APPENDIX I: **EXTERNAL REVIEW: COMMENTS AND RESPONSES**

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Note

An independent review of the 2nd Draft of the Report (dated the 3 August 2015) was undertaken by three reviewers (Alan Werritty, Rob Lamb and David Ramsbottom). Their comments are very much appreciated and our responses are recorded below.

A.1 Prof. Alan Werritty – Dundee University

A.1.1 General comments

Comment: Overall, this is an impressive piece of work and marks a significant advance on the way that flooding was handled in the first Climate Change Risk Assessment by Defra in 2012. One of the major weaknesses in that assessment was that the methodology for assessing the impacts of likely changes in flood risk was initially developed around the available data sets for England and then extrapolated to the other devolved administrations. At that time comparable data sets for Scotland and the other devolved administrations often did not exist, making extrapolation and consistency in reporting findings across the whole of the UK very challenging. This new report tackles that issue head on and tries very hard to work with or, where necessary adjust, nation-specific data sets so as to achieve a much higher consistency in the modelled outputs. This is still not perfect – and I mention some exceptions below where caution is needed in interpreting key findings – but a much more convincing UK-wide picture now emerges than before.

Response: Thank you

Comment: The Future Flood Explorer represents a major advance over RASP and provides a flexible new piece of software that works well for the CCRA. As with its predecessors, it struggles with data inputs of highly variable quality and contrasting spatial resolution, but it does provide an appropriate analytic kernel for this report. Whilst in my more detailed critique below, I raise concerns over some aspects of the report, in general the findings are robust and well-founded. I congratulate the authors on making a significant advance in a very challenging field.

Response: Thank you

A.1.2 Specific comments

Comment: A major difficulty in assessing the report was inconsistency in referencing the relevant literature in the main body of the report and the lack of a consolidated list of references at the end. I realise that both these will be dealt with in future drafts, but several of the weaknesses noted below arise, in part, because I was unable to follow the rationale for a specific method of analysis or the selection of a specific data set.

Response: We have addressed the referencing in the final report, including referencing to the Appendices, to aid navigation.

Comment: Mention is made of contrasting flood risk management legislation across the four nations, but the implications of this are not fully appreciated. The data sets generated by each of the devolved administrations are inevitably not consistent – both in the types of spatial units for which they are tabulated and mapped and the metrics used. For example, when the metrics used to report the probability bands for flows of varying return periods differ (Table 2.3), it is unclear exactly how a "single set of bands" has been developed.

Response: This has been done very simply. The 1:75 year boundary was chosen as representative of an insurance sector view of 'significant', but other boundaries would have been equally valid of course. We adopted three bands for simplicity. Where the bands chosen for the FFE do not coincide precisely with the probabilities of hazard data provided, then the FFE uses log-linear interpolation of the impact curves to calculate metrics for the chosen bands.

Comment: There are also differences in policy priorities that are glossed over. For example natural flood management is far more embedded in the statutory process of flood risk management in Scotland than is the case for England. SuDS regulations in Scotland are also more demanding than in England. The commentary in the main body of the report and the discussion at the end of the report need to reflect on how these challenges in contrasting metrics and significant differences in policy across four jurisdictions impact on the overall findings.

Response: We have strengthened the policy discussion leading to the selection of the adaptation measure in main report and particularly in the supporting, more detailed discussion, provided in Appendix G. We agree that in some cases the policies and implementation experience vary considerably from one country to another; nevertheless, we have opted for a consistent approach across the UK to better identify the variation in impacts of population and climate. We agree that in a future CCRA it may be appropriate to considered differentiating adaptation measures by country whilst maintain a consistent analysis method. The FFE would support this if required in the future. The FFE outputs in this report can be thought of as a number of "end member" scenarios; in reality, adaptation will vary between these end members across the nations of the UK.

Comment: The risk metric developed to characterise natural capital (the areal extent of protected areas – SPAs, SACs and Ramsar sites) is seriously flawed. Firstly, the actual concept of natural capital is a complex one and it is far from clear exactly how flooding impacts on natural capital stocks and flows – expressing it solely in terms of each site's areal extent is very crude. Secondly, the risk metric adopted (areal extent) fails to take into account the likely impact of a flood on sites of contrasting size – the loss of natural capital in a small species-rich wetland (eg the River Spey – Insh marshes SPA) is likely to be proportionately far higher than that arising from remobilising a large area of sandbanks that provides habitat for the harbor seal (the Firth of Tay and Eden estuary SAC). Thirdly, the omission of SSSIs (often with high natural capital) means that not all protected sites are included in the analysis. Getting a precise value for the scale of this omission is complicated by the fact that many sites have multiple designations as SACs SPAs, and Ramsar sites as well as being SSSIs, whilst other sites have single designations. But in broad-brush terms, protected sites across the UK comprise over 6,500 SSSIs (c. 2.85 million ha), 617 SACs (c. 2.90 million ha), 270 SPAs (c. 2.80 million ha) and 148 Ramsar sites (c. 0.79 million ha). Even accepting areal extent as a crude metric, reported values under "Present Day" values in Fig 7.5 are likely to be an under-estimate of the natural capital in protected sites. These in turn will impact on % changes in natural capital reported for the alternative adaptation scenarios.

Response: We agree and have used areal extent as a very simply proxy and recognise that all SPAs, SACs and Ramsar sites in the UK are also SSSI (i.e. the designations overlap). We incorporated additional discussion within the report to make this clear. On the final point, and this applies to other metrics, we believe that when estimates of present day metrics from the FFE are subject to under or over estimation, this will apply to estimates for future epochs. Estimates of changes in response to climate will therefore be robust.

Comment: Given that CCRA project C Aggregate assessment of climate change impacts on the goods and benefits provided by the UK's natural assets will also be addressing climate change impacts on natural capital, will the two reports be consistent in their definitions of protected sites and the way they define the risk metric for natural capital?

Response: We have edited the text to highlight the Project C report to the reader. Project C does not however assess flood risk and further analysis (but this was beyond the resources of this project) would be needed to identify those SPAs/SACs that are vulnerable to coastal/fluvial flooding.

Comment: The baseline spatial planning data for managing exposure to flooding are calibrated solely with reference to the EA's analysis for England. But comparable analysis for SEPA reveals that spatial planning has been far more successful in Scotland in inhibiting development on floodplains (see Ball et al. in press). I haven't had access to (Kazmierczak et al., in press), cited in Appendix E but, in summary, Ball et al. (in press) found that in 2012:

"of 529 planning applications in total on which SEPA gave advice during 2012, 406 responses resulted in an objection by SEPA, with 18 an objection in principle. 354 LPA [Local Planning Authority] decision notices were available for analysis for year 2012 (accessed through the e-planning portals on the LPA

websites). When matched to the SEPA advice, these indicated that 21 applications in total were granted contrary to SEPA advice during the year"

This 5.1 % failure to accede to SEPA's advice is much lower than the comparable figure for England and needs to be incorporated into the FFE modelling for Scotland.

Response: Thank you for this information. We have how reflected upon this in the discussion of the adaptation measures (Appendix E). For consistency across the UK however a value of 12% has been used here (reflecting the greater number of properties within England). This means the potential to improve the influence of the spatial planning measure in Scotland is likely to be overstated. This reinforces perhaps the recommendation made above that for future CCRA studies that baseline policies within each country are separately considered. The outputs of the FFE also indicate that spatial planning alone has a small impact on future levels of EAD, , because of interaction with other adaptations. Differences in efficacy of spatial planning across the UK will therefore not impact significantly on headline risks. On a point of detail, the figure of 5.1% failure of planning application in Scotland acceding to SEPA's advice is actually much higher than the equivalent figure in England, where 98% of applications were in line with the Environment Agency's advice in 2014.

Comment: Conversely, in terms of the uptake of RLP measures (mainly in the form of PLP for residential properties), England has a much higher uptake than Scotland possibly reflecting recent Defra initiatives (see Scottish Government 2015). Again this needs to be taken into account in the FFE modelling for Scotland.

Response: Thank you for this information. We have reflected this in the discussion of the adaptation measures (Appendix E). As noted above, the FFE has been applied using a single set of UK measures and the numbers for England have been used. This means the potential to improve the influence of the receptor level protection measure in Scotland may be overstated.

Comment: The section on coastal flooding specific to Scotland raises many issues all of them related to contrasts in coastal flood risk when compared with that for England. Some crucial differences are summarised in Werritty et al. (2012). Those most important for this CCRA report are (i) the relatively few opportunities for re-alignment (reflecting the dominance of rocky coastlines – especially in the north and west); (ii) the minimal number of local authority-funded coastal defences and partial information on their SOPs and their current state, (iii) the lack of statutory SMPs in Scotland (although some local authorities have developed them on a non-statutory basis) and, (iv) the lower threat posed by relative sea level rise for much of Scotland.

Inevitably, and for good reason, in the absence of equivalent Scottish data, the report sometimes resorts to seeking analogues from England. The following examples illustrate the potential pitfalls in making such arguments:

- In seeking to determine SoPs for Scottish coastal defences, there is the statement that "the west coast of Scotland is geomorphologically similar to south west England and sees a similar wave climate, and therefore uses the same uplifts in SoP" (p. 27). Whilst the two locations may share a similar wave climate, their geomorphological similarity is far from convincing. The west coast of Scotland is dominated by numerous fjords cut by Quaternary glaciers in highly resistant bedrock whereas coast of south west England is dominated by much shallower rias created by Holocene sea level rise in less resistant bedrock.
- For modelling the H++ scenario, there is the statement "taken directly from Environment Agency, 2011 with extension to Scotland and Northern Ireland through analogy" (p. 28). But the grounds to justify such an extension are not explored.
- The targets for realignment of "9% by 2030s, 14% by 2060s and 16% by 2080s as set out across the SMPs within England" may well be realistic for England, but should not be extrapolated as a UK target. Given a coastline with limited exposures of soft sediments and/or salt-marshes, they are far too optimistic for Scotland where also SMPs are not a statutory requirement.

Such extrapolations need to be handled with due caution and grounds more fully developed.

Response: Thank for these points. We have added additional discussion to Appendix E (under the discussion of managed realignment adaptation measure) and the have tried to caveat the findings in the main report accordingly. We have also included an additional discussion of these issues within Appendix G on the verification of the FFE results.

Comment: In verifying the FFE it is striking that predictions for England (when compared with the LTIS 2014) generally perform far better than predictions for Scotland and Wales. Thus, whereas for England "EAD estimates are consistent to within 20% for rivers, sea and surface water sources", for Scotland "counts of properties at risk agree to within 40%, with the biggest difference seen for residential properties at higher risk of flooding" and for Wales "properties at risk agree to within 40%, with the biggest difference seen for coastal risk for residential properties. In both Scotland and Wales incomplete data on flood defence assets necessitate extrapolation from England analogues in order to use FFE across the whole of the UK. Whilst accepting the need to make such extrapolations, the likely errors this generates need to be more clearly flagged. A localised 40% mismatch between modelled outputs and observed values raises serious questions on the performance of FFE.

Given the above, I strongly urge that the discussion chapter explicitly comments on the challenges posed by diverse data sets across the UK. This is not to undermine the very real advances made in CCRA 2017 when compared with CCRA 2102, but to be fully transparent on the challenges that still remain.

Response: Thank you. We have tried to reflect country differences in the discussion of the results where possible. Although given the range of differences inevitable and we have made simplifications. We also reiterate a point made earlier in our response: the FFE has been constructed in such a way that if present day risk estimates are biased, this will also be reflected in estimates for future climates, and therefore the *changes* in risk are robust.

Comment: These above comments are offered constructively and I hope will contribute to any further revisions to the report.

Response: We thank you for your very constructive and useful comments. They have indeed helped us strengthen the report.

Comment: References

Ball T, Werritty A, Rennie A and Illsley B (in press) Assessing the Effectiveness of SEPA's Flood Risk Advice in Planning Decisions, Centre of Expertise for Waters, James Hutton Institute.

Werritty A, Duck R, Dawson S, Ball T, Powell V, Dawson A and Muir D (2012) Coastal flooding in Scotland: a guidance document for coastal practitioners, Centre of Expertise for Waters, James Hutton Institute.

Scottish Government (2015) Assessing the Flood Risk Management Benefits of Property level Protection, Report by Jeremy Benn Associates.

A.2 Dr Rob Lamb – JBA Trust

A.2.1 Overview

It is appreciated that the draft is a work in progress and the headline messages are still emerging. It is also recognised that the project has generated a substantial and fairly complex evidence base. Therefore it seems fair that some of the key messages and evidence are still marked as to be confirmed in the draft.

Response: Thank you

A.2.2 Objectives

The two key objectives are to provide clear quantified messages about

a) Impacts of climate change and population growth on flood risk
b) Opportunities to manage risks through adaptation

Objective (a) is met through the use of flood risk data sets, change scenarios and the FFE "emulator" lookup approach. This appears to be an uncontroversial approach that incrementally builds on previous assessments. It may be that this remains the most appropriate approach in practice for the CCRA. However there is increasing attention in the literature to alternative methods of thinking about uncertainty (such as large ensemble climate change experiments, separation of social and technical aspects of uncertainty, analysis of climate change on weather events). It seems that there should be some wider discussion here of alternative approaches so that the analysis is placed in context.

Response: We acknowledge that other approaches are available or may be in the future, but given the focus of Defra, SEPA, NRW, NIRA on how FFE outputs match "official" figures for present day risk, we regard our approach as the best way to produce future risk estimates which are still broadly consistent with present day risks. A radically different approach would run the risk of losing key messages on response to climate and population change in argument about what the risk estimates mean.

For objective (b) there would be value in exploring the implications of changes to actual policy and practice, with more focus on the potential performance of these policies – this could provide a valuable commentary and some means of benchmarking alongside the long term projections of impacts. For example the 'managed adaptive' approach is often cited as an appropriate response to developing flood risk management solutions and measures, so how many schemes that have been delivered over the last 5 years have made allowance for this? The analysis seems to be geared towards prediction and modelling of impacts, but the stated objective to provide "clear quantified messages about … opportunities to manage risks through adaptation" implies a need to look more closely at how these opportunities are materialising in practice.

Response: We acknowledge that the adaptation represented in our approach is in this sense not realistic: we assume that the adaptations are predefined through to the 2080s, whereas there is clearly opportunity for changes in adaptation policy in response to changes in climate, population and our knowledge of these. Future adaptations are therefore unlikely to reflect any single Adaptation Scenario included here. The Adaptation Scenarios we have chosen should be regarded as providing a spectrum of approaches – and thus gives an idea of what might be achieved, rather than what will be achieved.

A.2.3 General comments

The report seems have a clear structure and to cover the necessary ground. However the present draft is poorly edited in several respects:

- There are numerous formatting, typographical and cross referencing errors throughout the report
- In several places terminology, data sets, concepts and external project references are discussed without first being introduced
- Some passages still read as though copied and pasted from other reports, and the quality of the writing is patchy, with some sections conspicuously more fluent than others
- An over-reliance on bullet points and lists of tables and figures in place of a well-formed narrative to guide readers through the results (although some bullets so appear to be formatting errors)

I found that I was constantly searching back and forth through the report in order to try to get a coherent view of the analysis, which led to a sense that the narrative is not yet strong enough. It is to be welcomed that the details are accessible, but lengthy tables of data should perhaps be included as appendices (and some of the supporting explanatory material in the appendices should perhaps be promoted to the main report). It would be very helpful for some further work to be done to generate clear summary plots that would augment the tabulated data.

The background to the study is well explained, but the report would be stronger if it began by setting out clearly the conceptual model of risk that is being used in terms of hazards, vulnerabilities and consequences, along with the sources of uncertainty in particular relating to future change. This should help later in identifying what is (and is not) taken into account when the broad uncertainty about climate change and development is reduced to a set of scenarios (see comments below), and then lead through into analysis of the results.

There are many references to relevant existing studies such as LTIS, NaFRA and others, as expected. However there does not seem to be a discussion of what could be learned from the wider technical and academic literature, see for example Wilby and Keenan (*Adapting to flood risk under climate change*, Prog. Phys. Geogr., 2012, DOI: 10.1177/0309133312438908), either relating to the generic structure of the analysis (which could be places in a more international context) or to findings about UK flood risk specifically.

Response: The text has been extensively rewritten in the drafts following the version reviewed, and therefore we now hope the report is more consistent and readable. The overarching discussion and international context of the work is a useful point and will be reflected (as we understand) in the CCRA Evidence Report.

A.2.4 Representation of time

Baseline assumptions

The discussion of what is taken to be “baseline” (S2.4.1) should be improved, perhaps with aid of a timeline diagram. Explain why the three specific epochs were chosen.

The note on p. 23 refers to NaFRA (without first introducing it) and other baseline data. It is “assumed the climate change from base date of the underlying climate analysis (for example 1990) to 2014 has already been observed and is included within the data provided on the present day flood risk system. This approach assumes that the national flood analysis completed for Environment Agency and Devolved Administrations includes any change in climate that may have occurred between the baseline period of climate analysis in UKCP09 (i.e. 1961-90) and today. This avoids an artificial jump in expected risks between the present day and the first future epoch”.

This would appear to overlook recent analysis that anthropogenic climate change is already affecting the risk of flooding in the UK. For example Pall et al. (*Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000*, Nature, Vol. 470, 2011, pp. 382–386) concluded that the England and Wales flood risk for Autumn 2000 had significantly increased with

anthropogenic emissions having most likely increased the chance of such flooding by a factor of about 2.5, i.e. the chance of such an event would only have been about 40% of its current level had anthropogenic emissions not occurred.

Evidence from such attribution studies, combined with analysis of non-stationarity in weather data (see e.g. references below) suggest that changes in the risks associated with extreme rainfall, especially relating to surface water flooding, may already be detectable and should be anticipated.

- Fowler, H. J., and C. G. Kilsby (2003), Implications of changes in seasonal and annual extreme rainfall, Geophys. Res. Lett., 30, 1720, doi:10.1029/2003GL017327, 13.
- Westra, S., H. J. Fowler, J. P. Evans, L. V. Alexander, P. Berg, F. Johnson, E. J. Kendon, G. Lenderink, and N. M. Roberts (2014), Future changes to the intensity and frequency of short-duration extreme rainfall, Rev. Geophys., 52, 522–555, doi:10.1002/2014RG000464.

It may be difficult to reconcile these studies with the types of information available for use in the FFE, but the apparent lack of discussion of these issues seems to be an important gap in the analysis that could be addressed at least qualitatively. The issue is particularly relevant given that the first epoch considered is the 2020s, for which the balance between climate change "signal" and variability may not differ very much from the present day situation.

Response: We acknowledge that current risk may be significantly (or at least detectably) different from the baseline; we agree with Dr Lamb that near future epochs and present day risks are affected by climate change, and perhaps significantly so; indeed the FFE outputs for 2020s indicate significant changes over the baseline. The priority for the CCRA is, however, changes in 2050s and beyond, and the effects of future climate change rather than changes that have already occurred.

Complex adaptation pathways

It is not clear whether the report considers the possibility that adaptation strategies could include elements of deferred or conditional decision-making (e.g. as discussed in the real options literature). The adaptation scenarios appear to be essentially fixed pathways, assessed with respect to each assumption about future states of the world. It is understood that this is not an easy task but the possibility of deferring some decisions may be particularly relevant to the assumed portfolios of adaptation measures (e.g. PLP versus community-scale schemes) and merits some discussion.

Response: Indeed, as discussed in a previous point, our adaptation strategies set the level of adaptation now and assume it to be fixed into the 2080s, which is an unrealistic assumption. Nevertheless, we regard our adaptation scenarios as being broadly representative of the plausible range of adaptations concentrating on different aspects of flood risk management; in reality the true adaptation pathway will depend on many factors apart from climate and population: funding for investment, costs of adaptation, what levels of risk are acceptable to the public etc.

A.2.5 What type of events should be considered?

The report includes the major sources of flood risk (rivers, coastal, surface water and groundwater). Page 18 essentially makes a case for simplifications in the way that data on these sources are combined, particularly in the separation of coastal/fluvial and surface water sources. This discussion appears to skim over defining what kind of "events" actually should be represented in a risk assessment at UK scale, presumably in order to simplify the use of available data sources to quantify risk.

There may well be necessary simplifications invoked, but recent nationally significant events have highlighted the importance of considering sources of risk jointly (Summer 2007: surface water and rivers; Winter 13-14: coastal storms and river flooding). What is the risk associated with significant compound hazards of this type, which may be best understood as discrete atmospheric events (at seasonal or multi-day level)? Is this risk changing?

As noted above, there is material in the scientific literature relating to the analysis of events in the context of climate change, and possibly to identify current limits of knowledge. There is also knowledge of correlations between sources of flood risk (e.g. Defra "dependence mapping" studies by Svensson, Hawkes et al., analysis of spatial dependence by Keef et al.) to draw on.

Response: One of the key aims of the work is to provide estimates of future risk that are directly comparable with current risk estimates, hence we concentrate on the type of metric that is currently available: annual average damages, counts of receptors in bands etc. A move to a more event based approach would require a shift in the way that metrics are interpreted, and could hinder the communication of key messages. Our approach, while not capturing some key aspects of what risk looks like, does give results which are directly comparable with current estimates.

A.2.6 Scenario development

Exogenous changes

The approach taken to representing uncertainty in future flood risk is a scenario-based analysis, which is introduced in Section 2.2 (Future changes in drivers of risk). The structure of the analysis is clearly presented in terms of exogenous and endogenous changes. Any scenario approach effectively involves collapsing a wide understanding of uncertainties into a small, manageable number of trajectories that "sample" possible future versions of the world. Ideally those scenarios would be chosen to capture plausible uncertainty about the future, to insulate against the potential for shocks, and do so without introducing biases that could lead to under-preparedness or mal-adaptations.

The report does not make clear why the chosen scenarios satisfy these conditions. Although there is plenty of detail about the sources of information, there does not seem to be any over-arching justification for the approach taken in the development and selection of the scenarios.

The risk metrics adopted seem relevant and make good use of available data sets. Being critical, could it be that they are too simplistic, for example should there be more consideration beyond flood depth to duration and hazard to people?

The comparison of probability bands across data sets (p. 27) is useful in itself.

It would be helpful to have a little more critical exploration of sensitivity to the assumptions made in the Standard of Protection change factors. For coastal, are these dependent on sea level frequency curves, which have been updated in Defra's coastal extremes projects in recent years (since Foresight)? There may be some concern at the treatment of waves in terms of the rigour applied in consideration of hazards, especially considering the Winter 13-14 storms where mean sea level was not the critical factor. It may be expected that there is more discussion on threshold capacity of collection and conveyance systems as these will be very influential in urban areas, which is where most of the receptors are.

Some further edits to ensure common language and terminology about change factors and in presentation of tables in Section 3 would be helpful. Graphical summaries would greatly improve the presentation, which is currently rather heavy-going with multiple large tables of numbers.

In the fluvial analysis, were the "heightened response" catchments form FD2020 considered in developing the H++ scenario?

Response: Our adaptation scenarios do reflect some plausibility in future, as the many influences on flood risk management policy mean that there is large uncertainty. Our Enhanced Whole System and Reduced Whole System scenarios represent plausible extremes of adaptation, based on current policy and realistic assumptions about how these could be improved or relaxed.

We acknowledge that our metrics are limited, and could omit some important aspects such as risk to people. Current national level risk estimates do not include this either, so introduction of new

metrics we feel would cloud the issue and detract from key messages. Nevertheless, some aspects of risk to people are captured (e.g. through residential properties and people at risk), and the response of different metrics to adaptation is reflected in the results (spatial planning affecting properties more than it affects EAD, property level protection not affecting numbers of properties and hence people at risk etc).

At the coast the relationships between sea level rise and the change standard of protection are updated to reflect the latest sea level rise projections (as discussed in Appendix C). The approach is a simplification and although we agree an approach based more detailed on a process driven analysis of the coastal standards (an equivalent to the CEH catchment analysis, for example, and as being developed at NOC and elsewhere) the development / application of this analysis more detailed was outside of the scope here.

Within the fluvial analysis the 'heighten response' under the H++ scenario was considered to apply to the whole catchment. This is now more clearly acknowledged as a simplification and an assumption that means the climate driven component of the fluvial risk under the H++ scenario is likely to be overstated (although it is unclear by how much). Although the FFE could readily reflect the spatial variation in climate change this spatial data on the H++ was not available.

Adaptation strategies

The development of adaptation scenarios based on managing probability, exposure and vulnerability seems to have a more satisfactory foundation than the selection of exogenous change scenarios, allowing the tree structure in S4.2 (Fig 4-1) to emerge from initial principles.

The discussion in S4.2 and the identification of the five adaptation scenarios provides a convincing framework for the analysis. I was not clear about what to take away from the discussion about the relationship with CCRA Method Statement (box on p. 52).

The drawback of this approach is that the scenarios are not always obviously based on consideration of actual policy and practice, and may be viewed more as 'game play' type assumptions. Some readers may expect to see more explicit links to actual policies and practices and their influence (or otherwise) – see earlier comments.

The "decision tree" on p. 51 leads to 5 out of a possible 27 adaptation pathways (six if the baseline is included). As noted above this does not include conditional strategies, which are acknowledged to be difficult to analyse within this framework. It would be helpful to see some discussion of what is being left behind by pruning the tree back from 27 to 5 braches. The text in the box on p. 55 says that a limited set was chosen because of resource constraints (reasonable) but not why this particular set is justified, nor what is left behind.

Should there be more attention given to other pathways containing "low adaptation" choices? This may be relevant to exploring the balance between investment in community-scale flood defences versus PLP or use of planning controls, and touches on the (very informative) discussion of insurance, which could incentivise property level adaptations.

Table 4-2 (Exposure to flooding): should we also consider land-banking for future flood defences and potential for relocation of settlements, even if only to dismiss them?

Tables 4-1 to 4-3 please include a summary also of how each lever is implemented in the FFE – i.e. what, specifically, is adjusted in the FFE to represent each measure?

Text box on p. 55: The comment about reduced whole-system adaptation relating to a counter-intuitive relationship between adaptation levels and experience of flooding was confusing. Is this a finding from the analysis, or a factual comment based on other observations?

Response: While linking our adaptation scenarios to actual policies and practice would be a worthwhile aim, at this level of analysis it is not possible to project current policies across all epochs

to 2080s. This is chiefly because in a national approach we necessarily make broad assumptions about adaptation, whereas in reality adaptation must be a much more "local" affair. This is reflected in current policy (which could be expected to continue), where the focus of national level regulation is to promote local planning (SWMPs, SMPs, CMPs etc) rather than a top down imposition of risk reduction measures. The FFE uses the adaptation scenarios to try to reconcile this conflict between national and local levels.

Limiting the number adaptation routes was discussed in some detail early in the project, after recognising both that resources for generating such information are limited, and that generation of more outputs could obscure key messages (the FFE already generates over 1 million metrics as implemented). We feel that our approach of grouping measures into PFA, EFA etc is a good compromise between exploring the different aspects of adaptation while simplifying the outputs to give an overview appropriate to the level of analysis undertaken.

A.2.7 Analysis of results

Section 7

In the text box on p 64, please clarify whether the statement that the count of properties "at risk" for Great Britain does not change with climate is a finding of the analysis here, or an independent statement.

Response: This is a result of the underlying assumptions about the fixed extent of the floodplain, so more of an assumption than a result.

On p. 65, the statement is made (2nd para) that population growth affects urban runoff significantly. Could this not also be an exposure effect?

Response: Indeed, there is an exposure effect for residential property, the key point here is that it will also affect non-residential properties (even if their number is unaffected by population change).

On p. 65 the final bullet point states that "as might be expected, adaptation is less effective … for more severe climate change scenarios". This reads like an important general conclusion. But surely this is conditional on the prescribed adaptation measures? How do we know that other strategies or levels of adaptation investment might not achieve better pay-offs? Please clarify.

Response: We have updated the outputs in response to other comments received on the in adaptation measures; the commentary has also been changed, so this point is no longer relevant.

On the maps in Figures 7-1 to 7-15 it is difficult to distinguish classes from the colour shading. Please add text labels to the regions giving the percentage numbers.

Response: We feel this would detract from the clarity of the figures; the detailed outputs are also provided in spreadsheets for users who want to see the actual numbers at reporting region scale.

It would be helpful to present the maps in Figures 7-10 to 7-15 in terms of the deviation from the "baseline" adaptation strategy.

Response: We now have several tables doing this which give a clearer picture of adaptation relative to the baseline.

In the bar charts (Figs 7-16 onwards) it would be helpful if some attempt can be made to place the changes on comparable scales.

Response: We have now done this (except for H++ because of the very different magnitude of the changes).

Section 8

The text at the end of p. 94 is not very clear and would benefit from being re-worked. For example

- "This relationship is not however as simple as this…" – refer to literature to clarify why
- "A calibration exercise has been carried out…" – where? what criteria were used to calibrate against? what evidence is presented to support this?
- "results show that this value of hc gives a length of defences which is broadly in line with realignment strategy" – please clarify what "broadly in line" means

Figure 8-2 is missing a key.

The description of S-Grid (S8.2) is rather vague and not sufficient to understand what this model really is and how it has been applied. Please clarify.

The statement that the S-Grid model "will also capture the dynamics of inundation due to tidal forcing" is rather a catch-all that may gloss over a lot of detail, especially for a model applied on a 1 km^2 grid, which is massively coarse for flood inundation modelling. In general, this section of the report appears to be a superficial treatment of the analysis and does not provide enough detail to help assess confidence or uncertainty realistically.

Where on the coast was the analysis done to generate the tidal forcing curve?

Response: This section has been updated in response to this and other reviewers' comments; a key added to figure 8-2 (now 7-2). More description of S-Grid has been added, especially focussing on its assumptions and how they affect confidence in the outputs. The aim of using S-Grid was to generate flood extents that are more realistic than a simple tide-surge level intersection with topography, which would tend to overestimate extents by neglecting propagation aspects. We regard it therefore as an appropriate model to use for this level of analysis. The tidal forcing curve is derived for each point around the coast, based on SC060064 'Coastal Flood Boundary Conditions'. Report published by the Environment Agency.

Section 9

Section 9 begins to bring together the results to form an evidence base. As noted in the introduction to this review, there is perhaps a need for another iteration in order to draw out the real "headline" results, although this terminology is used in Section 9.

In Section 9.2, p. 108, there is discussion of planning policy causing development to move from the floodplain to areas more prone to surface water flooding. This seems not to take account of the responsibilities and resources (especially mapping of surface water risk) available to LLFAs. Is this a gap in the FFE analysis?

In general the text in Section 9 is more readable than some other sections of the report. It would be useful still to see more detailed cross-referencing and citation of supporting evidence. Please add citations for "significant current level of adaptation in critical infrastructure", "groundwater flooding has occurred in the past", "evidence suggests those who suffer flooding are more likely to take risk-reducing actions" and other statements of evidence.

Response: The "real" headline results are now in a summary at the start of the report. The counter intuitive result about planning policy moving properties into higher risk areas does perhaps reflect a gap in the FFE; because adaptation is based on current planning policies, which do not take surface water risk fully into account (due to confidence in surface water maps). That will probably change in the future, but based on current approaches and our assumptions that the adaptation approach is fixed now, this cannot be represented in the FFE. More citations have been added.

A.2.8 FFE

Emulator approach

The approach uses information from various sources representing current or recent climate conditions to establish relationships between flood impacts and event probabilities. Projected changes in event probability and postulated adaptation strategies are then expressed as transformations of the curves on their probability scale, with interpolation and extrapolation as necessary. This approach is described reasonably clearly in Appendix F3.2-3.3 and necessarily involves some assumptions, which are stated in the text. It would be useful to see more analysis of sensitivity to the assumptions made about the end-points of the interpolation.

On p. 7 in Appendix F there is an assumption made about calculation areas containing mixed defence assets, in which case the dominant defence type and condition grade is taken. Please comment on why this is a better assumption than choosing the "weakest link" (worst asset/condition in the system).

Response: The end points of this interpolation at the low probability end of the scale do not make a significant difference to risk estimates; at the high probability end, impact curves are well constrained for fluvial and coastal sources (1:10 flood extents are provided). Surface water risk at high probabilities is less well defined in the input hazard data sets, being limited to 1:30 for England, Wales and Northern Ireland, and 1:10 for Scotland. The mention of a 1:5 limit in the appendix is an error (it refers to a previous version of the emulator), the emulator uses log-linear interpolation from the highest probability available in the hazard data to a probability value of one. Thus no "cutoff" is implemented; this is the most "assumption free" way of extrapolating to high probabilities.

Significant thought was given to how to identify representative standard of protection for a calculation area. While the "weakest link" approach is superficially attractive, we found that it generates many areas with a low SoP, because calculation areas can include multiple sets of defences. A typical example is a fluvial area with high standard defences along the main channel, but small lengths of much lower standard defences along a tributary bounding the calculation area. Use of the length weighted average is thus regarded as a much more robust way of defining standard.

WAAD

The analysis of economic damages in F4 is rather opaque. This is an important part of the analysis because the economic assessment is likely to be seen as a headline result. Therefore the report should be clearer about precisely what has been done, and enable an audit trail in the calculations. There is some information about data sources in Appendix A but F4 should include an explicit and comprehensive account of the sources that were used. References to the MCM Handbook are somewhat ambiguous and should be tightened up to say which edition and publication date. Similarly the "WAAD calculation tool" should be cross-referenced to specify version and date. Although S1.3 states that the report is not intended to allow the result to be reconstructed, in this case it should be possible for any reader to see precisely how Table A1-2 was constructed and to reproduce those calculations so that the basis of the economic analysis is properly understood. The relationship between the proposed values and the tables presented in recent versions of MCM Chapter 4 (MCM Online, 2015/16, or say MCM 2013, print, pp 128-130) should be explained.

The analysis makes use of return periods in years and annual probabilities. Therefore the "1-year" return period refers to a flood event that is certain to occur in every year, and this value feeds through into the "WAAD x RP" calculation in F4.2. This requires some explanation. It is stated in F3.2 that the onset of flooding is assumed to correspond to a 5-year return period event. On the other hand, MCM (2014, p. 130) assumes no damages for events more frequent than one in two years (0.5 AEP). These threshold assumptions are essentially heuristics, and the various alternatives may all be justifiable. However there should be some attempt to describe these assumptions coherently, with

reference to alternatives in previous publications, and to assess how sensitive the analysis is to those decisions.

As in other sections, this text reads as though it has been compiled from previous reports but not properly edited for the new context. For example, F4 and F4.1 refer to consistency with the Environment Agency's Long Term Investment Strategies, which seems a very reasonable approach. LTIS 2014 is mentioned (although no precise citation is given and so the use of the acronym LTIS relies on the reader knowing what this is). However F4.1 goes on to refer to "each LTIS Intervention Option" and a non-existent "section 4.4.1 above". How do LTIS Intervention Options relate to the Adaptation Measures and Scenarios? Where is section 4.4.1?

The construction of the average flood damage in F4.2 on p. 14 is confusing. Please revise to be more explicit about the quantity that is being estimated here. I find the calculation of WAAD based on the incremental contribution to risk from successive exceedance probability bands to be more straightforward (see lower panel of Table 4.32 in MCM, 2013 edition, p. 129, Routledge, ISBN 978-0 415-81515-4). Please express the calculation as a formula to ensure that the terms are precisely defined.

Response: WAAD is a well-established approach (with well-established criticisms) to estimating annual average damages in the absence of property specific flood depth information; we have implemented this according to the guidance in the MCM for fluvial and coastal flood damages. A WAAD approach is also used for groundwater and surface water damages, however these are the results of informed judgements (made during this project) not empirical measurements. We have included additional discussion of the assumptions made in Appendix F (F.2).

Verification

The discussion of uncertainties/assumptions in the FFE in Section 6.2.1 is a useful start, but does not really establish the validity of the approach. The first five bullet points (uncertainties) in S6.2.1 seem potentially important and deserve further work. These should be presented in order of importance and addressed systematically with further comments about why they matter and what the implications are.

The bullet point "Impact curve interpolation, shifting, calculation of annual averages…" seems to contain a number of important issues that should each be considered individually.

Where property counts in Scotland are discussed on page 61, have SEPA been asked whether the figures represent defended or undefended assumptions?

It would be helpful to explain why the statement that the FFE is "reproducing present day risk adequately" is informative, given that it is built on data about present-day risk, and therefore should be expected to. In general the discussion of checks of the FFE against the summer 2007 event (also in Appendix F) seems to offer useful and objective context.

Is the column headed "CCRA" in Table 6-2 referring to the FFE estimates?

On page 63, is the factor-of-10 overestimate for non-residential damages important for the overall conclusions of the report?

Response: Since these comments were made, the FFE has been updated to provide more consistent estimates of present day risk after discussion with Defra, SEPA etc (especially for surface water). The point that reproducing current estimates is (or should be) a trivial exercise is important: in reality the FFE does a lot of work in interpolating impact curves and calculating metrics to arrive back at present day risk estimates. It is impossible in the scope of this project to disaggregate the effects of every step in the emulation process, but the overall verification here does provide some confidence that the process is reliable enough for the purposes of the CCRA.

A.3 David Ramsbottom – HR Wallingford

A.3.1 General

I have not had time to review this in detail. The report covers a wide range of analysis at a high level and it is difficult to assess the accuracy and reliability of the results.

The absolute numbers provide the same message as the first CCRA, indicating a significant increase in flood risk with climate change. However a quick comparison indicates that there are significant differences, particularly in the balance between future coastal and river flooding.

The adaptation scenarios are of interest because they indicate the extent to which the impacts of climate change might be mitigated.

Response: It is reassuring that the reviewer finds the broad messages to be the same as the first CCRA; we do provide more detail in our results.

A.3.2 Method

Comment: The FFE method appears to be based entirely on the increase in flood probability for fixed (present day) flood areas. The impact of change in flood area on the coast is investigated in Chapter 8, although this is outside the main analysis and results.

If this statement is correct, I suggest that it is clearly stated at the beginning of the report so that the method used (including approximations) is clear.

Response: This is stated explicitly as assumption #3 in section 5.1.

Comment: The method used in the first CCRA was based on the Environment Agency's national flood modelling for England and Wales. The method based on probability was only used for metrics that were not covered by the modelling. This was because the relationship between the probability and the impact is non-linear, particularly in defended areas. Thus results obtained using the probability method were considered to be less accurate than results derived from the modelling.

Response: None required.

Comment: In my opinion, the method in this CCRA is more approximate than the method used in the first CCRA. It also does not cover wider issues such as health impacts. However it benefits from recent work on other sources of flooding and flooding in Scotland and N Ireland, and is able to provide a consistent approach across the UK.

Response: None required.

Comment: The approximate nature of the results may not matter if the purpose is to provide an indication of future change (which is highly uncertain) and an indication of the effectiveness of mitigation measures. From this point of view, the report has succeeded.

Response: Thank you. Our analysis focusses on future change rather than absolute values *per se*; given the many of the irreducible uncertainties involved this is considered the most robust presentation. Absolute values are presented, with detailed supporting results provided in Appendix H.

Comment: The report requires tidying up: there are numerous errors in figure numbers, page breaks, typos, etc. I have not listed these as I assume they will be addressed.

Response: These have been addressed in the final version**.**

A.3.3 Summary

Comment: It is a shame that the summary is incomplete. Part of the review should be to comment on the key findings.

Response: A comprehensive summary is now included.

Comment: Both this report and the first CCRA are based on national information that was available at the time. The first CCRA gave impetus to the work needed to fill gaps (particularly information for Scotland and N Ireland, and information on surface and groundwater flooding). This information was not available for the first CCRA but is clearly available for this CCRA.

Response: None required.

Comment: I suggest that the first two sentences of the ""Approach"" section are modified to reflect the fact that information on other sources of flooding and flooding in Scotland and Ireland was not available for the first CCRA.

Response: The report structure has now been streamlined and the section ordering modified. The comparison between the first CCRA and our analysis here will (we understand) be reflected in the CCRA Evidence Report.

Comment: More generally, there appears to be a deliberate policy of avoiding any mention of the first CCRA as if it doesn't exist. This seems odd, as the methods used for the risk assessment are exactly the same as the probability method used in the first CCRA, and much of the same type information is presented (e.g. changes in tidal water level frequency, fluvial flow frequency, etc.). There are also methods used in the first CCRA that are directly relevant to the second CCRA, but they are not referenced.

This also raises the question of continuity between the two CCRAs, and how differences between the two assessments will be explained.

Response: There is some overlap in the authors of the first CCRA and our report and, in developing our approach, we have built on the very useful lessons and experience from the first CCRA. We have not undertaken a comparison of the changes from first CCRA because many things have changed (the underlying data, the population projections etc) as well as the method. We understand the ASC are drawing out key differences in their synthesis. We have now added a reference to the first report in Chapter 2.

A.3.4 Main sections

Table 2-1

Comment: The risk metrics are influenced by the current requirements of flood risk management including changes in receptors within flood probability bands. As the flood extent is limited to the present day extent, it is likely that the number of receptors in the higher bands will drop in an unrealistic way.

Response: Indeed we do see this as receptors move from low probability bands into higher bands. However, as the focus is on higher probability bands, this is not a significant weakness.

Table 2-2

Comment: Should the first representative period be from 2015? Each CCRA should move on 5 years.

Response: The baseline epoch was specified as 2014 by the ASC.

Comment: Whilst the assumption regarding occupancy rates seems reasonable for a high level analysis, this is affected by changes in living styles (more 1-person occupancy) and types of properties (particularly flats). This may need a closer look in the future.

Response: No response required – but noted for possible future work.

Section 3.2.1

Comment: Sea level rise means bigger waves at the shoreline.

Response: We agree, and have further highlighted in the text the issue of depth-limited wave conditions around much of the UK.

Section 3.2.1

Comment: Change in SoP. This is one of the areas where there is more recent information in the first CCRA.

Response: None required.

Table 3-4

Comment: The accuracy of SoP data for coastal (and river) defences is often poor. This could be a significant source of error.

Response: We acknowledge that there is a weakness in SoP (and condition grade) data for flood defences; we have worked with the data providers to generate a robust method for gap filling (using current SoP, then design SoP, then a national average SoP etc).

Comment: In addition, flood defence freeboard does not appear to have been taken into account. This is the safety factor applied to defence crest levels to take account of uncertainty. If it is not included, any risk analysis that is based on SoP values will overestimate the risk.

This is because the risk analysis assumes a SoP for each defence that does not take freeboard into account. For example, a defence with a nominal SoP of 50 years could have an actual SoP of 200 years if the actual crest level (including freeboard) is used. This means that flooding will only start for events greater than 200 years, not 50 years as assumed in the analysis.

Response: We assume that the SoP (as provided in the supporting databases) reflects the 'best estimate' of the actual standard provided by the defence. We therefore use this directly without an attempt to take account of freeboard.

Table 3-5

Comment: See my comments on the WP D report.

Response: We have not had access to these comments.

Table 4-4

Comment: I was unclear about why some of the numbers in this table were selected. Why for example is 75% of the reduction in standard avoided for a 1 in 100-year defence but 50% for a 1 in 50-year defence for baseline adaptation? These numbers are derived from Table D3.

Response: We have revised our tables of defence SoP response to climate change in response to other comments received hopefully the rationale behind these numbers is now clearer.

Comment: It might help to summarise what decision makers would have to do to achieve these adaptation scenarios.

Response: We deliberately avoid summarising what decision-makers should do and have focused on providing the evidence to support them in the choices they make. The CCRA Evidence Report will (we understand) cover some of the 'what to do' question.

Table 6-3

Comment: This is a good illustration of the uncertainties in flood impact estimation including the effect of using different methods. These uncertainties should be reflected in the final results.

Response: We have attempted to report results to an appropriate level of precision; and also we focus on relative changes rather than absolute values to reduce the impact of uncertainty in present data estimates.

Table 7-2

Comment: As with Table 4-4, I was unclear about some of the numbers, for example:

- Why is the percentage increase in the number of people greater than the increase in number of properties for the 1:75 band with no population growth?

Response: The slight differences in increases for residential properties and people arise from different occupancy rates across the UK (these are defined by census area); an increase in the number of properties at risk will have a different impact on people according to the occupancy of properties affected.

Comment:

- Why are there negative numbers for infrastructure in the 2020s?

These queries may be covered elsewhere in the report, but I have not had time to study the results in any detail.

Response: Negative numbers for infrastructure result from receptor level protection implemented as part of the adaptation scenarios.

Figure 7-1 (etc)

Comment: Should these maps be in an appendix?

Response: Other reviewers are happy with these in the main body of the report; they have therefore been retained.

Figures 7-16 to 7-18; Table 7-8

Comment: This looks like a very important summary

Response: A better summary is now given at the start of the report, and more involved commentary given in section 8.

Chapter 8

Comment: I was unclear about this analysis. The very high sea level rises will overtop all defences, not just the vulnerable ones. Figure 8-8 shows flooding in areas where the defences are not vulnerable (for example, one metre of sea level rise in central London).

Response: The analysis is intended to identify specifically defences at risk of increased erosion due to sea level rise, rather than the broader aspects of increased coastal flood risk. The 1m rise identifies some properties at risk in east London (from defences downstream of the Thames barrier).

Chapter 9

Comment: 9.1.1 These results seem high for the 2020s, when the sea level is projected to have risen by 0.15m and river flows increased by 20%.

Response: These results have been revised using a changed definition of representative SoP, increases by 2020 are now less than in previous versions because there are now fewer undefended areas.

Comment: 9.1.1 I found the text hard to follow and suggest that it is expanded so that the key messages are clear.

Response: This section has been extensively rewritten, and should be much clearer now.

Comment: 9.1.3 I think the reason that the 1:75 band makes a bigger contribution is because the floodplain area is limited to the present day floodplain. This means that by the 2080s almost the

entire present day floodplain floods at 1:75 or more frequently. Less frequent flooding would still occur, but is outside the model domain and is therefore not reported in the results. In other words, this is method related.

Response: This is the most likely explanation; the contribution to overall risk from low probability floods is, however, small, and therefore ignoring potential increases in floodplain extent is not likely to introduce significant errors in risk.

Comment: 9.1.4 The increase in coastal flooding is much greater than projected in the first CCRA.

Response: The increase in coastal flooding is now much less since the methods used to define the representative SoP and its response to climate change have been revised following other comments received.