Technical annex: Flood modelling

July 2018

This annex provides supplementary detail on modelling of flood management for the National Infrastructure Assessment.

Assessing cost and benefits of different standards

Model description

The National Infrastructure Commission procured flood risk cost and benefit modelling support from JBA Consulting in collaboration with Sayers and Partners. A detailed explanation of model functionality is provided in their report *Floods standards of protection and risk management activities*, available on the Commission's website.[1]

The model assesses the costs and benefits of different standards of flood resilience, using the latest Environment Agency flood risk data.[2] The model was designed to help the Commission understand the public expenditure ('fiscal remit')[3] implications of different flood resilience standards. The model estimates the costs for a specified standard of protection for resilience against sea and river flooding, splitting out costs into capital and resource spend. As such, it is different from the Environment Agency's Long Term Investment Scenarios (LTIS) model.[4]

The Commission's role is to advise the UK government and hence the Commission's scope matches the responsibilities of the UK government. Flood risk management is devolved to Scotland, Wales and Northern Ireland. Modelling therefore covers England only.

Due to limitations in available data, resilience standards can only be reliably costed for river and coastal flooding. Hence the analysis below covers only these two sources of flood risk. Better data would be needed to extend the analysis to include surface water flooding.

The model uses two scenarios for population growth ('high' and 'low') and two scenarios for climate change ('medium' and 'high', consistent with rises in global mean temperatures of 2°C and 4°C respectively). Further details on these scenarios are available on the Commission's website.[5] The model also allows different approaches to flood management: for simplicity, protection provided by flood defences and property level measures were used to proxy for the full range of potential flood resilience investments.[6]

The model allows different standards of protection to be set for sea and river flooding in the 2050s,[7] across 8 settlement types defined by the Office for National Statistics.[8] The settlement types were simplified into 4 types by the Commission with standards considered for:

- Major cities (major and minor conurbations)
- other cities and large towns (towns above 10,000 people)
- rural towns (3,000-10,000 people)
- villages and hamlets (fewer than 3,000 people).

The model includes the costs of major capital maintenance, which are included in the capital results below. Routine maintenance is also modelled, but not included in capital expenditure, since it is assumed to score as resource expenditure.

The baseline

In the baseline, current standards of protection are maintained for existing sea and river defences. This is described in more detail in *Floods standards of protection and risk management activities* as the 'Continued Levels of Adaptation' baseline. The existing standards of protection vary with some rural areas having better protection than some cities. Different areas of the same city can have different levels of protection. The baseline roughly provides for protection to 0.1 per cent each year in areas of London; 0.5 per cent in parts of some large towns such as Northampton and some rural areas; 1 per cent in parts of cities, large and small towns, and villages. Some areas are undefended.

Modelled standards of resilience

The Commission looked at a range of standards for enhanced resilience to sea and river flood risk. The Commission tested the damage reduction and cost impacts of raising the levels of resilience, by:

- providing a national standard of resilience against flood risk, with probabilities of 1 per cent, 0.5 per cent and 0.1 per cent
- bringing all major cities up to the same level as London, with resilience against flood risk with a probability of 0.1 per cent[9]
- bringing all urban areas, including cities and towns with a population of 10,000 or above, to the same level as London, with resilience against flood risk with a probability of 0.1 per cent.

Estimating costs per property

Where properties currently have some level of protection, the cost per property of providing an enhanced level of resilience was parameterized using data on the costs of flood resilience schemes (see table 1). Modelled costs per property vary depending on whether a property is already protected, located in a dense or isolated area, and by the level of risk to the property.

Settlement Type	Coastal £, 000s	River £,000s
Major cities	10	16
Smaller cities and large towns	20	18
Rural towns	18	19
Villages	27	18

Table 1: Estimated cost ranges per property for coastal and river defences (£ thousand).[10]

The cost for protecting currently undefended areas was modelled by:

- assuming properties at risk higher than 3.3 per cent per year would be protected using property level measures, at a cost of about £9,000 per property.[11] This is because property level measures are effective for flood depths of between 60cm to 90cm.[12] Whilst flood depths corresponding to different return periods depend on the area, the Environment Agency estimates that properties at risk up to 2 per cent tend to be affected by depths up to 1 meter.[13] Hence, for modelling purposes, properties in the band nearest to 2 per cent (3.3 per cent in the model) are assumed to be protected by property level measures.
- assuming properties at risk lower than 3.3 per cent, and outside major cities, would be protected using new flood defences. The cost of these defences was calculated by using the average cost of those schemes in the Environment Agency's capital programme[14] that were built to protect fewer than 1,000 properties (to approximate "isolated" properties), are outside urban areas, and approximate "new" schemes (rather than refurbishment of existing ones).[15] The resulting cost is about £30K per property.[16]
- properties at risk lower than 3.3 per cent in major cities were also assumed to be protected using flood defences. The cost per property was assumed to be lower than the cost of protecting "isolated" properties, but higher than the cost of enhancing the protection of properties that currently have some level of protection. The cost per property was calculated using the upper limit (90th percentile) of costs of coastal and river defences, based on all the costs of all schemes included in the 6 year programme. The resulting cost is about £18K per property.[17]

Estimating benefits of damage avoided

The Commission calculated the benefits of the different standards by estimating avoided damage.[18] The model estimates direct property damages for different standards and population and climate scenarios. Indirect damages are then assumed to add a further 75 per cent of the direct damages, ie total damages are estimated to be 1.75 times the direct damage. The 75 per cent includes:

- 11 per cent indirect losses associated with emergency services and provision of temporary accommodation
- 16 per cent for risk to life and physical injury
- 43 per cent for impacts on infrastructure, transport, schools and leisure[19]
- 5 per cent for mental health effects[20]

The estimated uplift for mental health effects is subject to ongoing research, and may be an underestimate of true effects.

Results

Figure 1 shows the modelled results for a range of resilience standards, broken down into currently defended and undefended area costs, for a 'low population, medium climate change' scenario.

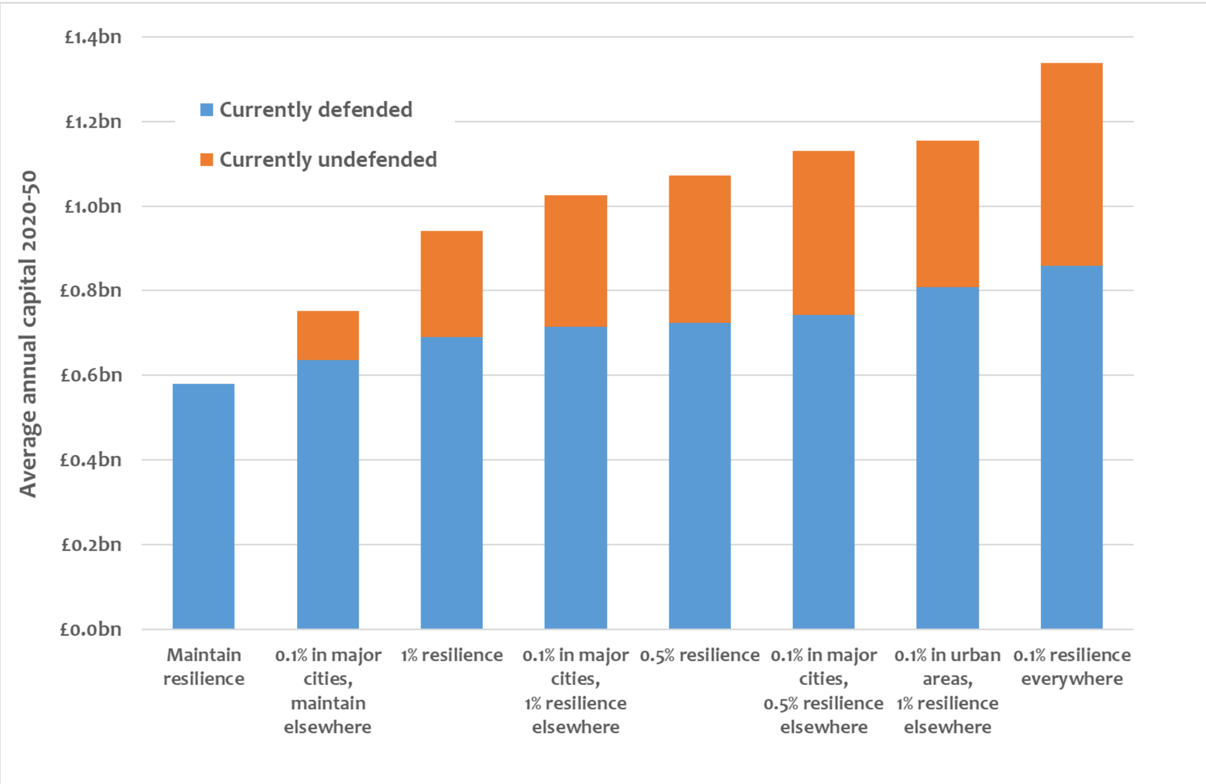

Figure 1: Estimated average annual public capital costs for standards of resilience to flooding from river and sea, 2°C increase in global mean temperatures climate scenario, low migration population scenario

Figure 2 shows the modeled costs for the same range of resilience standards, for a 'high population, high climate' scenario. This scenario requires around 60 – 125 per cent higher expenditure for the same standard of resilience. The model triggers replacement of defences as soon as the 2020s, to maintain current standards.

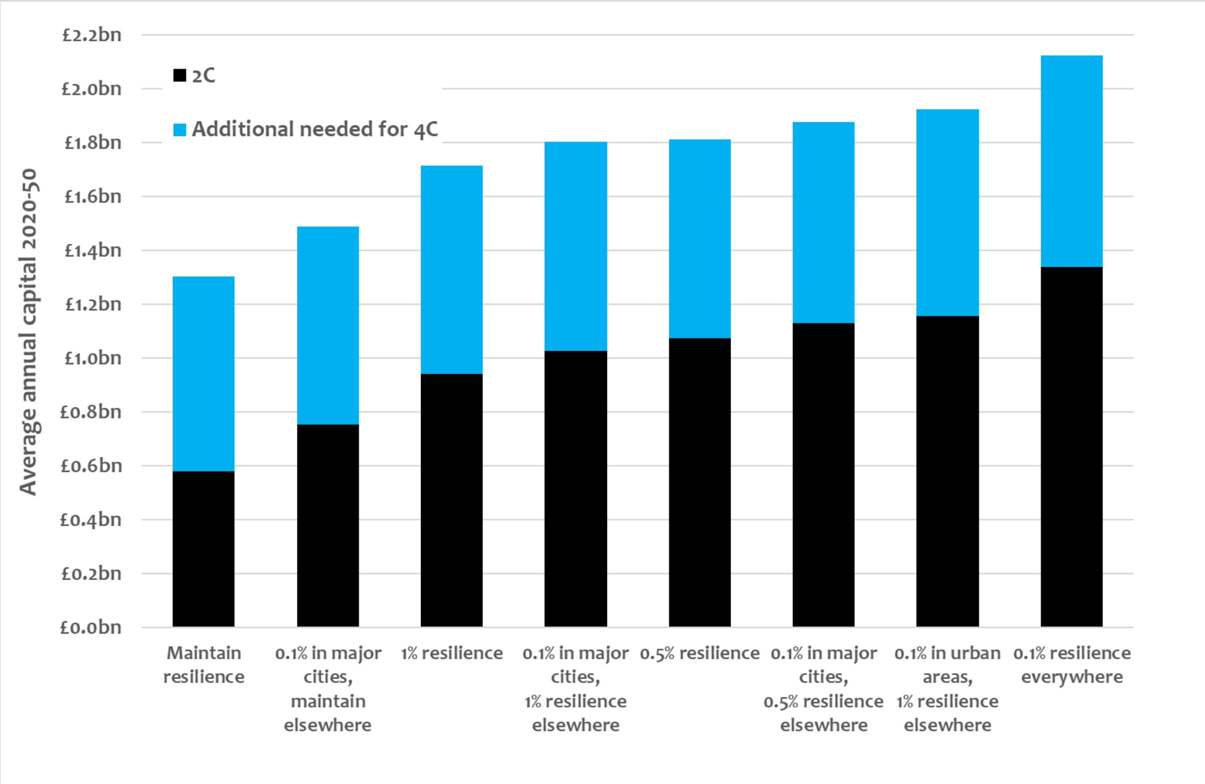

Figure 2: Estimated average annual public capital costs for different standards of resilience to flooding from river and sea, low population and 2°C increase in global mean temperatures climate scenario; and high population and 4°C increase in global mean temperatures climate scenario.

These costs represent the annual average level of capital expenditure required for a 30 year programme to deliver a set standard of resilience, by 2050. To compare them with the benefits of having a higher standard of resilience, they need to be converted into the equivalent annual cost of the higher standard. The difference between this, and the costs of maintaining the current standard can be compared to the difference in benefits.

The Commission calculated the cost of each standard as the annual cost, in 2050, at the point when the standard would be achieved. This can be considered as the on going 'steady state' cost of any given standard, relative to the cost of maintaining the baseline. This can then be compared to the benefits of the higher standard, calculated as the difference in expected annual flood damage from the higher standard relative to the baseline standard.

The annual cost is given by the on going cost of the additional stock of flood risk management capital deployed, calculated as the additional capital stock multiplied by the annual cost of that capital. The annual cost of capital was calculated as the sum of the opportunity cost of capital (the potential value that could otherwise have been obtained from the same public capital allocated elsewhere) and depreciation (the annual amount need to maintain the capital stock in the same condition).

The cost of capital was proxied by the government's Green Book discount rate of 3.5 per cent. Depreciation was estimated in a straight line over a 50 year asset life, to give a 2 per cent depreciation rate.

The Commission calculated the benefit of resilience standards as the reduction in annual sea and river flood damage in 2050. This was estimated as the change in the probability of damage occurring, given by the change in resilience standard, multiplied by the average damage per property, and then aggregated over the total number of properties at some risk of flooding.

Standard	Net benefit (£bn)
0.1% in major cities, maintain elsewhere	0.25-0.5
1% resilience	0.25-0.5
0.1% in major cities, 1% resilience elsewhere	0.25-0.5
0.5% resilience	0.25-0.5
0.1% in major cities, 0.5% resilience elsewhere	0.25-0.5
0.1% in urban areas, 1% resilience elsewhere	0.25-0.5
0.1% resilience everywhere	0-0.25

Table 2: Estimated net benefits (total benefits minus costs) for each standard of resilience, in the 'low population, medium climate' scenario.

Given the substantial uncertainties involved, it is important not to place too much weight on any given figure. Table 2 shows the net benefits of the different standards of flood resilience modelled are likely to be similar, with the exception of the very highest level of resilience modelled.

One important limitation of the approach adopted is that it is does not assess changes beyond 2050. It measures the 'steady state' annual net benefit of flood resilience standards, assuming a constant risk after 2050. Climate change means that risks are likely to continue to rise after 2050. However, the inevitable uncertainty of such long term estimates led the Commission to adopt the simpler approach set out here.

The costs of achieving each resilience standard in a 4°C world are much higher than for the same standard in a 2°C world, but so are the benefits. This might suggest a precautionary approach of building resilience against higher climate change. However, flood resilience can be designed to be enhanced incrementally. Measures that provide resilience in a 2°C world can be upgraded if it becomes apparent that a 4°C world is more likely. This 'adaptive management' is consistent with catchment based approaches using a range of interventions, rather than just conventional flood defences.[21] This is the most appropriate approach until there is more certainty on climate change impacts, allowing resilience standards to be increased over time.

End notes

[1] See Sayers and Partners and JBA Consulting for the National Infrastructure Commission (2018), Floods standard of protections and risk management activities
[2] Environment Agency (2018), Risk of flooding from rivers and sea – key summary information
[3] For further detail on the fiscal remit, see Chancellor of the Exchequer (2016), Remit letter for National Infrastructure Commission
[4] Environment Agency (2014), Flood and coastal risk management: long-term investment scenarios
[5] National Infrastructure Commission (2016), The impact of population change and demography on future infrastructure demand. The low population scenario used in the flood modelling, is the low migration variant discussed in that document, and the high population scenario is the high fertility variant. For climate change, the medium climate change scenario is a 2ºC increase in global mean temperature by the 2080s from the pre-industrial baseline, and the high climate change scenario is a 4ºC increase. These scenarios were established to inform the Climate Change Risk Assessment 2017, see Sayers et al. (2015), Projections of future flood risk in the UK. Sayers and Partners LLP report for the Committee on Climate Change.
[6] Hence in this annex 'protection' is used to describe the results from the model, whilst 'resilience' describes the standards.
[7] The model can set standards for the 2050s, specifically 2055. The Commission used the 2055 parameter to estimate costs up to 2050.
[8] Bibby and Brindley (2013), Urban and Rural Area Definitions for Policy Purposes in England and Wales: Methodology
[9] The Thames Barrier was designed for sea levels with an annual probability of 0.1 per cent: see Committee on Climate Change (2011), Protecting London from current and future flood risks
[10] Using information on projected expenditure in the Environment Agency's six-year Forward Investment Programme (covering 2016-2021), and actual costs through analysis of the Agency's previous Medium-Term Plan dating back to 2010 (covering 2010-2015). This is more detailed than the publicly available data at Programme of flood and coastal erosion risk management schemes accessed from www.gov.uk/government/publications/programme-of-flood-and-coastal-erosion-risk-management-schemes
[11] See Sayers and Partners and JBA Consulting for the National Infrastructure Commission (2018), Floods standard of protections and risk management activities: p35 Table 6-17 "Capital costs for RLR in existing properties" weighted by proportion implemented
[12] White et al. (2013), 6 steps to property level flood resilience
[13] Environment Agency (2015), Quantifying the benefits of flood risk management actions and advice
[14] Using information on projected expenditure in the Environment Agency's six-year Forward Investment Programme (covering 2016-2021), and actual costs through analysis of the Agency's previous Medium-Term Plan dating back to 2010 (covering 2010-2015).
[15] These are schemes with an initial standard of protection of 10 per cent or less, excluding those protecting more than 1,000 properties, and those that from the scheme's descriptor were obviously in urban areas or improvement of existing defences
[16] Commission calculations using data from Sayers and Partners and JBA Consulting
[17] Commission calculations using data from Sayers and Partners and JBA Consulting
[18] The current average annual economic direct damage in England is estimated to be about £0.9 billion. See p.112 of Sayers et al. (2015), Climate Change Risk Assessment. 2017: Projections of future flood risk in the UK. Published by Committee on Climate Change, London. Other estimates vary, see Penning-Rowsell (2015), A realistic assessment of fluvial and coastal flood risk in England and Wales. Damage can be significantly higher in years with major floods: e.g. £3 billion in 2007 and £4 billion in 2012, see UK floods: The winners and losers accessed from www.bbc.co.uk/news/business-26224680
[19] See Sayers and Partners and JBA Consulting for the National Infrastructure Commission (2018), Floods standard of protections and risk management activities: p22

[20] Defra (2004), Flood and Coastal Defence Project Appraisal Guidance, Economic Appraisal Supplementary Note to Operating Authorities

[21] For example, see: Reeder and Ranger (2011), How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project. World Resources Report Uncertainty Series, World Resources Institute. Sayers et al. Climate impacts on flood and coastal erosion infrastructure. Infrastructure Asset Management Arwin van Buuren et al. (2018), Introducing Adaptive Flood Risk Management in England, New Zealand, and the Netherlands: The Impact of Administrative Traditions, Review of Policy Research