)	10%	20%	30%
Lower (10th)	5%	5%	10%
Severn			
Upper (90th)	25%	40%	70%
Higher Central (70th)	15%	25%	35%
Central (50th)	10%	20%	25%
Lower (10th)	0%	5%	5%
Dee			
Upper (90th)	20%	30%	45%
Higher Central (70th)	15%	20%	25%
Central (50th)	10%	15%	20%
Lower (10th)	5%	5%	5%
NW England			
Upper (90th)	20%	35%	70%
Higher Central (70th)	20%	30%	35%

Climate Change estimate (percentile)	Total potential change anticipated for 2020s (2015-39)	Total potential change anticipated for 2050s (2040-2069)	Total potential change anticipated for the 2080s (2070-2115)
Central (50th)	15%	25%	30%
Lower (10th)	10%	10%	10%
Solway			
Upper (90th)	20%	30%	60%
Higher Central (70th)	15%	25%	30%
Central (50th)	10%	20%	25%
Lower (10th)	5%	10%	10%
Tweed			
Upper (90th)	20%	25%	45%
Higher Central (70th)	15%	20%	25%
Central (50th)	10%	15%	20%
Lower (10th)	0%	5%	5%

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 2115.

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

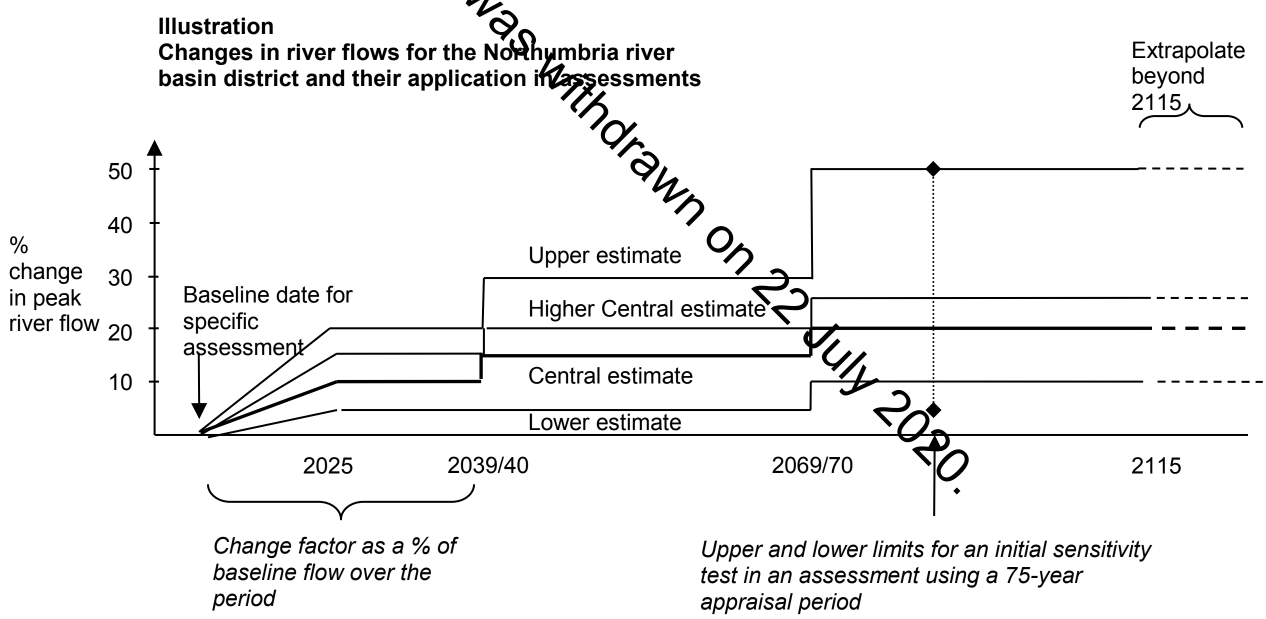

Figure 1 Changes in river flows for the Northumbria river basin district and their application in assessments

H++ limits

The research showed that a small number of modelled catchments, within each river basin district, exhibited significantly greater increases to river flood flows than the standard catchment. We are not able to provide guidance to help RMAs determine whether they may be managing one of these non-standard catchments. But a H++ scenario is provided that represents the Upper estimate of these non-standard catchments, see Table 3. For circumstances where the consequences of rare events could be extreme, RMAs may wish to test their designs and plans against the H++ scenario. Extreme consequences could include flooding of nuclear installations or large scale energy generating infrastructure, for which the scale of the flooding impact may extend far wider than the immediate locality of the flooding incident. This would help illustrate the risks such changes could present, but given that H++ estimates represent the Upper limit of climate projections that are considered plausible, it would not normally be expected for schemes or plans to be designed to/ incorporate built-resilience for the H++ estimate. 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 the study area will not be located within a non-standard catchment.

Table 3 H++ river flood flow scenarios for each river basin district

	Total potential change anticipated for '2020s' (2015-39)	Total potential change anticipated for '2050s' (2040-2069)	Total potential change anticipated for the '2080s' (2070-2115)
Northumbria	20%	35%	65%
Humber	20%	35%	65%
Anglian	25%	40%	80%
Thames	25%	40%	80%
SE England	30%	60%	120%
SW England	25%	50%	105%
Severn	25%	45%	90%
Dee	20%	30%	60%
NW England	25%	45%	95%
Solway	25%	45%	95%
Tweed	20%	35%	75%

NOTE: H++ allowances taken as 90th percentile from 'Enhanced High' impact curves for 50-year return period flood peaks, using high emissions for 2080s but medium emissions for 2020s and 2050s (Adaptation Sub-committee, 2015)

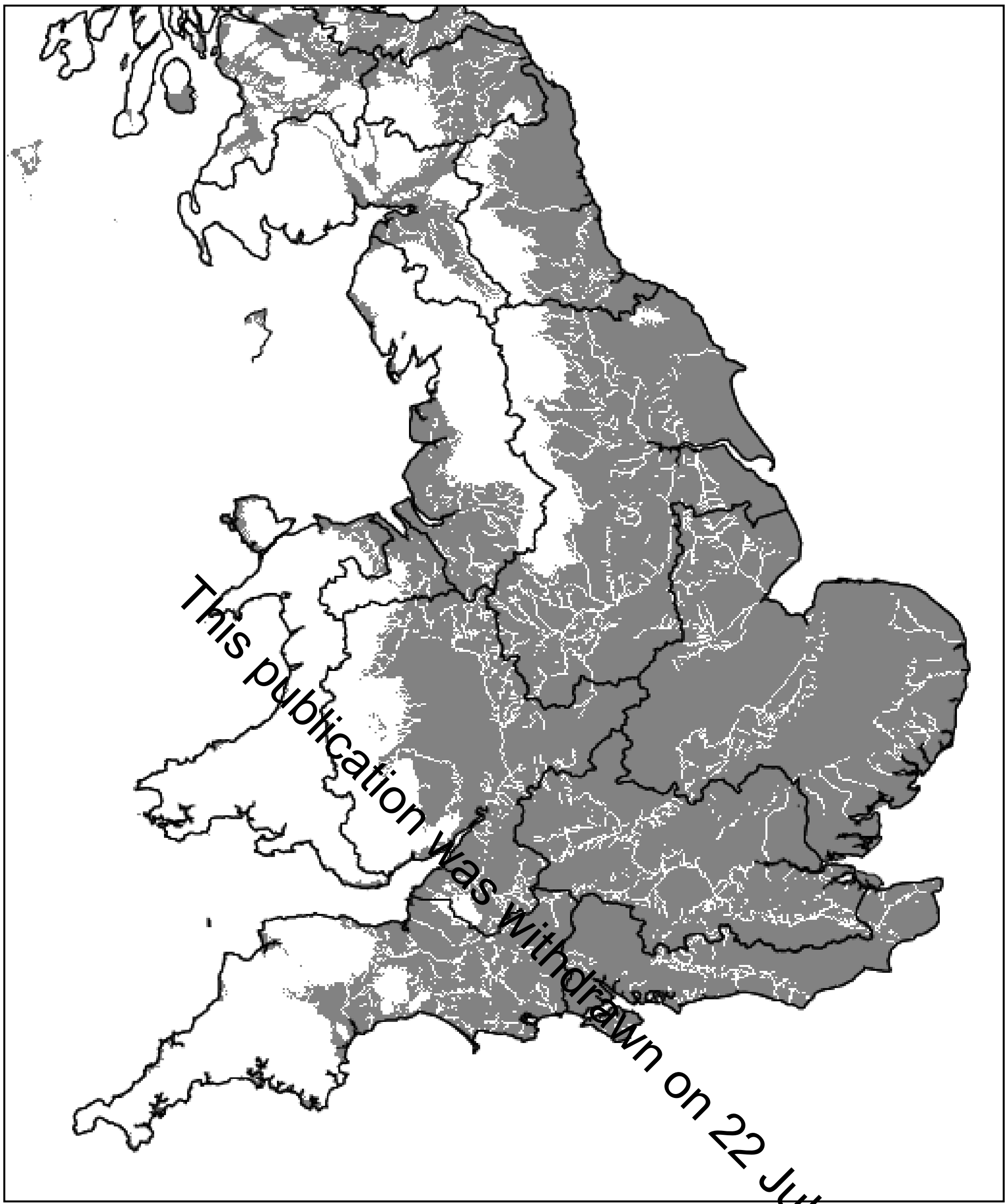

Figure 2 Map showing areas (grey) where the above non-standard catchment type is possible

A map showing the river basin districts for England and their names 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.

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 4 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.

Table 4 Change to extreme rainfall intensity compared to a 1961-90 baseline

Applies across all of England	Total potential change anticipated for '2020s' (2015-39)	Total potential change anticipated for '2050s' (2040-2069)	Total potential change anticipated for the '2080s' (2070-2115)
Upper estimate	10%	20%	40%
Central estimate	5%	10%	20%

As with river flows, it is recommended that the 2080s changes are used beyond 2115. The 2020s covers the period 2015 to 2039, the 2050s the period 2040 to 2069, and the 2080s the period 2070 and 2115. These ranges should be used in assessments in a similar way to 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 changes 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 and Coastal Projections Report, and are available through the user interface.

UKCP09 relative sea level rise projections account for future land level movements. They also, 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 2115. 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 potential sea level rise range 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 climate change allowances for their investment decisions. Instead, it is recommended that the upper confidence band (95th percentile) medium emission projection is used as the climate change allowance, see Table 5.

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 estimate and H++ scenario within this advice presented in Table 5 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-periods through the century are provided in Table 5.

The recommended climate change allowance can be taken directly from the UKCP09 user interface for the relevant location. The user interface provides a change estimate 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.

Table 5 Mean sea level allowance (compared to 1990 baseline, includes land movements)

Change to relative mean sea level	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.			

4. Change to storm surge

The 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, of the order of 100 years, the full range of natural variability will be accounted for.

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 considered more likely than 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.

Table 6 Change to storm surge

	Total potential change anticipated up to the 2020s	**Total potential change anticipated up to the 2050s**	**Total potential change anticipated up to the 2080s**
Upper end estimate	20cm	35cm	70cm
Recommended climate change allowance	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

Surge and mean sea level changes can be taken to be additive and changes to extreme coastal water levels can be evaluated by adding the mean relative sea level change to the current extreme coastal water level. The projections translate into assessments similar to the diagram for rivers.

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 small and more difficult to interpret. Recommended national precautionary sensitivity ranges for offshore wind speed and wave height are presented in Table 7.

Table 7 Recommended national precautionary sensitivity ranges for offshore wind speed and wave height

Parameter	**1990 to 2025**	**2025 to 2055**	**2055 to 2085**	**2085 to 2115**
Offshore wind speed	+5%		+10%	
Extreme wave height	+5%		+10%	

Annex 2 Methodology

This annex provides advice for applying climate change projections in Flood and Coastal Erosion Management

The quantified information provided in Annex 1 of this advice note sets out the climate change allowances 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.

The approach presented, 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.

Once the sensitivity analysis has been done, this methodology recommends the development of adaptation options planning for the degree of change represented by the climate change allowances, presented in Annex 1. However, rather than base options solely on the climate change allowances, the understanding from the sensitivity analysis can be used to refine the options for a wider range of future change. It may be necessary to undertake the sensitivity analysis 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 as follows:

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. 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 the following:

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

Understanding historic vulnerability to other drivers, such as land-use change can also be helpful in identifying areas that could be susceptible to future changes. 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 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 undertaking a sensitivity analysis across the appropriate range of change. This approach uses the tables in Annex 1 and will identify the following:

- 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 Central 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.

For investment appraisals the Central allowance will provide the focus for options consideration with the Upper and Higher Central climate change allowances providing a range to test the extent to which options can adapt.

The components of this step as follows:

Understand the range of possible future changes	Evaluate the potential range of change	Using the Central, Higher Central and Upper allowances 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 sensitivity to future changes	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 the assessment of sensitivity to future changes	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 the components of this step 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 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, Central, Higher Central and Upper allowances can help in representing the range of risks. But, there is still the chance, albeit 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 to understand the consequences of extreme change beyond the Central to Upper range and in situations where the consequences of flooding may be extreme (for example, nationally significant infrastructure, nuclear installations, sustainable urban extensions). 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 Central through to the Upper allowances. 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 allowance 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 climate change allowances presented within Annex 1. However, rather than base options solely on the climate change allowances, the analysis from Section C can also be used to refine the options so that they better reflect the wider range of future change.

For instance, an option could be developed to take account of the climate change allowances over the whole life of the plan, but have flexibility built-in to cater for the different changes suggested by the Upper, Higher Central and Central allowances. 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 inform adequately option 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
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.
Flexibility and Robustness		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 adjustment for changes in climate change knowledge in the future, and so be more cost-effective.

A number of conditional options may be 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.

There are a number of things to consider when deciding whether to implement an action straightaway or wait until more evidence is available:

- Is the current risk considered unacceptable?
- Could any delay lock-in irreversible impacts or limit flexibility to cope with future climate change?
- Are there opportunities to incorporate adaptation measures into planned maintenance or regeneration activities?

- Are there opportunities to implement adaptation measures that will have immediate or multiple benefits or are low cost?

Adaptation to climate change in one location 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. Consequential impacts on third parties should be avoided. Adaptation to climate change should be delivered consistently within a catchment or coastal cell in line with the FCERM National Strategy for England.

e. Monitoring, evaluation and review

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

FCERM decisions typically have long lifetimes. To support the implementation of the preferred option a record of the actions and assumptions should be made and secured for the lifetime of the plan and all information should be clear and accessible to later generations. If in the future the climate is different to that predicted, it should be clear how the timing, form and degree of the later interventions need to change and how this is to be monitored and evaluated using the triggers identified in Sections C and D above.

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 and is used for all projects applying for grant funding. The advice given here on climate change adaptation supports the appraisal guidance replacing Defra's Supplementary Note to Operating Authorities – Climate Change Impacts, 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 future risks and uncertainty in the magnitude of change.

Schemes involving Flood & Costal Erosion Risk Management Grant in Aid (FCERM GiA)

A Risk Management Authority may decide to recommend an investment decision that is not based on the climate change allowances in this advice. However where a contribution from FCERM GiA is being sought the investment appraisal supporting the application for grant must develop at least one option based on the advised climate change allowances so that it is possible, during the grant application process, to show the implications of any alternative climate change allowances which may influence the outcome of the application. Such an approach also ensures that the implications of alternative approaches to risk assessment and management can be more consistently compared and communicated.

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

References:

i. IPCC. Climate Change 2007: The Physical Science Basis (eds Solomon, S. et al.) 356–369, 408–420, 812–822 (Cambridge University Press, Cambridge, UK, and New York, 2007).http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

ii. A sea of uncertainty, Nature Reports, Climate Change, vol4 April 2010, J Lowe and J Gregory

iii. Sea level rise and its possible impacts given a 'beyond 4 degree C world' in the twenty-first century, Nicholls et al, 2011

iv. Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE, Isabella Velicogna. Geophysical Review Letters, Vol 36, 2009

v. Nature Reports, Climate Change, vol4 April 2010, J Lowe and J Gregory

vi. http://www.ice2sea.eu/

vii. Sea level rise and its possible impacts given a 'beyond 4 degree C world' in the twenty-first century, Nicholls et al, 2011

viii. Vermeer, M. & Rahmstorf, S. Proc. Natl Acad. Sci USA 106, 21527–21532 (2009)

iv. Pfeffer, W. T., Harper, J. T. & O'Neel, S. Science 321, 1340–1343, 2008.

x. Rohling, E. J. et al. Nature Geosci. 1 38–42 (2007).

xi. Vellinga, P. et al. 2008 Exploring high-end climate change scenarios for flood protection of The Netherlands. International Scientific Assessment carried out at request of the Delta Committee. Scientific report WR-2009-05. KNMI, Alterra, The Netherlands. See http://www.knmi.nl/bibliotheek/knmipubWR/WR2009-05.pdf.

xii. Pfeffer, W. T., Harper, J. T. & O'Neel, S. Science 321, 1340–1343, 2008

xiii. UKCP09 marine report, http://ukclimateprojections.defra.gov.uk/content/view/1969/500/

xiv. Hannaford, Jamie; Marsh, Terry J.. 2008 High-flow and flood trends in a network of undisturbed catchments in the UK. International Journal of Climatology, 28 (10). 1325-1338. 10.1002/joc.1643

xv. Zhang, X., F. W. Zwiers, G. C. Hegerl, F. G. Lambert, N. P. Gillett, S. Solomon, P. A. Stott, and T. Nozawa (2007), Detection of human influence on twentieth-century precipitation trends, Nature, 448, 461– 465, doi:10.1038/nature06025

xvi. Changing intensity of rainfall over Britain, Tim Osborn and Douglas Maraun, Climatic Research Unit Information Sheet no. 15

xvii. Met Office, The extreme rainfall of Summer 2007 and future extreme rainfall in a changing climate. S J Brown, M Beswick, E Buonomo, R Clark, D Fereday, D Hollis, R G Jones, E J Kennett, M Perry, J Prior and A A Scaife.

xviii. Developing H++ climate change scenarios for heat waves, droughts, floods, windstorms and cold snaps, Adaptation Sub-committee. Wade, S., Sanderson, M., Golding, N., Lowe, J., Betts, R., Reynard, N., Kay, A., Stewart, L., Prudholme, C., Shaffrey, L., Lloyd-Hughes, B., Harvey, B. (2015)

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