Chapter 5

Quantified flood risks: intra-urban

Chapter 4 quantified future catchment-scale flood risk across the country. Chapter 5 now evaluates potential changes in flood risk within urban areas for the four future scenarios.

The Precipitation and Urbanisation drivers of intra-urban flood risk are analysed and used to produce broad-brush national estimates of:

- Future annual damages
- The number of properties at ‘high’ risk of flooding.

5.1 Introduction

As explained in Chapter 3, it is important to differentiate between drivers of flood risk that operate at the catchment scale and those that affect urban areas – the investigation of urban flood risk requires modelling on a finer scale.

Attempts to model flood risks arising from the intra-urban drivers are hindered by the absence of an equivalent to the RASP risk-modelling tool that was the basis for our estimates of national flood risk on the catchment scale (Chapter 4). This chapter therefore describes the estimation of future nationwide risks in the urban area, which has been performed without recourse to national modelling. Instead, our calculations are based on the analysis of changes in two of the most important drivers of intra-urban flood risk, Precipitation and Urbanisation.

The analysis of intra-urban flooding used models of the sewer systems of three typical urban catchments to estimate the flood risks arising from the Precipitation driver. We validated our results by comparing them with published information on recorded flooding. The models allowed us to explore the performance of the catchments in terms of volume of floodwater, the number of properties flooded and the Expected Annual Damage (EAD). The test models covered only the main drainage network. We had to estimate the additional risks and costs associated with other pathways and receptors of intra-urban flooding, such as highways and their drainage systems. Based on published information, we derived factors for scaling up this flood risk to the national scale.

Our model estimated future flood risk, expressed as EAD, for the Medium High climate-change scenario, labelled National Enterprise in the project's terminology, from UKCIP98 for each test area. However, there is considerable uncertainty in deducing changes in precipitation over short periods in small urban areas from predictions of precipitation from models of climate change on the global and regional scale. Our analysis therefore took a range of simple percentages as representing possible increases in flood risk under the other three scenarios of climate change. Our study averaged the flood risks for the test catchments and scaled the results to the UK's population of 59 million in the 2001 census.

The project adopted a similar approach when estimating increases in flood risk arising from Urbanisation, another main driver of future flood risk.

Table 5.1 **Assumed values for increased urban rainfall for one socioeconomic scenario, providing the starting point for estimating increases in peak urban rainfall, presented as precipitation multipliers. The table illustrates the results for the 2080s relative to the present day**

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Possible precipitation multipliers	1.20	1.15	1.10	1.05

The methodology did not permit a fuller analysis of future risks taking into account other intra-urban drivers. Our analysis therefore took the Precipitation and Urbanisation risks, factored them by a socioeconomic driver multiplier and combined them to give a broad-brush picture of possible future intra-urban flood risks.

A study by UK Water Industry Research (UKWIR) has provided some limited precipitation change estimates. For this reason we were able to run the test models using data broadly applicable to one scenario of climate-change. This corresponded to the Medium High climate-change scenario, which the Foresight project associates with the National Enterprise socioeconomic scenario. In the absence of reliable estimates of future urban rainfall, we adopted a simple sensitivity approach in modelling the other three scenarios. For each scenario, we increased the peak rainfalls in the 2080s relative to the present day (see Table 5.1).

5.2 Changes in intra-urban flood risk owing to precipitation

5.2.1 Estimation of future precipitation

Our models of urban flood risk require hyetographs – graphs of rainfall intensity versus time – for current and future rainfall. We based our hyetographs on two rainfall sources. We adopted the methods developed by the Centre for Ecology and Hydrology of the

Natural Environment Research Council in its *UK Flood Estimation Handbook* which provides hyetographs for existing rainfall, with annual probabilities of 1 in 10, 30 and 100. Our models also built on hyetographs that were made available by UKWIR and which estimate urban rainfall for the 2080s under the Medium High emissions scenario of UKCIP98 for a number of sites in the UK.

There is a high degree of uncertainty in the predictions of UKCIP98 for rainfall in urban areas. The most recent publication, UKCIP02, shows different results from the UKCIP98 data and greater seasonal variability. In addition, neither prediction gives an adequate account for a number of aspects of urban rainfall, such as the local heat island effects, where urbanisation removes vegetation and causes other effects, resulting in elevated local temperatures. Nevertheless, in the absence of better estimates, we have used rainfall data from UKWIR.

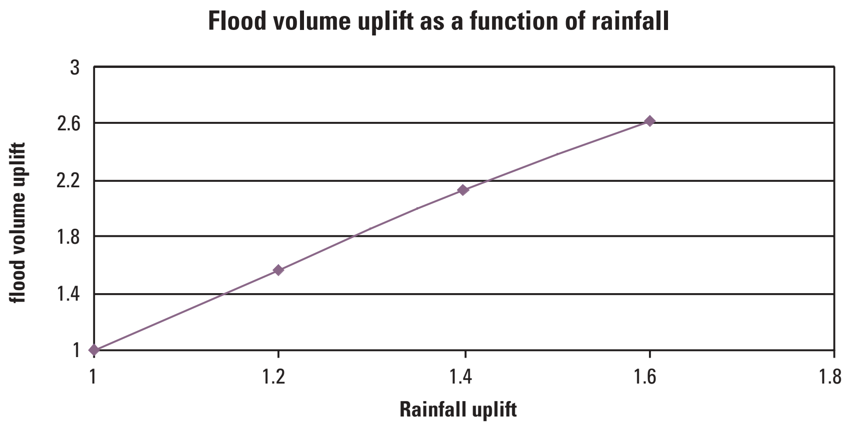
5.2.2 Changes in future precipitation

Sewerage undertakers made available to us computational models for existing main sewer systems for three urban catchments (see Table 5.2). The models' forecasts showed good correlation between the volumes of water flowing from flooded sewer systems and the increase in rainfall (see Figure 5.1). This agreement gives us confidence in predictions of the impacts for the other socioeconomic scenarios arrived at by scaling flood risks in line with the predictions of UKCIP98 for increases in rainfall.

Table 5.2 **Modelled catchments – the project analysed the main sewer systems for three representative urban catchment areas to gauge the number of properties at risk of flooding now and in the future**

Nature of catchment and location	Area (ha)	Impervious area (%)	Population	Population density (person/ha)	Number of properties	Property density (prop/ha)
1 Market town (northern England)	1,380	29	86,000	62	39,000	28
2 Inland city with major watercourses (Scotland)	3,930	34	260,000	67	77,000	20
3 Coastal city (Wales)	2,030	21	120,000	60	31,000	15

Figure 5.1 **Comparison of increased rainfall and flood volume for 1 in 30-year winter rainfall for a test catchment**



Techniques for modelling sewer systems are limited in analysing overland flow and flooding. Their predictions are based on highly simplified modelling of the pathways of flood flow above ground. The model appears to be accurate in simulating what happens below ground, but this is no longer so after floodwater reaches the surface. This leads to a disparity between recorded flood data and the model's predictions of properties at risk from flooding.

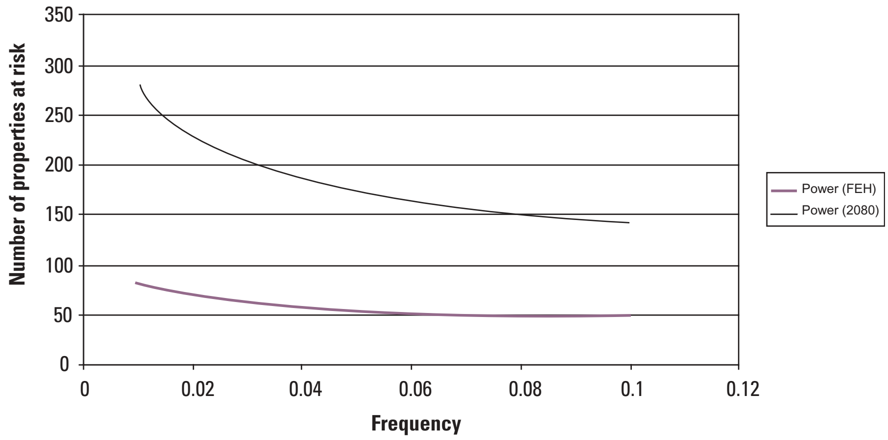
Analysis of the three test catchments showed that the nature of the catchment influences the relationship between flood volume and the recorded number of flooded properties. This makes it impossible to start with floodwater volumes predicted by the models and to derive any generic forecast of the number of properties flooded, independent of the catchment. We have therefore taken the recorded numbers of properties at risk of flooding as the basis of our forecasts. We used these numbers to scale up the increases in the volume of floodwater on a catchment-by-catchment basis.

Example – catchment 1

Catchment 1 has a relatively high terrain with average slopes. It has a sewer system made up of both combined and separate sewers. The land consists mainly of low-density residential properties.

The project calculated the number of properties at flood risk for 1 in 10-, 1 in 30- and 1 in 100-year storms for the rainfall today and in the 2080s. The results are shown in Figure 5.2.

Figure 5.2 **Numbers of internally flooded properties and frequency for main drainage failure for test catchment 1**



The curves resemble those commonly obtained for fluvial flooding and are not implausible but are uncertain due to the shortfalls in overland flood modelling.

5.2.3 Properties at risk and Expected Annual damages

The numbers derived for the test catchments provided a starting point for calculating the total numbers of properties at risk from flooding in the 1 in 10-year storm events for the present day and the 2080s (see Table 5.3).

Table 5.3 **Estimated numbers of properties in the UK at risk from main sewer flooding in 1 in 10-year event (based on total UK population in the 2001 census: Precipitation driver only)**

Test catchment	Population	Number of properties at risk of internal sewer flooding in 1 in 10 year event		Properties at risk per 1,000 population	
		Present day	2080s Medium High emissions	Present day	2080s
1	86,000	50	153	0.58	1.79
2	260,000	135	240	0.51	0.91
3	120,000	12	25	0.10	0.21
Averages for the test catchments	160,000	66	139	0.40	0.97
National	59,000,000	23,000	57,000	0.40	0.97

The next step of the analysis is to estimate Expected Annual Damages (EAD) for present-day rainfall and the forecasts of UKCIP98 for rainfall in the 2080s (see Table 5.4). The costings for flood damage derive from data from unit costs given by Penning-Rowsell *et al.* (2003). These give an average event damage for property flooding as £22,630 for an average flood depth of 0.2m. The analysis includes figures for the individual test catchments to illustrate the wide variation between catchments and hence the uncertainty in the results. In addition, for the 2080s, it is necessary to apply an uplift factor for the socioeconomic drivers. For the National Enterprise scenario a value of 4.5 has been taken for Building and Contents from Table 3.2.

Table 5.4 **Current and future risk from main sewer flooding only – whole UK; Precipitation driver**

Test catchment	Population	Present day			2080s Medium High emissions		
		Properties flooded per	Properties flooded per population	Expected Annual Damage £	Properties per year	Properties per 1,000 population	Expected Annual Damage £
1	86,000	5	0.058	110,000	16	0.187	1,600,000
2	260,000	15	0.057	340,000	30	0.114	3,100,000
3	120,000	3	0.024	68,000	5	0.041	510,000
Average for the test catchments	160,000	8	0.046	181,000	17	0.114	1,700,000
National	59,000,000	2,900	17	65,000,000	6,400	43	598,000,000

5.2.4 Other scenarios

The analyses presented above considered both present-day risk and risk in the 2080s from changing precipitation based on the National Enterprise/Medium High emissions scenario. In this section we extend these predictions to the other three scenarios.

The study estimated differences in rainfall between the UKCIP98, National Enterprise scenario and the other scenarios (see Table 5.5). UKWIR provided 'multipliers' for the increased rainfall in the 2080s for each individual test catchment. Multipliers for the other scenarios come from the 'sensitivity' multipliers (see Table 5.1). The data from UKWIR included only the differences in the rainfall multipliers for 10-year events of 6 hours duration. In the absence of other data, our analysis applied these factors for longer return periods.

Table 5.5 **Multipliers on rainfall for different climate-change and socioeconomic scenarios**					
Test catchment	Rainfall multiplier 2080s	Scenario multiplier referenced to National Enterprise/Medium High emissions (UKCIP98 rainfall)			
	UKCIP98	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	1.19	1.04	1	0.96	0.91
2	1.28	1.04	1	0.96	0.91
3	1.07	1.04	1	0.96	0.91

Applying the rainfall multiplier factors (see Table 5.5), together with the multipliers derived from the scenario sensitivity (see Table 5.1) and from the socioeconomic multipliers (Table 3.2) allows us to determine the changes in current flood risk for the other scenarios. The approach is to use the linear correlation with flood volume and the approximate numbers of flooded properties from the studies of the test catchments. This therefore gives an approximate way of estimating impacts under all four scenarios (see Table 5.6).

Table 5.6 **Multipliers for numbers of properties at risk and Expected Annual Damage for different futures scenarios**

Test catchment	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	1.7	1.2	0.2	0.4
2	1.9	1.3	0.2	0.5
3	1.5	1.1	0.2	0.4
Average	1.7	1.2	0.2	0.4

5.2.5 Other urban pathways

The analyses above considered only the impacts of main sewers on the internal flooding of properties. We now extend these predictions to other intra-urban flood pathways.

Water industry data provided the basis for estimates for the total numbers of properties currently at risk of sewer flooding in England and Wales (see Table 5.7).

Table 5.7 **Estimated numbers of properties at risk of flooding once in 10 years in England and Wales**

Flood type	Public sewer	Private sewer	Overland flow	Gutters etc	Total
Flooding of property	11,600	8,850	11,600	30,400	62,500
Flooding adjacent to property	4,640	3,540	4,640	—	12,800
Flooding of highways	2,320	1,770	2,320	—	6,410
TOTAL	18,600 (23%)	14,200 (17%)	18,500 (23%)	30,400 (37%)	81,700

Other property flooding was estimated by reference to the English House Condition Survey data. On this basis, the numbers of properties at risk from flooding according to the test models might be scaled up from those given in Table 5.3 by approximately 3.5. This will give an overall national figure for properties at risk and EAD. Combining this with the multiplier factors for the other three scenarios (see Table 5.6), gives multipliers of numbers of properties at risk of flooding from all causes of urban flooding under the four scenarios (see Table 5.8).

Table 5.8 **Future multipliers of flood risk from precipitation expressed as properties per year per 1,000 population – all causes of urban flooding**

	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Properties at risk of flooding per year per 1,000 population	0.16	0.41	0.40	0.38	0.36
Properties at risk of flooding per year	9,500	24,320	23,370	23,610	21,280
Properties at risk of flooding in 1 in 10-year event	81,700	215,000	200,000	195,000	185,000
Ratio to present day		2.6	2.5	2.4	2.2

The analysis suggests that under all scenarios flood risk will increase by a factor of more than 2 owing to changes in precipitation alone (see Table 5.8). There are only limited differences in flood risk between the scenarios for precipitation changes. This is largely because the base rainfall varies only by some 20%. The effects will vary between catchments. In some areas, the existing drainage will be resilient, having spare capacity, whereas in others, there may be no tolerance of any increase in rainfall. Nonetheless, even a small, unplanned-for increase in design rainfall is likely to cause the greatest initial effect, impacting on vulnerable properties.

In some areas, any further gradual increase in precipitation (as assumed here) may not necessarily lead to significant additional property flooding. Where there are larger increases in rainfall, there may be a threshold above which there is widespread failure of the drainage system resulting in a much greater impact on properties. Although in a number of areas, many, on higher ground, will still be secure, with the most vulnerable experiencing greater flood depths and damage, rather than the numbers necessarily increasing significantly.

Thus there is a significant distinction here between the actual physical effects of flooding (represented by the Precipitation driver) and the impacts where damage is also accounted for. Hence, in terms of EAD, flood risk might rise from £270 million per year to £4200 million per year under the consequences of the worst socioeconomic scenario, World Markets (see Table 5.9) and because of the economic differences between the scenarios, the economic flood risk may only increase by a modest amount to some £450 million per year under Local Stewardship.

Table 5.9 **Expected Annual Damages (in £ million per year) for flood risk for all intra-urban flood pathways and receptors owing to changes in precipitation**

Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
270	4,420	2,990	450	1,150

5.3 Changes in risk through urbanisation

Urbanisation is potentially an important driver of future flood risk in the urban area. There is virtually a linear relationship between the increase in the area of impermeable surfaces and increase in flow rate and volume. Some 30-50% of rainfall appears as runoff from a paved area (Elliott, 2003). Hence any increase in urbanisation would be reflected in an increase in volume of runoff and flow rate of roughly an equivalent amount. In the UK, about 7% of the surface area is urbanised. Of this, some 23% is open space (Handley *et al*. 2000). Increases in future risk are therefore functions of the increase of the impermeable urban area.

During the 1990s, the rate of urbanisation in England was relatively constant at around 5,000 hectares per annum. The most recent data, for 1996-98, indicate an average net loss of 5,400 hectares per year of undeveloped (greenfield) land to developed areas (ODPM 2003). This needs to be set against the total extent of urban land, which in England is 13.37 x 107 hectares. This is for greenfield sites only and shows that under current projections the increase in urban impervious surfaces would be less than 0.1% per annum. If current perspectives continue, most of this area will be treated in accordance with Planning Policy Guidance Note 25 (PPG25) *Development and Flood Risk*, or equivalent. Hence urbanisation might not contribute significantly to flooding in adjacent areas downstream. Nonetheless, our assessment assumes that all of this land adds to flood risk.

Many brownfield sites would also provide some storage and attenuation of runoff. Hence their development would influence flood risk. In the absence of data, we presume that development of this land increases the impermeable surfaces by some ten times the rate at which greenfield development takes place.

Urban creep such as house extensions and paved patios has also recently been shown to add some 7% to the area of impermeable urban surfaces. This is largely uncontrolled and we would expect it to add to flooding problems.

The next step in the analysis is to calculate the total increase in urban area (see Table 5.10). Taking all of these factors into account, we have derived a central estimate of a potential national increase in percentage impermeability due to urbanisation of 15%. This increase has been applied to the four scenarios for the 2080s (see Table 5.11).

Table 5.10 **Change in urban area – based on current developments – up to 2080**

	Units	Base case	Sensitivity
Current urban area	ha	130,000,000	130,000,000
Open space	%	23.0	23.0
Developed	%	77.0	77.0
Developed	ha	100,000,000	100,000,000
Average impermeability	%	33.0	50.0
Impermeable area	ha	34,000,000	51,000,000
Greenfield development	ha/year	5,000	5,000
Total greenfield development	ha	400,000	400,000
Impermeability	%	33.0	25.0
Greenfield impermeable area	ha	130,000	100,000
Brownfield/greenfield	Ratio	10	10
Brownfield impermeable area	ha	1,300,000	1,000,000

Table 5.10 **Change in urban area – based on current developments – up to 2080** (continued)

	Units	Base case	Sensitivity
Creep per property	%	7.0	7.0
Creep per impermeable area	%	21.2	14.0
Creep remaining	%	50.0	50.0
Future creep per impermeable area	%	10.6	7.0
Future creep	ha	3,600,000	3,600,000
Increased intra-urban impermeability	ha	4,900,000	4,600,000
Increased intra-urban impermeability	%	14.5	8.9
Total increased impermeability	ha	5,100,000	4,700,000
Total increased impermeability	%	14.9	9.1

Table 5.11 **Urbanisation will result in increases in the area of impermeable land surface by the 2080s that depend on the assumed socioeconomic scenario**

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Ratio to base case	2.0	1.2	0.75	0.5
Increase in impermeable area (%)	30	18	11	7.5

For the purposes of this project, it is reasonable to assume that the change in impermeable surface area is roughly equivalent to the change in rainfall intensity in terms of future change in flood risk. If we take the multipliers for numbers of properties at risk and EAD (see Table 5.6) and apply to them the multipliers for urbanisation (see Table 5.11), we obtain the effect of increasing the impermeable areas as shown (see Table 5.12). The outcome suggests that the changes in risk of flooding in the intra-urban area owing to urbanisation might be of a similar magnitude to that from the increases from precipitation.

Table 5.12 **Urbanisation – changes in properties at risk of flooding and Expected Annual Damage for the UK**

	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainablity
Properties at risk of flooding per year per 1,000 population	0.16	0.32	0.27	0.24	0.22
Properties at risk of flooding per year	9,500	19,000	16,000	14,250	13,100
Properties at risk of flooding in 1 in 10-year event	81,700	165,000	140,000	125,000	115,000
EAD (£ million per year)	270	3,460	2,065	290	720

5.4 Overall change in intra-urban flood risk

In order to obtain a broad-brush estimate of the overall change in intra-urban flood risk we have simply added the numbers of properties at risk and the EAD from the Precipitation and Urbanisation drivers. The methodology does not allow us to include impacts of other drivers nor any strict means of combining the risk from precipitation and urbanisation. The results are show in Table 5.13.

Table 5.13 **Present and possible future risks of intra-urban flooding for the UK**

	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainablity
Properties at risk of flooding in 1 in 10-year event	81,700	380,000	340,000	320,000	300,000
EAD (£ million per year)	270	7,880	5,055	740	1,870
Uncertainty range – EAD (£ million per year)	100-500	3,500-15,000	2,000-10,000	350-1,400	900-3,600

Some key points in connection with the analysis and the results are noted below:

- current computational models are inadequate for predicting intra-urban flooding with any accuracy. While their use to model below-ground piped drainage flows is probably reliable for the shorter return period events (typically up to ten years), once the return period increases and flow passes out of manholes and onto surfaces, subsequent predictions may overestimate the number of properties at risk by an order of magnitude.
- there is large uncertainty in the Precipitation multipliers. In addition, models for assessing flooding are not yet reliable. Hence the predictions we present here should be considered to be only within a range of uncertainty for the multipliers of less than one half and more than double.
- this study has shown that the change in intra-urban flood risk owing to Precipitation and Urbanisation are broadly similar.
- the most obvious result of this analysis is that flood risks increase substantially under all scenarios.