Flood and Coastal Defence Appraisal Guidance
FCDPAG3 Economic Appraisal
Supplementary Note to Operating Authorities – Climate Change Impacts
October 2006

1 Introduction and Background

Climate Change impacts on flooding and coastal erosion are a challenge and risk for Defra and Operating Authorities (i.e. Environment Agency, Local Authorities and Internal Drainage Boards). These impacts are well documented and include sea level rise and the potential increase in intensity, severity and frequency of coastal storms, and rainfall events affecting flooding in fluvial catchments and urban surface water systems. On sea levels for example, the period from 1960 to 1996 brought a rise of around 50mm at Lowestoft[1]. These impacts were captured in the 2004 Foresight report. Since the 1980s, Defra's response to such impacts has been as follows:

- promote policy guidance, based on appropriately precautionary allowances and sensitivity testing to enable Operating Authorities to take climate change impacts into account in planning, appraisal, decision making and operations;
- undertake an ongoing programme of related research in association with the Environment Agency and building on the work of other key research areas, notably from the Intergovernmental Panel on Climate Change (IPCC) and from UK Climate Impacts Programme (UKCIP);
- ensure guidance is kept under review as further understanding of the likely impacts of climate change develops.
- In Making Space for Water (MSfW), Defra undertook to review the existing guidance on climate change as part of a wider ranging review of appraisal guidance in 2007.

This supplementary note therefore provides interim policy guidance prior to the wider ranging review in MSfW and supports the publication of Planning Policy Statement 25 (PPS25) 'Development and Flood Risk'.

2 Updated Climate Change Policy For Flood and Coastal Management

2.1 Background

FCDPAG1[3] sets out the basis for considering climate change. Detailed sea level rise allowances are also recommended in FCDPAG3[3] . FDCPAG4[3] also set out advice on sensitivity testing. In April 2003, a supplementary note on climate change built upon the earlier FCDPAG guidance and updated precautionary allowances for sea level rise, together with sensitivity allowances for increased river flows; extreme rainfall, increased wave heights, and high and extreme wind speeds.

Prior to the supplementary note issued in April 2003, a further supplementary guidance note was issued in March 2003, which recommended whole life appraisals typically of 75-125 years, reflecting Treasury Green Book changes. This led to a need to consider longer term timescales, together with the inevitable longer term effects of climate change. The allowances and sensitivity ranges covered in this note therefore cover up to year 2115. In addition, this note covers changes to reflect most recent findings, such as in land movement[2] and the effects of thermo-expansion of the sea.

Whilst acknowledging the updates to allowances in recent years, climate change advice in the FCDPAG[3] documents is still relevant, particularly regarding: uncertainty, natural variability, flexibility in design, sensitivity analysis and ocean circulation changes. Research[4] ongoing within the Joint Defra/EA R&D programme[5], with a focus on improving flood and coastal management policy on

[1] DETR (1999) *Indicators of Climate Change*, Section 9 Sea Level Rise
[2] UKCIP (2005) *Updates to Regional net sea-level change estimates for Great Britain*.
[3] FCDPAG1 (2001:21); FCDPAG3 (1999:43)); FCDPAG4 (2000:15)

climate change impacts, will continue to improve our knowledge of the impacts, and policies will be adjusted as required, in future. Additionally, policies may be updated in the light of revised sea level rise information from IPCC, and any new approaches emerging from UKCIP.

2.2 Aims

In considering the context and background, and in covering England and Wales, this interim note on climate change policy *aims* to:

- Inform appraisers and decision makers of new climate change allowances and sensitivity ranges, and broadly how these should be applied.

- Remind appraisers and decision makers that Defra expects this supplementary guidance note to be applied to all future appraisals, strategies and management plans that are started from October 2006. However, practitioners and managers should be diligent to take on this guidance for work in progress, where it is clearly in the best interests of longer term outcomes and policies.

For consistent approach, most projects should use the recommended allowances and sensitivity ranges, ensuring that projects make provision for future changes in a consistent way and provide a valid basis for comparing investments. A managed approach is strongly recommended for public funded flood and coastal activities, to avoid any overly cautious responses and any knock-on affordability implications in the short term. An exceptional reason would be necessary to not apply this guidance on public funded flood and coastal management activities. This guidance should also be referred to when using PPS25 Annex B on climate change.

2.3 Regional sea level allowances

The new allowances are shown in Table 1. Key points to consider are as follows:

- Net sea level rise allowances incorporate thermal expansion of the oceans and melt from land glaciers and vertical adjustments of the land. Additional contributions from tidal surge and waves are not included.
- Global mean sea level rise projections up to the 2080s were taken from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) High estimates. Global mean sea level rise projections for the 2110s were extrapolated from the 2020s, 2050s and 2080s.
- Regional variations in net sea level rise allowances reflect latest information on vertical land movements[6].
- The baseline for calculating sea level rise for a given year is taken from 1990.
- There are significant uncertainties in climate change predictions and there may be studies that suggest allowances could be higher (for example, research from Thames 2100). However, figures in this supplementary guidance are considered most appropriate for flood and coastal risk management and planning, and should be used until further updates are provided.
- For more detailed information on assumptions and references associated with the new allowances, please refer to Annex A1.

[4] FD2020 project *Regionalised impacts of climate change on river* flows; and MAR Project 1.2 *Development and dissemination of information on coastal and estuary extremes*.

[5] http://defraweb/environ/fcd/research/default.htm

[6] Shennan, I. And Horton, B. (2002). Holocene land- and sea-level changes in Great Britain. *Journal of Quaternary Science*, **17**, 511-526.

Table 1: Regional net sea level rise allowances

Administrative or Devolved Region	*Assumed Vertical Land Movement (mm/yr)*	*Net Sea-Level Rise (mm/yr)*				*Previous allowances*
		1990-2025	*2025-2055*	*2055-2085*	*2085-2115*	
East of England, East Midlands, London, SE England (south of Flamborough Head)	-0.8	4.0	8.5	12.0	15.0	6mm/yr* constant
South West and Wales	-0.5	3.5	8.0	11.5	14.5	5 mm/yr* constant
NW England, NE England, Scotland (north of Flamborough Head)	+0.8	2.5	7.0	10.0	13.0	4 mm/yr* constant

*Updated figures now reflect an exponential curve, and replaces the previous straight line graph representations.

Refer to Annex A1 (ix) for examples on how to determine sea level rise for a given year.

2.4 Indicative sensitivity ranges

New indicative sensitivity ranges, covering peak rainfall intensity, peak river flow volume, offshore wind speed and extreme wave heights are shown in Table 2. Key points to consider are as follows:

- The peak rainfall intensity ranges should be used for small catchments and urban/local drainage sites. For river and stream catchments over, say 5km^2, the peak flow volume ranges should be used.
- The limited number of catchments researched to date supports applicability of a 20% allowance to the 2080s[7] for peak river flow volume. Research is ongoing[8] to assess *regional* variations in flood allowances. Current research thus far does not provide any evidence for the rate of future change but as a pragmatic approach it is suggested that 10% should be applied up to 2025, rising to 20% beyond 2025. For studies covering larger catchments (e.g. Thames/Severn/Humber) or some specialist studies, a scientifically justifiable range of peak flows and their probabilities should be subject to sensitivity testing, with further specialist advice sought for such analysis.
- Given the uncertainty attached to the indicative sensitivity ranges, sensitivity testing is necessary for public funded flood and coastal management activities, and advisable for any planning led activities. See Section 3 for examples demonstrating how sensitivity testing can be conducted.
- There are significant uncertainties in climate change predictions. However, figures in this supplementary guidance are considered appropriate in relation to flood and coastal risk management and planning, and should be used until further updates are provided.
- For more detailed information on the assumptions and references associated with the new allowances, please refer to Annex A2.

[7] Environment Agency/Defra (2005). *Impacts of climate change on flood flows in river catchments*. R&D Technical Report W5-032/TR, pp107.
[8] FD2020 project *Regionalised impacts of climate change on river flows*

Table 2: Indicative Sensitivity Ranges

Parameter	***1990-2025***	***2025-2055***	***2055-2085***	***2085-2115***
Peak rainfall intensity (preferably for small catchments)	*+5%*	**+10%**	*+20%*	*+30%*
Peak river flow volume (preferably for larger catchments)	+10%	**+20%**		
Offshore wind speed	*+5%*		**+10%**	*+10%*
Extreme wave height	*+5%*		**+10%**	*+10%*

Refer to Annex A2 (i) and (ii) for information on figures in bold and italic.

3 Application

3.1 What are the differences between *allowances* and *indicative sensitivity ranges ?*

The new *allowances* in this guidance refer to sea level rise, where the evidence base has improved leading to greater certainty. Sea level rise allowances should be used in calculations to determine the base case and any options that are compared to the base case. This therefore reflects a precautionary approach.

The *indicative sensitivity ranges* refer to peak flows, extreme rainfall, extreme waves and winds. Here, the degree of certainty in the figures is lower as we require further evidence and research to understand local and regional variations, and develop our management of uncertainty. Sensitivity analysis techniques should use the ranges to test the base case, as well as the options to determine how a decision is affected by climate change impacts. Decisions should then be made, taking into account the results of the sensitivity testing and different investment timing strategies.

3.2 What are the differences between *managed/adaptive* and *precautionary* approaches ?

Our response to climate change requires appropriate decisions on whether to consider a managed adaptive approach or whether to adopt a more precautionary approach. The following provides a brief explanation of this. Annex B also shows a flowchart of the two approaches.

Managed adaptive approach
A managed approach allows for adaptation in the future, and is wholly appropriate in the majority of cases where ongoing responsibility can be assigned to tracking the change in risk, and managing this through multiple interventions. This approach provides flexibility to manage future uncertainties associated with climate change, during the whole life of a flood risk management system. To consider a precautionary approach only, could lead to greater levels of investment at fewer locations. A managed approach is therefore important to ensure best value for money from public investment.

The managed adaptive approach aligns with MSfW, which requires a holistic and long term approach for flood and coastal management, and reinforces existing climate change policy[9] on ‘no-regrets’ actions and longer term adaptation. Both structural (e.g. physical changes to structures, upstream storage or a combination thereof) and non-structural solutions (e.g. land use changes, resilience,

[9] See FCDPAG1(2001:24)

statutory objections, relocation, public awareness) are necessary to ensure cost effective adaptation can take place in future years. In order to fully explore non-structural options alongside structural options, the sensitivity analysis of these options should become a more important component of appraisal and decision making, with care needed at screening-out stages to avoid discarding non-structural options without strong justification. See Figure 1 and the saw-tooth line to illustrate.

Precautionary approach
For some circumstances, future adaptation may be technically infeasible or too complex to administer over the long term of up to 100 years. These circumstances may occur where multiple interventions are not possible to manage the changes in risk. Therefore, a precautionary approach, perhaps with one-off intervention, may be the only feasible option, such as in the design capacity of a major culvert or in the span of a road bridge across a flood plain. See Figure 1 and the dashed line to illustrate.

3.3 Application of indicative sensitivity ranges

A decision will often need to be made on whether to take into account climate change now or at some future point in time. This decision will depend on the nature of the problem. For example, planning led intervention or a 'no-regrets' action might adopt a precautionary approach. If a managed/adaptive approach is aimed for, sensitivity analysis for climate change needs to be undertaken both at the earliest possible screening stages in the appraisal, and after the final options have been short listed.

Each option (whether at scheme, strategy or catchment level) will require appraisal, with and without modifications to accommodate climate change. In effect, two versions on an option should be presented. *'With modifications'* options should accommodate the sensitivity percentages within the hydraulic design and subsequent benefit cost analysis for those options. The '*Without modifications'* options should not accommodate the sensitivity percentages in the design and appraisal process. Option choice should then made following FCDPAG guidance.

A further level of sensitivity testing should then be applied to the preferred option (or say two close run options, if circumstances dictate), to optimise timing of investment and to identify when future adaptation would be best. Benefits and costs of different investment timings should then be compared for that option, to aid the decision on the best investment timing strategy.

3.4 Other considerations

Option appraisal and decision making involving any adaptation should consider how climate change impacts are managed over time. Presentation of the consequential saw-tooth effect in probability/consequence and associated efficiency, is one visible approach to showing how a preferred option may perform under different adaptive approaches. The diagram below shows the desired saw-tooth effect, as part of taking an adaptive approach.

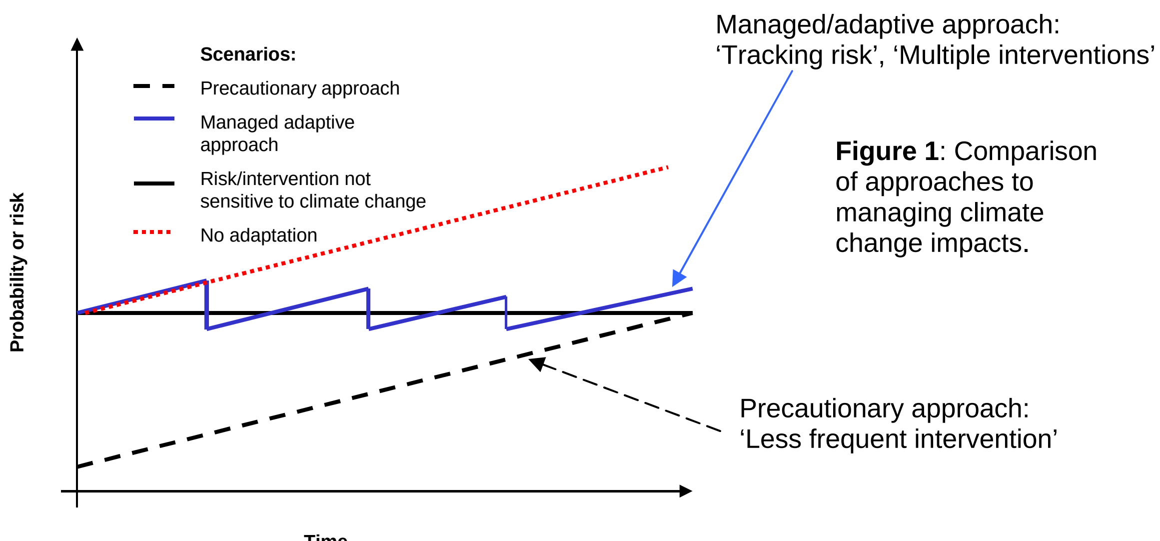

Figure 1: Comparison of approaches to managing climate change impacts.

4 Examples[10]

1 Fluvial - Precautionary approach.

In town C, the capacity of culverts under a trunk road, within an urban area, was increased to accommodate the 1 in 100 year flow and a possible increase in the flow by 20%. This decision is made because of the minimal cost of upsizing now, rather than the much higher costs of modification later, due to land acquisition and engineering complexity.

2 Fluvial - Adaptation approach.

The impact of climate change was assessed using the 20% increase in flows in the river P. However, defences could not be raised without raising the railway line, which was uneconomically viable. Therefore a decision was taken to: 1) bear the increased risk and accept that the standard of protection (now at 1 in 200 years) will reduce to 1 in 65 years in 50 years time; 2) adapt to the climate change risk using non-structural methods that include resilience, and negotiate with Network Rail to implement their own precautionary measures. These measures included possible track raising or realignment if any major rail reconstruction work was contemplated during the next 50 years.

3 Fluvial - Adaptation Approach. Smaller catchment

For a smaller river V, with slightly steeper upland valleys, sensitivity testing enabled the team to compare how the options' relative strengths changed. A screen-out stage included some broad sensitivity tests for climate change impacts using the parameters for peak rainfall intensity and peak river flows. This led to five options for further detailed appraisal, including some non-structural approaches: 1) Wall height increasing; 2) Bypass Channel; 3) large upstream storage; 4) Moderate U/S storage and Resilience; and 5) Bypass Channel with U/S Storage.

The options' benefits and costs were appraised with <u>and</u> without modification to accommodate climate change impacts, which led to the benefit cost analysis of ten options. The economic efficiency of the options was then compared and the preferred option selected as 4m) Moderate U/S storage and Resilience ('m' reflecting the modified option 4). Some further sensitivity testing then identified the optimal timing of investment for adaptation of this option. In essence, the approach led to a resilient solution which allowed for future increases in upstream storage capacity, rather than just building existing defences higher, now.

4 Fluvial - Adaptation approach. Large catchment

For river X, a large river catchment, a strategy considering £80m of work planned for a combination of raising and strengthening defences on line, along with managed realignment that would allow the estuary to spread into additional areas to reduce extreme flood events. This would also allow space for habitats to migrate inland and to counter the effects of coastal squeeze. A combination of solutions were sensitivity tested for climate change. Also, a test of sensitivity within a range up to 10%, (as well as 20%) up to the year 2115, was considered for peak river flow volume, to fully understand the scale of climate change impacts for that particular catchment.

5 Coastal – Hard Choices Approach; Application of Sea Level Rise Allowances

When sea level rise allowances were applied to the coastal defence improvement proposals at town B, the scheme was found to be not viable despite large numbers of property being at risk. The future damages avoided by the proposals were outweighed by the improvement costs, even with sea level rise factored in. Over the long term, upgrading the frontage would not be sustainable. Therefore the decision was taken to: 1) bear the increasing risk and accept the lower standard of protection afforded by the existing defence; 2) progress with modest and justifiable short term investment to sustain the existing defence over the remaining 40 year residual life; 3) focus efforts to realise more sustainable frontage management through land use change and eventual retreat beyond year 40.

[10] Place or river names depicted by a letter. Examples are based in part on actual cases.

Annex A Additional Technical Information

A1 Technical notes supporting Table 1, Regional net sea level rise allowances

(i) Global mean sea level rise projections up to 2100 were taken from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) under A1FI emissions (Table II.5.1), noting that the values for A1FI and A1T are incorrectly transposed in the IPCC report. Global mean sea level rise projections for 2115 were extrapolated.

(ii) Net sea level rise allowances are sensitive to assumptions about thermal expansion of the oceans, melt from land glaciers and ice caps, melt from Antarctica and Greenland, climate model sensitivity, greenhouse gas emissions, and vertical adjustments of the land.

(iii) Differential heating of oceans and changing ocean currents are not taken into account, but regional variations in sea level rise could be as high as $\pm$50% about the global mean[11].

(iv) Recent glacier mass balance modelling suggests that the contribution from melting mountain glaciers and ice caps may be half that used in the IPCC projections[12].

(v) Recent model evidence suggests estimated contributions from Antarctic and Greenland ice melt to sea level rise will need to be revised upwards[13] by as much as 5mm/yr[14].

(vi) The IPCC mean sea level rise projections reflect high emissions and high climate model sensitivity.

(vii) Regional variations in net sea level rise allowances draw from latest information on vertical land movements around the UK[15].

(viii) Contributions from tidal surge and waves, or the joint occurrence of fluvial and tidal flooding are not included. These effects are localised and model projections show mixed results[16,17].

(ix) All values are given with respect to 1990 and rounded to the nearest 0.5 mm/yr.
Calculation of sea level rise is worked out using the following two examples.

For the **south west region** sea level rise in **2020**:
3.5mm/yr * [30 years from 1990) = **105mm.**

For the **north east region** in **2065**:
2.5mm/yr to 2025 = 88mm; 7mm/yr between 2026-2055 = 210mm;
10mm/yr between 2056-2065 = 100mm $\therefore$ Total = 88 + 210 + 100 = **398mm.**

(x) The precautionary allowances for global mean sea level rise will be reviewed in 2007 in the light of the Fourth Assessment Report (AR4) of the IPCC.

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[11] Hulme, M., Jenkins, G. J., Lu, X., et al. (2002). *Climate change scenarios for the United Kingdom: the UKCIP02 Scientific report*, Tyndall centre for climate change research, Norwich, pp42-51.

[12] Raper, S.C.B. and Braithewaite, R.J. (2006). Low sea level rise projections from mountain glaciers and icecaps under global warming. *Nature*, **439**, 311-313.

[13] Schnellnhuber, H.J., Cramer, W., Nakicenovic, N., Wigley, T.M.L. and Yohe, G. (Eds.) (2006). *Avoiding Dangerous Climate Change. Cambridge* University Press, Cambridge.

[14] Ridley, J.K., Huybrechts, P., Gregory, J.M. and Lowe, J.A. (2005). Elimination of the Greenland ice sheet in a high CO2 climate. *Journal of Climate*, **18**, 3409-3427.

[15] Shennan, I. And Horton, B. (2002). Holocene land- and sea-level changes in Great Britain. *Journal of Quaternary Science*, **17**, 511-526.

[16] Woth, K. (2005). North Sea storm surge statistics based on projections in a warmer climate: How important are the driving GCM and the chosen emission scenario? *Geophysical Research Letters*, **32**, L22708, doi:10.1029/2005GL023762.

[17] Lowe, J.A., Gregory, J.M., Flather, R.A. (2001). Changes in the occurrence of storm surges in the United Kingdom under a future climate scenario using a dynamic surge model driven by the Hadley Center climate models. *Climate Dynamics*, **18**, 188-197.

A2 Technical notes supporting Table 2, Indicative sensitivity ranges

(i) Precautionary allowances shown in **bold** are taken from existing guidance[18,19]. These allowances do not reflect uncertainties due to climate model sensitivity (which can be large)[20].

(ii) Precautionary allowances shown in *italics* for peak rainfall intensity, offshore winds and extreme wave height have been scaled[21] in relation to global mean temperature changes[22] and rounded to the nearest 5%. These interim allowances require further review in time.

(iii) Expected changes in rainfall intensity are location, space- and time-scale dependent. The values given are applicable to daily rainfall totals over small catchments and urban drainage sites. Longer duration events (of 5-10 days) may show larger increases (e.g., up to +30% by the 2080s in Scotland[23]).

(iv) A precautionary allowance of +10% is given for 2025 on the basis of a recent study of 27 UK catchments that showed increases in *mean* winter flows of 4-9% by the 2020s[24]. Further research is needed to verify applicability to *peak* river flows.

(v) A single precautionary allowance is provided for peak river flow volume for 2055 onwards. The limited number of catchments studied to date supports applicability of the 20% allowance at least to the 2080s[25]. This interim allowance is under review.

(vi) Given the large inter-annual variability of seasonal river flows, statistically detectable *trends* are not expected to emerge in observed flows for several more decades[26].

(vii) Research is ongoing to assess *regional* variations in flood allowances[27], surge risk in major estuaries such as the Thames[28],and joint occurrence of tidal surge and fluvial flooding under climate change. Recent joint probability research provides further information on combining allowances[29 30].

(viii) Research is planned to review allowances for waves and wind speeds.

(ix) All national allowances will need to be reviewed in the light of the UKCIPnext scenarios (expected in mid 2008).

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18 Environment Agency/Defra, (2003). *UK Climate Impacts Programme 2002 Climate Change Scenarios: Implementation for Flood and Coastal Defence: Guidance for Users*. R&D Technical Report W5B-029/TR, pp46.

19 Defra / Environment Agency, (2005). *Framework and Guidance for Assessing and Managing Flood Risk for New Development – Full Documentation and Tools*. R&D Technical Report FD2320/TR2

20 Jenkins, G and Lowe, J. (2003). Handling uncertainties in the UKCIP02 scenarios of climate change. *Hadley Centre Technical Note 44*. Meteorological Office, Exeter.

21 'Pattern-scaling' techniques are widely used to obtain rough estimates of changes in surface weather variables in relation to global mean temperature changes. See: Hulme, M., Jenkins, G. J., Lu, X., et al. (2002). *Climate change scenarios for the United Kingdom: the UKCIP02 Scientific report*, Tyndall centre for climate change research, Norwich, pp42-51.

22 The emission scenario is the SRES A2 (Medium-High emissions) taken from Appendix II of the IPCC TAR. However, the results are insensitive to the assumed emission scenario.

23 Ekström, M., Fowler, H.J., Kilsby, C.G. and Jones, P.D (2005). New estimates of future changes in extreme rainfall across the UK using regional climate model integrations. 2. Future estimates and use in impact studies. *Journal of Hydrology*, **300**, 234- 251.

24 Wade, S. and Vidal, J-P (2006). *Effect of climate change on river flows and groundwater recharge. A practical methodology. Interim report on rainfall-runoff modelling*. UKWIR CL\04\C\Interim, London, pp75.

25 Environment Agency/Defra (2005). *Impacts of climate change on flood flows in river catchments*. R&D Technical Report W5-032/TR, pp107.

26 Wilby, R.L (2006). When and where might climate change be detectable in UK river flows? *Geophysical Research Letters*, under revision.

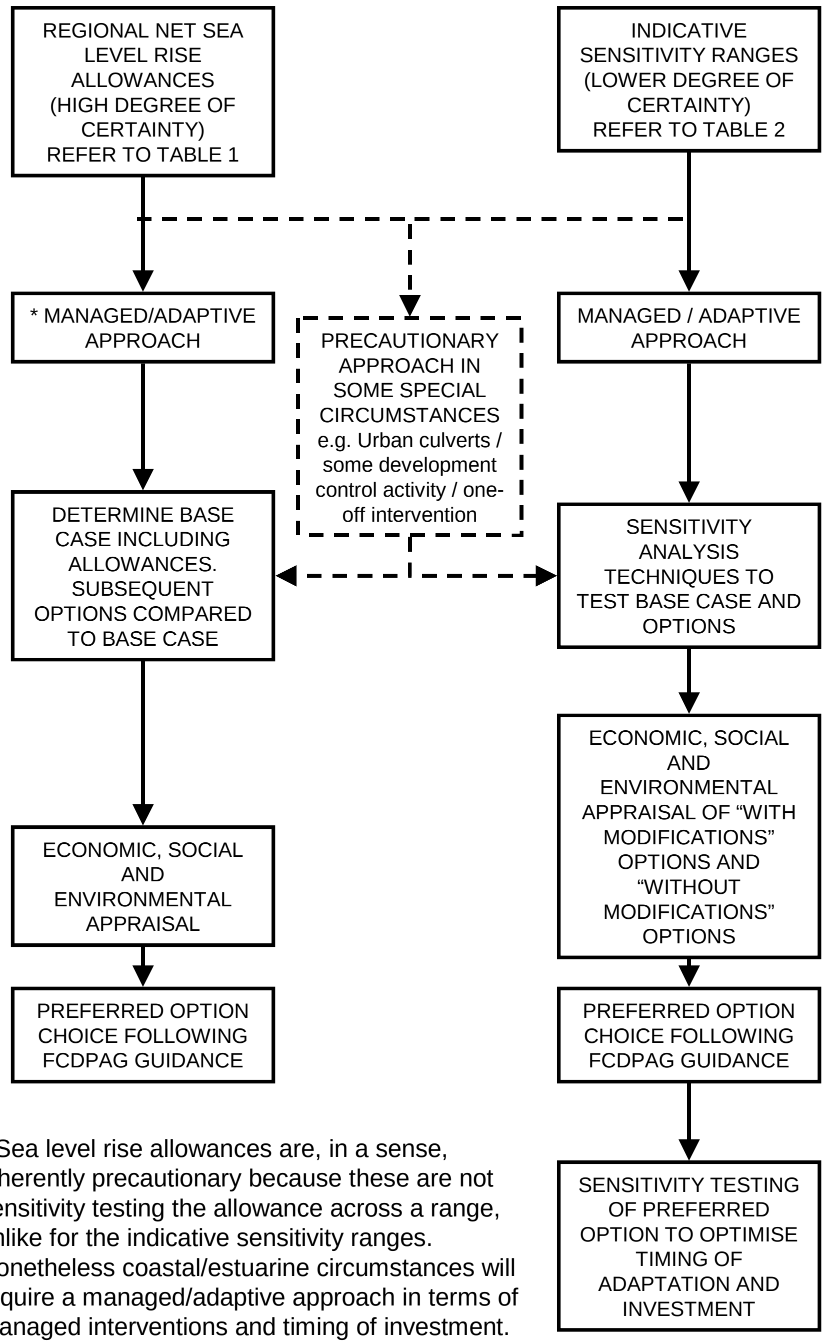
27 FD2020 project *Regionalised impacts of climate change on flood flows*

28 MAR project 1.2 *Development and dissemination of information on coastal and estuary extremes*

29 FD2308 project *Joint probability: Dependence mapping and best practice.*

30 Svensson, C. and Jones, D. A. (2005) Climate change impacts on the dependence between sea surge, precipitation and river flow around Britain. In proceedings from the 40th Defra Flood & Coastal Management Conference 2005, University of York, York, UK, 5-7 July 2005, pp. 6A.3.1-6A.3.10.

Annex B Flow chart highlighting the managed adaptive approach and precautionary approach



* Sea level rise allowances are, in a sense, inherently precautionary because these are not sensitivity testing the allowance across a range, unlike for the indicative sensitivity ranges. Nonetheless coastal/estuarine circumstances will require a managed/adaptive approach in terms of managed interventions and timing of investment.

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