Towards a flood resilient Eden Catchment, Cumbria

A submission to the Defra Flood Risk Management and Modelling Competition supported by United Utilities, Aviva and the Natural Environment Research Council (NERC)

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Abstract

'Resilience to flooding' does not equate to 'defended from flooding', but means using a portfolio of responses to reduce the probability of flooding, limit the exposure to flooding and reduce the vulnerability of those that are exposed.

We use the Future Flood Explorer (FFE) to emulate the behaviour of important aspects of Eden Catchment flood risk system and allow a rapid, yet credible, evaluation of the effects of climate and alternative adaptation strategies on flood risk. The FFE uses available datasets on the sources, pathways and receptors of risk to inform the emulation, ensuring the results are consistent with current risk estimates.

Our analysis suggests that by the 2080s, under the assumption of a continuation of current levels of adaptation, direct residential economic flood risk in the Eden could **increase** by 50-160%, assuming a 2^{o}C and 4^{o}C climate future respectively. To manage flood risk more effectively an 'enhanced whole systems' approach is needed. Such an approach is shown to be capable of not only maintaining current risk levels but **reducing** them; direct residential flood risk in the Eden reduces by 5-30%, assuming a 2^{o}C and 4^{o}C climate future respectively.

Keywords: Eden, strategic flood risk management, Future Flood Explorer, climate change, adaptation

Word count (excluding the abstract, references, author biographies and the acknowledgements): **4,999**

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The 2015/16 floods highlighted the considerable challenges that exist in delivering flood risk management in Cumbria. The diversity of land use, catchment behaviour, and the need to provide truly integrated solutions whilst balancing multiple criteria provide a real challenge. The National Resilience Review reinforced these challenges and places the notion of 'resilience' at the heart of flood risk management. But let's be clear, 'resilience to flooding' is not the same as 'defended from flooding'. It does mean however using a portfolio of responses to reduce the probability of a flood occurring, limit the exposure should a flood occur and reduce the vulnerability of those that are exposed. As set out by the Chief Scientist in 2015, to be successful as a society we need to learn to manage risk and not simply seek to avoid it; a philosophical and practical impossibility in the context of flood risk.

The Cumbria Floods Partnership (CFP), set up by Liz Truss in the aftermath of Storm Desmond, provides a fully inclusive and integrative process that has the potential to deliver a complex multi-faceted approach to flood risk management; the challenge now is doing so.

'After seeing first-hand the impact of the flooding in the north of England, it is clear that the growing threat from more extreme weather events means we must reassure ourselves, and those communities at risk, that our defences, our modelling and our future plans are robust.' Elizabeth Truss MP

Defra and the CFP recognise that a critical barrier to progress is the lack of credible decision relevant evidence. This evidence gap is reflected in the compelling practical challenge that belies the rather simple Competition Question:

'If you were responsible for managing the Eden catchment in Cumbria, what flood risk management approaches would you recommend, and why?'

This lack of evidence in part reflects the short-comings of traditional modelling approaches that are often too computationally intensive to explore multi futures and responses at a catchment scale (e.g. Beven *et al*., 2012, Kwakkel *et al*., 2013). Instead, the approach used here builds upon lessons from past national scale studies (e.g. Evans *et al.,* 2004a&b) and insights from international studies (e.g. Klijn, *et al*., 2004 and 2012, Bouwer, *et al*., 2010) to allow a rapid, yet credible, evaluation of the effects of climate change and alternative adaptation strategies on flood risk.

The Future Flood Explorer (FFE), the model used here, emulates the behaviour of important aspects of Eden Catchment flood risk system. The FFE uses available datasets on the sources, pathways and receptors of risk (many of which are available through open data initiatives) to construct the emulation (see Box 1). The FFE is capable of assessing risk from fluvial, coastal, surface water and groundwater sources; in the Eden only fluvial and surface water are significant.

Box 1 The Future Flood Explorer (Eden): Model basis

The Future Flood Explorer established for the Eden Catchment - FFE (Eden) - builds upon approaches used for the UK Climate Change Risk Assessment (CCRA) commissioned by the Climate Change Committee (and funded by NERC), and the assessment of Flood Resilience in Disadvantaged Areas commissioned by the Joseph Rowntree Foundation (see Sayers *et al.,* 2015 and Sayers *et al.,* 2016a). These two studies are used here together with a number of improvements to the FFE, including:

- ***Better spatial resolution:*** The FFE uses hazard model outputs to develop Impact Curves at an aggregated scale. The FFE(Eden) aggregates these results based census neighbourhoods (with an average size of 30 ha).
- ***A more detailed representation of vulnerability:*** The vulnerability of those exposed to flooding and the associated flood risk has been explored using two indicators. The first, the Neighbourhood Flood Vulnerability Index (NFVI), reflects the inherent characteristics of the individuals and the community that make a particular neighbourhood more or less vulnerable should a flood occur. The second, the Social Flood Risk Index (SFRI) combines the NFVI with the assessment of the probability and impact of flooding.
- ***An improved representation of natural flood management measures:*** To better respond to the challenge of the competition we have incorporated an enhanced representation of rural upland management measures within the FFE. For each point in the drainage network, we have calculated the proportion of land draining to that point that could be subject to natural flood management. Poorer quality upland agricultural areas offer perhaps the greatest opportunity for management: this is where a lot of runoff is generated, and because of its lower agricultural value it may represent a cheaper option for changing management methods than higher value land. We therefore identify Natural England's Agricultural Land Classification classes 4 and 5 (poor and very poor quality agricultural land) as the most likely area for runoff management. The FFE explores the impact of reducing runoff from these areas (table below), with the runoff reductions taken from research into test catchments across England and Wales (as used in the CCRA). The FFE's representation of natural flood management (NFM) embraces two key findings of these studies: the effect of NFM decreases with increasing catchment size, and it also decreases with increasing flood magnitude. We have scaled the impacts in the table below by the proportion of class 4 and 5 land within each point's contributing catchment, and also by a factor that reduces NFM's effectiveness for higher flows, and increases it for lower flows.

Agricultural Land Classification	CLA			Enhanced adaptation		
	2020s	2050s	2080s	2020s	2050s	2080s
Grades 1-3	0	-0.5%	-1%	0	-1%	-2%
Grades 4 and 5	0	-1%	-2%	0	-5%	-8%

How can we move towards flood resilience in the Eden?

What combination of measures is most likely to manage present and future risk best?

Much of the UK flood risk management policy guidance (e.g. Defra 2005, Environment Agency, 2014, SEPA, 2012) supports the concept that flood risk is best managed through a portfolio of measures implemented through a continuous processes of adjustment. These concepts where first promoted in the Foresight Future Flooding Studies (Evans *et al*., 2004a&b, Hall *et al*., 2003) and have since between taken forward international (for example, the Dutch Multi-Layer Safety, and US concept of 'buying down the risk' through multiple actions).

The future adaptation pathway will depend upon the reality of the change in climate, development and political (local and national) priorities. The CCRA Future Flooding report (Sayers *et al*., 2015) therefore sets out six alternatives adaptation strategies that implement a range of individual adaptation measures. Here we focus on the role of six individual measures (Figure 1) and their implementation as part of two alternative strategies: (i) a continuation of the Current Level of Adaptation (CLA), assuming flood risk management policy continues to be implemented as present into the future, and (ii) a more ambitious and innovative Enhanced Whole System (EWS) adaptation strategy. The future flood risk by the 2020s, 2050s and 2080s has been assessed for each of the CLA and EWS strategies, assuming a 2°C and 4°C climate (by the 2080s) / low population growth future. The results of this analysis are presented in Figure 2 alongside the present day assessment of flood risk.

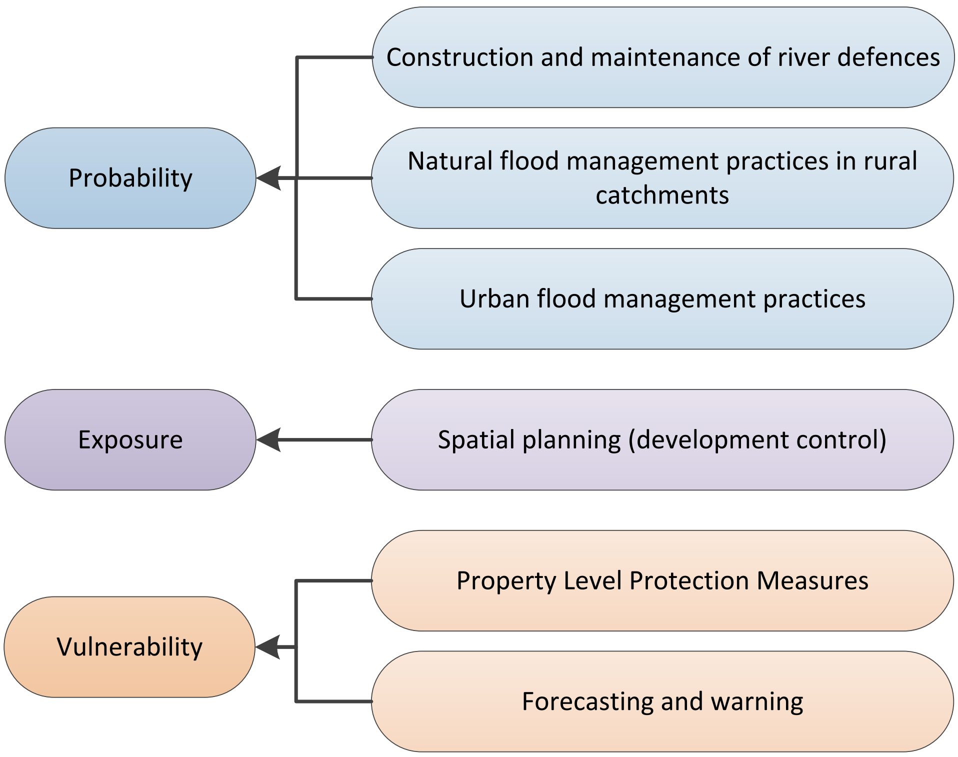
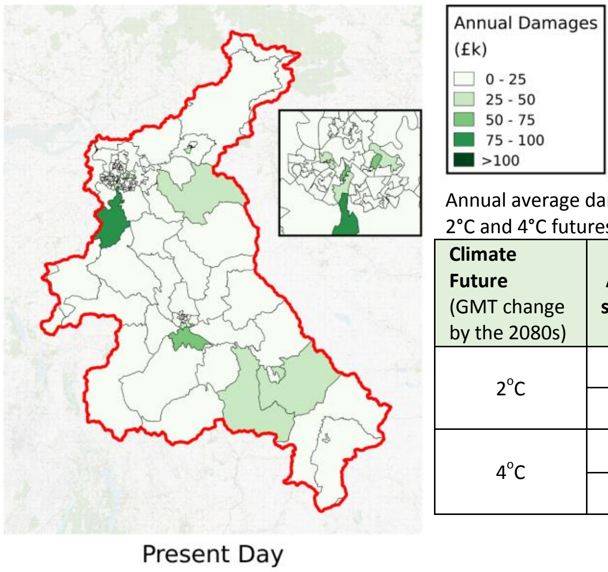


Figure 1 Individual measures considered here as part of the analysis of alternative strategies for the Eden

Note: Insurance is not considered here. This is not because it is perceived to be unimportant - it is critical to the speed of recovery and has a role to play in changing behaviour. The exclusion is a practical one to allow a focus on actions that may directly reduce economic risk.



Annual average damages in the Eden: CLA and EWS adaptation strategies under 2°C and 4°C futures

Climate Future (GMT change by the 2080s)	**Adaptation strategy**	**Annual average damage – residential properties (£)**			
		Present Day	2020s	2050s	2080s
2°C	CLA	£1.11m	£1.48m	£1.83m	£1.72m
	EWS		£1.08m	£1.02m	£0.81m
4°C	CLA		£1.73m	£2.21m	£2.91m
	EWS		£1.23m	£1.19m	£1.07m

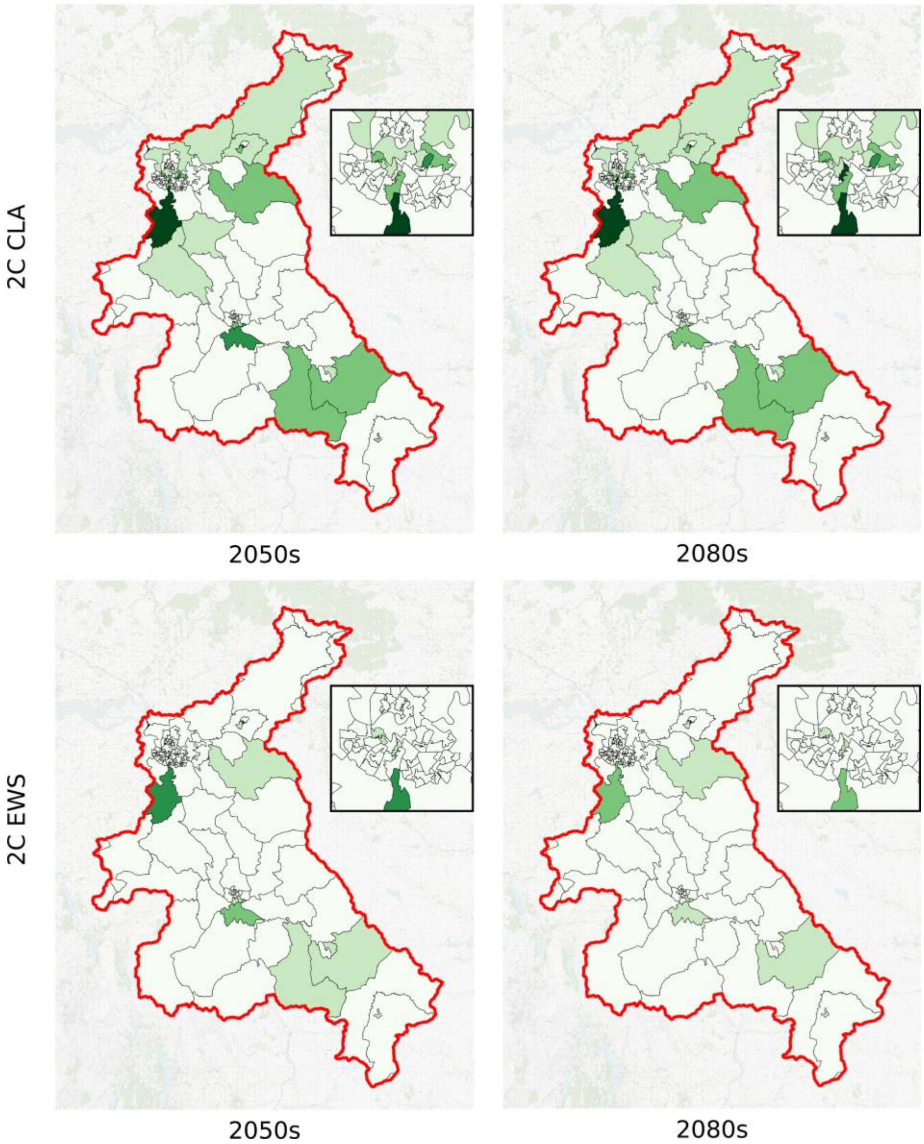


Figure 2 Annual average residential damages aggregated to LSOA census areas, for 2°C present day (top)**, for CLA 2050s and 2080s** (middle) **and EWS 2050s and 2080s** (bottom). (Insert) **Carlisle.** Contains OS data © Crown copyright and database right (2016).

What contribution do individual measures make to risk reduction?

An important strength of the FFE is its ability to disaggregate the contribution of individual measures to risk reduction. This quantified insight into the role each adaptation measure plays in the context of a broader portfolio of responses provides vital insights into which actions have the potential to be most effective and where effort should be focused.

Figure 3 compares the contribution of traditional defence measures, natural flood management measures and property level protection make to risk reduction (this is the reduction in risk when an enhanced approach to each adaptation is adopted). The figure presents the results for both the 2080s under a 2°C and 4°C climate future and assumes low population growth.

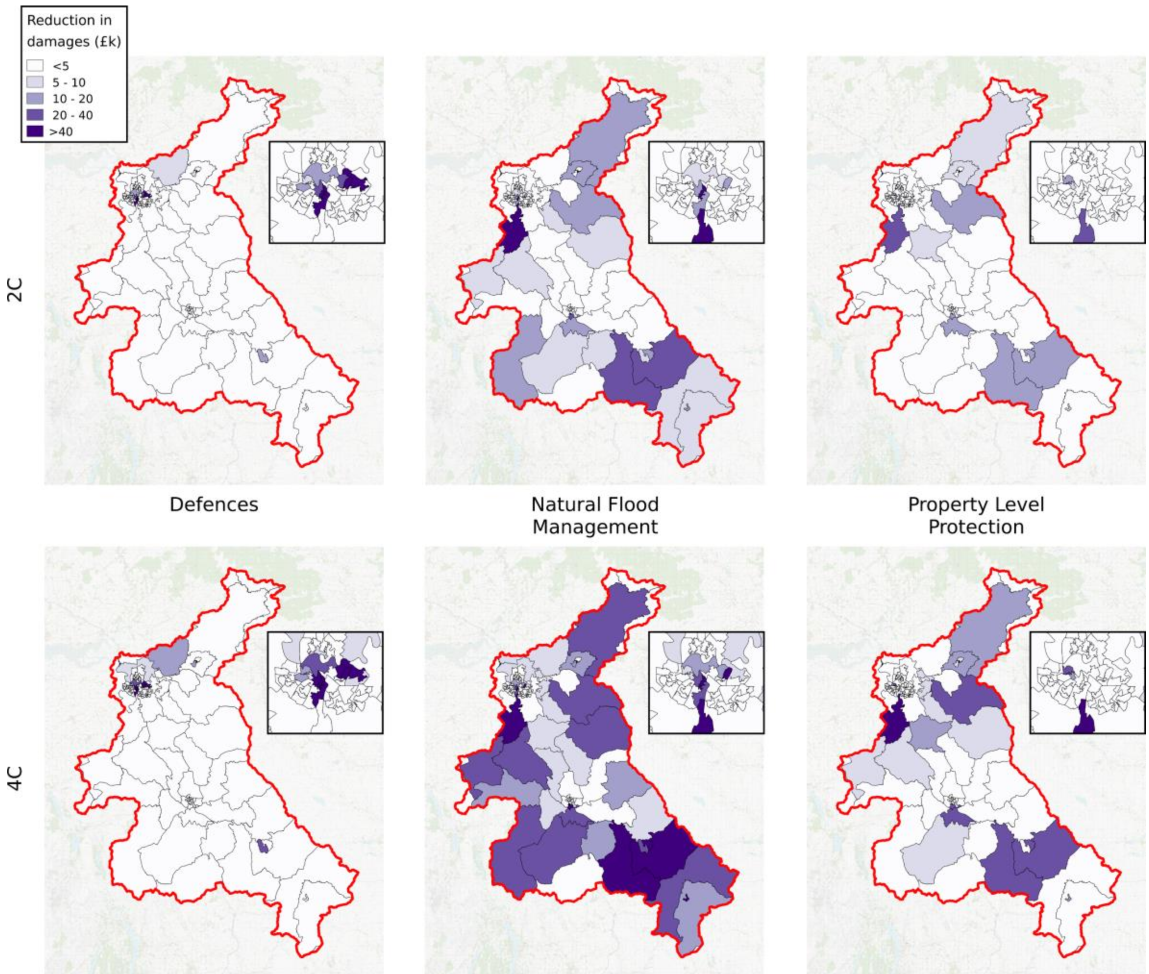


Figure 3 The contribution to risk reduction from defence, natural flood management and property level protection, for 2080s (assuming low population growth). (insert) **Carlisle.** Contains OS data © Crown copyright and database right (2016).

The FFE enables similar insights to be gained for all measures. Table 1, for example, presents the additional reduction in risk that may be expected if greater effort was directed towards one particular measure (assuming all other measures continue at current levels).

Table 1 The risk reduction achieved by focusing on a particular measure

Adaptation strategy	2°C		4°C	
	Annual Average Damages (£) (residential)	% change compare to CLA	Annual Average Damages (£) (residential)	% change compare to CLA
Continuation of current levels (CLA)	£1.72m	n/a	£2.91m	n/a
CLA plus an enhance approach to:				
Provision of flood defences	£1.33m	-23%	£2.17m	-25%
Managing rural run-off (NFM)	£1.26m	-27%	£1.82m	-37%
Managing urban runoff	£1.69m	-2%	£2.85m	-2%
Spatial planning (development control)	£1.72m	0%	£2.90m	0%
Property level protection	£1.48m	-14%	£2.48m	-15%
Flood forecasting and warning	£1.65m	-4%	£2.80m	-4%

The analysis reinforces the notion that there is no silver bullet to managing flood risk and a portfolio response will be needed. Both Table 1 and Figure 3 however suggest that not all measures are equally effective and provide useful insights into their relative importance in the Eden. In particular, the results highlight that:

- ***Well planned measures to manage run-off from the upland catchment have the potential to significantly reduce risk:*** The analysis highlights the significant contribution that NFM measures could make to reducing risk within the Eden. Both the absolute and relative contribution to risk reduction increases with climate change and reinforces NFM as a robust management choice (i.e. it continues to perform well across the range of climate futures tested).
- ***Improvements in formal flood defences are needed to protect key towns****:* The analysis highlights that improving defences (mostly in Carlisle) provides a significant contribution to risk reduction as part of a broader portfolio. Other smaller settlements are not generally protected by defences, and this is likely to remain the case in the future because of the difficulty in achieving favourable cost-benefit ratios for new defences in small towns, villages and sparsely populated areas.
- ***There is limited opportunity for changes in planning (i.e. development control) to play a significant role:*** The majority of future risk in the Eden will be associated with the existing stock of housing. For the projection used here, the population of the Eden catchment is expected to reduce by around 10% by the 2080s. This drop in population is likely to be offset by a reduction in household occupancy; nevertheless we would expect only a very limited increase in residential properties in the catchment. Development control will thus make an insignificant difference to future risk.
- ***Improvements in flood forecasting and warning are important but have limited ability to further reduce economic risk:*** The National Resilience Review highlights the challenges and importance of providing reliable and timely forecasts (HM Government, 2016). When extreme floods occur such improvements can be vital. The analysis presented here however suggests that such improvements likely to have limited impact on residential damages. This is because (i) flood forecasting and warning systems already provide a reasonable service (despite the

underlying gaps in science), (ii) there is a limit to reduction in residential property damage that can be achieved, regardless of the lead time given and the accuracy of the warning.

- ***Property level protection can make a significant contribution to risk reduction:*** While less than for NFM and defences, the reduction of around 15% is still significant.
- ***Urban runoff management makes only a small contribution:*** This reflects the relatively small contribution of surface water to total risk (around 6% of the total now and in the future).

Natural flood management measures can make a real difference in the Eden. Why is that?

Given the relatively modest reductions in flow produced by NFM, the significant reduction in risk appears surprising, and is worth investigating further. The potential reduction in fluvial flows by 2080s that natural flood management measures may achieve (if ambitiously, but realistically, implemented) is shown in Figure 4. As expected, the largest reductions are experience in the headwaters of the catchment, with smaller reductions further down the catchment. By Carlisle (towards the catchment outlet) there is a significant variation in reduction in the flow achieved in each watercourse. This is because of the differential opportunity for NFM measures in the associated upland catchments. In the Eden and Caldew, that drain large areas of Grade 4 and 5 land, the reduction in peak flows is around 5%; a smaller effect (2-3%) is achieved on the Petteril and other local streams that drain mainly lowland catchments of higher quality land.

The effectiveness of NFM reflects two important characteristics of the Eden catchment:

- **A high proportion of lower agricultural grade land:** The Eden Catchment contains a large proportion of ALC Grade 4 and 5 land (54% of the catchment, compared to an average of 23% for England). This provides a realistic opportunity to manage runoff across a large area without a significant impact on agricultural productivity.
- **A small change in flow translates to a significant reduction in the chance of a flood:** The Eden's location in north west England means its hydrological growth curves are relatively 'flat' (Figure 5). In other parts of the UK, growth curves are much steeper (e.g. as shown in Figure 5 for East Anglia). This means that for a given reduction in flow, the reduction in the chance of a flood is higher in the Eden than it would be, say, in East Anglia. In the north west, a 5% reduction in flow typically delivers a 25% reduction in the flood probability (i.e. a flow with 1% annual exceedance probability without NFM has a probability of 0.75% with NFM), whereas in East Anglia it delivers only a 15% reduction (i.e. a flow with 1% annual exceedance probability without NFM has a probability of 0.85% with NFM).

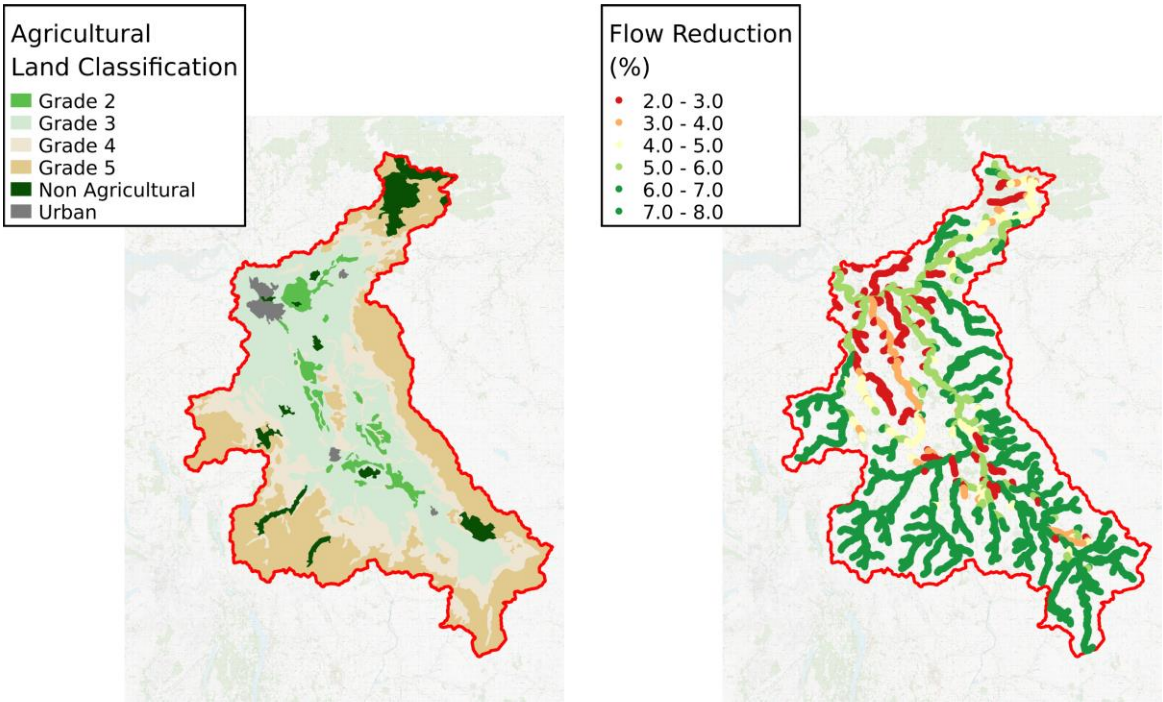
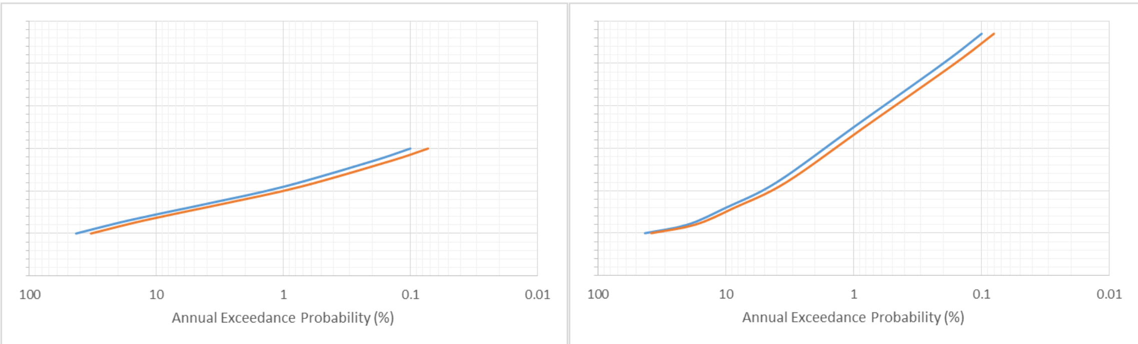


Figure 4 Land classification (left) and the reduction in flow represented by the natural flood management lever (right, 2080s, Higher lever setting). Contains OS data © Crown copyright and database right (2016).



Legend: Blue present growth curve. Orange flows after a 5% reduction from natural flood management.
Figure 5 Hydrological growth curves: (left) **North west of England.** (right) **East Anglia**

In a socially just approach to flood risk management the most vulnerable members of society would be the best protected. Is this the case in the Eden, and will it be in the future?

The NFVI in the Eden catchment is, on average, lower than many more vulnerable areas in the UK (e.g. Boston, Hull, Belfast). This catchment average message masks some important localised issues. The analysis highlights that the neighbourhoods with highest SFRI, both now and in the future, are located in Carlisle (Figure 6), with further isolated pockets in Penrith and Kirkby Stephen. Flood risk in these neighbourhoods today is, on average, slightly lower than for less vulnerable neighbourhoods (annual average damage of £5.45 per head in the most vulnerable neighbourhoods compared to a catchment average of £6.51 per head – see Table 2).

By the 2080s, assuming a broadly based portfolio of measures is implemented, flood risk increases for all at a similar rate. Under a management strategy that focuses on traditional flood defences however, the flood risk experienced by the most vulnerable increases at a faster rate than elsewhere. Property level protection is seen to have a much greater impact on risk in the most vulnerable neighbourhoods when compared to elsewhere (although it is assumed here that PLP is taken up equally by all, an assumption that emerging evidence suggestion many not be the case).

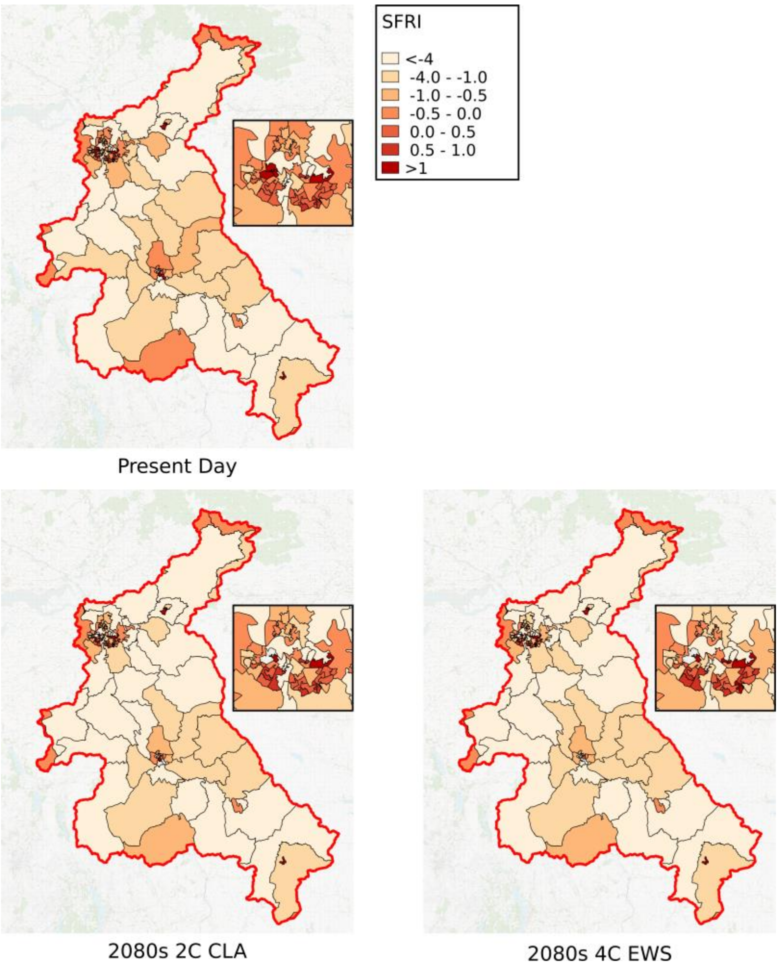


Figure 6 Quantifying social flood risk in the Eden using the SFRI. (Insert) **Carlisle.** Contains OS data © Crown copyright and database right (2016).

Table 2 Comparing flood risk for all properties, and those in the 20% most vulnerable areas

		Annual Average Damage (£)	
		per head	per head (top 20% by NFVI)
Present Day		£6.51	£5.46
2080s Continuation of current levels of adaptation (CLA)			
	2^{o}C and low population growth	£11.26	£9.45
	4^{o}C and low population growth	£19.00	£16.10
2080s CLA plus an enhanced approach to implementing:			
2^{o}C	Flood defences	£8.69	£7.91
	Property level protection	£9.71	£8.05
4^{o}C	Flood defences	£14.21	£13.32
	Property level protection	£16.21	£13.68

Which measures offer a robust choice given the wide range of uncertainties?

Without a thorough appreciation of the credibility of the evidence presented it is, of course, impossible to be confidence in any choice that is made. In particular it is important to understand those uncertainties that are largely irreducible (those associated with the future climate and population for example) and those that are associated with the data and models used (and may be reduced if shown to be important – although recognising that not analysis, however detailed is free from uncertainty).

- ***Uncertainties in future climate change:*** The reality of the future climate can not be known. The analysis present here explores this uncertainty through but considering a 2^{o}C and 4^{o}C future. The results confirm that a portfolio approach offers a hedge against this uncertainty
- ***Uncertainties in the rate of population growth:*** The analysis presented assumes a low population growth future. To explore the impact of this assumption on both changes in risk and the performance of individual adaptation measures the analysis has been repeat using a 'high population growth' scenario (Tables 3 and 4). The results show that flood risk increases in response to greater growth in population. This unsurprising result mask some subtle changes in the effectiveness of some individual measures. For example, natural flood management measures become slightly less effective because the population increases tend to be concentrated in the more rural south of the catchment, acting to increase risk exactly in those areas where NFM would be expected to be most effective.
- ***Uncertainties in the implementation of adaptation measures:*** Significant assumptions have been made in the likely priorities national policy will give to individual measures in the future, and their implementation – an issue discussed at length as part of the CCRA and the on-going JRF research. In part these are addressed here through the consideration of two alterative adaptation scenarios (the CLA and EWS strategies) and the role each individual measure may play in these. Many more adaptation scenarios, however, could (and should) be considered.
- ***Uncertainties introduced through the data, model and model structure****:* Like all models the FFE(Eden) and the associated analysis presented within this report is subject to number of assumptions and limitations (and many of these have been discussed previously, Sayers *et al.,* 2015, Sayers *et al.,* 2016a&b). FFE outputs will only be as good as the input data used, with significant uncertainty arising from uncertainty in hazard data, receptor data (e.g. from the national receptor database) and information on vulnerability (e.g. from multi-coloured manual approaches). The FFE also introduces some uncertainty through the emulation process.

In addition to the uncertainties discussed above it is important to reflect upon the omissions from the analysis presented here to. These include:

- The impact of **sediment** on flooding and the advantages and disadvantages of sediment source management (e.g. using NFM to manage sediment yields) and the pathway management (e.g. through dredging activities).
- The impact of flooding on **locally important infrastructure** and different approaches to securing these services (e.g. local protection, relocation, additional redundancy etc.).
- **Groundwater** flooding has been included here (although is already available through the FFE).
- The local practicality of the individual measures has not been explored. All flood issues are local and require informed **engagement and participation of local partners** to get them 'right'. No effort has been made in the development of this submission to engage with local communities or other stakeholders. Having said this the individual adaptation measures are credible reflections of current practice and what might be achieved.

- We have taken a narrow view of risk, **concentrating on residential economic damages**. While this is consistent with current cost-benefit approaches to evaluating flood risk management options (e.g. as stipulated by Treasury green book), it masks some important differences in the response to adaptation. For example, the reductions achievable from defences and NFM may be similar in terms of annual average damages, but their effect 'on the ground' will be very different – a virtual removal of risk below a standard of protection for defences, compared to a reduction in flood probability across a range of flood magnitudes for NFM.

Table 3 Population of the Eden catchment: Low and high population growth assumptions

	Low	High
Present Day	146,000	
2020s	146,000	150,000
2050s	139,000	156,000
2080s	131,000	167,000

Table 4 Sensitivity to uncertainties in population growth by the 2080s

	Low Population Growth		High population growth	
	Annual Average Damages (£) (residential)	% change compare to CLA	Annual Average Damages (£) (residential)	% change compare to CLA
2°C Climate Future				
Continuation of current levels of adaptation (CLA)				
All measures	£1.72m	n/a	£2.08m	n/a
CLA plus an enhanced approach to:				
Provision of flood defences	£1.33m	-23%	£1.59m	-24%
Managing rural run-off (NFM)	£1.26m	-27%	£1.61m	-23%
Managing urban runoff	£1.69m	-2%	£2.05m	-2%
Spatial planning (development control)	£1.72m	-0%	£2.06m	-1%
Property level protection	£1.48m	-14%	£1.84m	-12%
Flood forecasting and warning	£1.65m	-4%	£2.00m	-4%
4°C Climate Future				
Continuation of current levels of adaptation (CLA)				
All measures	£2.91m	n/a	£3.49m	n/a
CLA plus an enhanced approach to:				
Provision of flood defences	£2.17m	-25%	£2.55m	-27%
Managing rural run-off (NFM)	£1.82m	-37%	£2.41m	-31%
Managing urban runoff	£2.85m	-2%	£3.38m	-3%
Spatial planning (development control)	£2.90m	-0%	£3.48m	-0%
Property level protection	£2.48m	-15%	£3.04m	-13%
Flood forecasting and warning	£2.80m	-4%	£3.35m	-4%

What do we recommend?

A number of conclusions can be drawn from the analysis presented:

- **If current management approaches continue future risks are likely to increase:** By the 2080s, under the assumption of a continuation of current levels of adaptation, direct residential flood risk in the Eden **increases** by 50-160%, assuming a 2^{o}C and 4^{o}C climate future respectively. If high population growth is assumed the increase could be even more (over 200%). The increase in risk equates to a shift from a 20% chance of damages exceeding £10m in any 10 year period today, to a 33% chance in the 2080s for a 2^{o}C climate, or a 50% chance for a 4^{o}C climate.
- **An 'enhanced whole systems' approach to managing flood risk is needed:** The results confirm that there is no silver bullet to managing flood risk and reinforce the need for a more strategic approach to delivering flood resilience (Figure 7). This is, of course, a more ambitious endeavour than traditional flood defence. It will require a step change in the way we bring together the management of the urban and rural landscape to promote multiple sustainable outcomes for the people, economy and ecosystems of the Eden. Such an approach is shown to be capable of not only maintaining current risk levels but reducing them. By the 2080s, under the assumption of an 'enhanced whole system' adaptation strategy, direct residential flood risk in the Eden **reduces** by 5-30%, assuming a 2^{o}C and 4^{o}C climate future respectively.
- **Fluvial flooding is the greatest driver of present and future flood risk:** The FFE(Eden) includes both surface water and fluvial sources. Fluvial flooding however dominates the risk, with surface water accounting for only 6% of present day driect residential property damages (£); a contribution hat changes little under the climate futures used here.

Achieving an 'enhanced whole system' adaptation will require improvements to flood defences to be appropriately designed and maintained, forecasting and warning systems to be improved, natural flood management measures to be widely implemented and spatial planners encouraged to actively reduce risk (not just avoid increasing it). Within this broadly based portfolio of measures some more important (in terms of risk direct property damage) than others. This variation in contribution has been explored using FFE yielding three important insights:

- **Traditional defences (albeit designed to be adaptable) are likely to play a significant role in reducing future risk.** Flood defences will have a continued and important role to play in managing risk, especially in Carlisle. Our analysis suggests that by 2080s additional effort directed towards physical defences would reduce risk by between approximately 25% (when compared an approach that continues the current level of adaptation).
- **Natural flood management presents a significant opportunity and must be embraced if flood risk management strategies are to succeed.** As far back as 2004, 'Making space for water' (Defra, 2004), identified the need to take a 'whole catchment approach' but few examples exist in practice. The analysis presented here highlights that, within the Eden Catchment, the concept of working with natural processes to slow the flow in the catchment uplands is capable of providing a significant contribution to risk reduction. NFM can be expected to deliver multiple benefits for individuals, business and the environment beyond the narrow consideration of direct residential property damage considered here.
- **Careful consideration is needed to ensure flood risk in the most vulnerable neighbourhoods is well managed.** The analysis highlights that the most vulnerable neighbourhoods, both now and in the future, are located in Carlisle, with isolated pockets in Penrith and Kirkby Stephen. By the 2080s, assuming an enhanced whole system approach to adaptation is implemented, flood risk

increases for all at a similar rate. Under a management strategy that focuses on traditional flood defences however, flood risk experienced by the most vulnerable increases at a faster rate than elsewhere. If appropriately supported, property level protection has the potential to have a much greater impact on risk in the most vulnerable neighbourhoods.

Future opportunities to improve the analysis in the Eden

The Future Flood Explorer is a powerful tool to explore future changes in risk. The FFE has significant potential to be taken forward to support the development of the Eden Strategy (beyond this Competition). To do so, a number of improvements could be considered to:

Improve the local credibility of the analysis

Outputs from the FFE are only as good as input data. Various improvements to the data input data would be useful in this regard:

- **Take maximum advantage of local datasets to support the FFE (Eden):** Local flood modelling continues to be improved along with the understanding of the location and vulnerability of property and infrastructure. Understanding of defence standards and land use datasets also continually improve. The structure of the FFE allows these improvements to be directly used in analysis. ***Action:*** *Update the FFE using the most credible local data and model results.*
- **Improve the representation of impacts of climate change of fluvial flows:** The fluvial response to climate change used here is based on approaches developed some years ago (using Flood Studies Report regional growth curves). The latest analysis by CEH Wallingford provides an opportunity to improve this element of the analysis. ***Action:*** *Update the FFE using a greater spatial resolution of changes in fluvial flows and wider range of future climates.*
- **Improve the representation of impacts on natural capital and the representation of natural flood management responses:** The evidence for NFM is growing and the analysis presented here demonstrates its potential in the Eden. To improve confidence further analysis of the underlying processes in the Eden are needed. ***Action:*** *Update the representation of NFM measures within the FFE using finding from additional local analysis.*

Enable an optimisation of a portfolio based strategy

- **Improve the linkage between adaptation and investment planning:** Within the analysis presented here the focus has been on assessing risk. Decisions to adapt are, of course, typically based upon a consideration of costs and benefits. Incorporating a consideration of both costs and benefits into the FFE would link the adaptation scenarios more closely with the process of decision making. This would be relatively straightforward, and combined with the very fast runtime of the FFE (less than 1 minute for the Eden) this would support a formal (real options, Monte Carlo, continuous simulation etc.) based optimisation of the investments and disaggregation of the contribution of individual adaptation measures. ***Action:*** *To link the FFE with a high level, but credible, costing approach and sensitivity and optimisation method.*
- **Incorporate a range of additional risk and opportunity metrics:** The focus here has been on direct residential property damages. This is simply a function of Competition constraints on space. It will be important to reflect a much wider set of risk metrics and opportunities, reflecting social well-being, economy impacts, infrastructure services (locally and nationally), ecosystem services etc*.* ***Action:*** *To extend the range of metrics considered (building, for example, those set out in the CCRA, Sayers et al., 2015).*

The assessment of risk is only one input to the development of an ambitious and achievable a strategy. Many other influences will be important and range from gaining participation from a range of partners (locally and nationally), with each understanding the risks and opportunities and accepting that long term flood resilience relies upon a portfolio of approach delivering multi-benefits across multi-interests (Figure 7).

Figure 7 Golden Rules of Strategic flood risk management (Sayers *et al.*, 2014)

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Acknowledgements

The modelling analysis presented here builds upon approaches applied as part of the UK Climate Change Risk Assessment (CCRA) commissioned by the Climate Change Committee and the assessment of Flood Resilience in Disadvantaged Areas commissioned by the Joseph Rowntree Foundation. The contribution of these studies to the results presented here, and Defra's open data programme that supports them, and the Ordnance Survey for the provision of base mapping is gratefully acknowledged.

Statement of use