Environment Agency

Flood and coastal erosion risk management

Long-term investment scenarios (LTIS) 2014

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Acting to reduce climate change and helping people and wildlife adapt to its consequences are at the heart of all that we do.

We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

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Foreword

The last few years have seen serious flooding in many parts of England both inland and on the coast, most recently in the winter of 2013 to 2014. Nonetheless, England as a whole is demonstrably more resilient to the threat of flooding than it was 10 years ago. The government is investing record amounts in maintaining, repairing and improving flood defences, and there is a well-developed framework for managing present day risk. Since resources are limited, investment is targeted in the areas and activities that have the greatest impact on risk.

It is also important to look to the longer term. This was done by the Foresight study in 2004, and again in the long-term investment strategy in 2009. Since then, both the evidence and our ability to interpret it have improved considerably. This study, therefore, builds on previous work and seeks to set out the long-term level of investment nationally on flood and coastal erosion risk management that would be needed to fund all work where benefits exceed costs. It does so in a number of scenarios relating to the deterioration and ageing of flood risk management assets, extreme weather that may become more frequent, and the benefits of investment to provide, improve and maintain structures. The assessment of optimal investment is made only in terms of the costs of flooding that can currently be robustly estimated. It considers levels of investment against the costs of future damage avoided. There is no attempt to consider, for example, the effect of flooding on health or family life or other factors influencing investment decisions, nor to consider constraints on funding or the need to prioritise limited resources.

The analysis is sensitive to uncertainties such as climate change, development on the flood plain and changes in future costs. We now have a more complete analysis than has previously been available, which can:

- optimise investment over time
- link long-term projections to existing plans
- assess the risk of flooding from surface water alongside the risk from rivers and the sea
- assess the benefits of a range of measures, including structures and individual property protection
- explore the potential to reduce the consequences of flooding through flood forecasting and warning

Our purpose is to provide a guide to planning future investment. The work has been peer reviewed by Professor Jim Hall, Director of the Environmental Change Institute at the University of Oxford.

Sir Philip Dilley

Chairman

Executive summary

The long-term investment scenarios study (LTIS) is an economic assessment of future flood and coastal erosion risk management in the period 2015 to 2065.

There are currently around 2.4 million properties at risk of flooding from rivers and the sea in England. 748,000 of these have at least a 1% annual likelihood of experiencing flooding. About 3 million properties are at risk from surface water flooding in England, around 772,000 of which are at or above the 1% annual likelihood level. About 600,000 properties are at risk from both sources of flooding. At present, there is not enough evidence to include risk from groundwater flooding in this analysis.

The report builds on previous assessments. It uses the latest available data to assess the consequences of investment choices to reduce the risks of flooding and coastal erosion in England over the coming years. It identifies an approach to investing in flood and coastal erosion risk management (FCERM) over the long term that would achieve the greatest reduction in flood damage for any given amount invested. It also explores what actions may be necessary to cope with residual risk. It is important to note that this analysis does not, and cannot, identify individual flood and coastal management projects. Instead, it takes a long-term view of factors that affect flood and coastal erosion risks in order to explore a range of national investment scenarios.

This approach has allowed us to assess, for the first time, that planned investment should reduce overall flood and coastal erosion risk in England.

It indicates that current and proposed levels of investment closely align with a long-term investment profile that maximises benefits in terms of reducing flood damage. The proposed 6-year capital programme represents a larger capital commitment than ever before, and is made over a longer time period (2015 to 2021) than previous settlements.

In 2014 to 2015, Defra, the Environment Agency and its Regional Flood and Coastal Committees, local councils and local beneficiaries expect to spend around £930 million managing flood and coastal erosion risk, including £180 million additional funding to repair and maintain defences.

The current 'partnership funding' policy has already been successful in attracting external contributions. These have risen from £13 million in 2008 to 2011 to a forecast of around £140 million in 2011 to 2015.

Outline of the study

The study builds on the work carried out for the 2009 assessment and includes significant improvements and updates. We use the latest national assessments of present day risks of flooding from rivers, the sea and surface water, and from coastal erosion, and information on asset type, status and condition. In a significant advance on the 2009 study, our model is now able to model long-term risk, starting with a given investment level. It can also allocate investments more effectively, and we can now explore the links between investment level and risk. This study, therefore, builds on previous work and seeks to set out the long-term level of investment that would be sufficient over the study period to fund all activity to manage flood and coastal erosion risk where benefits are greater than costs, regardless of any constraint in funding, consideration of where the funding comes from or how it is balanced with other spending priorities. It then models the optimum profile of this investment that maximises benefits. It also shows that the funding committed in the government’s 6-year programme is consistent with this optimum investment profile. We have tested our findings against a range of possible climate change projections using the latest scenarios.

There are many uncertainties and the scenarios will need to be updated in future as new data and modelling becomes available. The long-term analysis cannot determine projects and programmes of flood and coastal erosion risk management work in individual communities and areas. We report our findings in national terms, covering England as a whole.

Main findings: costs

- Our assessment is based on the current location and condition of flood risk management assets, once all repairs from the winter storms of 2013 to 2014 are completed. Because of the age and condition of assets, investment is not expected to be uniform over time. Uncertainty increases in the longer term. We estimate that the optimal investment profile in the first 10 years will be around £750 to £800 million a year in present day costs. We expect this to rise from the 2020s to the 2040s to £850 to £900 million a year, although there is scope to influence this by choosing different policies. Once discounted to present values, the cost of funding all activity to manage flood and coastal erosion risk where benefits are greater than costs would be around £25 billion over the next 100 years. This takes into account the expected rate of deterioration of flood defences. Future damage from major storms may need additional repair funds.
- These costs would include spending on building and maintaining infrastructure owned both by the Environment Agency and other risk management authorities, and on other crucial functions such as flood forecasting and warning, data and mapping, and development control. These costs would also include investment by other contributors.
- The analysis cannot precisely optimise asset replacement intervals. In some cases, it could be beneficial to change the estimated timing of capital investments to achieve higher net benefits.
- The analysis assumes that capital expenditure will be 10% more efficient overall between 2015 and 2021, and that risk management authorities will hold costs down after that time. The long-term benefit of this commitment is significant.
- Government's current investment plans to 2020 to 2021, supplemented by forecast local contributions and targeted efficiency, closely align with our modelled economic optimum cost profiles. The level of investment planned for 2015 to 2021 is cost-effective regardless of future levels of climate change. This suggests that current plans take account of uncertainties and are compatible with a flexible investment strategy.

Main findings: benefits of investment, and future risks

- Investment in flood and coastal erosion risk management brings significant economic benefits. The net present value of the optimised long-term investment is £102 billion over 100 years. This is the difference between the economic benefit of the overall investment, and the cost of providing it. It would provide an overall benefit to cost ratio of about 5 to 1, while enabling interventions with lower benefit to cost ratios to go ahead provided they have a positive economic benefit. Benefits are valued according to the economic damages avoided by making the investment, including the benefits of protecting homes and businesses, farmland and infrastructure. We estimate that this will lead to a 12% reduction in flood damages over the next 50 years.
- This does not include economic growth benefits that could be achieved in areas where the standard of protection against flooding is improved over time, or other benefits such as health or reduced risk to life.
- With a stable investment programme for 2015 to 2021, based on existing capital investment plans for this period, and assuming that the performance of current assets and incident management service are maintained at current levels, we estimate that overall risk will reduce by around 5% by 2021, in comparison to present day risk. This is a provisional figure pending agreement and monitoring of the investment programme. This is the first time we have been able to estimate the overall impact of short-term investment plans on overall flood risk.
- Current flood risk would be far higher without the many decades of investment that have developed an extensive flood and coastal erosion risk management infrastructure. This infrastructure will need maintaining and improving to manage risk to acceptable levels. We

expect that existing structures will be upgraded in many areas, but there will always be significant residual risk to manage.

- Under optimum investment, we predict that over 2 million properties would benefit from cost effective replacement or new structures over the next 50 years, using current cost assumptions.
- Options such as resilience and resistance measures for properties are cost effective in many circumstances. If more properties put these measures in place, this would help to further reduce the impacts of flooding and the associated economic damages. Other approaches might include better land management to reduce run-off, and adapting some coastline to protect inland areas.
- The extent of damage avoided as a result of floods is also influenced by individual behaviours, the accuracy of forecasts and the timing and extent of warnings, and the responses to them.

Uncertainty and main future sensitivities

Uncertainty increases over the long term, and the findings are sensitive to assumptions made about climate change, development and costs of protection. The projections in this study are helpful in understanding future trends in investment demand and the range of uncertainty, rather than to fix a course now. The key sensitivities in this analysis include:

- The cost of providing flood and coastal erosion risk management structures could change in the long term. Further progress on efficiency, new approaches and technologies, or more efforts to reduce flood risk more widely such as land management practices or sustainable drainage, might push costs down. Rising costs of construction, supply constraints or unhelpful land management approaches might push costs up.
- A further 10% decrease in unit costs after 2021 could reduce the long-term risk by 15% compared with the present day. On the other hand, a 10% increase in unit costs after 2021 would raise the optimum level of investment slightly, while limiting the potential long-term reduction in risk. This demonstrates the importance of continuing to try and reduce the costs of flood risk management, as well as introducing wider policies that will impact on flood risk.
- If the medium projection of climate change is removed from the analysis, the long-term optimum investment would reduce by 13%, and risk would be reduced further. This provides some measure of the effect of climate change in the analysis.
- Future development on the flood plain will also be an important risk to manage. Our baseline scenario assumes effective development control in future. Without effective planning controls, pressure to build more homes would add up to 16% to the cost of optimal flood protection compared with the 'baseline' scenario. Even at this increased level of investment, the overall flood risk would not reduce over time. This scenario is unlikely but used as a 'worst case' comparison.
- Investing at strictly economic optimum levels in the long term does not mean that all communities would see the solutions they want, and not everyone would benefit from the same level of protection. However, there may be considerations that influence investment decisions that are not covered in the economic definitions and data used in this report. It is important, therefore, to recognise that the strict economic criteria used here cannot consider how investments might be made on the basis of local preferences, which are part of the government’s Partnership Funding policy.

Contents

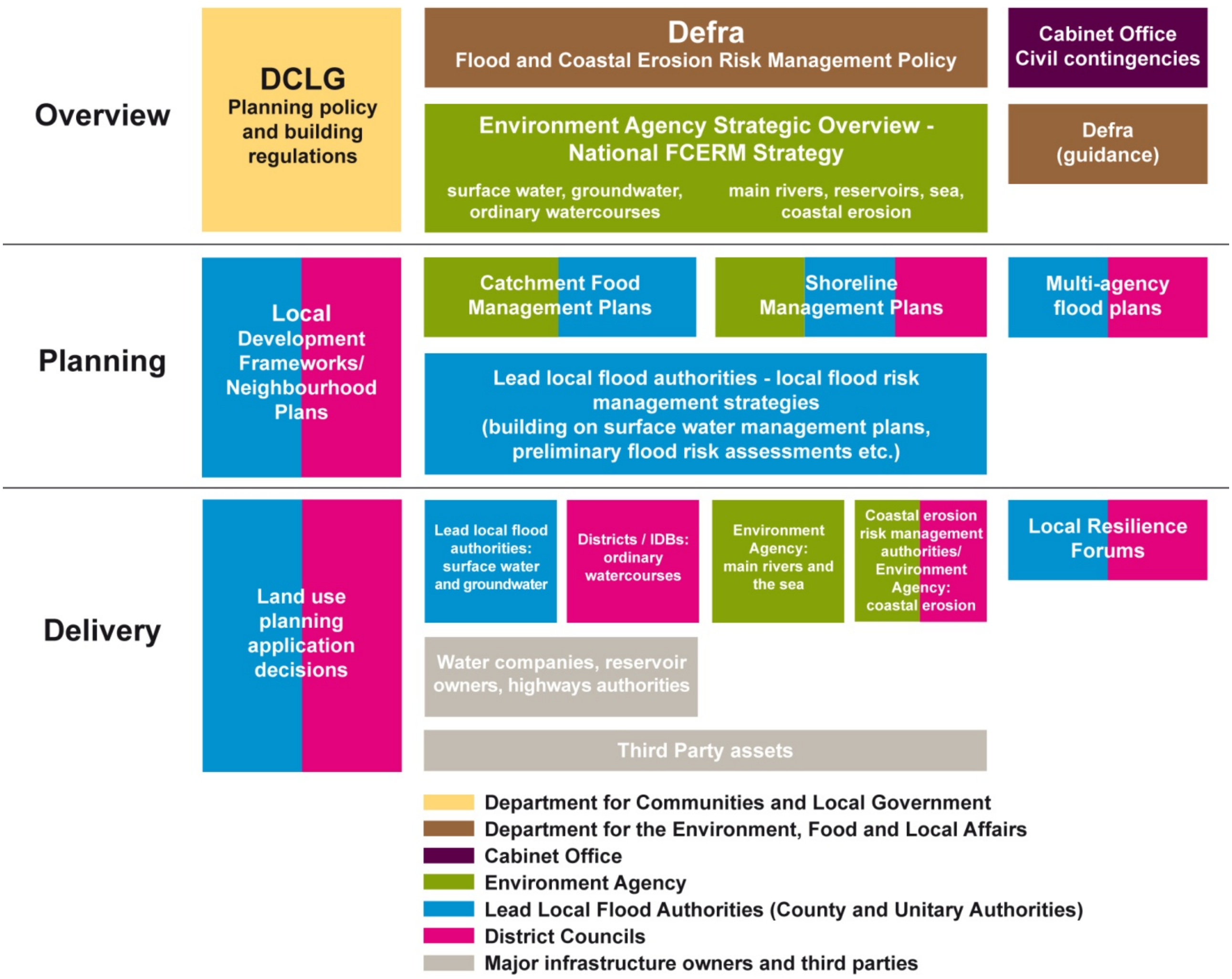
1. Context

This chapter describes the responsibilities for flood and coastal erosion risk management (FCERM) in England, and the Environment Agency's role in exploring long-term investment scenarios.

1.1. The Flood and Water Management Act 2010 and the national flood and coastal erosion risk management strategy for England (2011)

Government developed the Flood and Water Management Act (2010)[1] in response to the recommendations in the Pitt Review of the 2007 floods[2]. It implemented a number of the main recommendations in the review. In particular, it set out the roles and responsibilities of the flood and coastal risk management authorities and called for a national strategy to manage flood and coastal erosion risk in England[3] to be developed. Figure 1 below shows the main roles and responsibilities for flood and coastal erosion risk management in England:

Figure 1 Overview of the main roles and responsibilities for flood and coastal erosion risk management in England



The overall aim of the national strategy is to make sure that the risk of flooding and coastal erosion is properly managed by using the full range of options in a co-ordinated way. The strategy also sets out 5 measures by which these objectives will be achieved. These are:

- understanding the risks of flooding and coastal erosion
- avoiding inappropriate development in areas of flood and coastal erosion risk, and being careful to manage land elsewhere to avoid increasing risks
- building, maintaining and improving flood and coastal erosion risk management infrastructure and systems
- increasing public awareness of the risk that remains, and working with people at risk to improve the detection, forecasting and issue of warnings of flooding, planning for and co-ordinating a rapid response to flood emergencies and promoting faster recovery from flooding
- improving the detection, forecasting and issue of warnings of flooding, planning for and co-ordinating a rapid response to flood emergencies and promoting faster recovery from flooding.

This study supports the implementation of the national strategy by providing forecasts of the possible future costs of meeting these objectives to all risk management authorities.

1.2. Previous reports

This report builds on previous projections of future risk and investment needs for FCERM into the long term. Previous reports are described below.

1. Foresight – Future Flooding report 2004[4]

This project aimed to 'provide a challenging vision for flood and coastal defence in the UK between 2030 and 2100 and so inform long-term policy'. The study covered all of the UK, examining flooding from rivers and the sea, internal flooding in towns and cities and coastal erosion. It set out estimates of the numbers and values of properties at risk and the annual expected flood damage. It also estimated the economic, social and environmental consequences of flood and coastal erosion risks under 4 different climate change and development scenarios, and the cost of new engineering by the 2080s to reduce increased risk.

2. The long-term investment strategy (LTIS) 2009[5] and Flooding in England 2009[6]

In 2009, the Environment Agency published ‘Investing for the future – a long-term investment strategy' and 'Flooding in England' setting out, for the first time, a national picture of long-term flood and coastal erosion risk, and the costs of managing the risk. The analysis behind the reports was based on the 2008 national flood risk assessment. It used a new model to forecast risks and costs over the next 25 years. The analysis looked at a range of investment levels, with higher levels of investment generally achieving higher overall benefits. It also identified a ‘most favourable’ option among a small number of scenarios.

The LTIS 2009 examined 5 investment scenarios, testing the effects of different levels of investment on flood and coastal risk. In each scenario the costs and benefits were set out, including the damage avoided, for the period between 2011 and 2110, and the number of properties at risk in 2035. This has allowed an analysis of the long-term results of these investments. The modelling included the costs and benefits of assets to manage coastal, tidal and river flooding, together with the costs and benefits of managing coastal erosion. It did not include other risks such as surface water or groundwater flooding. It took account of the changing risk of flooding and future rates of erosion at the coast. The number of properties at risk was for flood only, as data on properties at risk from erosion was not directly comparable.

Data and analytical capability has improved since these earlier studies. This assessment:

- incorporates the latest data and science
- incorporates surface water flooding
- considers wider aspects such as incident management and individual property resistance and resilience to flooding
- explores a wider range of assumptions about the future, including additional climate projections
- explores a wider range of options and, for the first time, seeks to identify an economically optimal level of national investment and provide an overall national assessment of the impact this will have on the level of flood damages

2. Present day risk

There are 2.4 million properties at risk from flooding from rivers and the sea. 748,000 of these have at least a 1% annual likelihood of experiencing flooding. A further 3 million properties are at some risk from surface water flooding in England, around 772,000 of which are at or above the 1% annual likelihood level. About 600,000 properties are at risk from both sources of flooding.

The analysis in this report relies on current assessments of the overall level of risk faced[7], and an understanding of the effect that investment could have in changing that level of risk. This chapter describes the basic elements of risk and investment in the LTIS model, and outlines the sources of that information and levels of uncertainty involved. The technical appendices give further information on the inputs and methods used in this analysis.

The LTIS analysis is based on two main sources of risk:

1. Risk from rivers and the sea - this is based on the Environment Agency's national flood risk assessment, which was published in December 2013. This shows the chance of flooding from rivers and the sea (both along the open coast and tidal estuaries). The data is presented in flood risk likelihood categories, which indicate the chance of flooding in any given year. We also include coastal erosion and management in the assessment of future risks and costs. Coastal erosion risk is expressed differently from flood risk. Erosion is a process that causes land and properties to be lost over time, while flood is a recurring risk that can happen time and again. 700 properties could be lost to coastal erosion over the next 20 years, and about 2,000 could be lost in the next 50 years.

2. Risk from surface water - this is based on the Environment Agency's residential and non-residential property counts from the flood map for surface water, which was published in December 2013. These risks can be expressed in terms of the numbers of properties in areas at risk of flooding that experience a particular likelihood of flooding (Figure 2 and Table 1).

The 4 flood likelihood categories are:

- high: greater than or equal to 1 in 30 (3.3%) chance in any given year
- medium: less than 1 in 30 (3.3%) but greater than or equal to 1 in 100 (1%) chance in any given year
- low: less than 1 in 100 (1%) but greater than or equal to 1 in 1,000 (0.1%) chance in any given year
- very low: properties within flood risk areas but at less than 1 in 1,000 (0.1%) chance in any given year

Figure 2 Numbers of properties at risk

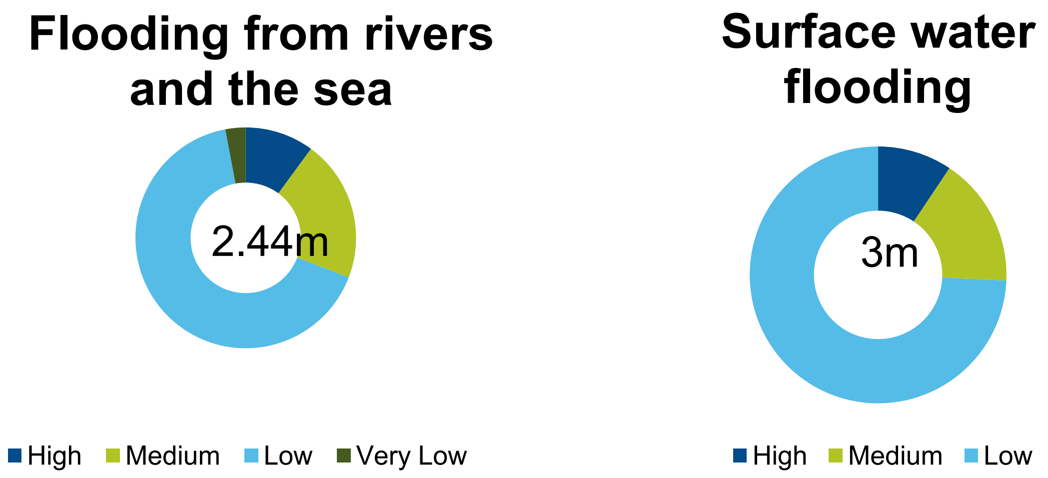


Table 1 Properties at risk from flooding

	Rivers and the sea (thousands) From National Flood Risk Assessment (NaFRA)		Surface water (thousands) From flood map for surface water	
	Residential	Non-residential	Residential	Non-residential
High	153,000	91,000	209,000	73,000
Medium	350,000	153,000	388,000	102,000
Low	1,274,000	329,000	1,809,000	423,000
Very low	72,000	21,000	Not assessed	Not assessed
Total	1,849,000	594,000	2,406,000	598,000

Three million properties are in areas at risk from surface water flooding. Of these, around 600,000 (20%) are also at risk of flooding from rivers and the sea. We estimate that about 1.7 million properties are at risk of surface water entering the property. This assumes an average property threshold height of 200 millimetres. This lower number forms the basis of the economic assessment in this report.

These numbers take account of the location and physical condition of flood risk management assets. We estimate the average annual economic consequences of flooding, based on the likelihood of these properties flooding, to be about £960 million from river and coastal flooding and coastal erosion, and £290 million from surface water flooding.

Estimating damages on a national scale is inherently difficult due to the complexities and uncertainties involved. Alternative methods, such as using insurance claims data, may give different and lower assessments, but there is little known about the scale of uninsured damages. All methods have uncertainty, but the national flood risk assessment is the only nationally consistent data on flood likelihood throughout the flood plain, which has been validated at a local scale and subject to external review most recently by the National Audit Office[8]. The long-term investment scenarios rely on a flood model for every area in the country, which can then be used to test options, scenarios and sensitivities. In reality, we would expect the consequences of flooding to be lower because measures are in place to reduce the effects of flooding where it cannot be prevented. This includes providing timely and accurate warnings, allowing householders and business owners to take action to protect their property, and responding to incidents to reduce the impacts of flooding. Resistance and resilience measures in properties also reduce the economic consequences of flooding. A third element of the risk assessment is, therefore, an assessment of the current effectiveness of these measures in reducing the expected level of economic flood damage. We estimate that nationally these measures currently reduce economic risk by about 10%.

At present there is not enough evidence to include risk from groundwater flooding in this analysis.

These assessments of present day risk are essential to this study, as future investment need would be expected to be sensitive to the current level of risk. While we have used these values as central estimates influencing the analysis, we acknowledge that there are ranges of uncertainty that we need to take into account. We have, therefore, carried out sensitivity testing of the results to determine whether they stand up to uncertainty in present day risk, particularly with reference to the recent flooding record. This is summarised in Appendix A.

2.1. Changes in risk

The main aim of this study is to investigate how risk might evolve in the future at varying levels of investment, taking into account other factors including climate change, asset deterioration and development in the flood plain.

In Chapter 6, we describe future risk in economic terms. In Chapter 10, we describe the results in terms of the likelihood of flooding people might experience in future. To fully understand the relationship between what we might spend in the long term, and the outcome in terms of risk, we need to bear in mind two related facts.

1. The risk faced today is the result of investment in the past to develop a resilient flood and coastal defence infrastructure that already prevents most of the damage that would happen if it did not exist. It is hard to quantify the level of risk that would exist today without any defences. But, as an example, in the winter of 2013 to 2014 when 7,700 homes and 3,200 commercial properties were affected by flooding, Environment Agency estimates suggest that 1.4 million homes and businesses were protected by defences.

2. In any of the scenarios examined in this study, most of the future investment is required to prevent increases in risk by maintaining and replacing structures, offsetting the factors that serve to increase risk. For example, if no investment were made, we estimate that over 50 years, the number of properties experiencing a 1% annual likelihood of flooding from rivers and the sea would increase from 748,000 to 1.29 million, and that overall economic damages would increase by approximately 250%.

3. Investment in flood and coastal erosion risk management (FCERM)

In 2014 to 2015, Defra, the Environment Agency, local authorities, internal drainage boards and local beneficiaries expect to spend around £930 million managing flood risk, including repairing defences damaged in the winter storms of 2013 to 2014. Annual investment has generally been increasing since the 1990s, providing more resilient flood defence infrastructure along with significant improvements in mapping, forecasting and warning, and responding to flooding.

This chapter sets out what the overall national level of investment in flood and coastal erosion risk management is spent on, and by whom. This establishes a cost baseline for our future investment modelling, which we can use to explain the implications of changes in funding levels. Table 2 shows how much investment is estimated to be made in 2014/15.

Government funding for flood and coastal erosion risk management in 2014 to 2015 totals £835 million, including the additional investment announced in February and March 2014 following the 2013 to 2014 winter storms[9]. Additional funding for 2014 to 2015 included £145 million to repair damaged defences, and £35 million for maintenance. Note that the assessment of optimum future investment in this study excludes the cost of repairing defences damaged in 2013 to 2014.

This is supplemented by significant amounts raised locally, particularly under the government's Partnership Funding policy, where the costs of managing flood risk are shared between government and local beneficiaries. Table 2 summarises both government and external funding. Note, additional investment such as money spent by households and businesses to reduce their own risk, and investment by infrastructure owners/operators and developers is not included here. While these costs are important, they generally provide benefits that are not captured in our main analysis model. We do, however, consider them later when we discuss managing residual risk.

Table 2 Breakdown of baseline investment

Investment	Description	2014 to 2015 value (£ million)
Defra	Defra retains a small proportion of the money it receives from HM Treasury for flood and coastal erosion risk management for schemes such as the Community Pathfinder projects.	9.4
Lead Local Flood Authority (LLFA)	Provided to LLFAs by Defra to support their new roles under the 2010 Flood and Water Management Act.	35.7
Local authority direct*	Spent by local authorities to manage flood and coastal defence assets they are responsible for. Excludes levies to manage land drainage. From 2014 to 2015 statistical release.[10]	40.0
Environment Agency revenue	Grant in Aid from Defra to support Environment Agency roles, including maintaining defences and other flood related roles.	226.4
Additional environment funding	Additional funding provided following last winter's floods to maintain defences.	35.0
Environment Agency capital	Grant in Aid from Defra for the Environment Agency, local authorities and internal drainage boards to provide new and improved flood defences.	343.8
Additional government funding	Additional funding provided following last winter's floods to repair and restore damaged defences, and to support implementation of the Somerset Action Plan.	145.0
Subtotal	**Government funding**	**835.3**
Local levy*	Funds raised locally to supplement Defra funding by responding to local priorities, including contributions to new flood defences.	31.0
Partnership funding*	Contributions from third parties towards new and improved flood defences (not including levy funding above).	61.0
Total		**927.3**

* Forecast

In examining the relationship between investment and risk, we have distinguished between variable costs, which directly improve results as investment is increased, and fixed costs that are necessary to support this, but do not produce better results with increased investment.

The current levels of protection in flood and coastal erosion risk management (FCERM) and the current level of residual flood risk are the result of many decades of investment. Likewise, the future relationship between investment and outcomes depends not only on future investment, but also on investments made in the past. The general trend over the last two decades has seen increased investment levels, providing a more resilient infrastructure to minimise flood impacts. The capital expenditure settlement from the government for 2015 to 2021 provides investment at historically high levels for building new and improved risk management assets.

The Environment Agency has set out an investment programme for 2015 to 2021. Future risk projections in this report assume that this programme will be implemented.

4. Methodology

The LTIS methodology is designed to assess the economically optimal level of future investment in flood and coastal erosion risk management (FCERM). In this chapter, we summarise the main concepts we used in making this assessment, and the main variables within the analysis that we have used to define investment scenarios. More detailed information about the assumptions used within the LTIS model can be found in the appendices.

This analysis builds on the work carried out for the 2009 assessment, but includes significant improvements and updates in many areas of the data and method.

4.1 Optimal investment in flood and coastal erosion risk management activities

The HM Treasury Green Book provides guidance as to how government investment programmes can maximise social benefit. In seeking to establish the annual average optimum investment level and results, the long-term study has sought to maximise net present value (NPV), where NPV is equal to discounted benefits less discounted costs. The optimal investment level in FCERM is the amount where NPV is at its maximum and cannot be improved further by increasing the budget available. If a funding constraint exists, the optimal level of investment would be that which funds only those projects above a higher threshold benefit to cost ratio. Hence, the unconstrained economic optimum modelled here represents a maximum economically rational total level of investment. In this context, investment covers the full range of capital and revenue activities that contribute to flood risk management. The approach to establishing the economic annual average optimum level of investment is outlined in Appendix B.

For any given national investment level, investments are added in 'merit order'. The investments that bring the most benefit in relation to costs are added in first. There will then be gradually diminishing returns as the next most beneficial investments are added in order until the annual average optimum level is reached. In this study, this assessment is carried out at the level of FCERM "systems", where a system is defined as a collection of assets that protects a discrete area of a catchment, or the coast.

At the optimal total investment level, the options that contribute the most to net present value could go ahead in every area in the long term. Activities could be funded by central government, local government, households or businesses that would benefit.

Once the level of annual average optimum investment is defined, the methodology allows us to examine some more detailed underlying issues, including:

- The impacts of investing at a level higher or lower than the optimal level, in terms of a change in the net present value of investment, and the change in expected level of flood damage in the future.
- The most efficient allocation of resources between activities. The overall finding is that results are maximised when marginal benefit per pound of extra investment is the same across all risk management activities. At this point, it is impossible to increase results by switching funds from one activity to another. There are some limitations in the evidence of marginal economic benefits across all activities. We have focused, in this report, on the overall level of investment. We recognise that further work would be needed, in particular to assess the balance between capital and revenue spending in managing flood defences.
- The timing of investment. Our study has, for the first time, assessed the likely progress in managing risk as a result of the planned investment programme over the next 6 years. We also assess how the longer term investment 'profile' could change in future. The method is fit for the purpose of showing the trend, but the timing of asset replacements is not precise.

4.2 Scenarios

To assess annual average optimum investment we have to make assumptions about the main factors that could change. We have, therefore, constructed scenarios in LTIS to test the uncertainty in the analysis against two main factors. These are climate change and the level of development in the flood plain. Changing either of these requires us to reconsider the most appropriate investments to make in each activity or location. Appendix C summarises the main inputs and assumptions to the modelling. The 'baseline' scenario uses estimates for climate change taken from UK Climate Projections 2009 (UKCP09) medium projection. This replicates the approach taken in appraising individual investments (see Appendix E for further details). This scenario makes no allowance for additional development in the flood plain. Or, if development does take place, we assume that risks are managed outside of government flood and coastal investment budgets. Note, this scenario may underestimate risks slightly as we do not account for the low probability of flooding to new properties built within the flood plain under current planning policy with flood risk mitigation measures. We have looked at the following variations to the baseline scenario:

- Using the 'upper-end' or high climate projections from UKCP09 and Environment Agency guidance (see Appendix E for further details). This gives us a view of the investment needed if peak river flows and sea level rise proceed faster than estimates suggest.
- We have also run the analysis with no allowance for future climate change, to quantify the expected effect of climate change on future risk.
- Without development control. Our baseline scenario assumes there will be effective development control in the future. We have also looked at a scenario where development in the flood plain follows projected rates of population growth suggested by the Office for National Statistics. This is an unrealistic assumption but it is useful as a sensitivity test. This is helpful in the debate about where the costs should fall if pressure for future housing needs to be met by building in flood plains. We do not account for the natural increase in the value of protected assets due to economic growth. The rate of development is derived directly from population projections[11] using the main projection from the climate change risk assessment report. The growth factor is assumed to be evenly distributed around the country.

The LTIS scenarios, showing the combinations of these factors, are set out in Table 3.

Table 3 LTIS scenarios

Scenario	Climate change factor used	Development assumption
Baseline (Scenario 0)	Medium	Controlled development
1	Medium	Without development control
2	High	Without development control
3	High	Controlled development
4	None	Controlled development

For each scenario we have estimated how the net present value of investment (NPV) increases as more investment is added into the system, until the optimum (maximum NPV) is reached.

5. Optimum investment

The following sections set out our evidence base for LTIS by describing the impact that investment at varying levels might have on long-term flood risk. We start by assessing the level of investment in flood and coastal erosion risk management (FCERM) that would maximise economic return using our 'baseline' set of assumptions, and the impact that this might have on risk in the future. We define the 'optimum', under a given scenario, as the long-term level of investment that would be sufficient over the study period to fund all activity to manage flood and coastal risk where benefits are greater than costs.

We then set out a more detailed analysis, including:

- The timing of investments (that is, whether costs rise, remain the same, or fall over time). This includes the likely impact of existing investment plans in place for 2015 to 2021, and the decisions that will be needed for later periods.
- The impacts of any future changes in unit costs (which allows us to sensitivity test the results for future efficiency, changes in technology, or cost pressures).
- The level of residual risk and options for reducing it further.
- The implications if resources are not allocated as cost effectively as possible.
- Considerations beyond the economic analysis that might influence decisions on the appropriate level and timing of investment.

Based on the current location and condition of flood defences, after all defences damaged in the winter of 2013 to 14 are repaired, we assess the cost to society (public and/or private investment) of providing optimum long-term flood and coastal protection is in the range of £790 million to £920 million a year over time. This represents a total investment of about £25 billion over the next 100 years when expressed in discounted present value terms. This is our 'baseline' finding based on assumptions that we have sensitivity-tested, including a 'medium' rate of climate change and a targeted improvement of 10% efficiency in capital spend to be achieved between 2015 and 2021. On this set of assumptions, investing more than this would not be cost effective because the additional cost would outweigh the additional benefits gained.

These costs would include spending on building and maintaining infrastructure owned both by the Environment Agency and other risk management authorities, and on other crucial functions such as flood forecasting and warning, data and mapping, and development control. This assessment only considers investment that helps to reduce flood risk. When setting the annual average optimum investment level we do not take into account other benefits from work to reduce flooding, such as environmental improvements or improved land drainage. We also assume that the capacity of watercourses is maintained at current levels. Under the current funding policy, the costs would be split between government and those benefiting from flood defences.

The main assumptions in this 'baseline' result are that the climate will change in line with the medium rate of change in UKCP09 projections, and that no allowance is made for development in the flood plain. This is the same set of assumptions that we used for all of the scenarios in the 2009 LTIS report. The model works by setting an investment ceiling and establishing the best results achieved within that ceiling. This means that to find the annual average optimum investment level, a range of investments must be tested to define how the maximum possible net present value changes with total investment. This is why Figure 3 below shows the results of 6 possible investment levels, increasing from IP1 to IP6.

Figure 3 and Table 4 set out the long-term investment and risk results at varying levels of investment around the top of the net present value curve. It sets out the points that have been tested to define the curve and describes the maximum net benefits that can be achieved for each level of investment.

Figure 3 Variation of net present value with investment level, indicating an annual average optimum investment level (baseline scenario)

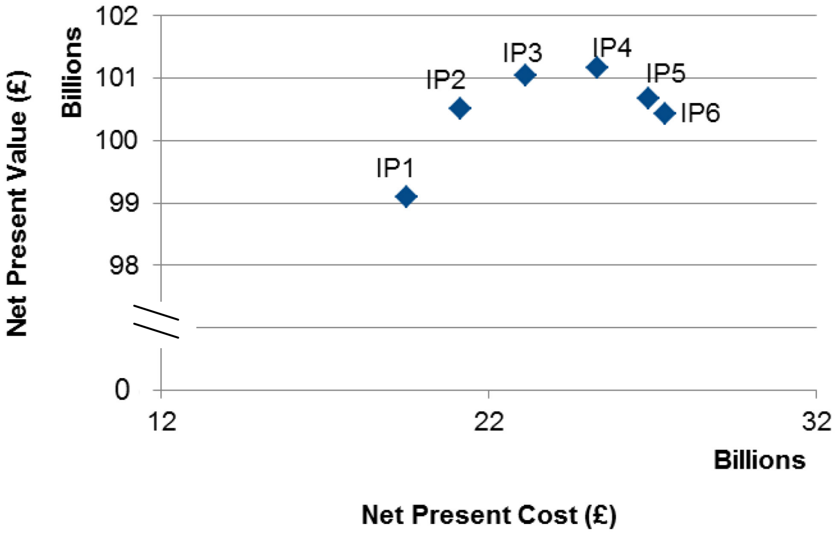
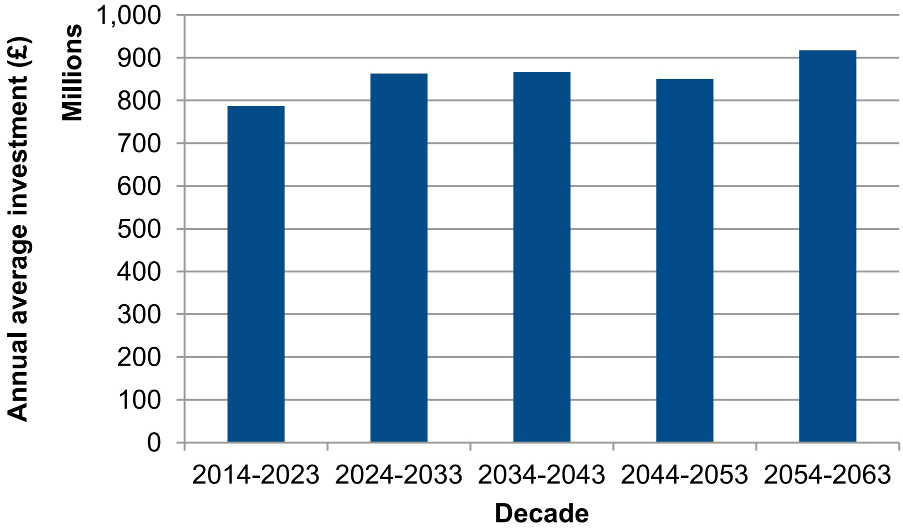


Table 4 Costs and benefits of a range of investment levels

	Costs		Benefit	Net present value
Investment level	Whole life discounted present value £ billion	Long-term annual average (Expected variability between decades) £ million per year	Whole life discounted present value £ billion	Whole life benefits - costs £ billion
IP1	20.1	660 (620 - 690)	119	99
IP2	21.8	720 (670-760)	121	99
IP3	23.6	780 (720-830)	124	100
IP4	25.4	860 (790-920)	127	102
IP5	27.1	910 (830-980)	128	101
IP6	27.6	930 (840-1,000)	128	100

The highest net benefit was found at a total whole life cost of £25 billion (scenario IP4 in the table above). There is uncertainty over the timing of investment needed, but our current assessment is that, in the first 10 years, the estimated investment needed will be in the range of £750 to £800 million a year in terms of present day costs. We expect this to rise from the 2020s to the 2040s to £850 to £900 million a year, reflecting the expected lifetime of our current asset base and the likely impact of climate change over time (Figure 4). This outlines an approximate trend. There will be peaks and troughs of demand over time. It also assumes typical asset deterioration rates. Future damage from major storms may need additional repair funds. Cost uncertainty will increase in the future. The overall long-term cost may be higher or lower depending on future changes, including climate change (see Chapter 7).

Figure 4 Modelled long-term investment need (IP4) - annual averages over the next 5 decades (costs in present day terms)



The quantification of net benefits here includes investments to manage river and coastal flooding, coastal erosion, as well as surface water flooding. The approach to assessing surface water costs and benefits is subject to greater limitations, and is described in Appendix D.

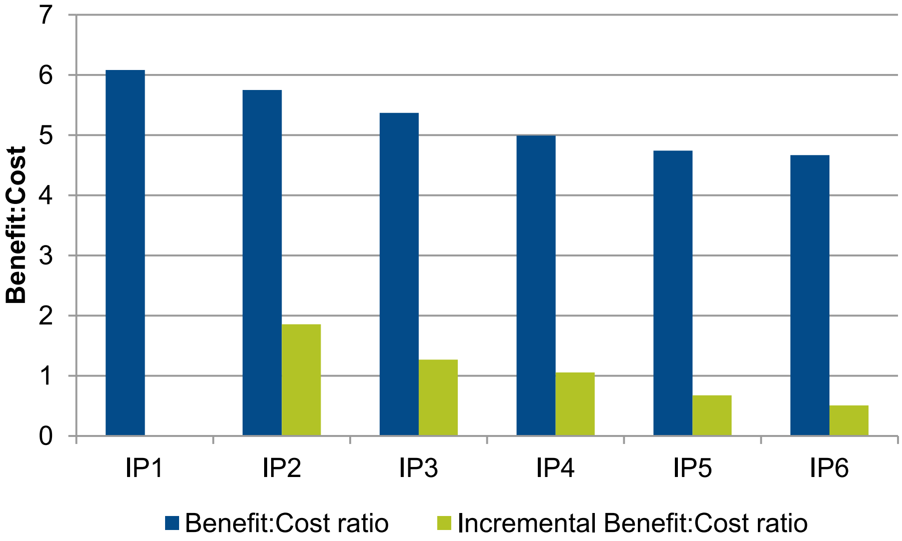
The economic benefit of the investment, discounted to present value cost, is £102 billion, giving a benefit to cost ratio of about 5 to 1. This is based on the economic damages avoided by the investment, and the total cost of FCERM. It assumes existing properties and levels of economic activity, so may underestimate future benefits in areas benefiting from economic growth or where other benefits beyond flood risk management are being achieved.

As with any economic business case, all costs and benefits are discounted to present values using the discount rates for long-term projects set out in HM Treasury's Green Book.

At the annual average optimum investment level, it should be possible over the long term to invest in the approach in every location that is expected to meet the highest economic return on investment.

Figure 5 below shows the benefit to cost ratio for each of the investment levels (IPs) set out in Table 4 above. The incremental benefit to cost measure describes how much the additional benefits for each investment level, over and above the last one, outweigh the additional cost. Once this drops below 1, the annual average optimum level of investment has been reached.

Figure 5 Benefit cost ratios of different investment levels

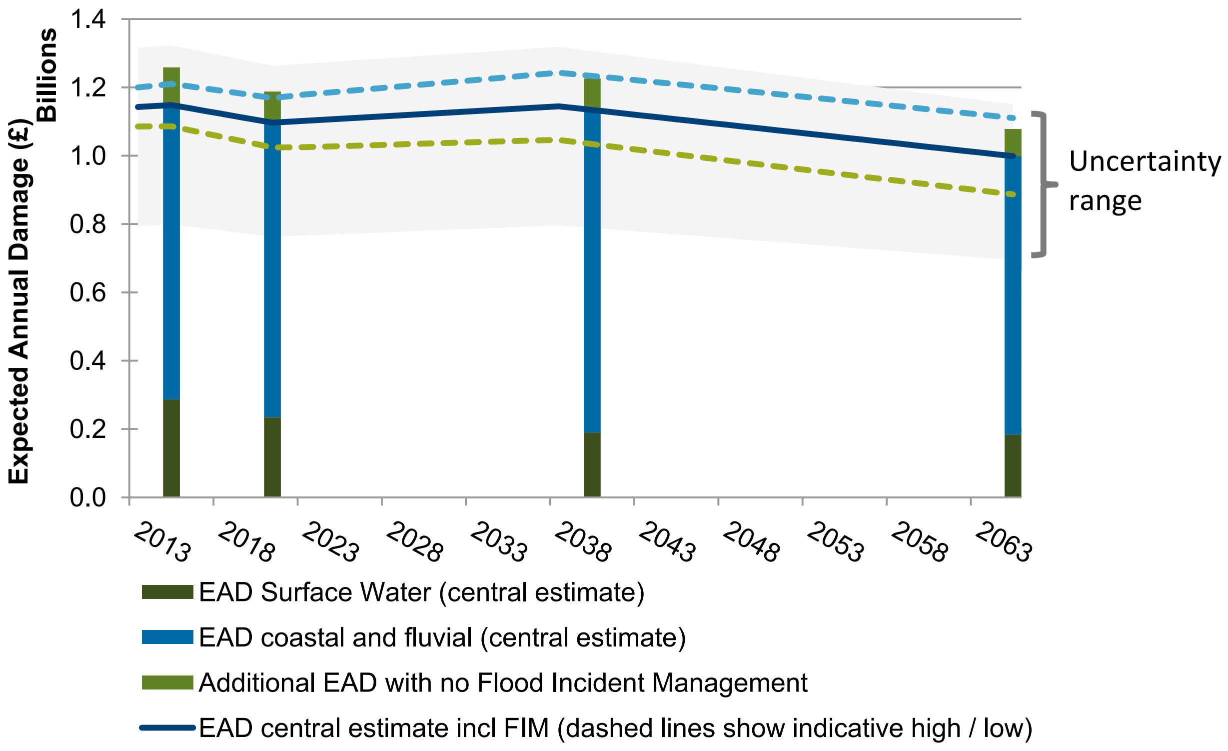


6. Future risk projections

The annual average optimum level of investment would be expected to reduce flood damages by 12% in the long term.

Figure 6 sets out the separate factors that contribute to overall flood risk from the investment model, and shows how they might change over time. At the annual average optimum investment level, risk is expected to reduce by 12% in terms of expected annual damage, over this period.

Figure 6 Projected change in national risk associated with assessed annual average optimum investment level



This study uses the expected annual damages as the measure of risk, because this allows a more subtle understanding of the benefits of investment. It captures all reductions in flood risk from investment, and the benefits of flood forecasting, warning and emergency response are also recognised by a reduction in the consequences of flooding. The overall conclusion is that a reduction of 12% in present day expected annual damage is possible in the long term. The components of this assessment are listed below, alongside the assumptions used to link investment to risk outcomes in each case.

- River and coastal risk (including coastal erosion). The model for estimating long-term risk from rivers and the sea selects the mix of investments, both in maintaining and improving the defence infrastructure in each system in England that achieves the highest overall net benefits. All of the relevant costs are included and related to specific changes in risk. The majority of these benefits come from managing flood risk rather than coastal erosion, and the economic consequences of coastal erosion are a relatively small proportion (approximately 2.5%) of the total over the study period. However, this could increase in the future as more properties will be at risk of coastal erosion over time.
- Surface water risk. Measures to manage surface water are harder to model, as less is known about the impact of investment on future risk. The most important limitation is that the cost of maintaining existing systems that provide an ongoing benefit are not included, because they are not mapped at a national level and investment in their maintenance is not included in the

cost baseline for this study. The analysis in this report effectively assumes that existing drainage systems are maintained to current capacity, and focuses instead on additional improvements that could be made from new measures. We have analysed the costs and benefits of managing surface water flood risk to cope with a range of extreme rainfall events. We found that at least £30 million a year could be invested cost effectively in measures such as sustainable urban drainage schemes. The costs and benefits of this investment are included in the long-term risk reduction (Figure 6). This more than offsets the anticipated effect of climate change and urban creep, reducing risk in some of the most vulnerable areas. It seems likely that future investments in sewer and local flood risk management could help to manage these risks over this time period, at least in places where sewers are near capacity and development may intensify. Not all potential investments can be included in the current report, however, as there is insufficient evidence to assess precisely what measures will be needed and what the costs and benefits would be. 'Annual average optimum' investment in managing surface water could be higher, but cannot currently be established precisely.

- Flood incident management. The impact of current levels of service in flood incident management, and the current number of resistance and resilience measures being taken out in properties, in reducing the consequences of flooding, are set out in Chapter 10. We have made a fairly conservative assumption that this level of service is maintained in the long term, rather than identify an 'annual average optimum' where risk is reduced further by investing more. Again, we have done this because of the difficulty in measuring changes in economic benefits resulting from increasing or decreasing investment in this area. We also assume that the future cost of these measures will remain steady, in real terms.

In the risk profile above, much of the reduction occurs after 2040. This is the consequence of a set of assumptions in the modelling determining when major investments will be required, based on the anticipated rate at which assets will deteriorate and, therefore, need replacing. Other factors could influence the timing of investment decisions, and we examine some of the implications of this in Chapter 8.

There is significant uncertainty in estimating how risk will change over time. The impact of climate change is quantified in Chapter 7. The condition and location of flood and coastal defences is well understood and represented in our model. We use the latest research on defence deterioration rates and their performance in extreme events.

Besides future uncertainty, it is also important that we recognise the uncertainty in current risk assessments described in the introduction, and their potential impact on our conclusions. We have used central estimates of present day risk to form the baseline. But, to better understand the potential impact of uncertainty on the reliability of our results, we have also sensitivity tested this in a 'low risk' version of the analysis. This considers the possibility that the central estimate of risk might overstate the likelihood of flooding in some locations. The method we used was to re-set the flood likelihood values in each system to the lower boundary of the relevant category (high, moderate, low or very low). This reduced the assessment of present day expected annual damages from river and coastal flooding by one-third. Under this revised set of assumptions, the model suggested broadly the same set of investments. In most locations, a reduction in expected damages, and thus potential future benefit of preventing them, was not big enough to trigger a different decision. Put simply, this means that the assessment is robust to a much more conservative assessment of present day risk. This is explained in more detail in Appendix A.

6.1 Changes since the 2009 analysis

The 2009 LTIS stated that annual investment in FCERM would need to double over 25 years to hold risk steady. Using the same assumptions on development and climate change, the new analysis suggests that risk could be further reduced (12%), and the cost increase more modest, than the 2009 analysis suggested.

There are several reasons for this:

- Cost reductions. As well as increasing efficiencies in capital projects since 2010 by 15% (which were assumed in the original LTIS), costs have also reduced significantly in providing other services not related to asset management. This new analysis also assumes that the unit costs of providing new and improved defences will reduce by another 10% between 2015 and 2021, which the Environment Agency is committed to achieving.
- Provided this 10% capital efficiency target is met, and that unit costs are held down after 2021, this not only lowers the cost of providing defences, but also increases the number of activities that can be considered cost effective.
- Targeting investment to maximise the net present value (NPV). We have refined our modelling to seek out the economic annual average optimum level of investment in each one of the 3,000 asset systems in England. We have also added the option for a higher level of protection (1 in 200) where this is economically justified. The previous LTIS report, published in 2009, used a different prioritisation technique, which was not capable of maximising economic net benefits. The current method uses strict economic criteria that will not target policies that maintain or improve risk unless the investment in doing so, compared with the next-cheapest option, outweighs the benefit. This approach can show how future risk can be reduced for a lower cost. We have explored the implications of this strict economic targeting, and the options for investing to achieve a more even distribution of risk.
- Longer term horizon. We have explored more of the options around timing of investments. As with the 2009 report, costs and benefits are assessed over 100 years. We have extended our proposed cost profiles from 25 to 50 years, and this produces a more gradual increase in costs than the 2009 report, while capturing more of the major investments needed in the long term.

7. Climate change and development

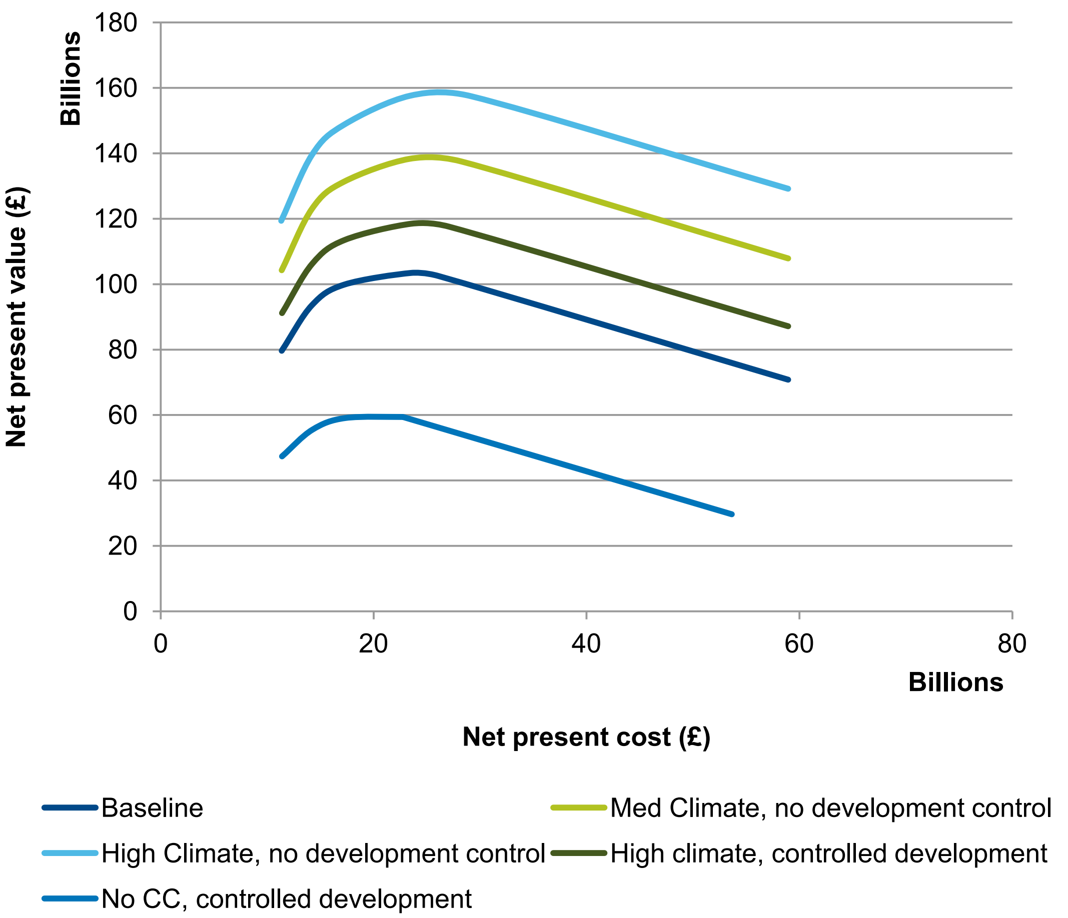
Assumptions about future climate change and development in flood risk areas affect both the optimum level of investment and long-term flood and coastal erosion risk. We have analysed the potential impacts of these.

The long-term annual average optimum level of investment in flood and coastal erosion risk management will vary according to the external factors that we have used to define the LTIS scenarios. Climate change and development in the flood plain would both be expected to increase risk and, therefore, potentially also increase the benefits of reducing risk. This could make more expensive options worthwhile in some places. We have explored medium and upper-end climate projections, as well as a 'no further change' scenario to make comparisons. We have also considered two development scenarios; a baseline scenario assuming development is controlled and risks reduced, so that development in future has no impact on risk or investment. As a comparison, we have also considered a scenario where development is not controlled, and numbers of properties in the flood plain increase in line with national population projections.

We define the annual average optimum as the level of investment that yields the highest net benefits under a given scenario. We can revise the investment curve set out in Figure 3 for each of the scenarios described in Chapter 4.

Figure 7 plots the net present values (NPVs) of given levels of investment in flood protection across the range of climate change and development scenarios. Note, here we use a wider range of net present costs to better illustrate the shape of the curves.

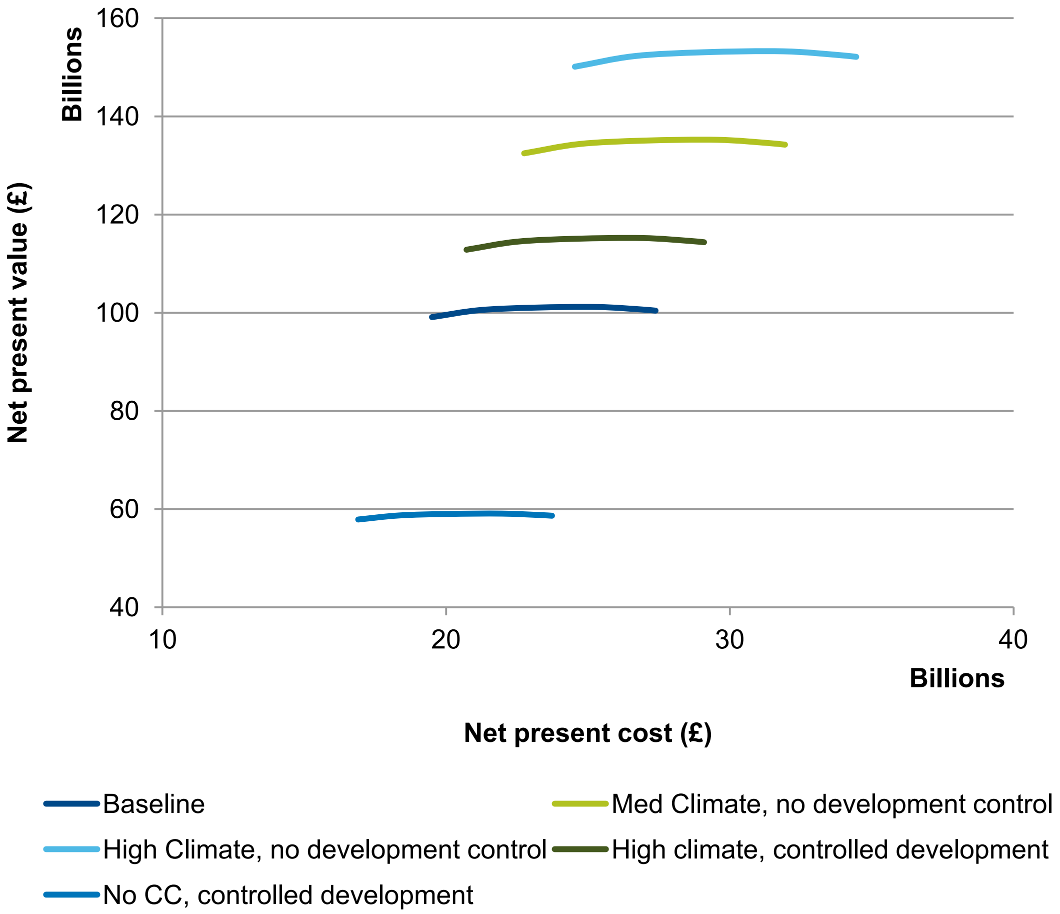
Figure 7 Net present value affected by a range of scenarios, over a wide range of investment levels



The right hand end point of each curve represents a theoretical maximum level of investment, with a high level of protection applied everywhere regardless of the costs.

We can show the differences in annual average optimum investment level between the scenarios more clearly by narrowing the range of values on the graph's axes, to focus on values around the optimum (around the top of the curve). By focusing on the range of investment near to the optimum, we have been able to identify the relevant costs and benefits more precisely (Figure 8).

Figure 8 Net present value affected by a range of scenarios, over a narrow range of investment levels



The assumptions of climate change and development alter both the annual average optimum level of investment as shown above, but also the level of risk resulting from a specified investment level. Table 5 shows the annual average optimum level of investment from the figures above, and translates them into an equivalent annual level of investment. It also shows how sensitive the level of risk is to the choice of scenario.

Table 5 Optimum level of investment and change in expected annual damages for different future climate change scenarios

Scenario	Optimum investment (Present value whole life over 100 years)	Long-term annual average investment (Expected variability between decades) £ million a year	Change in expected annual damages (50 year)
1 Baseline (med climate change (CC))	£25.4 billion	860 (790-920)	-12%
2 (High CC)	£27.1 billion	920 (850-980)	-4%
3 (no CC)	£22.1 billion	750 (690-800)	-24%

Our modelling suggests that removing climate change from the analysis will decrease long-term costs by about 13%, compared with an assumption of medium climate change. The level of investment planned to be made between 2015 and 2021 is cost effective regardless of the assumption made about climate change. This suggests that current plans adequately take account of uncertainties and represent 'no regrets' investments. This is compatible with a flexible investment approach that does not require long-term investment decisions to be taken today.

Therefore, maintaining the level of investment made in recent years would be enough to keep the current flood and coastal defences in their current state in the long term for a 'present day' climate, because this is similar to the long-term optimum once climate change has been removed from the analysis. But, maintaining the standard of protection for defences will cost more if we assume that the climate is changing. Chapter 8 (Figures 10 and 11) provides more detail on this issue, including the cost profile over time to achieve a specific outcome, with or without a climate change assumption. There is significant uncertainty projecting this far into the future - a level of uncertainty that not even these scenarios can capture. Given this, we believe future investment levels and risks should be reviewed in line with developing scientific information on climate change.

Using the high climate change projection rather than the medium projection adds £60 million (7%) to the average annual cost for the 'baseline' scenario, and limits the reduction in national risk to 4% compared with today. The gap between 'medium' and 'high' 1% more properties would fall into the moderate or high risk categories if investment was maintained at the annual average optimum level for the baseline scenario while the climate changed in line with the high projection. While this is a noticeably smaller gap than the difference between the baseline and the no climate change assumption, it should be remembered that we have not modelled a 'low' climate change factor, so in fact the relationship between optimum investment and all possible climate change scenarios is probably linear.

Our modelling also suggests that the benefits of maintaining control over development in the flood plain are significant. In our 'worst case' scenario, where we assume development increases in line with population projections, the additional cost in whole life terms could be around £4 billion. The number of properties at high and medium risk in this scenario would rise by about a quarter compared with the assumption that planning controls are fully effective in controlling flood risk from new development.

Population projections[11,13] indicate that 30% more people may be living in England in the 2060s. There is no obvious way of estimating how much of this development may take place in areas at risk of flooding. Where development does go ahead, it must be shown to be necessary, safe and resilient to flooding, and it must not increase risk to others.

The Environment Agency does not object to development in flood risk areas where that development complies with the National Planning Policy Framework. Examples of resilience measures that would allow development to go ahead in a flood risk area include:

- having adequate flood risk mitigation, such as flood risk management schemes
- floor levels being above the expected flood levels
- demonstrating that people will be safe in and around buildings

Figures for April 2013 to March 2014[7] show that over 99% of 58,161 new homes had planning outcomes in line with Environment Agency advice. So, for the purpose of the long-term investment scenarios it is reasonable to exclude increased population growth and increased development as a factor in the baseline scenario.

Despite this, it is important to recognise that there may still be an impact on investment from the need to defend the additional risk from new development even where it is built in line with planning guidance. Even where risk from new development is managed with adequate flood risk mitigation, it increases residual risk even if only slightly. Under current policy, this would not contribute to the economic case for community defences. If development was evenly spread, within and outside the flood plain, and in areas at varying levels of risk, there would be a proportionate increase in the value of assets being defended and more expensive approaches to managing risk might be considered in some areas.

8. Timing of investments

The long-term annual average investment need gives an approximate picture of the total amount of investment, but there is uncertainty over the timing of investment needed. Our current assessment is that in the first 10 years, the estimated demand for investment is in the range of £750 to £800 million a year in terms of present day costs.

This is expected to rise from the 2020s to the 2040s to £850 to £900 million a year, although there is scope to influence this by the choice of policy used. Chapter 9 includes some examples of approaches that might vary costs in the long term, and the implications for future risk. This gives an approximate trend. There will be peaks and troughs of demand over time because of the need to replace specific assets at specific times. It also assumes typical asset deterioration rates. Future damage from major storms may need additional repair funds.

In the previous section we set out the headline long-term levels of risk, but acknowledged that the timing of future investments can be complex. We can describe the impact of existing investment plans on risk in the relatively short term. This will help to understand how risk might change over the next few years, and in the longer term.

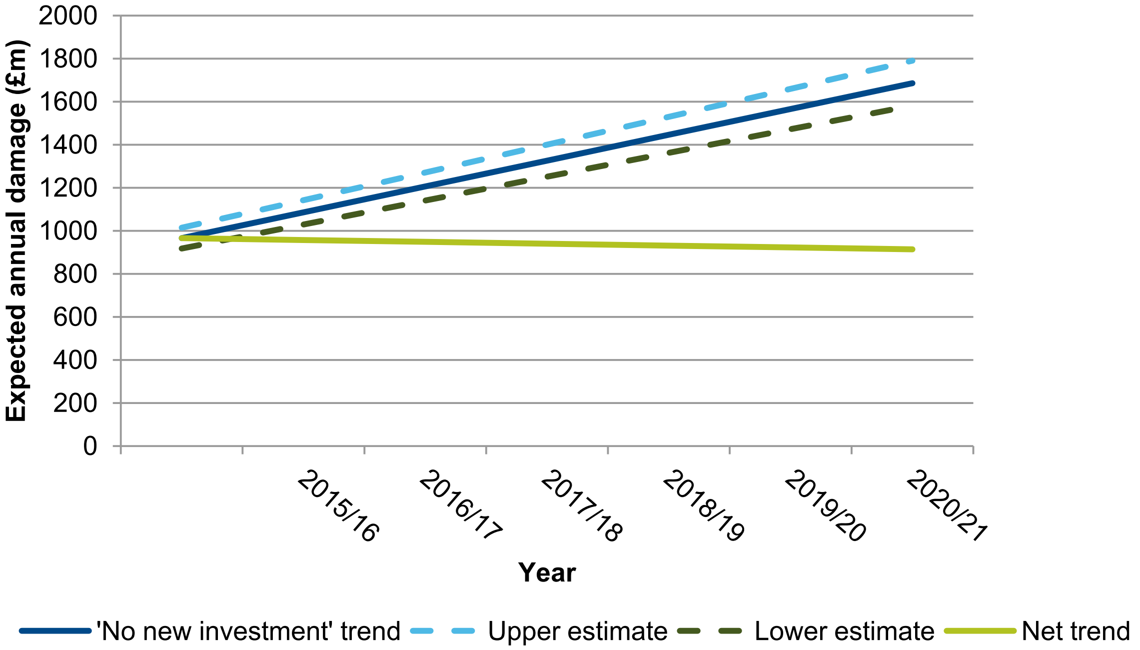
Our analysis incorporates the 6-year capital investment programme for flood and coastal erosion risk management in England, which has been developed alongside plans for contributions under the Partnership Funding approach, and efficiency gains. This investment programme comprises projects with quantified benefits that offset the increase in risk from asset deterioration that would result if the investments were not made. Investment in asset maintenance is assumed in business cases for capital projects. This limits the onset of asset deterioration, with the aim of achieving the lowest possible whole life cost to achieve a specified level of service. Decisions have not yet been taken on the level of central government flood defence maintenance budgets or the level of efficiency achievable beyond 2015 to 2016. Solely for the purposes of this analysis, we have assumed investment in asset maintenance continues to achieve the same outcomes as at present.

With a stable investment programme for 2015 to 2021, based on existing capital investment plans for this period, and assuming that the performance of our current assets and incident management service are maintained at current levels, we estimate that overall risk will reduce by around 5% by 2021, compared with present day risk. This is a provisional figure pending agreement and monitoring of the investment programme. This is the first time we have been able to estimate the overall impact of short-term investment plans on flood risk.

The estimates of the annual benefits of capital and revenue asset management are overlaid in the long-term 'no new investment' trend (see Appendix D, Table D1 for definition of 'no new investment') in Figure 9. This shows how risk could potentially change over the next 6 years, for flood risk from rivers and the sea only.

The reduction in expected annual damages (EAD) to properties may appear modest given the large investment involved, but most of the benefit (the reduction in EAD) is needed to counteract the steep increase in risk that would result if no new investment was made. Note, this is a preliminary figure pending agreement and monitoring of the investment programme.

Figure 9 Preliminary assessment of the trend in national expected annual damages for 2015 to 2021



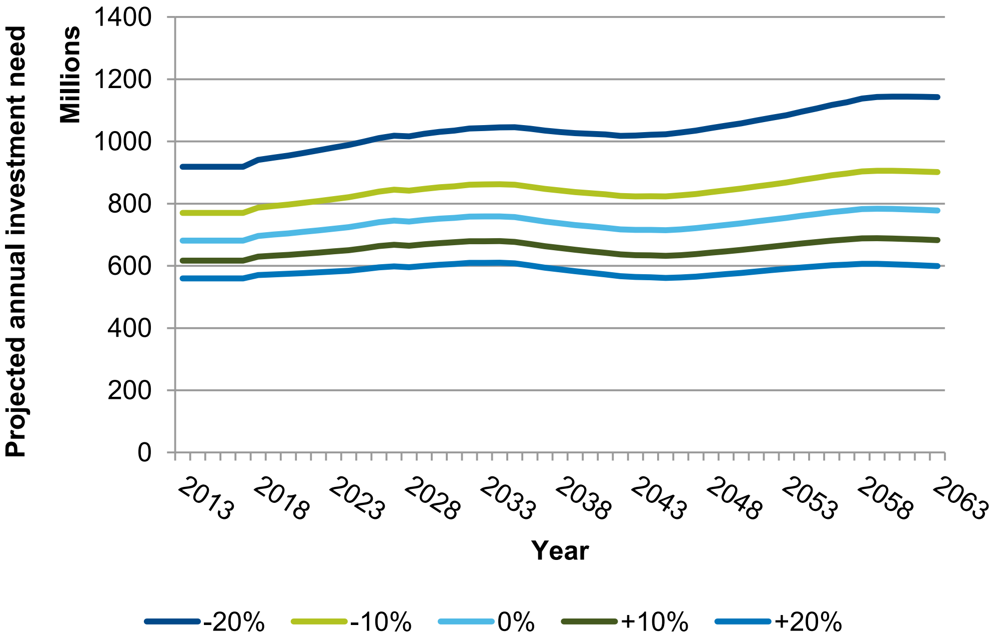
Based on this preliminary data, we expect investment through to 2021 to save around £2.7 billion (£2.2 billion to £3.2 billion based on the upper and lower boundaries in Figure 9) in flood and erosion damages during this 6-year period. This is compared with damages that would otherwise occur under a 'no new investment' assumption. This could reduce expected annual flood damages by 2021 by about 45% (35%-55%), relative to not investing over this period. Investments made during the next 6 years will also yield benefits over a much longer period, and the damages avoided over the next 50 years will be substantial.

The long-term risk profile we described in the previous section is based on replacing or upgrading assets when they are projected to deteriorate to a specified lower condition grade, based on research on asset deterioration rates. This produces a cost profile based on investing most heavily to replace and upgrade assets in the longer term rather than in the next 10 to 15 years. Consequently, this defers the possible reduction in risk to the later period.

This is not, however, a precise method for timing important investments. It is reasonable to assume that some investment could be brought forward or delayed. Our modelling assumptions may underestimate the maximum optimum investment, and, therefore, potential risk reduction in the next 10-15 years, by replacing assets when they deteriorate to a specified condition, rather than investing to maximise risk reduction. More detailed data and modelling techniques may allow us in future to investigate the relative costs and benefits of alternative asset replacement criteria. This would include optimising replacement intervals based on whole life cycle analysis.

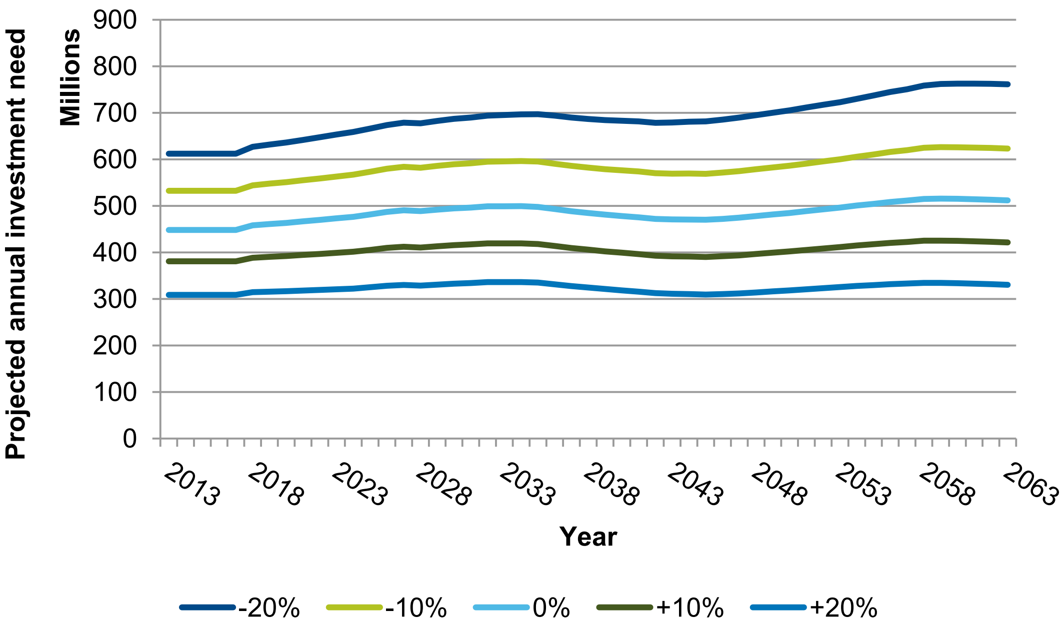
The condition of assets and our knowledge of deterioration rates suggest that annual investment need will probably vary over time, but after 2021 we cannot be precise about the timing of investments. The asset replacement rules in our model tend to produce peaks and troughs of expenditure in individual years, but these cannot be taken as annual expenditure forecasts. The charts below identify the overall trend by 'smoothing' these variances to give a more realistic picture of potential changes in time. This averages out some year-to-year differences, which are due to the model's assumptions around timing of asset replacements. One way of explaining the potential variation in investment need through time is to consider the investment necessary to achieve specific results over the period of the study. In Figure 10, the '0%' cost profile would maintain risk at current levels over the entire period. The other lines would achieve a steady improvement or deterioration towards the stated result, so that it was reached at the end of the period. A 10% reduction is close to our assessment of the annual average optimum investment in the 'baseline' scenario, and the overall cost is similar. A 20% reduction is achievable, but above our estimate of annual average optimum investment. That is why there is a large increase in cost compared to the other cost profiles.

Figure 10 Long-term investment to manage expected annual damages (EAD) relative to present day medium climate assumption. Percentages indicate change in EAD from present day to Year 50



The scale of the uncertainty around climate change can be illustrated by comparing the cost profile to maintain current risk to the equivalent cost profile with climate change removed from the analysis (Figure 11)

Figure 11 Long-term investment to manage expected annual damages relative to present day - comparative assessment using unrealistic assumption of no further climate change



Comparing this with the baseline case (Figure 10), modelling suggests that the impact of climate change is to increase costs overall. It also shows that with climate change it will be more difficult to reduce expected annual damaged (EAD) significantly over time. With climate change removed from the analysis, the relationship between investment and the levels of risk reduction shown above is approximately linear, whereas with climate change, it is noticeably more expensive to reduce risk by 20% because at this point, in this scenario, the optimum level of investment has been exceeded.

Climate change is expected to increase the loadings on river and coastal risk management structures, increasing the likelihood and severity of flooding and coastal erosion. The differences in costs between Figures 10 and 11 in this section provide an estimate of the potential costs of managing that risk. Note that this shows the difference in costs to achieve a specified level of risk, with or without a climate change assumption. The difference is higher than the difference between optimal levels of investment discussed in Chapter 7, because optimum investment without climate change would achieve much more risk reduction than optimum investment with climate change.

If future climate change exceeds the medium projection assumed in our baseline, either investment might need to increase to manage risk (again, this is quantified in Chapter 7) or there will need to be careful choices made about how to manage the uncertainty. A flexible approach to investment in the long term will allow investment levels to be assessed appropriately as further evidence emerges on the likely impacts of climate change on flood and coastal risk.

9. Sensitivity to future unit costs

We assume that the Environment Agency will reduce the cost of capital investments overall by 10% between 2015 and 2021, and hold costs down after that. The long-term benefit of this is significant.

If there were no improvements in efficiency, the level of annual average optimum investment would increase by 3%. But more importantly, this would mean that the best potential long-term result would be to only hold risk at current levels rather than to reduce it significantly.

The 'baseline' assessment suggests that investing an average of £860 million a year could reduce risk, cost effectively, by 12% in the long term. This assumes that the unit costs of new and improved flood defences will reduce by 10% between 2015 and 2021, and remain steady in real terms after that. The latter point is very important because this lowers unit costs compared with the present day for the entire period on which the analysis is based. This increases the number of actions that can be considered cost effective in the long term, resulting in significantly better reductions in risk over time. Our analysis does not, at this stage, assume any efficiency gains by 2021 in non-capital costs.

Using the current cost base for both capital investments and other activities, that is, assuming no further efficiency gains, we estimate that an annual average optimum investment could be £880 million a year. This would hold risk steady in the long term. Improving efficiency, therefore, both reduces the optimum investment, while improving the outcomes that can be achieved over time.

The cost of providing flood defences could change in the long term. Further progress on efficiency, new approaches and technologies, or more measures used to reduce flood risk such as land management practices or sustainable drainage might reduce costs. Inflation, supply constraints or more damaging land management might increase costs.

A further progressive 10% decrease in unit costs after 2021 could reduce the long-term risk by 15% compared with the present day. On the other hand, a 10% increase in unit costs after 2021 would raise the optimum level of investment slightly, while limiting the potential long-term risk reduction. This demonstrates the importance of continuing to reduce the costs of flood risk management, as well as of wider policies that will impact on flood risk.

The main analysis assumes no further change in unit costs beyond 2021. We are, however, able to show how the results would change if unit costs changed after that. Again, this is not simply a case of reducing the estimated cost of achieving a specific result. Lowering the unit costs could potentially make viable some investments, whose costs would otherwise have exceeded their benefits. Therefore, unit costs change the relationship between investment and results. Table 6 illustrates this relationship. Case 0, included for comparison, is optimum investment in the baseline scenario.

Table 6 Sensitivity of long-term investment and levels of risk to unit cost scenarios

Case	Unit cost assumptions		Long-term annual average optimum investment	Levels of risk (change in EAD)
	2015 to 2021	2021 to 2065	(per year)	% change over 50 years compared with present day
0	10% efficiency in capital programme	10% capital efficiency achieved and locked in	£862 million	-12.1%
1	10% efficiency in capital programme	Further 20% decrease in unit costs between 2021 and 2065	£810 million	-14.6% (-18% if investment at £860 million per year)
2	10% efficiency in capital programme	Further 10% decrease in unit costs achieved between 2021 and 2065	£836 million	-13.4% (-15%)
3	10% efficiency in capital programme	10% increase in unit costs between 2021 and 2065	£883 million	-11.3% (-9%)
4	10% efficiency in capital programme	20% increase in unit costs between 2021 and 2065	£916 million	-10.7% (-5%)

The impacts on risk look relatively modest. This is partly because much of the investment is actually absorbed in offsetting the impacts of asset deterioration and climate change, and major changes in risk are difficult to achieve without large increases in investment. But the incremental benefits or disbenefits of changes in unit costs are significant. For case 1, for example, the long-term improvement in risk is about 20% compared with the baseline case. If we 'normalise' the changes by assuming we invest at the level of the baseline (that is, £860 million) in each case, the difference on risk is greater (see figures in brackets in 'Levels of risk' column). For example, case 1 gives a reduction in risk of 18%, which is a 50% greater risk reduction compared with the baseline case.

10. Managing residual risk

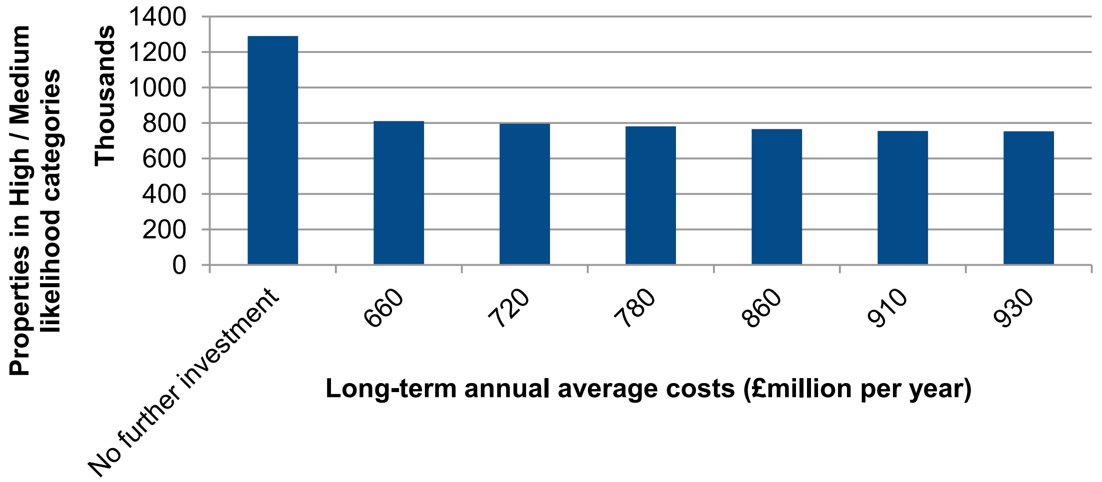
The current risk of flooding would be far higher without the many decades of investment that have developed an extensive flood and coastal risk management infrastructure. Our main analysis shows that more investment could further reduce the risk some people face, but there will always be significant risk to manage. We call this 'residual risk'.

Our approach throughout this study has been to focus on the economic damages caused by flooding and coastal erosion. We believe this is the right approach for a study on investment scenarios, as it is best suited to capturing small changes in risk over time, and the benefits of action to reduce the impacts of flooding such as through flood forecasting, warning and emergency response. However, there are other ways of quantifying risk that focus more directly on the numbers of people who would continue to experience flood risk.

In this section, we take the risk outcomes described in Chapter 6 and explain what this might mean in terms of the level of risk experienced in the future from the point of view of people and property. Even if average annual investment reaches its optimum level, there will be significant residual flood risk in 50 years' time. It is important to examine the reasons for this in more detail and to explore other ways of reducing risk that are not captured by the economic analysis in Chapter 6. This may include measures to protect properties from flooding or limit the damage caused by flooding (resilience and resistance measures), changing the way land is used upstream to reduce flood flows, and schemes that will change the location of defences (managed realignment).

As explained in Chapter 2, 748,000 properties currently face an annual likelihood of experiencing flooding from rivers and the sea of 1% or greater. Without investment, we estimate this would increase to approximately 1.29 million properties over the next 50 years. Figure 12 below shows how we expect investment at the levels explored in Chapter 5 would reduce this figure. (See Table 4 for more detail of these investment levels).

Figure 12 Properties at high/medium risk in the 2060s, with varying levels of long-term investment

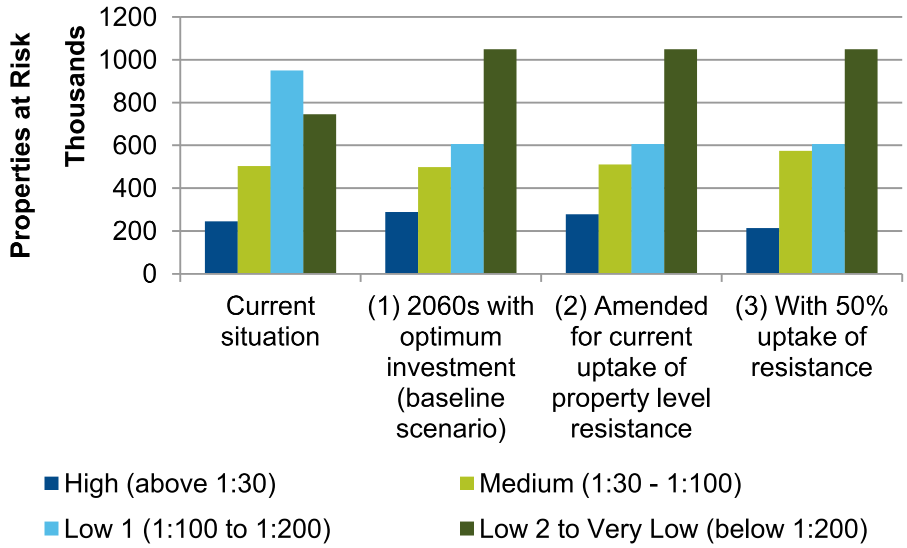


This representation of risk captures the effect of asset deterioration and climate change moving properties into the high or medium likelihood categories for flooding from rivers or the sea, offset by the effect of new or replacement defences moving properties into lower likelihood categories. However, it excludes surface water risk, changes in likelihood that do not cross the medium to low threshold and the impacts of measures (such as flood forecasting and warning) that will reduce the impacts of flooding when it occurs.

The approach taken in this study is to optimise the economic benefits from investment, rather than to move households from one risk category to another. This concentrates investment in areas where the economic case is strongest. While it is clearly cost effective to decrease risk significantly in some areas, this would not be possible everywhere under current cost assumptions. Reducing costs would alter this situation in some cases, as explained in Chapter 9, and wider options to reduce risk are described below. Nonetheless case (1) in Figure 13 shows that overall, significant reductions in the likelihood faced by many properties would be expected, even over the very long term. For this analysis, we have sub-divided the 'low' category into sub-categories to provide more detail of the distribution of properties at risk across categories. The most significant change over 50 years indicated by this analysis is that 300,000 properties currently at 1 in 100 to 1 in 200 risk would move into the lower likelihood category, below 1 in 200. This demonstrates that, in economic terms, it is often more cost-effective to improve protection for a large number of properties at 'medium' risk of flooding than for a smaller number at 'high' risk.

We have, therefore, also considered the potential role of additional measures that could be taken for individual properties, to reduce risk further, particularly for those experiencing the highest levels of risk. This is also illustrated by Figure 13 below.

Figure 13 - Properties at risk in 2060s, with and without additional resistance measures



10.1 Properties - resistance and resilience measures

Figure 13 also highlights the role that resilience and resistance measures for individual properties have in reducing risk in circumstances where community defences are not a long-term solution. We cannot yet precisely measure the maximum potential impact these measures could have. But clearly, the more work that is done to protect properties or improve how flood incidents are managed, the further this would reduce the damage from flooding.

Our analysis of annual average optimum investment is based on maintaining and replacing the existing flood defence infrastructure. Based on the evidence we have, this assumes that a small number of households use resistance and resilience measures. But, it does not consider more properties using these measures, or alternative ways of reducing the likelihood of flooding in communities.

There are a number of different measures people can take to help stop flood water getting into their home or business. Resistance measures include installing removable floorboards and barriers, and airbrick covers, using sandbags or fixing non-return valves to drains and pipes. These will reduce the effects of flooding when community flood defences cannot reduce risk. Resilience measures such as tiled floors, lime plaster for walls or raised plug sockets help to minimise the damage flood water can cause if it does get into property. In the baseline scenario we described in the previous chapter, we have assumed a level of reducing risk based on the estimated number of properties currently using these measures.

Existing evidence[12] suggests that if more properties took these measures, residual risk could be significantly reduced and that the best investment in terms of economic return would be to roll out resistance measures to properties at highest risk. Figure 13 shows how the number of properties at particular levels of risk could change compared with the picture now (0) and the 'annual average optimum' assessment over the longer term (1). We have looked at two scenarios: based on the current level of uptake of resistance measures of 3 to 5% (2), and a much higher uptake of 50% of households facing the highest level of risk (3).

Outcomes for case (2) are relatively small compared to the overall numbers at risk, resulting in about 12,000 properties in the 'high' category moving to a lower risk category. For case (3) we have assumed that 50% of the 153,000 households at high risk (that is greater than or equal to a 1 in 30 chance of flooding per year) from river and coastal flooding have measures installed, and that these improve the average likelihood of flooding from an average of 1 in 20 to 1 in 50 per year. We estimate the costs of this approach over the next 20 years could be around £300 million, the benefits could outweigh costs by a factor of 3, and about 75,000 households at high risk of flooding could benefit. This is consistent with earlier assessments[12], which concluded that 190,000 properties potentially could benefit where the benefits at least match the costs.

We have not integrated this analysis into the economically annual average optimum scenario, but the overall balance of benefits and costs suggests that property level measures could have a significant role and a more comprehensive analysis would be beneficial.

This is intended to give an indication of how measures could reduce the risk of flooding in properties in a way that is clearly economically worthwhile and that we can readily relate to the risk profiles produced by the LTIS model. Resistance measures can also be appropriate for non-residential properties, for surface and ground water flooding and for properties in areas outside the highest category of risk. Resilience measures tend to be more expensive than the resistance measures costed above, particularly if retrofitted, but may also provide benefits in some areas.

10.2 Other options to reduce risk

There is scope for alternative approaches to reducing risk in areas where community level defences are not available, although we are not yet able to quantify their potential benefits within the LTIS analysis. Some examples are:

- Natural flood management. The risk of flooding and coastal erosion cannot be managed solely by hard defences due to cost and sustainability. Alternative approaches, working with natural processes and rural land-use options can contribute to a more sustainable approach. We work with natural processes to reduce flood risk by protecting, restoring and emulating the natural regulating function of catchments, rivers, flood plains and coasts. These can reduce the risk of flooding by reducing run-off from catchments, and natural sediment behaviour can provide resilience to coastal flooding and erosion. These measures are usually used together with hard-engineering measures. They can also provide wider benefits to people and wildlife by making traditional defences more resilient to climate change, creating or restoring habitats, improving biodiversity, capturing and storing carbon, reducing sedimentation and improving water quality.
- Managed realignment. This aims to achieve sustainable flood defences by recreating eroded saltmarsh and mudflat habitats. Sometimes new defences are created further inland, but thanks to the natural buffer zone, those new defences can be cheaper to build and require less maintenance.

11. Allocation of resources

All of the analysis assumes an economically rational approach to allocating resources using strict economic criteria, and does not factor in some constraints that might exist. These might include the need to time major investments to meet annual revenue and capital spending limits.

The assumption underlying the main analysis is that resources are allocated in an optimally cost effective way. We are able to explore some of the trade-offs involved in allocating resources. The main investment variable in the analysis is around managing flood and coastal defences. There is some more limited evidence around the benefits of varying investment in surface water improvements and flood incident management. Varying the level of investment in these measures may affect results, but we do not currently have enough evidence to explore this in detail.

Within the variable costs in the model, there are some trade-offs that might affect the assumption of cost effective allocation of resources. The optimised balance will depend on levels of innovation and operational efficiency in maintenance as well as capital projects.

A less than optimal balance between capital and revenue funding could increase whole life costs. In particular, the balance between whole life cost and risk depends on the timing of asset replacement. Our analysis model does not currently guarantee that assets are replaced at the economically optimum interval, although the assumptions underpinning timing of investment are reasonable. This is because we use asset condition and deterioration rules to work out the timing of replacement. We cannot yet model changes in economic return that would happen if the replacement took place sooner or later.

12. Other considerations

Factors other than economics are also likely to play a role in investment decisions.

There may be considerations influencing investment decisions that are not covered in the economic definitions and data used in this report. It is important to recognise that the strict economic criteria used here cannot consider how investments might be made on the basis of local preferences, which are part of the government's Partnership Funding policy.

Local preferences might, for example, aim to prevent the current standard of protection in particular areas deteriorating, rather than to achieve the highest net benefit from investment. This could alter the framework for investment decisions in areas where the economic analysis suggests it will not be cost effective to replace existing assets.

The approach we have taken in this study is to apply strict economic criteria to determine whether to maintain or improve protection. We have explored at a high level what the implications might be of taking different approaches, and the impact this would have both on the net present value of the overall investment and the level of risk.

- Investing to prevent deterioration. This would replace all systems where the decision applied in the model is either 'no new investment' or 'maintain crest level', with a decision to 'maintain risk' (see Table D1 in Appendix D for definitions). It would prevent increases in risk anywhere in England. This is expected to approximately double the long-term costs, and reduce risks by around 15% in the 2060s compared with present day risk. The additional investment above the baseline case would, on average, have a marginal benefit to cost ratio well below 1, although the overall benefit to cost ratio would still be around 2.5.
- Investing in the most expensive option in each system that is cost effective overall. When evaluating options (See Appendix D, Table 1), a more expensive option will not be selected if the marginal benefit compared to the next cheapest option is outweighed by the marginal cost. This is the principle illustrated in Figure 5 - marginal benefit from higher investment can be outweighed by marginal costs without bringing the overall benefit to cost ratio below 1. In this case, the additional investment would have a marginal benefit to cost ratio compared to the baseline of about 0.4 to 1, and would add around 40% to the long-term costs. This is somewhat more efficient in achieving further risk reduction, and would reduce risks in the 2060s by about 18% compared with present day risk. While the additional investment is not cost effective, it is important to recognise that the analysis in this study applies decisions at system level, whereas investments in reality may be appraised at a sub-system level. In some cases, it is possible that higher levels of protection could be justified in some places within a system, even if it cannot be justified across the system.

Under a changing climate, widespread flooding such as the events experienced in 2007 could become more common in future. It is difficult to estimate the effects of these events in terms of stretching emergency response capability, and causing disruption to critical infrastructure that could have serious consequences for the wider economy, because they are disproportionate compared with floods affecting smaller areas.

In identifying the annual average optimum level of investment in flood and coastal erosion risk management, we have taken into account the economic impacts of flooding that make up the majority of overall risk. This includes the cost of managing emergencies as a fixed proportion of the expected direct economic damage anticipated at particular levels of protection. This relationship is a reasonable assumption for most observed flood emergencies. However, significant widespread flooding may stretch the ability of emergency responders to provide the expected level of service, with potentially serious consequences. Environment Agency research suggests that an event as serious as the widespread national flooding experienced in 2007, currently could have around a 1 in 25 chance of happening in any given year, depending on how the severity of the event is characterised[14].

We have excluded economic benefits related to risk to life from the LTIS analysis, due to the difficulty of predicting loss of life from flooding. Again, this may not affect the outcome for most instances of flooding, but severe widespread flooding might be more likely to involve significant loss of life.

In summary, we are able to quantify optimum investment in economic terms, which can provide a guide to future investment decisions. This assessment would change if other objectives, such as targeting specific risk outcomes, were used in place of the economic objective. The assessment of potential flood damages in economic terms is crucial in quantifying the benefits of investment and, therefore, in identifying a future optimum investment level. Further developments in quantifying these impacts, particularly those associated with relatively infrequent, widespread episodes of flooding, may therefore influence future assessments of optimum investment.

13. Further actions and research

This section describes how the analysis in this report contributes evidence for investment in managing flood and coastal erosion risk in England, and sets out the actions to further develop this approach to investment.

The 6-year investment programme, published alongside this study, represents the early phase of implementation. Our analysis suggests that this investment programme should achieve a reduction in the overall level of risk, and set a foundation on which an economically optimised long-term standard of protection can be implemented. Nonetheless, some choices remain on the timing of investment, and planning investment for the longer term requires flexibility to respond to changes in the evidence used to produce this analysis.

The actions necessary to develop and implement this evidence-based approach are therefore:

1. Alongside other risk management authorities, implement the 6-year investment programme, reducing risk for 300,000 households, achieving 10% efficiency savings and supplementing government funding with a 15% external contribution.
2. Work to reduce the consequences of flooding, for example by encouraging households and businesses to introduce resistance and resilience measures, and further improving how flooding incidents are managed. We recognise the benefits of these measures, at current service levels and take-up rates in this analysis, but we have not fully explored their potential in the long term. In particular, we have not fully integrated their costs and benefits with the analysis of community-level defences. Future work should also, therefore, establish the optimised longer term contribution that these measures can make to managing risk.
3. Keep progress under review, assess new evidence, and update and report on evidence that affects the findings in this report, in particular the amount and timing of future investment needed. Future milestones include revised Environment Agency risk assessments, and the climate change risk assessment due in 2017.
4. Carry out further work to develop the evidence on long-term risk and investment. The current LTIS report builds on the progress made in previous reports (Table 7) and sets the direction for the future. Recognising some of the remaining evidence gaps will set the direction for further research.
5. Revise the scenarios to support future investment plans. This is the first time we have related medium term plans to long-term results, but we recognise that there is currently relatively little detail available about programmes beyond 2021. As investment plans are built into the longer term, revised long-term scenarios will help monitor and review progress, as well as set future direction.

Table 7 Development of long-term investment studies

Report	Year	Features
Foresight	2004	2080 horizon. Climate change and development scenarios. Estimates of future risk from varying investment.
LTIS1	2009	System scale asset modelling to improve knowledge of the relationship between investment and future risk. Incorporation of rates of flood defence deterioration. Scenario-building based on varying application of flood management decisions at system level according to consequences. Identifying preferred investment scenario.
LTIS2	2014	Ability to identify optimal investment that maximises net present value. Included non-asset management activity and surface water risk in the model. Improved definition of the timing of investment, including the quantified benefit of existing plans. Better definition of changes in risk rather than 'net' change. Better knowledge of risk baseline from more recent National Flood Risk Assessment (NaFRA) and new surface water mapping. Representation of climate uncertainty.
Future LTIS	-	Better representation of infrastructure in the model. Optimisation of the timing of replacement of ageing defences. Better knowledge of the relative benefits of different activities to help define the correct balance of resource allocation between them. Build the relationship between changes in watercourse capacity and risk into the analysis. Quantification of the benefits of property level measures and soft engineering measures, including managed realignment and natural flood management. Evidence for optimising surface water investments, including the cost of maintaining systems. New Environment Agency risk models, for which future investment modelling will be an influencing factor. More comprehensive modelling of uncertainties - particularly further modelling of the impact of uncertainties on the optimum investment profile. Develop a more comprehensive adaptive approach to optimise decisions recognising future risks and uncertainties.

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The work has been peer reviewed by Professor Jim Hall, Director of the Environmental Change Institute at the University of Oxford and we are grateful to Professor Hall for his advice.

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List of abbreviations

AEP	Annual exceedance probability
AIMS	Asset information management system
CC	Climate change
EAD	Expected annual damages
FACET	Flood and coastal erosion tool
FCERM	Flood and coastal erosion risk management
FIM	Flood incident management
IP1 - IP6	Investment plans used to test a range of investment levels
LTIS	Long-term investment scenarios*
NaFRA	National flood risk assessment
NCERM	National coastal erosion risk mapping
NPV	Net present value
NSR	Non-structural responses
SWMP	Surface water management plan
UFMfSW	Updated flood map for surface water
UKCP09	UK climate projections 2009
WAAD	Weighted annual average damages

* 'long term investment strategy' when referring to 2009 report

Appendices

Appendix A - Uncertainty in present day risk

Recent flooding and current risk

This analysis uses the National Flood Risk Assessment (NaFRA) national flood risk model to estimate present and future risks. The model is based upon statistical and physical understanding of the probability and consequences of floods throughout England. Using a risk model allows us to estimate risk and prioritise investment even in places where flooding has not yet occurred. Another way of considering current risk is by reviewing the recent history of flooding. The last 15 years have seen a number of widespread floods, particularly in 1998, 2000, 2007, 2012 and 2013 to 2014 that have caused huge economic impacts, as well as some years in which losses have been much lower than the long-term average. A recent history of flooding is not comprehensive enough to determine by itself a national assessment of annual damage, although recent years have shown the impacts that flooding can cause. Figure A1 summarises notable flood events since 1998, along with a summary of numbers of households affected. Note, this data is households only and does not include non-residential property, infrastructure or agriculture.

The average damage recorded in this period appears lower than the estimated average annual loss in our national assessments, although this in itself is unlikely to be a complete record. In reality, while we continue to understand more about flood risk, some uncertainty in present day and future risk estimates is unavoidable. The approach we have taken in this report is to base our investment modelling on the national assessments described above, but to sensitivity test this result, assuming lower present day risk to make sure that the outputs are reliable given this uncertainty.

Sensitivity of LTIS to initial flood probabilities and expected annual damages (EAD)

The National Flood Risk Assessment (NaFRA) uses modelled flood events to calculate flood probabilities. We use the probabilities to assess economic damages using a method called weighted annual average damages (WAAD). WAAD is a method for assessing economic impacts of flooding for residential and non-residential properties and is used to calculate expected annual damages (EAD). In NaFRA, flood probabilities are represented by likelihood bands, with upper and lower bounds. In the LTIS baseline and future projections, we have used a central estimate of each likelihood band. For the present day, this is the same assumption used by NaFRA.

To examine how sensitive the results could be to changes in initial probabilities, we have re-run the model, setting the probabilities to the lower bound of the band in which it falls. This will give a ‘lower bound’ for the overall national economic risk (EAD). We have modelled future risk and investment from this initial ‘low EAD’ starting point and compared the results for the medium climate projection with no additional development (Table A1).

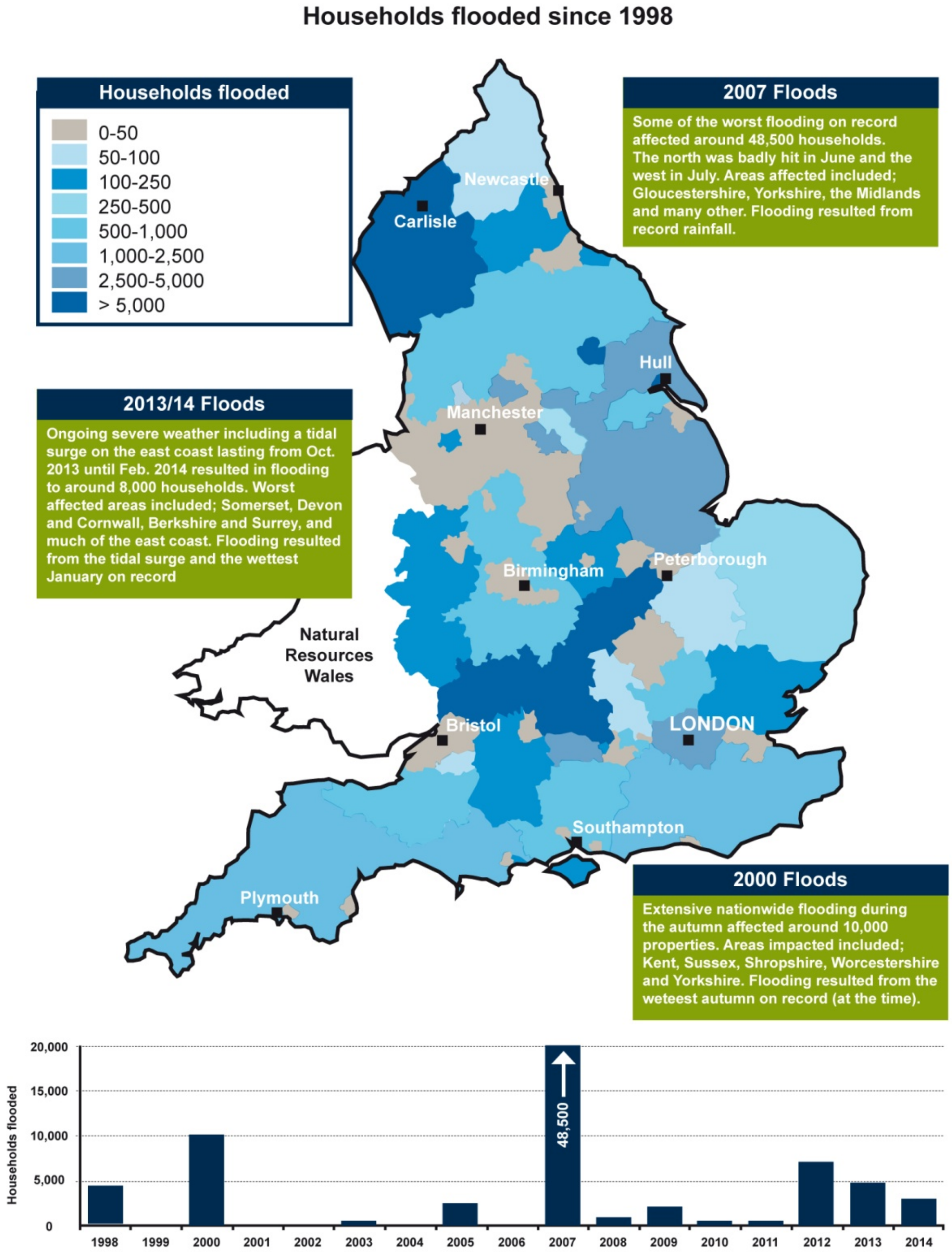
Table A1 Sensitivity of LTIS to uncertainties in initial flood probabilities and EAD

	Present day EAD river, coastal and surface water	Long-term annual average optimum investment	Change in risk
	(£ million)	(per year)	% change over 50 years compared with present day
Baseline – central estimate	£1.14 billion	£862 million	-12.1
Lower starting EAD value	£0.79 billion	£860 million	-11.3%

Our model shows the initial EAD has very little impact on either the annual average optimum investment or on the percentage change in risk. It does, of course, affect the absolute risk and also the whole life benefits of a given level of investment. It also has a small impact on the overall benefit to cost ratio of the national investment.

The overall investment analysis appears to be relatively insensitive to uncertainties in the present day EAD. This is in line with expectations for an analysis that seeks optimal investment in a sector where benefits typically outweigh costs many times over. In the areas of highest risk, where the greater proportions of investment are made, the highest levels of protection are still economically justified even if conservative assumptions are used for quantifying risk.

Figure A1 Households flooded since 1998



Appendix B Economic framework

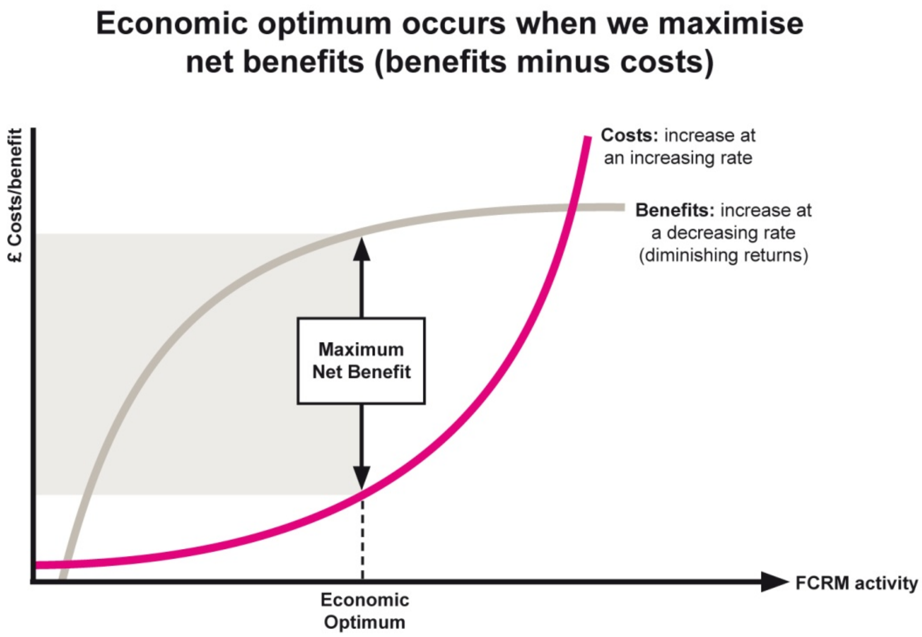
B1 Introduction

The current programme to develop the long-term investment scenarios study produced a number of methods to provide evidence for the long-term changes in risk and impacts of investment decisions. We are, for the first time, able to identify the 'roughly right' level of national investment in flood and coastal erosion risk management (FCERM), from which we can work back to identify the impacts of funding assumptions.

Also shaping our work was the need to include all areas of FCERM investment. This study has established an economic model that can inform the overall level of funding across all FCERM activities, and can test the sensitivity to main influencing factors and uncertainties.

B2 The economic framework

Figure B1 Illustration of the economic annual average optimum



The economic framework is based on the idea of the economic annual average optimum. As investment in FCERM activity is increased, this is the point at which the costs begin to increase faster than the benefits decrease. It is also the point at which the net benefit is at a maximum. Below this point (to the left in Figure B1), it is economically advantageous to invest more. But above this point, the additional cost is not matched by additional benefits, so further investment becomes unwise.

This economic model works for total costs and benefits, but does not reflect how investment could or should be divided between different activities.

We have designed the flood risk and cost evidence to inform the economic model. There are many uncertainties, and we also draw attention to the level of confidence in the main findings.

B3 Possible investment plans

Figure B2 shows how we can build a series of investment plans and use these to provide a range of evidence for long-term assessment. We use these to:

- examine the 'annual average optimum' investment level and associated results

- examine a range of potential realistic alternate scenarios, ranging from the current investment and additional plans to test potential alternative investment strategies
- investigate the investment 'mix', as well as the residual risk

Definitions

Investment plan - describes an investment level over a period of time. Much of our modelling uses a 50-year period, and examines potential investments over this time. Investment means total funding including capital and revenue. Total long-term investment can be an annual series, or within given time periods, or an overall total during the period. In this review, investments are in present-day prices, that is real terms, so they have not been adjusted for inflation. The present value (PV) of future investments is calculated using standard HM Treasury discount rates for projects.

Optimum - under a given scenario, the long-term level of investment that would be sufficient over the study period to fund all activity to manage flood and coastal risk where benefits are greater than costs.

Net present value (NPV) - the difference between the present value of a stream of costs and a stream of benefits.

Present value - the capitalised value of a stream of future costs or benefits.

Scenario - we use 'scenario' to mean a set of factors that influence the future risks of flooding and erosion. Examples are climate change and development of property in the flood plain.

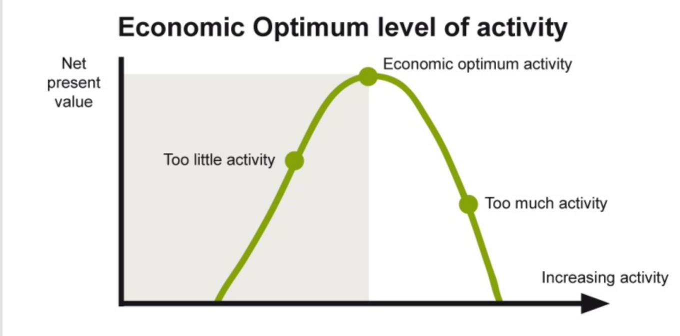
Uncertainties – there are several main uncertainties we can test to understand the reliability of model results. These include the costs of carrying out FCERM projects, and the baseline (present day) level of risk.

Figure B2 Illustration of how the economic framework applies to different scenarios

Economic optimum framework – Summary of key concepts

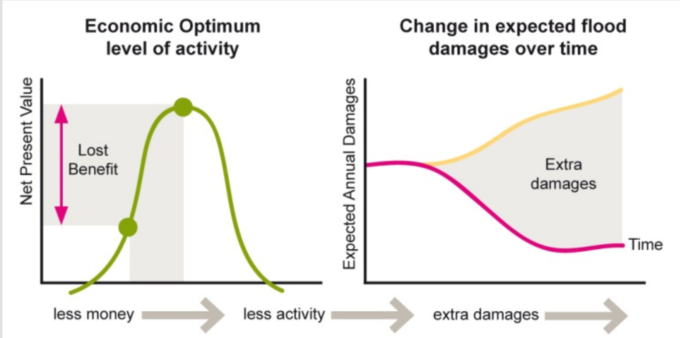
Net present value (NPV) is used as an indicator for the overall results of FCERM activity. If we implement activities in priority order, NPV will first rise, then fall once we exhaust worthwhile projects. Optimum investment occurs when NPV is maximised.

This principle is applied in Chapter 5 of the main report.



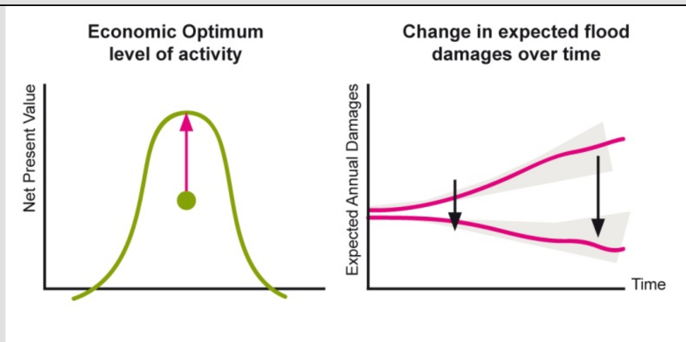
If fewer funds are available than the optimum analysis indicates are required, this would lead to a lower level of net benefit. This can be expressed as additional expected flood damages over time, over and above the baseline damage profile.

This principle is applied in Chapter 6 of the main report.



If we do not allocate funds efficiently between different activities, NPV will be below its true potential. This is illustrated by the green circle in the chart on the right. Improving efficiency can reduce damages.

There is limited evidence to quantify these impacts, but the principle is discussed in Chapter 11.



NPV is influenced by costs and benefits. If the underlying damages of flooding increase, perhaps because of flood plain development, the benefits of intervening increase. This increases the optimal investment level, although it may also lead to additional expected damage at the same time.

This principle is applied in Sections 7 and 8 of the main report.

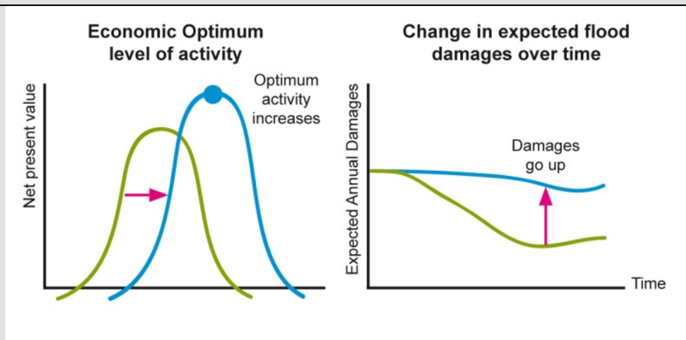


Figure B2 shows how the approach can be extended to include alternative scenarios. It is important to understand how different potential futures could effective today's decisions.

Appendix C Main assumptions

Some of the major factors and assumptions influencing the results in the LTIS are listed below with the relevant data sources.

Data or model feature	Assumption
Cost baseline	All prices are based on present day costs. All flood and coastal costs and economic impacts are to the same baseline, unless otherwise stated. Future costs, damages and impacts are assumed to have present-day equivalent values using standard 'Green Book' discount rates for long-term projects. We have assumed median (50%ile) unit costs, so the assessment does not include cost contingencies or risk allowances.
Unit costs	The Environment Agency has committed to achieve a 10% increased efficiency overall for the capital programme between 2015 and 2021. The cost baseline has been amended to reflect this. We have also carried out sensitivity analysis to quantify the effect of changes in unit costs, both increases and decreases, beyond 2021.
Risk baseline	The main risk baseline is the National Flood Risk Assessment (NaFRA). This includes the most recent modelling and data on risk, including an updated review by local teams to ensure likelihood categories are appropriate. We have used the latest version of the Multi-Coloured Manual (Flood Hazard Research Centre, 2013), including updates to the weighted annual average damage (WAAD) factors used in the risk assessment. We have used the updated flood map for surface water as the baseline for assessing surface water risk.
Climate change	We have included both medium and upper end climate change scenarios, as well as a version of the results with no allowance for climate change. This represents the future risk and investment needed from an unchanged 'present day' climate. See Appendix E for further detail.
Development in the flood plain	Properties in the flood plain are taken from the National Receptor Dataset V1.1 (http://www.geostore.com/environment-agency/WebStore?xml=staticweb/xml/dataLayers_NRD.xml). This contains information on residential and non-residential properties to reflect the present day distribution and types of property at risk. We have tested two scenarios. Firstly, no additional development. Secondly, a scenario assuming numbers of properties in the flood plain increase in line with population projections. This scenario has applied the increase in property numbers evenly across England.
Valuation of benefits	We assess flood damages and the benefits of flood risk management statistically, by multiplying the modelled likelihood of flooding by the flood damage for each type of property. The 'no new investment' damages form an important baseline to compare benefits. Headline flood damages and benefits are reported in terms of direct damages to residential and non-residential properties. Other damages, such as damage to infrastructure, services and agriculture, and emergency costs are often accounted for in the project appraisal. So, these wider damages are included in the parts of the model that determine appropriate policies in individual flood risk management systems.
Asset condition and deterioration	We gather flood and coastal asset type and condition grade from the latest national asset database, the Asset Information Management System (AIMS). The data was downloaded before this dataset

	included the impact of the damaging storms of winter 2013 to 2014, so the modelling does not reflect any asset deterioration during this winter. Asset condition, fragility and deterioration are based on research and development on asset performance, so the model includes the benefits of maintenance and investment in the future. As well as tracking deterioration of individual assets, the model also has trigger points for asset replacement.
Management decisions choice	The LTIS model selects, for a range of investment levels, the best combination of management decisions across all asset systems in England that will achieve the highest overall contribution to net present value. The management choice for each system can range from 'no further investment in defence structures' to improve to a 1 in 100 year or 1 in 200 year standard of protection. An important assumption here is that there is a rational system for allocating resources to maximise net present value. We have made no assumptions about where the costs should fall to manage risk, for example to suggest a split of investment between government and local beneficiaries.
Investment counterfactual	The counterfactual is a 'no new investment' scenario. In other words, the benefits are measured as the difference between the damage that would occur with a particular level of investment and the damage that would occur if no investment was made.

Reference

Flood Hazard Research Centre at Middlesex University. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal'. Available from: http://www.mcm-online.co.uk/manual/

Appendix D Models used for LTIS

River and coastal risk

The following Figure (Figure D1) shows the process to be followed to develop the scenarios. It is based on the Flood and Coastal Erosion Tool (FACET) model, as that captures the majority of funding and risk reduction. But, the other areas of flood and coastal erosion risk management (FCERM) investment are added, notably the non-structural responses (ANSR) tool, which assesses the potential for residual risk to be reduced further than would be possible by just using physical flood defences (Environment Agency, 2014). By running the models side-by-side, we can target the overall economic case for each investment plan as well as supporting the analysis of investment distribution between activities.

Figure D1 Outline process for LTIS modelling - original model design

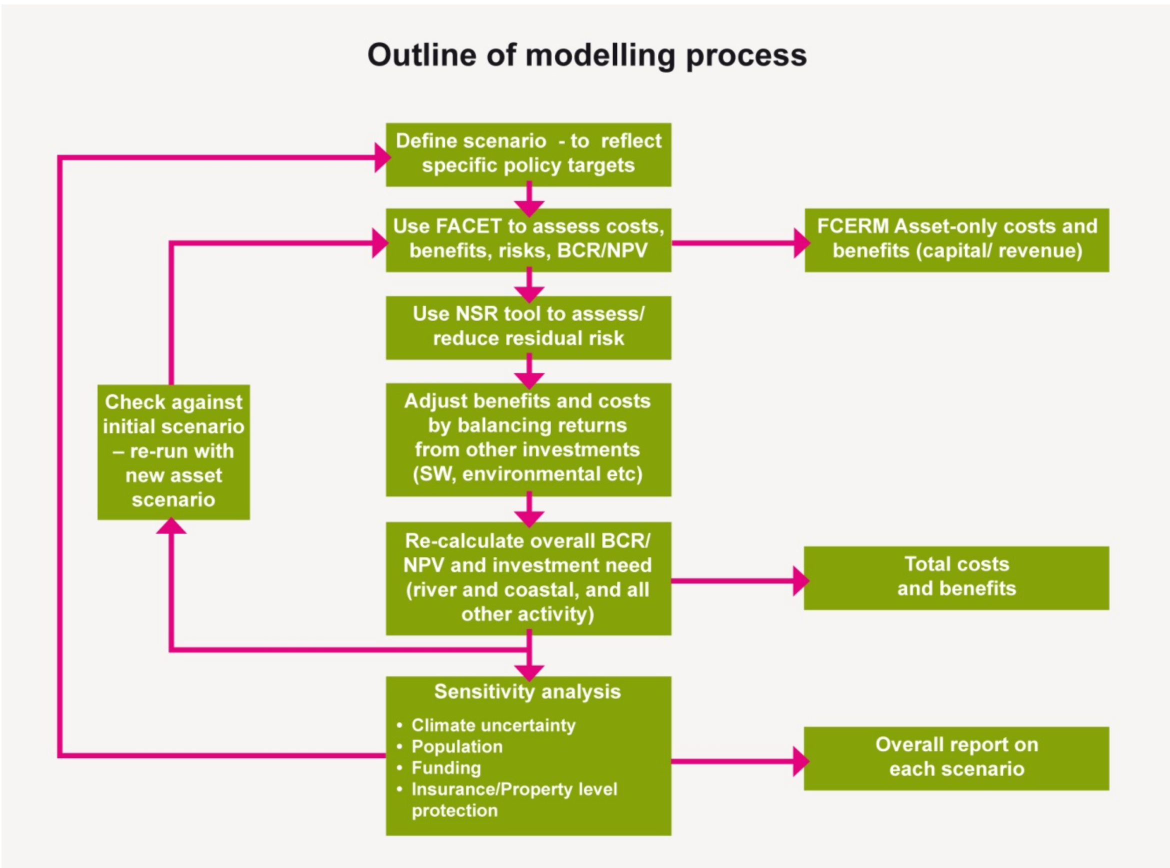


Figure D2 Outline structure of the flood and coastal erosion tool (FACET) for long-term river and coastal risk and cost modelling

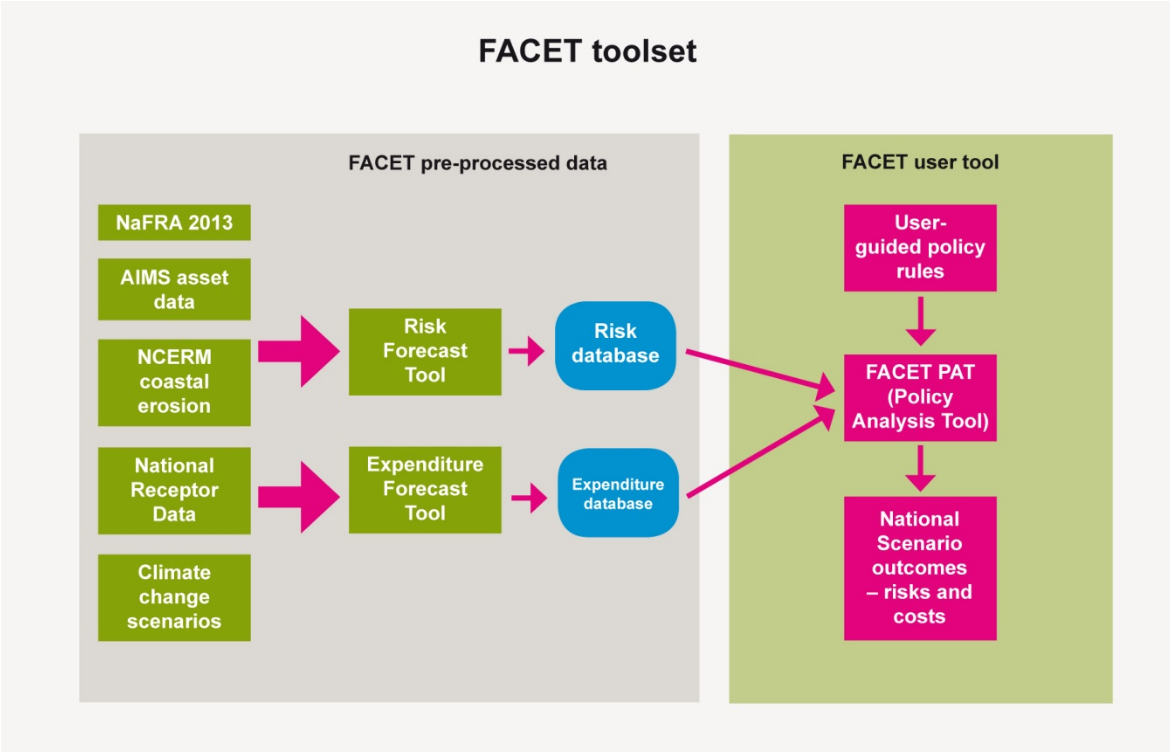


Table D1 Explanation of flood risk management options used in the current study

Management decision	Change to expenditure	Change to risk
1) No new investment in defence structures	No expenditure on maintenance or replacement of defence structures.	Structures may degrade over time and risk may increase. Active assets such as barriers are generally considered to remain operational in the risk calculation for this option.
2) Maintain crest level	Maintain and replace current assets to their existing crest levels.	The level of flood risk will increase over time due to climate change.
3) Maintain current flood risk	Maintain current assets, replace with larger/longer/more robust structures. Build new assets.	The level of flood risk will remain static as the size of defences keeps pace with climate change.
4) Improve	Maintain and replace current assets. Assets to be replaced with larger/longer/more robust structures (1 in 100). Build new assets.	The level of flood risk reduces as assets are replaced with ones that offer a better standard of protection.
5) Improve +	Maintain and replace current assets. Assets to be replaced with larger/longer/more robust structures (1 in 200). Build new assets.	The level of flood risk reduces as assets are replaced with ones that offer a better standard of protection.

The options outlined in Table D1 are selected by taking account of the costs and benefits, over the long term. Different policies can be selected in different areas depending on the estimated level of risk and costs of managing the risk.

Coastal erosion

Costs and benefits of managing coastal erosion are included in the FACET model. In this case, we make use of the latest available National Coastal Erosion Risk Management (NCERM) erosion projections under two scenarios - 'hold the line' and 'no active intervention'. The long-term costs and risks of each option around the coast are used alongside the flood risk management estimates to determine the most cost effective policy mix overall, given any particular long-term investment level.

Surface water risk

We completed a desk-based study, using readily available data and information. We developed a spreadsheet tool to present the results from this assessment. Specifically, the approach we used for this phase used the following information:

- number of properties (property counts) affected by surface run-off/ordinary watercourses - use existing updated flood map for surface water (UFMfSW) property counts for the 3.33% annual exceedance probability [AEP] rainfall event (or 1 in 30 chance of occurring in any given year) and the 0.5% AEP
- calculated flood damages - use a single typical damage applied to residential and non-residential properties, using data gathered by the Environment Agency following the summer 2007 flooding
- future flood risk: from surface water management plans (SWMPs) and integrated urban drainage pilot studies and first edition SWMPs, identify the relationship between rainfall and property counts and use this to predict future increases in flooded properties due to climate change
- future flood risk: apply increase in flood damages due to increase in paved area and due to climate change
- costs and benefits of investment, using typical benefit to cost ratios from SWMP data

Reference

Environment Agency. (2014) Quantifying the benefits of flood risk management actions and advice. Synthesis Report (Draft), SC090039.

Appendix E Climate scenarios and projections

We have considered 3 climate change scenarios in this study. Climate change factors follow the Environment Agency's 2011 report 'Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities' (Environment Agency 2011). This acts as supplementary information to Defra’s policy statement on Appraisal of Flood and Coastal Erosion Risk Management (2009) and the Environment Agency’s Flood and Coastal Erosion Risk Management Appraisal Guidance, as well as supporting the FCERM National Strategy for England. The advice in Environment Agency (2011) is based on government's policy for climate change adaptation. It builds on the UK Climate Projections from 2009 (UKCP09).

The UKCP09 projections are the most up to date national climate projections suitable for the long-term investment scenarios study. The Met Office Hadley Centre has, more recently, compared its HadCM3 model, which underpins UKCP09, with models from 20 modelling centres from around the world (the CMIP5 model ensemble) used to develop the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report. It found that its performance remains competitive in representing long-term average climate changes.

We note that UKCP09 remains a valid assessment of the impact of climate change on the UK and adaptation planning.

- The climate models underpinning UKCP09 simulate long-term climate averages as well as those in CMIP5.
- There is little evidence of major shifts in the climate change projections between UKCP09 and CMIP5.

We also note that there are some modest differences; summers are moderately drier in the UKCP09 projections compared to CMIP5.

When assessing the potential change to river flood flows using UKCP09, a large range of sensitivity tests were run. Some of those were designed to investigate the effect of wetter summer monthly rainfall totals compared to UKCP09 summer projections. Given this extensive sensitivity testing, we are confident that river flow scenarios remain valid given this challenging research area. However, if any extra summer rainfall comes in very intense storms (Kendon et al, 2014), there is likely to be more flooding and more flash flooding in very small, responsive catchments, especially urban or steep catchments. We look forward to having improved scenarios in future to further assess the impacts on flood risk.

Our long-term investment scenarios also assess how coastal flooding may change as a result of increasing mean sea level, large-scale land movement, and changes to wave climate and storm surge. Our LTIS 'medium climate change scenario' is based on an above-median probability estimate of the medium emissions scenario, in line with Environment Agency (2011). We chose to use that, as we were aware of the debate and improving understanding of dynamic ice sheet loss and its potential contribution to global mean sea level within the research in the IPCC fifth assessment report.

For river flows, we assess the percentage changes in peak flows for different areas, and convert these to changes in return period for the required time periods.

Medium scenario

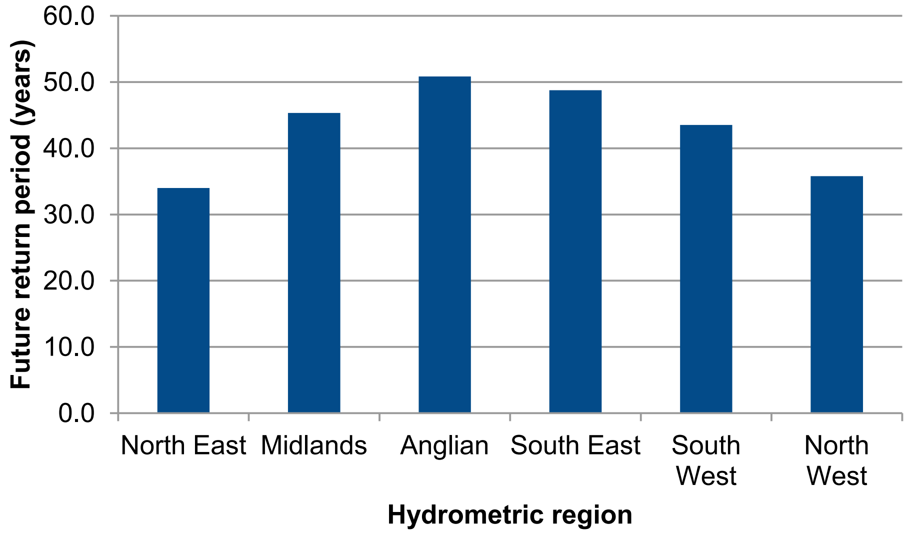
These climate change factors for river flows are based on the advice to flood and coastal risk management authorities for adapting to climate change (Environment Agency, 2011). For changes in river flows, we use a different factor for each region. Values are updated to the new years for LTIS 2014, so that change factors represent changes from 2014 to the required time (Table E1).

Table E1 Peak flow change factors (%) - Medium climate scenario

River basin district	LTIS target period - percentage change in peak flow relative to 2014 (assumed date of current flood estimates) - Medium estimate				
	2014	2023	2038	2063	2113
Anglian	0	2.6	5.2	10.7	18
Humber	0	2.6	5.2	9.3	13
Northumbria	0	2.6	5.2	9.3	13
North West	0	3.9	6.7	12.2	19.5
South East	0	2.6	7.3	15.7	23
Severn	0	2.6	7.3	14.3	18
Solway	0	3.9	6.7	10.8	14.5
South West	0	3.9	6.7	12.2	19.5
Thames	0	2.6	5.2	10.7	18
Tweed	0	3.9	6.7	12.2	19.5

In order to assess the impact of these changes on risk, we have converted changes in flow to changes in return periods, using a calculation tool developed in previous LTIS and National Appraisal of Assets at Risk (NAAR) studies. We have used this tool to determine the revised changes to return period in line with the factors in the table above, and those used in the NaFRA model to assess future changes in risk.

Figure E1 Example of changes in return period corresponding to a sample change in peak flow – impact on current 100-year flood of a 20% flow increase



For mean sea level change, we adopt the recommended rates of relative sea level rise in Table 5 in Annex 1 (Environment Agency, 2011). These include 'upper end' estimates that we have used in the high climate scenario, and the change factors that we have used in our medium climate scenario. We have followed the guidance for making investment decisions. This is to use the upper (95%ile) value for mean sea level change as a more appropriate measure than the medium (50%ile) value for the medium climate projection. We have adjusted mean sea level rise figures to take account of regional rates of vertical land movement. We reference sea level rises to a baseline date of 2014.

Coastal flood risk is also affected by other factors such as waves, storm surge and beach levels. Together with mean sea level, these can all influence the rate of discharge across coastal flood defences. Overtopping discharge rates for the future have been extracted from the Coastal Defence Vulnerability 2075 report (HR Wallingford 2002). Factors are provided for 3 defence types: seawall, embankment and shingle beach, and for 5 locations: Lincolnshire, Dungeness, Lyme Bay, Swansea Bay and Fylde, and for 3 probabilities 1 in 20, 1 in 50 and 1 in 200. These were interpolated where necessary and combined with the sea level rise projections to assess the overall impact on flood risk.

'Upper end' scenario

Changes in peak flows for the upper end scenarios are assessed in the same way as for the medium scenario. Peak flow factors are shown in Table E2.

Table E2 Peak flow change factors (%) - Medium climate scenario

River basin district	LTIS target period - percentage change in peak flow relative to 2014 (assumed date of current flood estimates) - 'Upper end' estimate				
	2014	2023	2038	2063	2113
Anglian	0	7.8	13.3	24.3	39.0
Humber	0	6.5	9.7	15.2	22.5
Northumbria	0	6.5	9.7	15.2	22.5
North West	0	6.5	11.8	21.5	32.5
South East	0	7.8	19.8	39.3	54.0
Severn	0	6.5	14.0	25.2	32.5
Solway	0	6.5	11.8	21.5	32.5
South West	0	7.8	13.3	24.3	39
Thames	0	7.8	13.3	24.3	39
Tweed	0	6.5	11.8	18.8	22.5

Note: For the Thames river basin catchments we apply the 2050s factor also for the 2080s. The upper end estimate is the upper end change for the most sensitive river type in a catchment. In the Thames there is a mix of chalk, gravel and clay types of catchment. The chalk catchments are the most sensitive to increasing rainfall. If we use that for the whole Thames, we would overestimate the upper end scenario, and correspondingly the flood risk and the costs to respond.

For relative mean sea level change we use the upper end estimate (Environment Agency, 2011) and include allowances for other coastal factors in a similar way to the medium scenario.

'Without further climate change' scenario

None of the changes to water levels, return periods, sea level and overtopping rates described above are applied. Instead, we assume these factors will remain at their 2013 levels. The change in risk over time is influenced by the change in replacement and maintenance policies and asset deterioration.

Climate change and the FACET expenditure model

Climate change can affect costs as well as risks. In particular:

- Climate change defence replacement cost: a factor is applied to the replacement cost when defences are replaced with larger assets to account for impacts of climate change.
- Defence replacement standard of replacement target cost: an additional cost factor is applied when a replacement defence is required to provide a higher standard of protection accounting for the impact of climate change.

Since river defence structures will not be exposed to all the effects of climate change (for example, storm surge), the impact of climate change on river defence costs was reduced, based on research into the relative impacts of different climate change factors for calculating the change in replacement volume (and cost) for these types of defences.

These cost factors were originally developed for the first LTIS in 2009. We have reviewed and updated these as part of the latest assessment.

References

Environment Agency. (2011) Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities (GEHO0711BTZU-E-E). Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297379/geho0711btzu-e-e.pdf

UK Climate Projections. (2009) Available from: http://ukclimateprojections.metoffice.gov.uk/

Elisabeth J Kendon, Nigel M. Roberts,Hayley J. Fowler, Malcolm J. Roberts Steven C. Chan & Catherine A. Senior. (2014) Heavier summer down pours with climate change revealed by weather forecast resolution model. Nature Climate Change, June 2014. Available from: http://www.nature.com/nclimate/journal/v4/n7/full/nclimate2258.html

HR Wallingford. (2002) Coastal Defence Vulnerability CDV2075.

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