APPENDIX C: **CLIMATE CHANGE PROJECTIONS**

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C.1 Coastal flooding

C.1.1 Climate change indicator: Sea level rise

The UKCP09 provides an assessment of Relative Sea Level Rise (rSLR) around the UK coastline. This data is used together with published advice in England and Wales (Environment Agency, 2011) and Scotland (CREW, 2012) and directly in Northern Ireland as follows:

- **For the scenario based on a 2° change in Global Mean Temperature** – The low emissions 50%ile as published by UKCP09 is used to estimate the rSLR. The average values within each coastal region are taken directly from the UKCP09 data without modification. These values are equivalent to the lower end estimate from Environment Agency, 2011.
- **For the scenario based on a 4° change in Global Mean Temperature** – At higher temperature changes UKCP09 is known to exclude a number of processes important to sea level rise. Therefore the approach adopted here is based on assumptions that underlie the values reported in Environment Agency, 2011 (personal communication with Bill Donavan, Oct 2014). This is based upon an interpolation of the High (A1Fi) scenario (95%) plus an allowance of 17/100cm per year (i.e. notionally 6°C and reported as the *Upper Change Factor,* Environment Agency, 2011) and the Medium (A1B1) scenario (95%) (.i.e. notionally 2.8°C and reported as the 'Change Factor', Environment Agency, 2011).
- **For the scenario based on H++ change** – The values reported in Environment Agency (2011) H++ Scenario are used directly for the whole of the UK (in the absence of specific information from Northern Ireland or Scotland). Variations in H++ values arise from the baseline adjustment described below.

A summary of these results are presented in Table C1-1.

Table C1-1 Relative sea level rise (m) – from a baseline of 2014.

	2 Degrees			4 Degrees			H++		
Region	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
England and Wales (based on CDV 2075 and corresponding JP Regions used for NaFRA)									
Lincolnshire (East coast)	0.03	0.13	0.26	0.14	0.37	0.64	0.14	0.60	1.43
Dungeness (South-east coast)	0.03	0.14	0.26	0.14	0.37	0.64	0.14	0.60	1.43
Lyme Bay (South-west coast)	0.03	0.15	0.28	0.15	0.38	0.66	0.14	0.59	1.42
Swansea (Mid-West coast)	0.03	0.13	0.25	0.14	0.36	0.63	0.15	0.60	1.43
Flyde (North-west coast)	0.02	0.11	0.21	0.14	0.34	0.59	0.16	0.62	1.45
Scotland (locations based on CREW, 2014)									
Edinburgh	0.02	0.08	0.17	0.13	0.32	0.55	0.15	0.55	1.30
Aberdeen	0.02	0.09	0.18	0.13	0.32	0.56	0.14	0.55	1.30
Wick	0.02	0.11	0.21	0.14	0.34	0.59	0.13	0.54	1.28
Lerwick	0.04	0.16	0.30	0.15	0.39	0.67	0.10	0.51	1.26
Ullapool	0.02	0.09	0.18	0.13	0.32	0.56	0.14	0.55	1.30
Stornoway	0.02	0.11	0.22	0.14	0.34	0.59	0.13	0.54	1.28
Tobermory	0.02	0.08	0.16	0.13	0.31	0.54	0.15	0.56	1.30
Millport	0.02	0.08	0.16	0.13	0.31	0.54	0.15	0.56	1.30
Northern Ireland									
NI - All	0.02	0.09	0.17	0.13	0.32	0.55	0.13	0.52	1.23

Note: The UKCP09 data and the associated reports provided climate change with reference to a baseline period 1961-90. All other data used within the analysis presented here is assumed represent a baseline of 2014. Climate change between 1990 and 2014 is therefore assumed to be represented within the data on the Standard of Protection of defences, the hazard mapping etc. Based on this assumption the baseline of the climate change values has been adjusted to 2014 using a basic interpolation. The interpolation assumes 2014 sea levels have risen from 1990 levels in accordance with the 2°C scenario, rises future epochs are therefore reduced to compensate for this rise. Rises for the 4°C and H++ scenarios use the same adjustment factor.

C.1.2 Associated changes in the Standard of Protection of coastal defences

A relationship between rSLR and the change in the Standard of Protection (SoP) provided by a given defence was established for England and Wales during the Foresight Future Flooding Study (Evans et al, 2004a&b). The analysis presented within Foresight was based on the original high level Risk Assessment for Strategic Planning method (Hall, et al., 2003) that in turn based upon the Coastal Defence Vulnerability (CDV) studies (HR Wallingford, 2002) and the National Assets at Risk (NAAR) Under Climate Change studies undertaken by Halcrow (Halcrow, 2001).

The CDV2075 studies provide change factors for three defence types; seawall, embankment and shingle beach, for five locations: Lincolnshire, Dungeness, Lyme Bay, Swansea Bay and Fylde, and for three return periods (years) 1:20, 1:50 and 1:200. Within the NAAR2001 studies these relationship were generalised to relate the present day standard of protection afforded by a defence to a future standard (Halcrow, 2001). These relationships were then extended in the Foresight studies and recast as a function of Sea Level Rise (reflecting the dominance of sea level rise in driving a change in return period of overtopping). Examples of future SoPs are shown in figure C1-1.

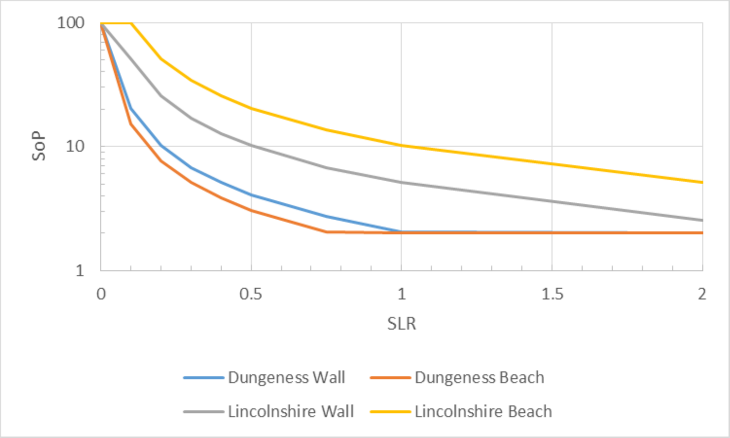


Figure C1-1 Standard of protection as a function of sea level rise for two coastal locations and two defence types, based on a current standard of 100 years.

All LTIS studies since have been based on the CDV2075 analysis, but given the LTIS studies have to date been based on the post-2008 NaFRA models (Gouldby *et al*, 2008) it has been possible to directly consider changes in overtopping volume rather than the proxy of changes in Standard of Protection.

Note:

No similar studies are available for Scotland or Northern Ireland. The results for England and Wales have therefore been extended to Scotland and Northern Ireland through analogy to similar coasts in England and Wales as follows:

Location	Equivalent region
Edinburgh	East Coast
Aberdeen	East Coast
Wick	East Coast
Lerwick	South West
Ullapool	South West
Stornoway	South West
Tobermory	South West
Millport	North West
NI - All	North West

The equivalence between coastal locations is based on the following rationale. For the east coast of Scotland, coastal geomorphology and wave climate is equivalent to the east coast of England, as locations here will be exposed to broadly the same condition in the North Sea. For north western Scotland, conditions are more likely to be like those in south west England, exposed to south westerly prevailing winds and wave conditions unprotected by Ireland. For south west Scotland and all of Northern Ireland, conditions are taken from the Irish Sea coasts of England, as protection from prevailing winds and waves by Ireland is likely to be significant.

Table C1-2 Changes in the standard of protection of coastal defences: Assuming a 2^{o}C change in GMT (from 1990 baseline) by 2020s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day standard (return period, years)	**Future standard of protection (return period, years)**													
Coastal defence type:	**Vertical Wall**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
50	50	33	50	29	50	50	50	50	50	50	50	50	50	50
100	100	66	100	44	100	100	100	100	100	100	100	100	100	100
200	200	164	200	147	200	200	200	200	200	200	200	200	200	200
Coastal defence type:	**Embankment**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
50	50	33	50	50	50	50	50	50	50	50	50	50	50	50
100	100	49	100	100	100	100	100	100	100	100	100	100	100	100
200	200	82	200	200	200	200	200	200	200	200	200	200	200	200
Coastal defence type:	**Shingle beach**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
50	50	33	50	50	50	50	50	50	50	50	50	50	50	50
100	100	49	100	100	100	100	100	100	100	100	100	100	100	100
200	200	82	200	200	200	200	200	200	200	200	200	200	200	200

Table C1-3 Changes in the standard of protection of coastal defences: Assuming a 2 °C change in GMT (from 1990 baseline) by 2050s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day standard (return period, years)	**Future standard of protection (return period, years)**													
Coastal defence type:	**Vertical Wall**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	5	7	6	7	6	8	8	6	5	10	8	10	9	8
20	8	7	15	7	9	12	12	9	8	14	12	17	13	12
50	25	7	44	7	31	41	39	31	27	48	39	50	44	39
100	38	15	100	10	63	61	58	47	41	71	59	83	66	79
200	102	37	200	33	94	163	154	124	110	190	156	200	177	118
Coastal defence type:	**Embankment**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	8	7	6	7	6	10	10	9	8	10	10	10	10	8
20	13	7	9	10	9	20	19	16	14	20	20	20	20	12
50	25	7	44	17	31	41	39	31	27	48	39	50	44	39
100	64	11	100	33	63	100	97	78	69	100	98	100	100	79
200	178	19	200	50	189	200	200	200	192	200	200	200	200	200
Coastal defence type:	**Shingle beach**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	8	7	6	7	6	10	10	9	8	10	10	10	10	8
20	13	7	9	10	9	20	19	16	14	20	20	20	20	12
50	25	7	44	17	31	41	39	31	27	48	39	50	44	39
100	76	11	100	50	63	100	100	93	82	100	100	100	100	79
200	200	19	200	66	157	200	200	200	200	200	200	200	200	197

Table C1-4 Changes in the standard of protection of coastal defences: Assuming a 2 °C change in GMT (from 1990 baseline) by 2080s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day standard (return period, years)	**Future standard of protection (return period, years)**													
Coastal defence type:	**Vertical Wall**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	3	4	3	3	3	4	4	3	3	5	4	5	4	4
10	3	4	3	3	3	4	4	3	3	5	4	5	4	4
20	4	4	8	3	5	6	6	5	4	7	6	8	6	6
50	13	4	23	3	16	20	19	16	15	24	20	27	21	20
100	20	8	61	5	32	30	29	24	22	36	30	40	32	39
200	53	20	153	17	48	80	77	63	58	95	80	108	86	59
Coastal defence type:	**Embankment**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	3	4	3	3	3	4	4	3	3	5	4	5	4	4
10	4	4	3	3	3	6	6	5	4	7	6	8	6	4
20	7	4	5	5	5	10	10	8	7	12	10	13	11	6
50	13	4	23	9	16	20	19	16	15	24	20	27	21	20
100	33	6	61	17	32	50	48	40	36	59	50	67	54	39
200	93	10	123	26	96	141	134	111	102	166	140	189	150	117
Coastal defence type:	**Shingle beach**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	3	4	3	3	3	4	4	3	3	5	4	5	4	4
10	4	4	3	3	3	6	6	5	4	7	6	8	6	4
20	7	4	5	5	5	10	10	8	7	12	10	13	11	6
50	13	4	23	9	16	20	19	16	15	24	20	27	21	20
100	40	6	61	26	32	60	57	48	44	71	60	81	64	39
200	106	10	123	34	80	161	153	127	116	189	160	200	172	98

Table C1-5 Changes in the standard of protection of coastal defences: Assuming a 4 °C change in GMT (from 1990 baseline) by 2020s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day standard (return p	**Future standard of protection (return period, years)**													
Coastal defence type:	**Vertical Wall**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	5	7	6	6	5	5	5	5	6	7	6	7	5	5
20	7	7	15	6	8	8	8	8	9	10	9	10	8	8
50	24	7	44	6	25	26	26	25	29	33	32	34	27	26
100	36	14	100	9	50	40	39	38	44	49	47	51	40	39
200	96	36	200	30	75	106	105	100	116	132	127	135	107	105
Coastal defence type:	**Embankment**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	7	7	6	6	5	8	8	8	9	10	9	10	8	8
20	12	7	9	9	8	13	13	13	15	16	16	17	13	13
50	24	7	44	15	25	26	26	25	29	33	32	34	27	26
100	60	11	100	30	50	66	65	63	73	82	79	85	67	66
200	167	18	200	46	151	185	183	175	200	200	200	200	187	184
Coastal defence type:	**Shingle beach**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	7	7	6	6	5	8	8	8	9	10	9	10	8	8
20	12	7	9	9	8	13	13	13	15	16	16	17	13	13
50	24	7	44	15	25	26	26	25	29	33	32	34	27	26
100	72	11	100	46	50	79	79	75	87	99	95	100	80	79
200	191	18	200	61	126	200	200	200	200	200	200	200	200	200

Table C1-6 Changes in the standard of protection of coastal defences: Assuming a 4 °C change in GMT (from 1990 baseline) by 2050s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North Wes
Present day standard (return period, years)														
Coastal defence type:	**Vertical Wall**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	2	3	2	2	2	2	2	2	2	3	3	3	2	2
10	2	3	2	2	2	2	2	2	2	3	3	3	2	2
20	3	3	6	2	3	3	3	3	3	4	4	4	3	3
50	9	3	17	2	10	11	11	10	11	13	13	14	11	11
100	14	6	45	4	20	16	16	15	17	20	19	21	16	16
200	37	14	113	12	30	43	42	40	44	53	50	55	44	43
Coastal defence type:	**Embankment**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	2	3	2	2	2	2	2	2	2	3	3	3	2	2
10	3	3	2	2	2	3	3	3	3	4	4	4	3	3
20	5	3	3	4	3	5	5	5	6	7	6	7	5	5
50	9	3	17	6	10	11	11	10	11	13	13	14	11	11
100	23	4	45	12	20	27	26	25	28	33	31	35	27	27
200	65	7	90	18	60	75	74	69	77	93	88	97	77	74
Coastal defence type:	**Shingle beach**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	2	3	2	2	2	2	2	2	2	3	3	3	2	2
10	3	3	2	2	2	3	3	3	3	4	4	4	3	3
20	5	3	3	4	3	5	5	5	6	7	6	7	5	5
50	9	3	17	6	10	11	11	10	11	13	13	14	11	11
100	28	4	45	18	20	32	32	30	33	40	38	41	33	32
200	74	7	90	24	50	86	85	79	88	106	100	110	88	85

Table C1-7 Changes in the standard of protection of coastal defences: Assuming a 4 °C change in GMT (from 1990 baseline) by 2080s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North Wes
Present day standard (return period, years)														
Coastal defence type:	**Vertical Wall**													
2	1	2	1	1	1	1	1	1	1	2	1	2	1	1
5	1	2	1	1	1	1	1	1	1	2	1	2	1	1
10	1	2	1	1	1	1	1	1	1	2	1	2	1	1
20	2	2	3	1	2	2	2	2	2	2	2	2	2	2
50	5	2	10	1	6	6	6	6	6	8	7	8	6	6
100	8	3	26	2	12	9	9	9	10	12	11	12	9	9
200	21	8	65	7	17	25	24	23	25	31	29	32	25	25
Coastal defence type:	**Embankment**													
2	1	2	1	1	1	1	1	1	1	2	1	2	1	1
5	1	2	1	1	1	1	1	1	1	2	1	2	1	1
10	2	2	1	1	1	2	2	2	2	2	2	2	2	2
20	3	2	2	2	2	3	3	3	3	4	4	4	3	3
50	5	2	10	3	6	6	6	6	6	8	7	8	6	6
100	13	2	26	7	12	16	15	14	16	19	18	20	16	15
200	37	4	52	10	35	43	43	40	45	54	51	56	44	43
Coastal defence type:	**Shingle beach**													
2	1	2	1	1	1	1	1	1	1	2	1	2	1	1
5	1	2	1	1	1	1	1	1	1	2	1	2	1	1
10	2	2	1	1	1	2	2	2	2	2	2	2	2	2
20	3	2	2	2	2	3	3	3	3	4	4	4	3	3
50	5	2	10	3	6	6	6	6	6	8	7	8	6	6
100	16	2	26	10	12	19	18	17	19	23	22	24	19	18
200	43	4	52	14	29	50	49	46	51	61	58	64	51	49

Table C1-8 Changes in the standard of protection of coastal defences: Assuming a H++ change in GMT (from 1990 baseline) by 2020s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day standard (return period, years)														
Coastal defence type:	**Vertical Wall**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	4	5	5	5	5	5	5	5	5	5
10	5	7	6	6	4	5	5	5	8	6	7	6	5	5
20	7	7	16	6	6	7	7	8	13	9	10	9	7	8
50	24	7	47	6	21	23	24	26	42	30	33	29	23	26
100	35	14	100	9	43	35	36	39	63	46	50	43	34	38
200	94	36	200	29	64	93	95	104	168	122	132	116	91	102
Coastal defence type:	**Embankment**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	4	5	5	5	5	5	5	5	5	5
10	7	7	6	6	4	7	7	8	10	9	10	9	7	8
20	12	7	9	9	6	12	12	13	20	15	17	14	11	13
50	24	7	47	15	21	23	24	26	42	30	33	29	23	26
100	59	11	100	29	43	58	60	65	100	76	83	72	57	64
200	165	18	200	44	128	163	167	183	200	200	200	200	160	179
Coastal defence type:	**Shingle beach**													
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	5	5	5	5	4	5	5	5	5	5	5	5	5	5
10	7	7	6	6	4	7	7	8	10	9	10	9	7	8
20	12	7	9	9	6	12	12	13	20	15	17	14	11	13
50	24	7	47	15	21	23	24	26	42	30	33	29	23	26
100	71	11	100	44	43	70	71	78	100	91	99	87	68	77
200	189	18	200	59	107	187	191	200	200	200	200	200	182	200

Table C1-9 Changes in the standard of protection of coastal defences: Assuming a H++ change in GMT (from 1990 baseline) by 2050s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day standard (return period, years)														
Coastal defence type:	**Vertical Wall**													
2	1	2	1	1	1	1	1	1	2	2	2	2	1	1
5	1	2	1	1	1	1	1	1	2	2	2	2	1	1
10	1	2	1	1	1	1	1	1	2	2	2	2	1	1
20	2	2	4	1	2	2	2	2	3	2	2	2	2	2
50	6	2	11	1	6	6	6	6	8	8	8	8	6	7
100	8	3	29	2	11	9	9	9	13	12	12	12	9	10
200	23	8	72	7	17	25	25	25	34	31	32	31	24	26
Coastal defence type:	**Embankment**													
2	1	2	1	1	1	1	1	1	2	2	2	2	1	1
5	1	2	1	1	1	1	1	1	2	2	2	2	1	1
10	2	2	1	1	1	2	2	2	3	2	2	2	2	2
20	3	2	2	2	2	3	3	3	4	4	4	4	3	3
50	6	2	11	4	6	6	6	6	8	8	8	8	6	7
100	14	3	29	7	11	15	15	16	21	20	20	19	15	16
200	40	4	58	11	33	43	43	44	59	55	56	54	43	46
Coastal defence type:	**Shingle beach**													
2	1	2	1	1	1	1	1	1	2	2	2	2	1	1
5	1	2	1	1	1	1	1	1	2	2	2	2	1	1
10	2	2	1	1	1	2	2	2	3	2	2	2	2	2
20	3	2	2	2	2	3	3	3	4	4	4	4	3	3
50	6	2	11	4	6	6	6	6	8	8	8	8	6	7
100	17	3	29	11	11	18	19	19	25	24	24	23	18	20
200	45	4	58	14	28	49	49	51	67	63	64	62	49	52

Table C1-10 Changes in the standard of protection of coastal defences: Assuming a H++ change in GMT (from 1990 baseline) by 2080s

Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	NI - All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day standard (return period, years)														
Coastal defence type:	**Vertical Wall**													
2	0	1	1	1	0	1	1	1	1	1	1	1	1	1
5	0	1	1	1	0	1	1	1	1	1	1	1	1	1
10	0	1	1	1	0	1	1	1	1	1	1	1	1	1
20	1	1	2	1	1	1	1	1	1	1	1	1	1	1
50	2	1	5	1	2	3	3	3	3	3	3	3	3	3
100	4	1	12	1	5	4	4	4	5	5	5	5	4	4
200	10	4	30	3	7	10	10	11	14	13	13	13	10	11
Coastal defence type:	**Embankment**													
2	0	1	1	1	0	1	1	1	1	1	1	1	1	1
5	0	1	1	1	0	1	1	1	1	1	1	1	1	1
10	1	1	1	1	0	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	2	2	2	2	1	1
50	2	1	5	2	2	3	3	3	3	3	3	3	3	3
100	6	1	12	3	5	7	7	7	9	8	8	8	7	7
200	17	2	24	5	14	18	18	19	24	23	23	23	18	19
Coastal defence type:	**Shingle beach**													
2	0	1	1	1	0	1	1	1	1	1	1	1	1	1
5	0	1	1	1	0	1	1	1	1	1	1	1	1	1
10	1	1	1	1	0	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	2	2	2	2	1	1
50	2	1	5	2	2	3	3	3	3	3	3	3	3	3
100	7	1	12	5	5	8	8	8	10	10	10	10	8	8
200	19	2	24	6	12	21	21	21	27	27	27	26	21	22

C.2 Fluvial flooding

C.2.1 Climate change: Changes in peak river flows

Changes to peak river flows are derived using the following evidence:

- **England and Wales** (as used provided in Environment Agency, 2011) is based on FD2020 (Reynard et al., 2009). This guidance does not include west Wales; the values for this region have therefore been taken as the average of Severn and Dee regions as being geographically closest and of similar hydrology.
- **Scotland** is based on the soon to be published SEPA report based on the CEH study (Prudhomme, 2012) (equivalent to FD2020 study undertaken for England and Wales)
- **Northern Ireland** is based on analogy with nearby regions of England and Scotland (North West and Solway in England; Solway, Clyde and Argyll in Scotland). Guidance specific to Northern Ireland is available (Sloan, 2009), which gives increases in flows of 10% for 2030s and 30% for 2080s across the region (uplifts for 7 hydrometric areas are given, but the variation between these is small), for emissions scenarios corresponding to a 3°C temperature rise. The change factors for the 2020s and 2050s based on catchments in England and Scotland are reduced slightly to better match the RPS guidance.

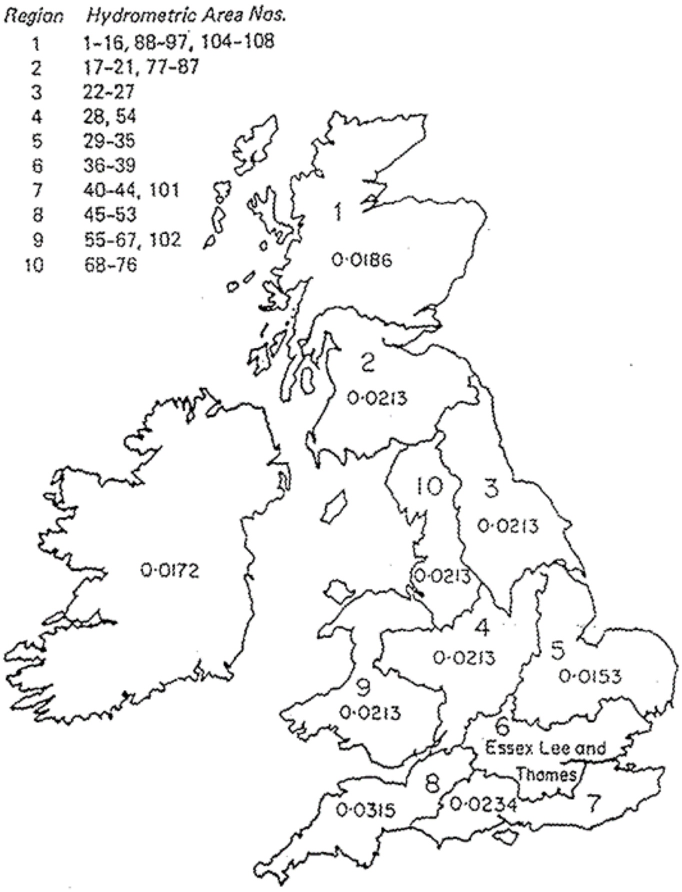
H++ values are taken from the outputs of work package D.

Table C2-1 Change factors (% increase) for river flows for the UK.

Country	Region	2 °C			4 °C			H++		
		2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
England and Wales	Northumbria	5	8	13	16	21	31	54	90	178
	Humber	3	8	13	16	21	31	54	90	178
	Anglian	-3	3	10	18	24	42	56	93	170
	Thames	-3	3	10	18	24	42	56	93	185
	South East	-3	8	15	18	33	56	59	103	205
	South West	5	10	18	21	28	47	56	98	198
	Severn	0	8	13	16	28	42	56	95	190
	Dee	5	8	13	14	21	29	54	88	175
	North West	10	15	20	19	26	43	56	95	193
	Solway	10	18	18	19	26	40	56	95	193
	Tweed	8	13	23	19	26	32	54	95	183
	Western Wales	3	8	13	15	24	36	53	90	179
Scotland	Orkney and Shetland	11	19	27	16	22	33	59	100	200
	North Highland	7	13	18	14	19	29	56	93	185
	West Highland	12	21	30	22	30	45	59	105	208
	North East Scotland	5	9	13	8	11	17	51	85	173
	Argyll	12	21	30	22	30	45	59	105	208
	Tay	6	11	16	13	17	26	54	90	208
	Clyde	8	14	20	17	23	34	56	98	183
	Forth	7	12	17	14	19	28	56	95	195
	Solway	7	13	18	16	21	32	56	95	193
	Tweed	6	10	14	11	15	23	54	90	183
Northern Ireland		7	13	21	13	21	39	50	90	180

C.2.2 Relating changes in peak river flow to a change in the return period of storm water level

The relationship between a change in flow and a change in the probability of that flow being exceeded (equivalent to a change in standard of protection for defended systems) has been determined using the method first detailed in the National Assets at Risk Study (Halcrow, 2001) and used in Foresight and LTIS. The analysis undertaken in 2001 provides a lookup table for each Hydrometric Region that relates a percentage change in flow to a change in return period. Although the analysis was completed some time ago the relationships remain credible and fit for the purpose here.The hydrometric regions used and the associated regional growth curves are outlined below.



Region	Hydrometric Area Nos.
1	1-16, 88-97, 104-108
2	17-21, 77-87
3	22-27
4	28, 54
5	29-35
6	36-39
7	40-44, 101
8	45-53
9	55-67, 102
10	68-76

Figure C2-1 The FSR regions (from NERC, 1975) used to determine the relationship between peak flows under climate change

Table C2-2 Relating changes in a percentage change in peak river flow to change in return period of the in-river water level (from Halcrow, 2001)

Region 1 (in Figure C1-2)

		Current Return Period of in river water level (T_{old})								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	-10	2.7	3.2	7.4	15.5	40.7	84.5	174.9	947.2	1961.1
	-5	2.3	2.7	6.0	12.3	31.6	64.3	130.8	679.8	1382.3
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.8	2.1	4.2	8.2	20.1	39.6	77.9	375.8	740.1
	10	1.6	1.8	3.6	6.9	16.4	31.8	61.7	287.9	559.0
	15	1.5	1.7	3.1	5.9	13.6	25.9	49.6	224.4	429.9
	20	1.4	1.5	2.8	5.0	11.4	21.4	40.5	177.6	336.0
	25	1.3	1.4	2.5	4.4	9.7	17.9	33.4	142.5	266.4
	40	1.1	1.2	1.8	3.0	6.3	11.1	20.0	79.0	143.1

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0305(Ln Told)^-0.6553)*PCC))
Tnew is the return period in the future; Told is the current return period; PCC is the percentage change in river flow.

Region 2 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2	2.33	5	10	25	50	100	500	1000
	-10	2.7	3.1	7.2	15.0	39.3	81.1	167.3	901.4	1863.3
	-5	2.3	2.7	6.0	12.2	31.1	63.1	128.1	663.9	1349.0
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.8	2.1	4.3	8.3	20.4	40.3	79.4	384.0	756.9
	10	1.6	1.8	3.7	7.1	16.9	32.9	64.0	300.1	583.6
	15	1.5	1.7	3.2	6.0	14.2	27.2	52.3	238.3	457.4
	20	1.4	1.5	2.8	5.2	12.0	22.8	43.2	191.8	363.8
	25	1.3	1.4	2.5	4.5	10.3	19.3	36.2	156.3	293.3
	40	1.1	1.2	1.9	3.2	6.8	12.3	22.4	90.2	164.4

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0306(Ln Told)^-0.7107)*PCC))

Table C2-2 continued

Region 3 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	2.9	3.5	8.2	17.2	45.4	94.0	194.6	1052.0	2176.4
	-5	2.4	2.8	6.3	13.0	33.3	67.7	137.7	715.0	1453.5
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.7	2.0	4.0	7.9	19.2	37.7	74.3	358.5	706.3
	10	1.5	1.7	3.3	6.3	15.0	29.0	56.3	262.8	510.5
	15	1.4	1.5	2.8	5.2	11.9	22.7	43.4	196.5	376.8
	20	1.3	1.4	2.4	4.3	9.6	18.0	34.0	149.6	283.3
	25	1.2	1.3	2.1	3.6	7.9	14.5	27.1	115.7	216.6
	40	1.0	1.1	1.5	2.3	4.7	8.2	14.7	58.1	105.4

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0412(Ln Told)^-0.7271)*PCC))

Region 4 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	2.8	3.3	7.3	15.0	38.5	78.8	161.6	862.6	1777.9
	-5	2.3	2.8	6.0	12.1	30.8	62.3	126.1	650.2	1319.2
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.7	2.0	4.2	8.3	20.6	40.7	80.5	391.4	772.4
	10	1.5	1.7	3.6	7.0	17.1	33.6	65.7	311.2	606.7
	15	1.3	1.5	3.1	6.0	14.4	28.0	54.3	250.9	483.6
	20	1.2	1.4	2.7	5.1	12.2	23.6	45.3	204.8	390.7
	25	1.1	1.2	2.3	4.4	10.5	20.0	38.2	169.1	319.4
	40	#NUM!	1.0	1.7	3.0	6.9	12.9	24.1	100.8	185.5

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.04(Ln Told)^-0.926)*PCC))

Table C2-2 continued

Region 5 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	2.5	2.9	6.6	13.6	35.5	73.4	151.6	818.6	1693.9
	-5	2.2	2.6	5.7	11.6	29.6	60.1	122.2	633.8	1288.4
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.8	2.1	4.4	8.7	21.4	42.1	83.0	401.1	790.1
	10	1.7	1.9	4.0	7.7	18.4	35.9	69.8	326.4	634.1
	15	1.6	1.8	3.6	6.8	16.1	30.9	59.3	269.2	516.2
	20	1.5	1.7	3.2	6.1	14.1	26.8	50.8	224.7	425.5
	25	1.4	1.5	2.9	5.5	12.5	23.4	44.0	189.4	354.7
	40	1.2	1.3	2.3	4.1	9.0	16.4	29.9	119.9	217.7

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0225(Ln Told)^-0.6605)*PCC))

Region 6-7 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	2.5	3.0	6.7	14.0	36.5	75.3	155.4	838.4	1734.0
	-5	2.2	2.6	5.8	11.7	30.0	60.9	123.6	641.1	1303.1
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.8	2.1	4.4	8.6	21.1	41.6	82.1	396.7	781.8
	10	1.7	1.9	3.9	7.5	18.0	35.1	68.2	319.7	621.3
	15	1.5	1.7	3.5	6.6	15.5	29.9	57.4	261.1	501.0
	20	1.4	1.6	3.1	5.8	13.5	25.7	48.8	215.9	409.3
	25	1.3	1.5	2.8	5.2	11.9	22.3	41.8	180.5	338.4
	40	1.1	1.3	2.2	3.8	8.3	15.2	27.7	111.6	203.0

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0249(Ln Told)^-0.6835)*PCC))

Table C2-2 continued

Region 8 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	2.8	3.3	7.5	15.3	39.4	80.8	165.7	884.4	1822.7
	-5	2.4	2.8	6.1	12.3	31.1	63.0	127.6	658.1	1335.1
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.7	2.0	4.2	8.3	20.4	40.3	79.6	387.0	763.8
	10	1.5	1.7	3.5	6.9	16.8	32.9	64.3	304.4	593.6
	15	1.4	1.5	3.0	5.8	14.0	27.1	52.6	243.0	468.6
	20	1.2	1.4	2.6	5.0	11.8	22.7	43.5	196.6	375.0
	25	1.1	1.2	2.3	4.3	10.0	19.1	36.4	160.8	303.9
	40	1.0	1.0	1.6	2.9	6.4	12.0	22.4	93.6	172.4

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0401(Ln Told)^-0.8917)*PCC))

Region 9 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	2.8	3.4	7.9	16.5	43.4	89.7	185.2	997.6	2061.4
	-5	2.4	2.8	6.2	12.7	32.6	66.2	134.5	697.1	1416.2
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.7	2.0	4.1	8.0	19.5	38.5	75.9	367.0	723.4
	10	1.5	1.7	3.4	6.5	15.5	30.1	58.6	274.9	534.6
	15	1.4	1.5	2.9	5.4	12.5	24.0	46.0	209.6	402.6
	20	1.3	1.4	2.5	4.5	10.3	19.4	36.7	162.5	308.5
	25	1.2	1.3	2.2	3.8	8.5	15.8	29.6	127.9	240.1
	40	1.1	1.1	1.6	2.5	5.2	9.2	16.7	67.1	122.3

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0390(Ln Told)^-0.7444)*PCC))

Table C2-2 continued

Region 10 Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	3.0	3.6	8.2	17.1	44.3	91.0	186.8	996.0	2051.4
	-5	2.4	2.9	6.4	12.9	32.9	66.7	135.1	696.9	1413.4
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.7	1.9	4.0	7.9	19.3	38.2	75.5	366.8	724.2
	10	1.5	1.7	3.3	6.3	15.2	29.7	58.0	274.4	535.4
	15	1.3	1.5	2.7	5.1	12.1	23.4	45.2	208.9	403.2
	20	1.2	1.3	2.3	4.2	9.8	18.7	35.8	161.6	308.6
	25	1.1	1.2	2.0	3.5	8.0	15.1	28.7	126.8	239.8
	40	1.1	1.2	1.9	3.2	6.8	12.3	22.4	90.2	164.4

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0479(Ln Told)^-0.8594)*PCC))

Ireland Analysis

		Current Return Period (Told)								
Flood Discharge	Change %	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000
	-10	2.9	3.5	8.5	18.5	50.3	106.2	223.5	1250.3	2619.8
	-5	2.4	2.8	6.4	13.4	34.9	71.6	146.9	775.3	1585.8
	0	2.0	2.3	5.0	10.0	25.0	50.0	100.0	500.0	1000.0
	5	1.7	2.0	4.0	7.7	18.4	35.9	70.2	333.7	653.6
	10	1.5	1.7	3.3	6.0	14.0	26.5	50.7	229.6	441.0
	15	1.4	1.5	2.7	4.9	10.8	20.1	37.5	162.3	306.0
	20	1.3	1.4	2.3	4.0	8.5	15.5	28.3	117.5	217.7
	25	1.2	1.3	2.0	3.4	6.9	12.2	21.9	87.0	158.5
	40	1.1	1.1	1.5	2.2	4.0	6.6	11.1	39.4	68.6

Model for the change is Tnew = Exp(LN(Told)*(Exp(- 0.0407(Ln Told)^-0.6034)*PCC))

C.3 Surface water flooding

C.3.1 Climate change: Changes in storm rainfall depth and intensity

Most of the previous understanding of effects of climate change on rainfall has been based on longer duration (daily or longer), non-extreme rainfall depths; quantifying changes to surface water risk requires an understanding of effects on extreme (typically rarer than 1 in 30 annual exceedance), short duration (1-6 hours) storms.

The guidance *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities* (Environment Agency, 2011) recommends change factors for extreme (annual probability less than 20%) daily rainfall totals. This does not however cover shorter duration storms (of critical interest to surface water flooding) and is strictly applicable to England only.

Recent research has investigated the potential for climate change to affect the storms of relevance to surface water risk. Westra et al (2014) give an overview of the available evidence; in particular the Clausius-Clapeyron equation indicates that the saturated water content of the atmosphere increases by 6% per °C temperature increase. As the water holding capacity of the atmosphere is a key control on rainfall depths for short duration storms, these could be expected to increase in line with the capacity indicated by the Clausius-Clapeyron equation. For example, a 4°C increase in temperature would produce a 24% increase in rainfall. Other evidence from climate models indicate that intense rainfall increases are broadly in line with those predicted by the Clausius-Clapeyron equation, but with considerable scatter. Kendon et al (2014) used a 1.5km resolution climate model to predict probabilities of intense rainfall in the southern UK in 2100 under the RCP8.5 climate scenario (which predicts global mean temperature rise of 4°C, with similar increases in temperature in the UK). They found that the probability of rainfall intensities of 28mm/hr (equivalent to a current 1 hour duration 1 in 30 year storm) increased by a factor of four; for typical UK depth-duration-frequency curves, this is equivalent to doubling the rainfall depth. Chan et al (2014) also used a 1.5km resolution model, again covering the southern UK, finding that 20 year 1 hour rainfall depths increased by 10%, again under the RCP8.5 scenario in 2100. All the research referenced above has in part been funded by NERC.

Recent research for UKWIR (UKWIR, 2015a&b) indicates that the climate uplifts should be approximately double those given by the evidence described above, and therefore the values given in Table C3-1 are used as the rainfall uplifts for future climates. These uplifts are applied across the UK, for all return periods and storm durations. Uplifts for H++ are taken from WP D outputs.

Table C3-1 Change factors for daily extreme rainfalls for all return periods and durations 1-6 hours.

Climate change factor	Global Temperature Increase	2020s	2050s	2080s
Lower	2°C	+0%	+10%	+20%
Medium	4°C	+10%	+20%	+50%
H++	6°C	+17%	+35%	+70%

C.3.2 Relating changes in rainfall depth into the return period of runoff

The change in the chance of surface water flooding does not respond directly to changes in rainfall, it also reflects the way runoff is produced. Various approaches exist to transform rainfall depths into runoff; for example, in England and Wales, uFMfSW (updated Flood Map for Surface Water) uses different calculation methods for urban and rural runoff:

- For **urban runoff**, a single percentage runoff (70%) and storm water sewer capacity (12mm/hr) are used to calculate how much rainfall infiltrates pervious areas and is carried away by the sewer system; what remains is runoff
- For **rural runoff**, the ReFH infiltration model is used, based on local catchment descriptors BFIHOST and PROPWET.

These methods produce percentage runoff that depends on the rainfall depth, storm duration, and local parameters such as the rainfall depth-duration-frequency curve and catchment descriptors. These factors lead to a complex relationship between climate change uplifts to rainfall and increases in runoff (i.e. a 10% increase in rainfall depth will not in general lead to a 10% increase in runoff).

A simplified treatment of runoff is used in the FFE. A nationally (for England and Wales) representative relationship has been developed linking rainfall and runoff for urban and rural areas assuming a nationally representative depth-duration-frequency curves and a storm duration of 3 hours everywhere. (For more information on how this is done, see Appendix F Annex A). As surface water flood mapping approaches applied in Scotland and Northern Ireland use similar representations of runoff and drainage capacity to England and Wales, the same simplified treatment is applied everywhere.

Climate change uplifts for surface water flooding return periods are then calculated as follows:

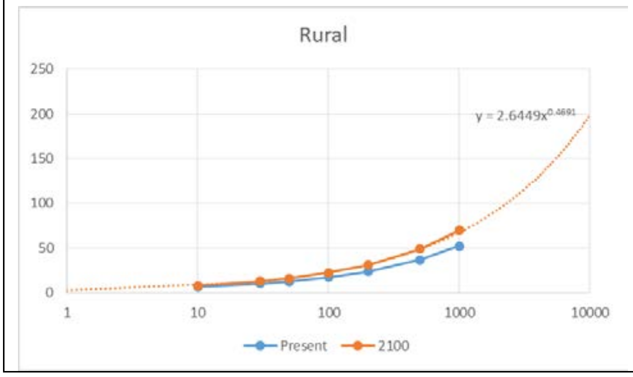
1. The rainfall-runoff relationship is applied to the present day depth-frequency curve, to produce a runoff-frequency curve
2. The depth-frequency curve is uplifted by the climate change increase (e.g. +10%), and the rainfall-runoff relationship applied, to produce a future runoff-frequency curve
3. The future runoff-frequency curve is then used to calculate the future probability of present day runoff values; these probabilities are then used to scale the impact curve.

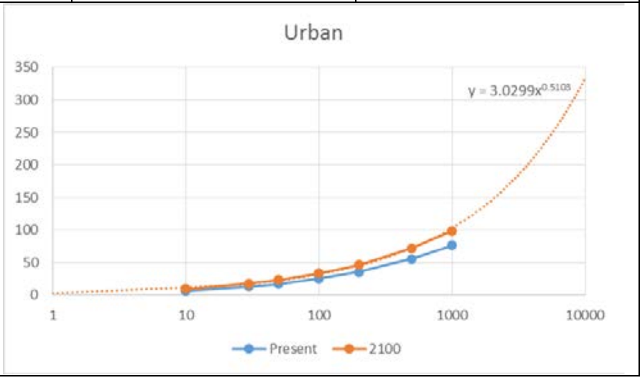
Example results are shown in Table C3-2. The numbers show, for example, that a present day 30 year storm will generate 10mm of runoff in a rural area; in 2100 climate change means that 10mm of runoff will have a return period of only 18 years. The impacts estimated from a 1 in 30 year present day flood extent will therefore occur in the future with a probability of 1 in 18. For this example, the climate change uplifts are broadly consistent for rural and urban areas, and therefore do not need to be treated differently. This may not always be the case (especially when runoff management options are applied to urban areas only); where there are significant difference between uplifts for urban and rural areas, an average is used, weighted according to the urban area within the Calculation Area. Urban area is defined using Corine land cover data.

In Northern Ireland, the approach for urban and rural runoff calculations used in surface water flood mapping was the same as in England and Wales, using the same parameters, apart from a slightly higher urban runoff coefficient of 80%. When the runoff and associated change in return periods are calculated using 80% urban runoff, these are very similar to the values found for England and Wales. The same shifts in return period are therefore used in Northern Ireland and England and Wales. For Scotland, similar parameters for runoff and drainage capacity are used; the same runoff model as the rest of the UK is therefore used.

Table C3-2 Present day runoff (national average) and equivalent 2100 return periods (assuming 20% uplift), based on the runoff-frequency curves shown in the bottom row for rural and urban areas.

Return period	**Rural**		**Urban**	
	Present runoff (mm)	2100 Return Period	Present runoff (mm)	2100 Return Period
30	10	18	13	17
100	17	56	25	63
1000	52	580	76	560





C.4 Groundwater flooding

The approach to groundwater flooding has used the BGS Groundwater Susceptibility Model (extended to Northern Ireland), an analysis of the Futureflows data and changes to groundwater references in reference sites. This approach is described separately in Appendix D.

C.5 References

Chan S.C., Kendon E.J., Fowler H.J., Blenkinsop S. and Roberts N.M. (2014). *Projected increases in summer and winter UK sub-daily precipitation extremes from high-resolution regional climate models*. *Environmental Research Letters* 9.

CREW (2012). *Coastal Flooding in Scotland. A guidance document for coastal practitioners.* http://www.crew.ac.uk/sites/www.crew.ac.uk/files/publications/coastal_flooding_in_scotland.pdf

Environment Agency (2011). *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities.* Environment Agency.

Evans et al. (2004a). Future *flooding scientific summary: volume 1 - future risks and their drivers.* Government Office for Science.

Evans et al. (2004b). Future *flooding scientific summary: volume 2 - managing future risks.* Government Office for Science.

Halcrow (2001). *Final Report: Extension of National Appraisal of Assets at Risk from Flooding and Coastal Erosion.* Defra.

Hall, J., Dawson, R., Sayers, P., Rosu, C., Chatterton, J., & Deakin, R. (2003). A methodology for national-scale flood risk assessment. *Proceedings of the Institution of Civil Engineers - Water & Maritime Engineering 2003, 156(3), 235-247*.

HR Wallingford (2002). *Coastal Defence Vulnerability 2075.* Report SR590. Report by HR Wallingford for Department for the Environment, Food and Rural Affairs (Defra).

Kendon E.J., Roberts N.M., Fowler H.J., Roberts M.J., Chan S.C. and Senior C.A. (2014). *Heavier summer downpours with climate change revealed by weather forecast resolution model*. Nature Climate Change Letters, DOI: 10.1038/NCLIMATE2258

NERC (1975). Flood Studies Report (FSR). Published by Natural Environment Research Council, London.

Prudhomme, C., Crooks, S., Jackson, C., Kelvin, J. and Young, A. (2012). *Future flows and Groundwater Levels*. Environment Agency Technical Report SC090016/PN9.

Reynard, N.S., Crooks, S., Kay, A.L. and Prudhomme, C. (2009). *Regionalised Impacts of Climate Change on Flood Flows*. Environment Agency R&D Technical Report FD2020/TR.

Sloan, A. (2009). *Undefended Flood Plain Mapping With Climate Change: Climate Change Methodology*. Report IBE0119_AS_RW02 by RPS for the Northern Ireland Rivers Agency.

UKWIR (2015a). *Rainfall Intensity for Sewer Design Final Report*. UKWIR Report 15/CL/10/16-1.

UKWIR (2015b). *Rainfall Intensity for Sewer Design Guidance for Water Companies*. UKWIR Report 15/CL/10/16-2.

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*. Reviews of Geophysics, 52, 522–555.