APPENDIX G: **EXPLORING THE VALIDITY OF PRESENT DAY RISK ESTIMATES AND VERIFYING THE FUTURE FLOOD EXPLORER**

Contents

G.1 Validity of data provided on present day risks

Note: **Peer review of the underlying methods used to assess present day flood risk**

England and Wales. The present day analysis used here is taken largely from the NaFRA products: The underlying methods used to generate NaFRA have been reviewed via various papers (Hall et al, 2003 and Gouldby et al, 2008) although there is no single paper setting out the latest methods. There has been no 'formal' validation of the results; NaFRA outputs are checked as part of a local output review process by the Environment Agency. Primarily this is because of the difficulties in validating national scale probabilistic risks to date. In recognition of this the NAO Report in 2011 (NAO, 2011) called for greater effort to be directed towards communicating / understanding the confidence in NaFRA analysis and validating the outputs. Significant effort has been made in seeking to address these points and continue to be an area of activity research, and most recently the FORUM project (funded by NERC) has been exploring how the application of NERC science can help specifically in the validation of the assessments (and is has been used to support the validation efforts presented in this Appendix).

Scotland and Northern Ireland: The national risk approaches in Scotland and Northern Ireland approach the assessment of flood risks in a different way to England and Wales. The approaches used are however equally lacking in validation (given the inherent difficulties in doing so).

The key point for the CCRA analysis present here is that nationally recognised data and information that EA, SEPA, RA are confident in (or at least recognised as the best available by the authorities) is used.

G.1.1 England: Validation of present day flood risk using observations from 2007

The Future Flood Explorer (FFE) has the ability to explore impacts for spatially coherent events, representing widespread flooding. This capability is used here to compare data on flood risk provided by the Environment Agency against the observed damages during 2007 widespread flood event in England.

Background

The validity of the present day risk estimates (as reported across the UK) continues be a subject of debate and has, for England, been questioned (Penning-Rowsell, 2015). To explore the validity of the results, the ability of the FFE to estimate damages associated with widespread spatially coherent events has been used to estimate damage during an equivalent of the 2007 flood event in England, and compare this with the observed damages (as presented in Chatterton et al, 2010) from both surface water and fluvial sources. Particularly badly hit were Yorkshire, Worcestershire, Gloucestershire and Oxfordshire, with unprecedented impacts on residential and non-residential properties and infrastructure. Total economic costs for the floods are estimated at around £3 billion. Chatterton *et al* estimates are based on insurance claims data, and include adjustments to allow for uninsured properties coverage.

Approach to validating the present estimates of risk against the 2007 floods

The FFE has been used to estimate number of properties affected and the total economic damages for residential and non-residential properties in England. The number of properties was estimated through a lookup of impacts from fluvial and surface water calculation areas, using the relevant estimated return period of the 2007 floods (as described below).

Consideration of defence breaches and other asset failures

The look up was performed using defended impact curves, as there was little evidence for a significant contribution to 2007 damages from breaching.

Estimating damages per flooded property

Estimation of damages from the numbers of properties affected is not straightforward: since the FFE uses the Weighted Average Annual Damages (WAAD) to estimate annual damages, no direct estimates of damages related to a specific probability of flood event are available. To estimate damages from the 2007 floods, a representative damage value per flood event is calculated based on the WAAD tables (see Table G-1); a value representative across return periods has been used. For example, if the WAAD value for a SoP of 10 years is £1,426, this implies a damage of £14,260 per flood event occurring or being exceeded, on average, once in 10 years. This value is multiplied by the estimated number of properties affected (residential) or total floor area (non-residential) to give a total economic damage estimate.

The estimated event damages compare reasonably well with claims data presented in Chatterton et al., which gives figures of damage to residential property per flood event of £20-40k. These are financial losses, and a basic conversion to economic losses predicted by FFE gives a range of £12.5-20k (conversion factors between economic and financial losses are given in Chatterton et al.). No distinction between sources of flooding is made in the claims data, but this could be expected to represent damages from a mix of fluvial and surface water flooded properties. Using a damage per flood event higher than that from claims for fluvial and one lower for surface water (which tends to be shallower and of shorter duration) therefore seem to be reasonable and is adopted here (Table G-1).

Residential property					
SoP	**Fluvial**	**Damage per flood event**		**Surface water**	**Damage per flood event**
1	4815	4815		1605	1605
2	4815	9630		1605	3210
5	2880	14400		960	4800
10	1426	14260		475	4750
25	623	15575		208	5200
50	266	13300		89	4450
100	66	6600		22	2200
200	34	6800		11	2200
Representative value		**£15k**			**£5k**
Non-residential property					
SoP	**Fluvial**	**Damage per flood event**		**Surface water**	**Damage per flood event**
1	66	66		22	22
2	66	132		22	44
5	35	175		12	60
10	26	260		9	90
25	14	350		5	125
50	6	300		2	100
100	2	200		1	100
200	1	200		1	200
Representative value		**£350/m^2**			**£125/m^2**

Table G-1 Representative damage values per flood event based on WAAD tables

Estimating the return period of fluvial flooding

The return periods of the fluvial floods are based on peak flows recorded across the UK network of gauging stations, taken from the National River Flow Archive, using only stations suitable for pooling analysis (this ensures the reliability of gauging for high flows). The annual maximum recorded in 2007 for each gauge station is compared with a generalised logistic distribution fitted to the annual maxima series for that gauge, to estimate the probability of exceedance of the 2007 value. This gives a set of points and an associated return period for each. These are transformed to a grid using a triangular irregular network (TIN) and linear spatial interpolation (see Figure G-1). The return period for each fluvial calculation area is then sampled from the grid.

This approach is a simplification. The approach ignores the different spatial correlations possible between flows in the same catchment and flows in neighbouring catchments. Also, as not all watercourses are gauged, smaller streams (in particular) may not be represented well. Some flooding from ordinary watercourses will however be represented approximately in the surface water hazard maps, and therefore the surface water element will approximate risk from these.

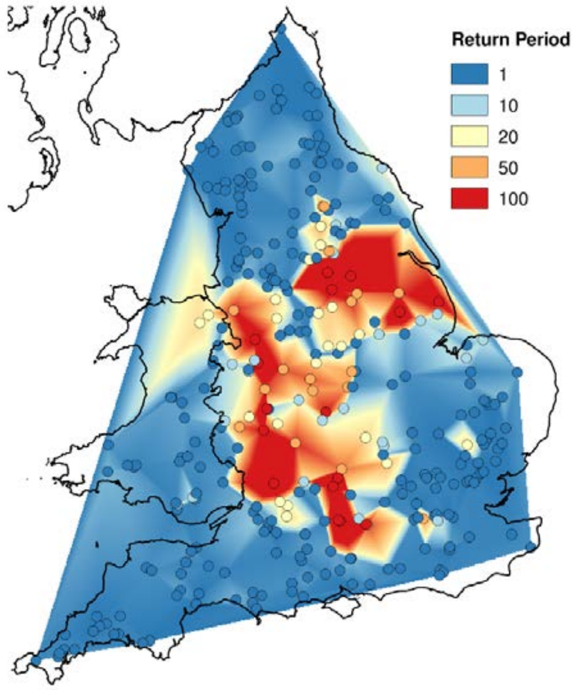

Figure G-1 Return periods calculated for fluvial flooding in 2007.

Estimating the return period of surface water flooding

For surface water flooding, gauged hourly rainfall data for June and July 2007 are used (provided by Newcastle University for this study). A running total of 6 hour rainfall totals is calculated and the maximum 6 hour total for each gauge recorded. This maximum is then compared to the FEH DDF model to estimate the return period of rainfall; as for the fluvial data, this is gridded using a TIN and then sampled to surface water calculation areas. 6 hour duration has been used as it has been noted that surface water flooding in 2007 was associated with longer duration storms (typically up to 12 hours). The resulting map of return periods is shown in Figure G-2.

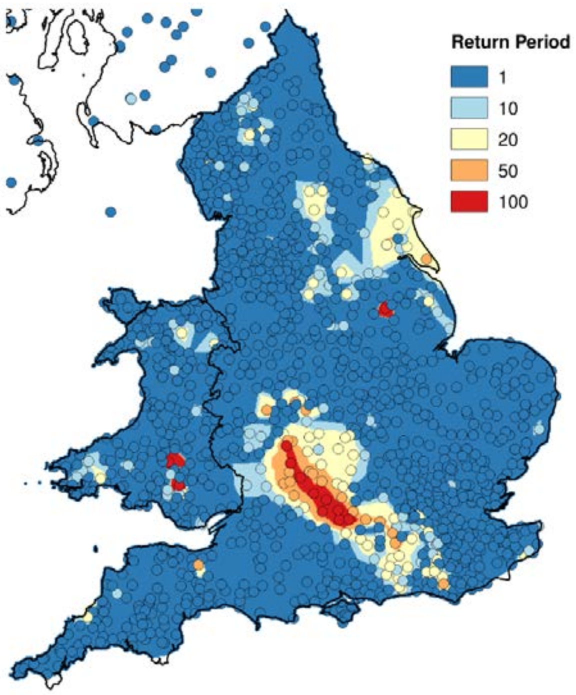

Figure G-2 Return periods calculated for surface water flooding in 2007.

Results and discussion of the comparisons with the 2007 floods

The results from the FFE are compared with estimated properties affected and damages presented in Chatterton et al (2010) in Table G-2.

Table G-2 FFE outputs compared with estimates based on claims data from 2007.

Metric	Estimated by FFE			Estimated in Chatterton et al.
	Fluvial	Surface Water	Both sources	
Residential properties affected	64 000	99 000	163 000	74 000[1]
Residential direct economic damages	£960bn	£490m	£1.4bn	£1.2bn
Non-residential properties affected	51 000	58 000	110 000	8 000[2]
Non-residential direct economic damages	£2.9bn	£2.3bn	£5.2bn	£740m
Total damages direct and indirect	£6.2bn	£4.7bn	£10.9bn	£3.2bn

[1]Average of two estimates of 48 000 and 65 000, which is then adjusted for an assumed insurance coverage of 76%.
[2]Average of two estimates of 7 300 and 8 000, adjusted for insurance coverage

The FFE results for residential properties are higher than those estimated in Chatterton et al., by 16% for damages and by a factor of 2.2 for property counts. Potential reasons for the discrepancies are:

- A systematic overestimation of risk in the NaFRA data used as the basis for FFE (as hypothesized by Penning-Rowsell, 2014)
- Uncertainty in the WAAD approach and identifying a damage per flood event from the WAAD tables (an issue that would influence damage estimates only)
- The FFE surface water property counting method and WAAD tables have been calibrated to match LTIS 2014. This calibration appears to be inconsistent with the number of properties flooded in 2007 and may indicate in a systematic overestimation embedded in the property counting method used in LTIS 2014.

Non-residential property counts and damages are significantly overestimated (overestimated by a factor of greater than 10) and damages (overestimated by a factor of 7). In addition to the reasons listed above for residential property, the difference could be due to the way non-residential properties are defined in the National Receptors Dataset (NRD). The NRD lists 21m residential properties and 7m non-residential properties, implying around 1 in 4 properties are non-residential; Chatterton et al's estimates imply around 1 in 10 flooded properties are non-residential. This could be a genuine difference (for example because non-residential properties are more likely to lie in industrial areas located on floodplains); or it could be an artefact of the way the NRD is generated from address and building polygon data. There may therefore be many NRD points associated with each non-residential insurance claim, and many not associated with a claim at all (two examples are shown in Figure G-3). This highlights the potential difficulty in using receptor data for different purposes: NRD may be appropriate for long term averages of economic damages, but less appropriate for calculating insurance losses for specific flood events, where some filtering of the receptor data may be required to extract properties likely to produce a claim.

There could also be differences in insurance uptake for residential and non-residential properties; figures for insurance uptake given in Chatterton et al, indicate 76% uptake for residential properties and 90% for non-residential, so this probably is not a significant factor. Policy holders not claiming for fear of increasing premiums may be a further factor.

The results are nonetheless encouraging. The underlying data used within the FFE does well in estimating residential damages, and the number of properties flooded agrees to within a factor of approximately 2. The non-residential damages and property counts show very large discrepancies, but this exposes broader weaknesses in the way properties are identified in NRD and damages assigned through WAAD.

The differences seen between FFE outputs and the damages estimated for the 2007 floods could be reduced through improvements in the FFE itself and in the underlying risk data it uses (e.g. NaFRA). Because NaFRA focusses on annual averages and counts of properties at risk, a direct comparison between NaFRA and damages from a specific event is not possible; nevertheless it would be useful to understand what the 2007 event, and others, tell us about how well NaFRA represents true risk (as done in Penning-Rowsell, 2015). A better understanding of how WAAD relates to event based damages would be helpful in this, but generating consistent estimates of damages from insurance claims data is subject to large uncertainties. Estimates of damages for non-residential properties is likely to be subject to more uncertainty than those for residential, partially arising from the issues of classifying non-residential properties discussed above. This is represented in the large differences in WAAD values across the non-residential sector, which mean damages are very sensitive to building classifications.

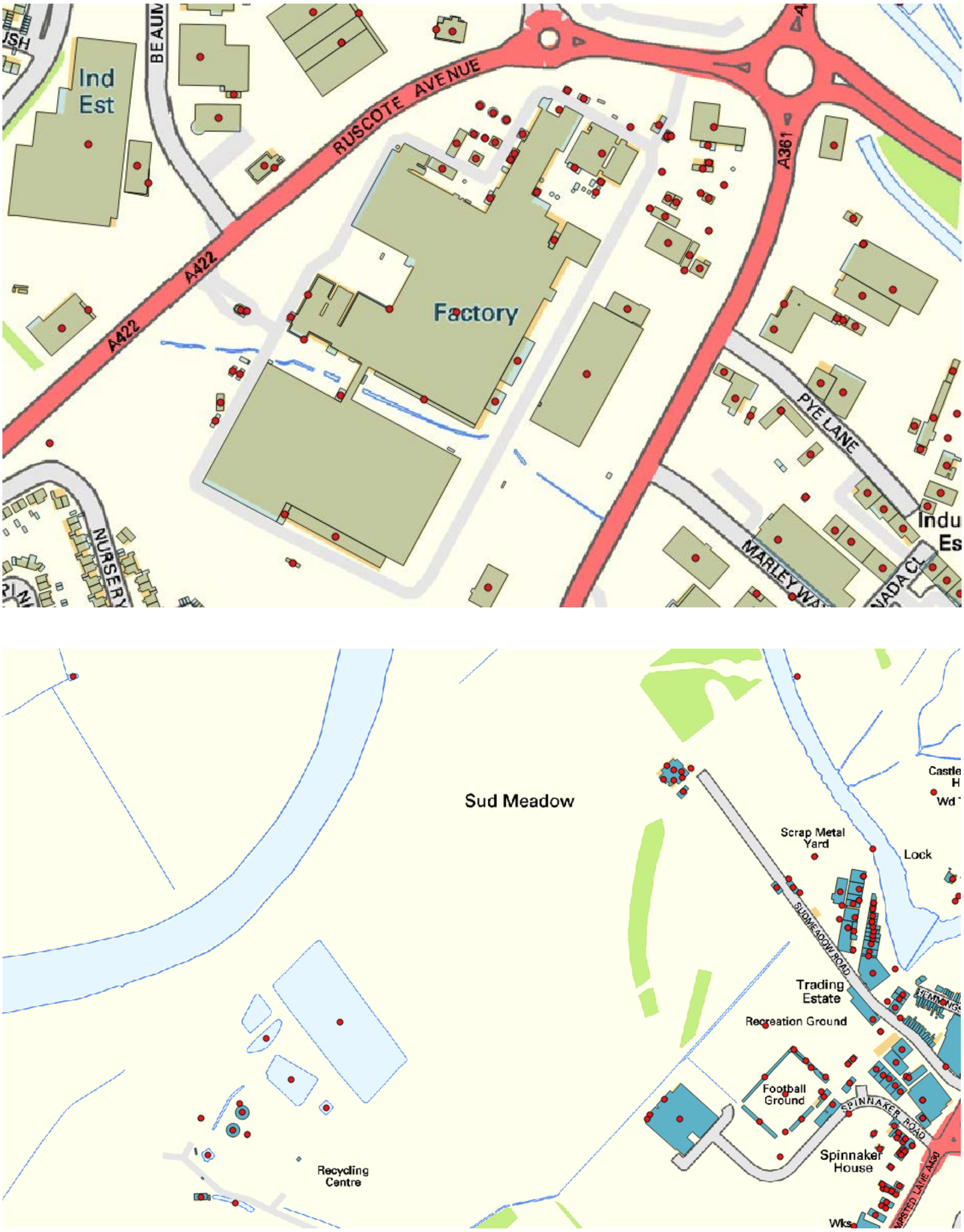

Figure G-3 Non residential NRD points and correspondence to buildings. In Banbury (top), a single factory site is associated with multiple NRD points. In Gloucester (bottom), many NRD points on the floodplain are not associated with any property of interest here.

G.1.2 Northern Ireland: Validation of present day surface water flood risks

Validation against surface water flooding in Belfast in 2008 using information on emergency flood payments and associated flow record (provided by the Northern Ireland Rivers Agency) has also been explored. The correspondence between hazard maps and recorded claims for emergency payments related to recent surface water floods was however weak. More detailed analysis of the underlying datasets (beyond the scope of this study) is therefore recommended before a meaningful comparison can be made. This is however recommended for future study.

G.2 Verification of the FFE

G.2.1 Verification of the FFE: Present day estimates

As discussed in the preceding sections the estimates of present day risks estimated by the FFE reflect input datasets as provided by various authorities (Environment Agency, Natural Resources Wales, SEPA and the Northern Ireland Rivers Agency). These underlying data are assumed to the best available and their validity (beyond the validation activities described in G.1) is not questioned in the context of the verification of the FFE outlined here. Instead the verification process focuses on the uncertainties introduced by the FFE in the creation of the emulation, including for example:

Marshalling the input datasets

- **Extrapolation to Scotland and Northern Ireland using analogues from England**: On occasion the lack for the necessary data from Scotland and Northern Ireland necessitates extrapolation from England analogues in order to build the FFE for use across the whole of the UK. This is particularly the case at the coast where the data needed to estimate the impact of climate change on defence standards is not readily available. It is therefore assumed that the west coast of Scotland is similar to south west England and hence climate change will have a similar impact. This assumption is recognised as a weakness. 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. This will react differently to climate change when compared to the south-east of England. Additional research (similar to that undertaken for the CDV2075 studies undertaken in England) is however needed before this assumption can be readily relaxed.
- **The interpretation of standard of protection.** The definition of the Standard of Protection afforded by a defence varies across England, Wales, Northern Ireland and Scotland and often within each country. It is assumed here that information on Standard of Protection provided reflects the 'best estimate' of the actual standard (i.e. the present day return period in years of the storm event where river levels exceed the crest of a defence or overtopping of a coastal defence is significant). The SoP data provided is therefore used directly (without an attempt to take account of freeboard). It is understood that in some case this interpretation may be directly appropriate; in Scotland for example it is understood that the term Standard of Protection reflects a consideration of both 'condition' and 'geometry'.
- **The interpretation of condition grade:** Condition grade is used as a proxy for chance of structural failure (i.e. a breach) during a given storm event and the process of interpolating between defended and undefended impact curves to represent different defence performance scenarios
- **Infilling data gaps within the data provided:** Invariably the data provided has not been complete. In particular information of the SOP and Condition Grade has have many gaps. Within the pre-processing of the data into the FFE these gaps are filled. For example the Design SOP is used as a proxy for the Current SOP where this is missing in the data for England. Where significant gaps are filled effort is made to ensure that proxy value is sensible. For example, before a comparison between Design_SOP and Current_SOP where both exist in the data

provided for England should a reasonable correlation and no evidence of a systematic bias. This process and assumptions of filling data gaps are discussed more completely in Appendix F.

Creating the emulation

- **Aggregation to a common scale:** The FFE aggregates risk information to a Calculation Area scale and compiles Impact Curves at this scale. This inevitably involves a simplifying the underlying datasets that often have a greater spatial resolution.
- **Interpolation processes**: Impact curve interpolation, calculation of annual averages, calculation of receptors in property bands etc. will all affect output metrics.
- **Simplifications made in EAD calculations**: The FFE uses the WAAD approach; damages in the FFE are based on non-residential sector average damages etc. which may not coincide exactly with the methods used in other risk estimates provided by the authorities.
- **Counting proces**s: Property counting methods for surface water are likely to be different in the FFE and in the methods used by the authorities (see Appendix F).
- **Simplified treatment of defence fragility**: The FFE uses a simplified representation of defence failure, interpolating between defended and undefended curves; methods used by the authorities may be limited to defended scenarios (Scotland) or a more complex probabilistic approach (England and Wales).

To demonstrate these assumptions do not impact the ability of the FFE to reasonably reproduce the underlying data a series of verification tests have been applied (Table G-3). These tests compare outputs of the emulator for the present day with risk metrics supplied by the authorities. Some reported metrics are for probability bands which do not coincide with those used in the FFE, and in these cases the nearest band has been used. Results are summarised as:

- For **England**, EAD estimates are consistent to within 20% for rivers, sea and surface water sources. For flooding from rivers and the sea, properties at risk of flooding greater than 0.1% also agree to within ~20%; The FFE estimate for properties at risk greater than 1:75 is less (by ~20%) than the LTIS estimate for 1:100, as expected. For surface water, the discrepancy is larger: ~50% for both 1% and 0.1%. The discrepancy for 1% will arise partially from the different probabilities used (FFE actually used 1.33%) Some difference between risk is to be expected as the LTIS figures are based on NaFRA runs with a full probabilistic treatment of breaching, whereas FFE uses an approximate representation of breaching based on condition grade. The larger differences seen for properties at risk from surface water is likely to be because property counts for surface water are very sensitive to depth thresholds and counting methods used.

- For **groundwater in England**, the EA's estimate of 122,000 – 290,000 properties at risk of flooding from groundwater (excluding those also at risk of flooding from rivers and the sea, with no indication of probability) is broadly consistent with the FFE's estimate of 110,000 (taken as total number at risk from off-floodplain PSD and Clearwater flooding).

- For **Scotland**, counts properties at risk agree to within 40%, with the biggest difference seen for residential properties at higher risk of flooding. Again there is likely to be some difference due to the treatment of defences (it is unclear whether the SEPA figures are for defended or undefended), and because of different property counting methods used for surface water. For higher probability bands, some of the discrepancy will be because of the different probability bands used; as might be expected, the FFE estimates (1:75 probability) are larger than SEPA's (1:50 probability)

- For **Wales**, properties at risk agree to within 40%, with the biggest difference seen for coastal risk for residential properties. This may be due to the different treatment of defences in FFE and in NaFRA (the basis for NRW figures).

- For **Northern Ireland**, the only figure available is 46,000 properties at risk, with no indication of a probability or sources of flooding associated with this. FFE estimates for all sources, for greater than 1:75 and 1:200 are given; the 1:200 estimate agrees well with the Rivers Agency figure.

Overall, the results of these tests provide some reassurance that the FFE is reproducing present day risk adequately (as provided by the relevant bodies for the UK's constituent countries) and as such (given the assumption that the present day estimates reasonable) the estimates of future changes will also be fit for purpose for the analysis presented here. Although it has been impossible to disaggregate the specific drivers of the differences in each country, one difference is likely to be the surface water property counting methods and different assumptions that may be made at a detailed processing level.

There is a notable difference between the countries: FFE outputs for England appear to fit the "official" figures better than those for Scotland and Wales. The difference between England and Wales is surprising, as estimates for both countries are based on NaFRA and the National Receptor Dataset (with the risk assessment carried out before the Environment Agency and Natural Resources Wales were split). The difference may reflect a difference in the quality of the data sets used in NaFRA, even when the same approach is used. For example, defence data may be of different quality in England and in Wales; this may interact with the different approaches used in NaFRA and FFE to give the different discrepancies seen. A further difference (which will apply to Scotland too) may be caused by the relative contributions of different sources of flooding, and the role of defended and undefended areas. FFE and NaFRA both make some attempt to represent defence fragility; SEPA's figures assume a defended scenario with no fragility.

Comparison with the official figures highlights the difficulty in assembling consistent data sets across the UK, and comparing a UK consistent approach with figures from constituent countries, which are based on different hazard and risk assessment methods. The FFE uses the same approach across the UK, but in doing this, an exact match to the methods used by relevant authorities in the individual countries is not technically possible. Nevertheless, as the focus of this project is estimating changes in risk, rather than absolute values, our consistent approach is still valid, and avoids drawing false conclusions about spatial patterns of risk caused by different risk assessment methods in different countries.

Table G-3 Comparison between present day risk estimates provided by flood risk management bodies and those from FFE.

England – present day risk as reported in LTIS 2014	EA	FFE
Expected Annual Damages		
Rivers and sea	£800m	£660m
Surface Water	£200m	£200m
Properties at risk from flooding from rivers and sea		
At least 0.1% AEP	2,400,000	1,900,000
LTIS at least 1% AEP (1:100) and FFE at least 1.33% AEP (1:75)	750,000	620,000
Properties at risk from flooding from surface water		
At least 0.1% AEP	1,700,000	1,400,000
LTIS at least 1% AEP (1:100) and FFE at least 1.33% AEP (1:75)	770,000	430,000
Properties at risk from flooding from groundwater (Environment Agency, 2015)		
EA unknown probability and FFE total properties at risk	120,000 – 290,000	110,000
Scotland – present day risk provided by SEPA	SEPA	FFE
Expected Annual Damages (to be published Dec 2015 – based on sum of local strategies – email communication)		
Residential and non-residential (direct and indirect)	£250m	£275m
Properties at risk from flooding from rivers, sea and surface water		
Residential - at least 0.1% AEP	140,000	180,000
Non-residential - at least 0.1% AEP	33,000	42,000
Residential – SEPA at least 2% AEP (1:50) and FFE at least 1.33% AEP (1:75)	70,000	97,000
Non-residential – SEPA at least 2% AEP (1:50) and FFE at least 1.33% AEP (1:75)	19,000	25,000
People at risk from flooding from rivers, sea and surface water		
SEPA at least 2% AEP (1:50) and FFE at least 1.33% AEP (1:75)	140,000	200,000
Wales – data provided by NRW key flood facts	NRW	FFE
Properties at risk from flooding from rivers and the sea		
Residential - at least 0.1% AEP	150,000	110,000
Non-residential - at least 0.1% AEP	60,000	59,000
Properties at risk from flooding from rivers		
Residential - at least 0.1% AEP	69,000	60,000
Non-residential - at least 0.1% AEP	35,000	35,000
Properties at risk from flooding from the sea (including tidal)		
Residential - at least 0.1% AEP	80,000	48,000
Non-residential - at least 0.1% AEP	25,000	24,000
Northern Ireland	Rivers Agency	FFE
Quoted figure of properties at risk (no indication of probability or whether residential only, sources)		
Properties at risk - unknown probability	46,000	
Properties at risk – FFE at least 1.33% AEP (1:75), rivers, sea and surface water		29,000
Properties at risk – FFE at least 0.5% AEP (1:200) , rivers, sea and surface water		44,000

G.2.2 Verification of the FFE: Future flood risk estimates (comparisons with the LTIS, 2014)

The Long Term Investment Scenarios (LTIS) explore how much should be spent to reduce risk (in England) based on optimizing the Net Present Value of the alternative investment choices within England. This contrasts with the aim of the CCRA study presented here to explore the potential future change in risk and the influence of different Adaptation Scenarios on that risk across the whole of the UK in a consistent way. As a result of this difference, and in some instances changes in capability since the publication of the LTIS, there significant differences in the underlying assumptions that make it impossible to draw a direct comparison between the results presented here and those within the Long Term Investment Scenario. These key differences include:

Epochs considered: The flood analysis presented here adopts the time horizons used consistently across the CCRA studies, namely 2020s, 2050s and 2080s. Within the LTIS 2014, changes in risk by 2023, 2038, 2063 and 2113 are considered.

Climate change (fluvial): The flood analysis presented here adopts three climate change scenarios as used consistently across the CCRA studies, namely 2^o, 4^o change in GMT by the 2080s and a H++ change (as provided by Project D of the CCRA). The LTIS studies use three different climate change scenarios. Two are based directly on the climate change factors (so-called 'medium', and 'upper end' factors) from the Environment Agency's 2011 report 'Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities' (Environment Agency 2011), the third is a *no climate change* scenario. In both studies the percentage uplifts represent changes from 2014 to the required time.

Table G-4 Changes in peak flow (%) used within LTIS and CCRA (here)

Region	CCRA 2C Scenario			CCRA 4C Scenario			LTIS Medium Scenario		
	2020s	2050s	2080s	2020s	2050s	2080s	2023	2038	2063
Northumbria	5	8	13	16	21	31	2.6	5.2	9.3
Humber	3	8	13	16	21	31	2.6	5.2	9.3
Anglian	-3	3	10	18	24	42	2.6	5.2	10.7
Thames	-3	3	10	18	24	42	2.6	5.2	10.7
South East	-3	8	15	18	33	56	2.6	7.3	15.7
South West	5	10	18	21	28	47	3.9	6.7	12.2
Severn	0	8	13	16	28	42	2.6	7.3	14.3
North West	10	15	20	19	26	43	3.9	6.7	12.2
Solway	10	18	18	19	26	40	3.9	6.7	10.8
Tweed	8	13	23	19	26	32	3.9	6.7	12.2

Note: Within the LTIS the upper end climate change scenario was adjusted downwards. This was because the estimate is the upper end change for the most sensitive river type in a catchment and when applied to whole catchment this would overestimate the upper end scenario. This correction was made, for example in the Thames. This correction has not been made in the CCRA studies.

In both the CCRA and the LTIS changes in flow have been converted to changes in return periods, using a calculation tool developed in previous LTIS and National Appraisal of Assets at Risk (NAAR) studies.

Climate change (coastal): For mean sea level change, both studies adopt the same underlying philosophy (used to construction the relative sea level rise values in Table 5 in Annex 1, Environment Agency, 2011) but are interpolated within the CCRA report (here) to the three climate scenarios of 2^o, 4^o change in GMT by the 2080s and a H++ change (as set out in Appendix C). In both the LTIS and the CCRA presented here the results of CDV2075 (Gouldby, Sayers, Mulet-Marti, Hassan, & Benwell,

2008) analysis, are used to estimate the impact on rSLR on coastal defences. In LTIS the analysis directly assesses changes in overtopping rate, whereas here a change in Standard of Protection is inferred here (see Appendix E).

Climate change (surface water): As set out in Appendix D of LTIS (2014) a simplified approach is taken to assessing changes in surface water risks in LTIS. The approach used was as follows:

- Count the number of properties affected by surface based upon the existing updated flood map for surface water (uFMfSW) (within the 3.33% annual exceedance probability [AEP] rainfall event and the 0.5% AEP).
- Calculated the associated flood damages using a single typical damage applied to residential and non-residential properties (as gathered by the Environment Agency following the summer 2007 flooding)
- Determine the future flood risk form the risks estimated in the surface water management plans (SWMPs) and integrated urban drainage pilot studies. Use these estimates to develop a relationship between rainfall and property counts and use this to predict future increases in flooded properties due to climate change and apply an increase in flood damages due to increase in paved area and due to climate change
- Estimate the costs and benefits of investment, using typical benefit to cost ratios from SWMP data

The FFE uses a more sophisticated approach in the consideration of climate change, adaptation and their influence on runoff, and then directly uses the Impact Curves and the WAAD values to drive a change in damage.

Given the uncertainty in the surface water property counting process and the associated damages the WAAD values used within the FFE have been calibrated using the LTIS approach (as described further in Appendix F). As a result the comparison between LTIS and FFE gives a good match in terms of EAD.

Climate change (groundwater): Excluded from LTIS (although included here) hence direct no comparison is possible.

Population growth and associated development control: The LTIS studies considered two development scenarios (i) a baseline scenario of no development in the floodplain (assuming development is controlled appropriately to avoid any increase in risk), and (ii) development is not controlled, and numbers of properties in the flood plain increase in line population increases assumed to be 30% by the 2060s and evenly distributed across England. Within the CCRA analysis presented here a spatial variation in the population growth is included (see Section 3) and a more realistic assumption regarding the effectiveness of development control made (see Appendix E).

Adaptation measures and scenarios: A number of differences exist between the LTIS studies and the CCRA. Perhaps most the most important difference are (i) CCRA considers a broader range of adaptation measures and their effectiveness, and (ii) without resource to a benefit: cost assessment. Within LTIS the Policy for each FRMS is chosen to maximize the benefit cost ratio. Within the CCRA the adaptation measures are predetermined based on the characteristics of the present day flood defences (for example a different approach is applied if the present day standards are lower or higher). Although the adaptation measures used within the FFE (as set out in detail in Appendix E) they are unlikely to provide a cost optimal approach (as is provided by the LTIS investment decision rule).

Despite the foregoing discussion, a comparison of the results is attempted in table H-3 for two LTIS scenarios. In compiling the results attempts have been made to look at the most comparable FFE outputs. They need to be read, however in the context of the significant differences between LTIS and CCRA as outlined above. Failure to do so will simply lead to false conclusions.

The main conclusions from the comparison of LTIS and FFE outputs are:

- For the **LTIS baseline scenario**, which represents no further investment in FCERM, an increase of 250% in EAD and 70% in properties at significant risk of flooding is predicted by LTIS. FFE predicts significantly smaller increases for EAD (46%) and a slightly larger increase than LTIS for properties at significant risk (80%). A direct comparison is difficult in this case: the FFE includes population growth, which could explain the larger uplifts for property counts; the FFE results also include some level of adaptation, which could explain the smaller increase in EAD.
- For the **LTIS optimum investment** strategy, both LTIS and the Enhanced Whole System adaptation within the FFE predict a decrease in damages by 2050, by roughly 10%, indicating that adaptation is sufficient to offset climate change and reduce risk slightly. This close agreement is partially due to efforts to align flood defence adaptation in FFE with LTIS (as described in Appendix E). The FFE outputs are also affected by population growth (which will tend to increase risk), and adaptation measures not represented in LTIS (tending to reduce growth). The final FFE figure that matches LTIS is consistent with this. The result indicate that for a highly ambitious adaptation scenario, the FFE's adaptation defined at national scale match the LTIS optimum which is tailored to Flood Risk Management System scales.

Table G-4 Comparison between LTIS and FFE outputs

England only	LTIS 2014	CCRA		
Present Day	All properties	Residential	Non-Residential	All properties
Expected Annual Damages				
Rivers and coast	£800m	£240m	£430m	£660m
Surface Water	£200m	£32m	£160m	£200m
Groundwater	no estimate	£56m	£100m	£160m
Properties at risk from flooding from rivers and sea[1]	2,400,000	1,300,000	590,000	1,900,000
LTIS at least 1% AEP (1:100) and CCRA at least 1.33% AEP (1:75)	748,000	400,000	210,000	610,000
Properties at risk from flooding from surface water	1,700,000	1,000,000	365,000	1,400,000
LTIS at least 1% AEP (1:100) and CCRA at least 1.33% AEP (1:75)	772,000	290,000	140,000	430,000
Properties at risk from flooding from groundwater	no estimate	360,000	170,000	520,000
LTIS baseline risks by 2050 (LTIS - Medium climate change and no development - FFE 2 Deg climate future - low population growth)				
Increase in EAD by 2050s (LTIS - assuming no further investment in FCERM and FFE - Reduced Whole System adaptation)[2]	250%	70%	34%	47%
Properties at risk from flooding from rivers or the sea				
LTIS at least 1% AEP (1:100) and CCRA at least 1.33% AEP (1:75)	1,290,000	750,000	260,000	1,000,000
Do something by 2050 (LTIS optimum investment - Medium climate change and no development - FFE 2 Deg climate future - low population growth)				
Change in flood damages by 2021s (assuming all current plans go ahead)	-5%	not estimated		
Change in flood damages by 2050s (LTIS - optimum spend and FFE EWS Adaptation)	-12%	-18%	-7%	-11%

G.3 References

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