The Economics of Climate Resilience: Appraising flood management initiatives – a case study

CA0401

A REPORT PREPARED FOR DEFRA AND THE DEVOLVED ADMINISTRATIONS

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Abstract

This report presents a framework for appraising different adaptation actions, focusing specifically on the appraisal of flood risk management initiatives. Those interested in having a broad overview of the appraisal framework should refer to Section 2, which discusses the different appraisal methodologies, and Section 4.1, where a step-by-step guide for appraisal is set out. Section 3 is a detailed case study, showing how the robust decision making methodology is used to appraise a set of Natural Flood Management (NFM) measures. This will be of interest to those seeking a detailed understanding of how an appraisal is carried out, or to those involved with NFM. Section 4.2 gives an overview of how flood damage can be measured in a range of sectors, and will be of interest to stakeholders in those sectors seeking to quantify the effects of flood damage.
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Executive Summary

The Climate Change Risk Assessment (CCRA) identifies numerous climate change risks and opportunities. It recognises that, unless appropriate adaptation action is taken to respond to these, the UK could incur significant costs and/or miss out on important opportunities. As part of the response to addressing these risks and opportunities, the Economics of Climate Resilience (ECR) has been commissioned by Defra and the Devolved Administrations (DAs) to inform the UK’s first National Adaptation Programme and the adaptation plans of the DAs.

- The first part of the ECR – Phase 1 – provides evidence that will assist policymakers and wider stakeholders in understanding the extent of current and expected adaptation actions, the relative effectiveness of those actions and the barriers to their implementation.

- This part of the ECR – Phase 2 – focuses its attention on how robust decisions can be made when considering alternative adaptation actions.

There is substantial literature and guidance on how interventions by government should be appraised. The most frequently cited guidance in the UK is Her Majesty Treasury’s (HMT) ‘Green Book’. It describes how the economic, financial, social and environmental assessments of a policy, programme or project should be brought together to aid efficient decision making.

However, it is also widely recognised that the application of standard appraisal techniques may not be appropriate when considering alternative adaptation actions. This is because climate change risk and other social, demographic and economic uncertainties may be present. Further, any appraisal method must also take into account the range of different indirect benefits and costs that are regularly associated with adaptation actions. This leads to an important question that this report has set out to address:

- What are the most appropriate methodologies for appraising alternative adaptation options?

In the report we examine a range of appraisal methodologies that includes: multi-criteria analysis (MCA); cost-effectiveness analysis (CEA); scenario-based cost-benefit analysis (CBA); robust decision making (RDM); and real options analysis (ROA). These methodologies differ in terms of their approach to modelling uncertainty, their approach to measuring costs and benefits, and how intensive they are to implement. Selecting the appropriate methodology will depend on the specific conditions of the project being appraised. The methodologies and their advantages and disadvantages are summarised in Table 1.
Table 1. Advantages and disadvantages of each appraisal methodology

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Brief Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-criteria analysis (MCA)</td>
<td>Part or wholly qualitative-based approach, which provides a ‘ranking’ of initiatives based on monetary and non-monetary criteria</td>
<td>Allows appraisal to be conducted in the absence of/limited amount of quantitative data</td>
<td>Limited to relative assessments of alternative policy options</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Outputs are appraisal-specific – i.e. cannot be generalised more widely</td>
</tr>
<tr>
<td>Cost-effectiveness analysis (CEA)</td>
<td>Quantitative approach which identifies the policy option providing a specific output/benefit at the lowest cost</td>
<td>Useful when a specific output/objective is needed to be met</td>
<td>Not applicable when a single initiative is being appraised, or when considering multiple initiatives providing different levels of the required benefit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can be used when comprehensive quantitative cost data is available for monetising costs but not benefits</td>
<td>Implicitly ignores potentially significant co-benefits</td>
</tr>
<tr>
<td>Scenario-based cost-benefit analysis (SBCBA)</td>
<td>Quantitative approach which assesses costs and benefits (in monetary form) across different scenarios/states of the world</td>
<td>Accounts for uncertainty surrounding flood risk without being computationally or data intensive</td>
<td>Potentially difficult to gain consensus on the appropriate scenarios to use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provides numeric outputs, allowing for cardinal comparisons between initiatives</td>
<td>Risk of not capturing the extent of uncertainty surrounding climate change, especially under ‘deep uncertainty’</td>
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<td></td>
<td></td>
<td>Easily understood for non-technical audiences.</td>
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<tr>
<td></td>
<td></td>
<td>Allows for the application of risk-based rules</td>
<td></td>
</tr>
<tr>
<td>Robust decision making (RDM)</td>
<td>Quantitative approach which assesses the proposed initiatives across all plausible states of the world, and identifies the initiative most robust across these</td>
<td>Captures deep uncertainty – leaves ‘no stone unturned’</td>
<td>Can be computationally and data intensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provides numeric outputs</td>
<td>Potentially difficult to interpret for non-expert audiences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provides a clear picture of which initiatives are optimal in different states of the world</td>
<td>Value function for deriving costs and benefits needs to be well calibrated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ranges of plausible parameter values need to be known</td>
</tr>
<tr>
<td>Real options analysis (ROA)</td>
<td>Extension of CBA which estimates the ‘option value’ associated with each initiative i.e. the option to delay or adjust in the future. Calculates the NPV of each initiative given the particular actions that could be taken given different states of the world being realised, and the probabilities of these occurring</td>
<td>Accounts for learning about the nature or extent of flood risk going forward. – captures the value in delaying or adjusting a particular initiative. Useful when comparing large irreversible options with smaller-scale flexible options</td>
<td>Can be computationally or data intensive – requires the assignment of probabilities to scenarios at various future time periods</td>
</tr>
</tbody>
</table>

Source: Frontier Economics
Considering these options specifically in the context of flood risk management, we find that an appraisal method based on the principles of **robust decision making (RDM)** offers practitioners, in the majority of cases, the most reliable approach to choosing between alternative adaptation options. This is because the approach is extremely comprehensive and is designed to deal with the specific issue of ‘deep uncertainty’: a situation where it is not possible to say with any confidence whether one future state of the world is more plausible than another. This is the type of situation most likely to be prevalent when considering alternative adaptation options.

Our understanding of the effectiveness of RDM is highlighted in a specific flood management case study in Pickering, a historic market town in North Yorkshire. The town has been particularly susceptible to flooding, with major floods having occurred four times in the past 13 years. The most recent floods, in 2007, were the most serious, causing an estimated £7 million of damage to businesses, homes, and local infrastructure. In response, a package of natural flood defence measures was developed for the Pickering area, as part of the ‘Slowing the Flow’ project. These measures are the focus of our appraisal which we use as a case study to examine the potential for using each of the appraisal methodologies described above. On the basis of the framework set out in **Figure 1** below, we conclude that it is most appropriate to use a methodology drawing on the benefits of RDM.

**Figure 1. Framework for gathering data and selecting appraisal methodology**

![Diagram](source: Frontier Economics)
We develop a simplified RDM approach that allows useful and robust outputs to be produced and exploits all the available data, but is not too computationally or data intensive. This ensures an appraisal analysis which is proportionate to this small-scale project.

The approach develops multiple flood risk scenarios. The range of scenarios we use captures those key uncertainties about different states of the world that are likely to have a material impact on the appraisal decision. We understand that there are many other factors that generate uncertainty over the appraisal decision; for example, the valuations used to measure costs and benefits, the assumed effectiveness of each measure in providing flood protection and the choice of appraisal horizon and discount rates. We perform sensitivities around these parameters to determine whether the robustness of the appraisal decision made is affected by different assumptions about the values used. This keeps the analysis tractable without any loss of generality.

Our analysis suggests that the case for the implementation of the flood defence measures in Pickering is strong:

- **The package of measures is highly robust to the level of future flood risk.** Under central estimates, the measures generate large net benefits across all flood risk scenarios.

- **The measures continue to be robust in light of changes to the majority of parameters used in the appraisal analysis.** Under most of the sensitivities considered, the measures generate net benefits across all levels of flood risk. It is only when significant reductions are made to the appraisal horizon, or when the lower bounds of all data ranges are used, that the measures tend to generate net costs. However, both of these sensitivities can be considered to be extreme and we think that only limited weight should be placed on them.

- **Estimates are conservative.** Most estimates of particular benefits, especially those accrued through flood and erosion regulation, are conservative. Consequently, the measures may generate significantly larger net benefits than those estimated here, and be robust to the future level of flood risk across a greater number of sensitivities.

It is likely that most appraisals of adaptation actions will be in the context of deep uncertainty. As such, RDM will be a particularly useful approach when there is a high probability that different options could be ranked differently in different future states of the world. A limitation of the RDM approach is that it is difficult to develop a single net present value estimate for each option. In many ways this is also its strength. This is because it provides a rich source of
information for each option in different states of the world. Decision makers can draw on this information to test out decision rules and provide a range of evidence to support their arguments for a particular option.

In the course of considering how to apply appraisal techniques in the flood management setting, we find not only that the *measurement* of the avoidable flood damage costs is important, but also that the *type* of avoidable flood damage costs will vary significantly across sectors. This is a particularly critical area that requires careful measurement if appraisal of adaptation actions is to be carried out successfully. Our analysis indicates that, in order to be prepared to carry out effective flood management appraisals, there is significant work to be carried out in a number of sectors.

In particular, we have identified the following data gaps:

- **Agriculture**: There is a lack of UK-specific data and methodologies, particularly in relation to damage functions for plant material, soil, agricultural buildings, and their inventory. In the absence of this, international data sources would have to be used.

- **Energy**: In general, more research is needed on the capital repair costs for energy infrastructure, the interdependency effects, and the lost output for thermal stations. For flood-specific information, more evidence is required on the hypothetical damages caused by different flood severities to the energy sector.

- **Health**: Several direct costs specific to hospitals require quantitative data development. Information on delay costs to patients is outdated, while mental health cost data faces substantial limitations. Interdependencies are also an area lacking research-based evidence.

- **Transport**: Gaps in the underlying figures are significant. The road maintenance and repair cost per kilometre requires further data to improve its accuracy and the delay costs to road and rail travel should use updated numbers. Finally, scour effects and wider network effects are not quantified and suggest potential areas for future research.
1 Introduction

The Climate Change Risk Assessment (CCRA), published by Defra in January 2012, identifies numerous climate change risks and opportunities. The evidence on climate change indicates that the UK faces a significant degree of risk from climate change and extreme weather conditions, particularly from flooding and heat waves.

The CCRA established that, unless appropriate adaptation action is taken to respond to these risks, the UK could face a significant amount of damage that would lead to significant financial, economic, and social costs.

In the context of the findings from the CCRA, the Economics of Climate Resilience (ECR) was commissioned by Defra to inform the UK’s first National Adaptation Programme (NAP). The NAP will focus on helping UK businesses, local authorities and civil society to become more resilient or ‘Climate Ready’ to climate change impacts. An important part of the NAP will be to consider adaptation actions which are likely to be effective in the context of climate change impacts.

Phase 1 of the ECR has provided evidence that will assist policymakers and wider stakeholders in understanding the extent of current and expected adaptation actions, the relative effectiveness of those actions, and the barriers to their implementation. The Phase 1 ‘Synthesis Report’ shows that, in a range of sectors where there are significant risks of damage caused by changing weather conditions, there are important decisions to be made over which adaptive actions should be pursued.

Phase 2 of the ECR asks the question ‘How are adaptive actions to be appraised?’. This report addresses that question by providing practical insights on how robust decisions can be made when considering alternative adaptation actions. The CCRA identified a number of risks to the UK, including flooding, heat waves, and drought. Flooding is already identified as a significant risk to the UK in the National Risk Assessment, and the CCRA projects that it will pose an increasing threat as the climate changes.  

Phase 2 of the ECR asks the question ‘How are adaptive actions to be appraised?’. This report addresses that question by providing practical insights on how robust decisions can be made when considering alternative adaptation actions. The CCRA identified a number of risks to the UK, including flooding, heat waves, and drought. Flooding is already identified as a significant risk to the UK in the National Risk Assessment, and the CCRA projects that it will pose an increasing threat as the climate changes.  

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1 The Synthesis Report is available at:  

2 CCRA Summary of Key Findings, page 6, available at:  
The report recognises that there are some very specific circumstances associated with adaptation actions. These include the existence of deep uncertainty of climate change and its impacts, which must be taken into account when applying cost-benefit techniques as a decision tool.

The report is structured as follows:

- **Chapter 3** focuses on the area of flood risk management and the use of appraisals methods in this context. The chapter sets out the range of adaptation actions that are likely to be considered in flood risk environments. It highlights the specific aspects of flood risk and the implications these have for appraisals. These factors include deep uncertainty, indirect costs and benefits, and the measurement of non-monetary costs and benefits. The chapter concludes with a description of the different cost/benefit-based appraisal methodologies that are available and the different contexts where they are likely to be most applicable.

- **Chapter 4** considers what appraisal methodology is most appropriate to apply to a specific flood management initiative in Pickering. Pickering is an ancient market town in Yorkshire which has a prone to river-flooding at times of very heavy rainfall. We have carried out an appraisal of a range of flood management initiatives that have been considered in Pickering. We describe each step of our approach and show the results for the initiatives.

- **Chapter 5** provides lessons in the use of appraisal methods in flood risk management scenarios. It is divided into two parts. The first part draws on the Pickering case study and develops general lessons for decision makers looking to apply appraisal techniques to assess adaptation actions in the flood risk management context. The second part looks at a particularly important area of measurement: the value of the benefits of improved flood protection. For four specific sectors – agriculture, health, energy and transport – we have explored the different types of damage that are likely to arise as a result of flooding. It is important that the costs of such damage are measured robustly in a cost-benefit appraisal. In this regard we have assessed what information is currently available to estimate costs and what evidence requirements will need to be developed to provide robust measures.

Finally, the report has an Annex providing additional material from the Pickering case study.
2 Flood risk management and the use of appraisal methods

In this chapter we discuss the use of different appraisal methods to help select flood risk management options. We describe the policy context, and the fact that flooding will have potential impacts in a wide range of policy areas. We then explain that the key issues for appraisal in relation to flood management are uncertainty, non-monetary costs, and indirect costs and benefits. We describe various alternative appraisal methodologies and their strengths and weaknesses in relation to flood management.

2.1 Flood risk management strategy

Flood risk is likely to increase as a result of climate change and changing land use. It should be noted that the damage from flooding depends on the type of water involved. Flooding from large rivers can be very extensive, with deep water and high flow velocities. In contrast, surface water flooding is typically shallower. Urban flood waters are at higher risk of being polluted by sewage, with additional risks to health, higher repair costs, and longer periods of disruption (HR Wallingford et al., 2012; Pitt, 2008b).

The most recent assessment of the potential impacts of climate change is the UK Climate Change Risk Assessment (CCRA). This identifies the risks and opportunities climate change is likely to bring for different sectors. Areas expected to be affected by flooding include damage to properties, agriculture, health, transport, energy, business, and the natural environment. Some of the projected risks are described below:

- In relation to buildings, present day Expected Annual Damage (EAD) to residential and non-residential properties is of the order of £1.3 billion for the UK as a whole. HR Wallingford et al (2012) estimated that about six million properties are currently at risk of flooding, of which three million properties are at risk of flooding from rivers or the sea, and four million are at risk from surface water flooding (one million properties are at risk of both types of flooding). The EAD is an estimate of the average annual damage to property and contents. The total damage could be much higher if other assets and indirect and intangible losses are included.

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4 The EAD is an estimate of the average annual damage to property and contents. Total damage can be much higher if other assets and indirect and intangible losses are included.
In relation to agriculture, around 50,000 hectares are currently at risk of frequent flooding\(^5\) in England and Wales, and this is projected to increase to around 200,000 ha by the 2080s. At a lower frequency of flooding,\(^6\) around 200,000 ha are currently at risk, projected to increase to over 500,000 ha by the 2080s (equivalent to about 5% of all agricultural land).

In relation to business, Expected Annual Damage is currently £500 million, projected to increase to over £1,500 million by the 2080s. This is from expected damage to buildings and disruption to the supply chain.

We discuss sector-specific flood damage further in Chapter 4. It is clear that the threat from flooding confronts decision makers in a range of different policy levels. The decisions made in some policy areas may affect the options and outcomes in others. For example, a flood management measure taken in a local area might reduce the overall level of flood risk, but there may be further adaptation actions needed to mitigate the costs of flood damage for a specific sector.

Ideally, the decision-making process will allow for some degree of coordination between the different ‘levels’ of decision making. It would be difficult for all stakeholders to have full input on every process, and for each decision to be optimal, given decisions made elsewhere. However, it should be feasible to have a more streamlined process, whereby stakeholders contribute to the wider decisions on flood risk management while independently pursuing additional sector-specific adaptation measures.

**Options for reducing flood risk**

There is a wide range of potentially applicable flood risk management options. The options will generally fall into one of two categories: ‘hard’ and ‘soft’ measures.

Hard measures typically use large engineered physical structures (e.g. flood barriers) to alter the direction of water or for a physical barrier. Soft measures, referred to as natural flood management measures (NFM) on the other hand, aim to reduce the peak flow of the water, such as through improving the porosity of the soil or the capacity of plants to intercept water. NFM measures can either reduce runoff (e.g. farm management to increase filtration) and/or attenuate flow (e.g. riparian tree planting, flood plain reconnection). They are more effective at reducing the frequency of flooding for high probability fluvial events (e.g. less

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\(^5\) Frequency of at least once every three years

\(^6\) Frequency of 1 in 10 year events
than a one in twenty year return period) compared to extreme events (e.g. one in 200 year return period). NFM measures can either be considered alone or as part of a package alongside other soft or hard engineering measures.

NFM measures can also provide important wider benefits such as improving water quality, carbon sequestration and habitat restoration. NFM measures are only likely to be pursued effectively if these benefits are incorporated within the overall assessment of their costs and benefits.

Examples of such measures are provided in Table 2 below:

Table 2. Examples of potential flood risk management options

<table>
<thead>
<tr>
<th>Type of measure</th>
<th>Potential Policy options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hard Measures</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reinforced Flood Walls</td>
</tr>
<tr>
<td></td>
<td>• Embankments</td>
</tr>
<tr>
<td></td>
<td>• Flood Storage Bunds</td>
</tr>
<tr>
<td></td>
<td>• Reinforced dams</td>
</tr>
<tr>
<td><strong>Soft Measures</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Woodland planting</td>
</tr>
<tr>
<td></td>
<td>• Farm-level measures</td>
</tr>
<tr>
<td></td>
<td>• Adaption-action plans</td>
</tr>
<tr>
<td></td>
<td>• Debris dams</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

2.2 Flood risk management and key issues for appraisal

Choosing between adaptation initiatives is difficult because of the significant uncertainty about the impact of future climate change conditions, and also because adaptation measures are likely to be complementary to other policy goals. We discuss these and other important characteristics and challenges below.

7 The EU Green And Blue Spaces (GRaBS) project running from 2008-11 considered a range of climate change adaptation actions, including some NFM measures.
Uncertainty

There is uncertainty surrounding the flood risks that particular areas of the UK face both today and in the future. One of the primary drivers of flood risk is climate change. There is uncertainty both as to the degree of climate change that will occur and the implications this will have for rainfall patterns, the permeability of the land, and the amount by which sea levels rise (which will affect the risk of coastal flooding).

Flood risk can also be affected by non-climate change factors. These include urban planning issues where, for example, the expansion of urban areas with less natural permeable ground coverings leads to faster surface run-off into watercourses in the event of heavy rainfall.

The key challenge is the uncertainty about the effect of these drivers (and any changes in these drivers) on the risk of flooding, with no clear value function linking changes in drivers to changes in flooding levels in particular areas. As a result, there are many potential future levels of flood risk, with no clear consensus over which levels are more likely than others.

There is also likely to be uncertainty about the effectiveness of some initiatives in abating flooding, given that there has been insufficient time to-date to test the efficacy of some of the proposed schemes.

There may also be uncertainty in the valuations placed on the costs and benefits, or the technical characteristics, of a measure. For example, if a benefit is valued using a WTP survey, the survey will have a limited sample size, and so there will be a degree of imprecision in the valuation. A different survey might produce different estimates. But these are better thought of as alternative prior assumptions, rather than alternative states of the world. ‘Valuation uncertainty’ can therefore be distinguished from ‘state of the world uncertainty’. Alternative assumptions of values can be better captured through sensitivity analysis rather than encapsulated within scenarios.

Indirect impacts

It is important that the appraisal methodology and decision analysis includes a broad outlook on the range of potential costs and benefits associated with each adaptation option.

Although flooding has direct effects in terms of the damage and disruption it causes, it can also create indirect costs. For example, the cost of the stress it places on individuals whose homes are flooded, or the cost of its environmental effects, such as damage to the local ecosystem. On the other hand, some flood defence initiatives include ‘natural’ measures which create additional indirect benefits, such as planting trees and woodland shrubbery (which can generate...
benefits through sequestering CO₂), generating habitats, and having amenity value.

As there is likely to be a range of indirect impacts associated with some flood management initiatives, the appraisal techniques applied to adaptation options should incorporate the identification and valuing of wider co-costs and co-benefits.

**Multiple initiatives and non-monetary outcomes**

There are a large number of potentially suitable schemes to manage flood risks in particular areas. These include from sea walls, catchment-level initiatives made from more robust materials, and home-level measures. As such, the appraisal methodology must allow the user to adequately assess and choose between these potential initiatives.

The localised nature of flooding in some areas means that many potential flood defence initiatives are on a small scale, such as the natural flood management initiatives in Pickering, which we consider in the next chapter of this report. Further, most of these measures are unlikely to be mutually exclusive (and most likely to be complementary), so it is possible that packages of different initiatives could be implemented.⁸

In theory there are several different combinations of measures that are possible, although in practice selecting the ‘optimal’ mix could be extremely challenging. There are often outcomes that are very difficult to measure in monetary terms. The framework of an appraisal methodology must show the potential costs and benefits associated with such outcomes, and how the appraisal approach will factor such measures into the analysis.

It is important that the appraisal methodology has the flexibility to allow for the assessment and selection of packages as well as individual flood defence initiatives.

**Proportionality and pragmatism**

The extent or depth of the analysis should be tailored to the relative size, impacts, and risks of the proposal. Not all appraisals will require in-depth cost-benefit analysis.

Many local flood defence initiatives are small scale; they also tend to be relatively inexpensive, at least in the context of wider government policy options. As the cost of any appraisal should be proportionate to the expected investment made,

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⁸ The flood defence initiatives we will consider in Pickering actually consist of packages of smaller more specific measures.
it should be possible to implement the appraisal methodology at a relatively low cost. This is more likely to be possible if the appraisal follows a practical and pragmatic approach, which is easy to understand and implement. It is important that those implementing it and those acting on the results can explain clearly the steps that have been taken, the data that has been gathered, and what drives the outputs that have been created.

The main goal is to provide the best available evidence for decision makers in proportion to the amount of resources and time available. As such, where information is available from previous research and studies, an appraisal should draw on established values of costs and benefits, rather than commit substantial resources to repeating analysis.

2.3 Flood risk management and appropriate appraisal methodologies

Adaptation decision framework

Appraisal methodologies are not carried out in isolation, but are part of a broader decision-making process. This is presented in Ranger (2010). Decision makers must first structure the problem, define the policy objectives, and assess the vulnerabilities. After this they must define and shortlist the potential options. The options are then appraised, after which the selected option is implemented and monitored.

There is a significant amount of guidance on appraisal of government interventions; the guidance most often referred to is HM Treasury’s Green Book; Appraisal and Evaluation in Central Government and its supplementary guidance. Other government departments and agencies will also offer guidance in specific areas.

Many alternative appraisal methodologies have been developed and used. In general, these methodologies are either refinements or variants of cost-benefit analysis (CBA). CBA can be viewed as the central basis underpinning all methodologies.

We discuss the strengths and weaknesses of these appraisal methodologies in the context of addressing flood risk management options. This is intended to give a broad view of how the different methodologies can be used. The purpose of appraisal is to expose the real choices available and compare the outcomes of alternative investment options. Care is needed to ensure these methodologies are applied in an appropriate manner.

The choice of appraisal can also be an iterative process; information relevant to the choice of appraisal methodology might only become evident when the
appraisal is underway. For example, a relatively complicated and data-intensive approach may seem feasible at the outset of a study, but may become less feasible as the actual data on costs and benefits are assessed. There needs to be flexible and open application of these methodologies, in order to best understand the relative merits of the different options available.

Cost-benefit analysis

Cost-benefit analysis (CBA) is the most widely used technique for appraising government policy options. It is recommended for appraisals across all government sectors, and specifically in the context of flood management.9

CBA monetarily values all relevant costs and benefits, both private and social, of all initiatives being appraised. These are then discounted, so that benefits delivered now are valued more highly than benefits delivered in the future. The total net present value (NPV) of each option is calculated. Generally, a decision is based on choosing the alternative with the highest net benefit.

Provided that reliable data on costs and benefits are available, the advantage of this approach is that it is widely understood and easy to implement. It also accounts for all costs and benefits, guaranteeing that an appraisal of flood management initiatives will capture any relevant co-costs and co-benefits associated with them. Since co-costs and co-benefits can be highly significant in the context of flood risk management, it is advantageous to be able to incorporate them on an equivalent basis as monetary values.

A number of refinements to the standard cost-benefit analysis methodology are available. Methodologies for capturing uncertainty include Scenario Analysis, Real Options Analysis, and robust decision making, which all capture uncertainty in different ways. Multi-Criteria Analysis is concerned with how costs and benefits can be compared when monetary valuation is difficult.10

Scenario-based cost-benefit analysis

A significant limitation of CBA in its application to flood risk management is that it does not explicitly tackle uncertainty. In the case of uncertainty, simple CBA would use the mean expected values of any random variables and calculate the results in this ‘central’ scenario. This might be of limited value if, for example, the ‘central’ scenario itself is not especially meaningful, or if some strategies perform particularly well or poorly in certain states of the world.

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The natural extension is to compare outcomes for a small number of discrete scenarios. In scenario-based CBA the costs and benefits of each strategy in each state of the world are calculated in turn. The scenarios are then assigned probabilities and the strategy with the highest probability-weighted value is chosen. Note that other decision rules could potentially be applied here, e.g. ‘Maximin’ or ‘Low Regret’ (see boxed text).

### Decision criteria and risk-based rules

Using the expected value of initiatives as the basis for decision making is the widely accepted way of making appraisal decisions across all government sectors, and in relation to flood management. This involves choosing the initiative which generates the greatest net benefit/probability-weighted net benefit. However, basing decisions on expected value does not take uncertainty fully into account.

Alternative decision-making tools, termed risk-based rules (RBR) account for uncertainty by incorporating the risk of sub-optimal outcomes occurring under certain states of the world; in this case, under particular scenarios representing given levels of flood risk. Such rules have been cited widely in both government and academic literature in recent years (see Ranger et al. 2010), and are particularly applicable to SBCBA, ROA and RDM approaches.

At a high level, we will consider two risk-based rules, both of which make use of the scenario-specific outputs:

- **‘Low Regret’ (guaranteed good outcome)** – under this rule, the optimal initiatives are those which provide a ‘positive outcome’ under each possible scenario.

- **‘Maximin’ (best in worst case scenario)** – under this rule, the optimal initiative is that which provides the ‘best outcome’ in the scenario where the outcomes are the lowest.

By accounting for risk and uncertainty, these rules capture some of the lessons learned from the RDM approach, as there is a direct parallel between the optimal initiatives under ‘Low Regret’ rule and the ‘robust strategies’ identified under RDM.

We note that in making appraisal decisions, risk-based rules can be used in conjunction with other measures based on expected value. This is recommended in the context of appraising flood management initiatives. For example, the above-mentioned Defra policy statement notes that decision making should be balanced and should not rely solely on a single metric, but instead “make use of an appropriate combination of approaches … to arrive at a preferred option”. Later in this section we consider how combinations of decision rules can be used to make appraisal decisions.

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Any set of scenarios used in a CBA should capture the factors which are most uncertain in relation to flood defence initiatives, or which are expected to have the most leverage in terms of the relative performance of the different options. In the context of flood management, the level of flood risk is a key uncertainty which will need to be captured. The decision on whether to use scenario-based CBA will rest in part on the degree to which decision makers feel comfortable in developing flood risk scenarios.

There is likely to be a large range of potential future levels of flood risk and, in turn, a large number of potential scenarios. However, it is not practical to use a large number of scenarios in CBA. It follows that the challenge is to develop a small number of scenarios that decision makers and stakeholders feel adequately summarises the wide range of possible levels of flood risk, but is also meaningful and acceptable to diverse policy audiences. If this cannot be achieved then this approach will be too difficult to pursue.

Using a small number of scenarios ensures that the analysis is clear and readily comprehensible and, if a quantitative approach is chosen, is likely to be much less computationally (and data) intensive than using a larger number of scenarios. It also makes it easier to see the ‘bigger picture’: to compare initiatives between scenarios and, ultimately, to identify the drivers of value in each initiative and interpret the results accordingly.

There is a risk that, by limiting the possible ‘future states of the world’, the extent of uncertainty surrounding flood risks will not be sufficiently captured in the analysis; in other words, there is a decreased likelihood of identifying a state of the world which may actually be realised. If decision makers and stakeholders are not comfortable with this approach, or if there is unlikely to be a consensus of understanding on local flood risk, then this option is not recommended. Those carrying out the appraisal process ought to offer their views on whether the evidence supporting a scenario-based approach can hold up to scrutiny.

The scenario-based approach is pragmatic and one that can be readily understood by the non-technical audiences who would be engaged directly or indirectly with the decision-making process. However, there are some valid reservations about this approach, particularly in situations where there is ‘deep uncertainty’.
Deep uncertainty

‘Deep uncertainty’ refers to a situation where stakeholders do not know, or cannot agree on, the prior probabilities of different states of the world occurring. This is distinct from ‘risk’, in which case the prior probabilities are known and principles, such as expected utility maximisation, can be readily applied.

In a less extreme case of deep uncertainty the probabilities are not known, but the range of possible states of the world might be known. For example, summer temperatures in the UK are projected to increase by between +1°C and +5.2°C by 2050.12

In a more extreme case of deep uncertainty, the range of temperature increase would also be unknown. Under such deep uncertainty, the standard appraisal tools are difficult to apply and may not accurately represent the goals of decision makers, in which case decision rules such as Maximin or Low Regrets become attractive, as they can be used to guarantee a certain level of outcome.

2.3.2 Robust decision making (RDM)

Scenario-based CBA compares the performance of different options across a small number of discrete scenarios, whereas robust decision making (RDM) seeks to compare their performance across all plausible states of the world. RDM is a relatively new appraisal strategy introduced by Lempert et al. (2003)13, and first applied in the context of climate change adaption by Groves and Lempert (2006)14. It was designed specifically to conduct appraisals in situations of ‘deep uncertainty’. Groves and Lempert describe their technique as “a decision analysis based on the concept of identifying strategies robust over a wide range of often poorly-characterized uncertainties” (Groves and Lempert, 2006).

Assessing initiatives in the different scenarios ensures that the uncertainty over climate change and other factors which drive uncertainty over flood risks are taken into account in the appraisal process. Also, by defining optimal initiatives as those that perform well across all potential future states of the world, uncertainty is accounted for directly in the decision-making process.

12 Murphy et al (2009), UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter

Flood risk management and the use of appraisal methods
RDM is carried out by identifying the different parameters that are uncertain, and assuming a range of plausible values these could take. All different combinations of parameters are then created, giving a large number of potential states of the world. No initial assessment is made of the likelihood of these scenarios. However, it is important that care is taken when deciding the upper and lower bounds of possible states of the world. If the analysis goes beyond plausible states of the world and also considers implausible states, this may cause results to tip in the wrong direction.

RDM then assesses how each of the management initiatives performs under each scenario. There are likely to be millions of combinations of states of the world and comparisons of management initiatives. The goal is to search for the states of the world where the proposed management initiatives ‘outperform’ against a particular benchmark. A standard cost-benefit measure is used for this process. The difficulty here is in generating cost and benefit data for so many different states of the world. In a scenario-based CBA it is possible to simply ‘assume’ these values, as the number of scenarios is small, but this shortcut is not available when the number of scenarios is very large, as in RDM. For this reason the costs and benefits must be calculated using a ‘value function’. This calculates each cost and benefit as a function of the scenario parameters and aggregates them, automatically populating the matrix of outcomes. It is the duty of the analyst to ensure that the assumed relationships are plausible and fit the data well, which will require further analytical work.

RDM could be thought of as a continuous version of scenario-based CBA, where all possible scenarios are considered and given equal probability, and where more conservative decision rules may be applied. The value in this is that by considering the whole range of plausible scenarios, RDM leaves ‘no stone unturned’. This is particularly useful if the different parameters of uncertainty are uncorrelated, in which case the areas ‘between’ the stylised scenarios are reasonably likely. This information will add value if the outcomes in the ‘between’ areas of probability space are different to the focal scenarios.

RDM can go further than being a continuous version of scenario-based CBA by using a clustering algorithm to generate a small number of scenarios which aim to capture the key driving forces in deciding between the initiatives. There are different ways of presenting the output, but the key is to provide information that allows the observer to see in a high level form the degree to which some management initiatives are outperforming others under different types of scenarios. Different decision analysis options could be applied to help differentiate further between the performances of the initiatives.

The level of detail required in carrying out RDM will depend on how complex the structure of outcomes proves to be (in terms of preferred option). If the
whole probability space can be accurately summarised on the basis of a small number of scenarios, carrying out the full RDM is unnecessary, and a simpler scenario based analysis will be sufficient. Determining the appropriate amount of meta-analysis of outcomes across scenario space will also depend on appetite for comparing different decision rules. Ultimately, some rule or other must be used.

An assessment about the capacity to implement, explain and interpret this approach will also be needed. Further, its proportionality will need to be considered in each individual appraisal case.

2.3.3 Real Options Analysis (ROA)

Real options analysis extends the principles of CBA to allow for learning about the nature or the extent of climate change and its impact on the efficacy adaptation option(s) being considered (CCRA, 2012).

The Green Book Supplementary Guidance Accounting for the Effects of Climate Change (2009) makes particular reference to the real options approach, suggesting it can be used as a tool to incorporate the uncertainty of climate change and the value of flexibility into decision making when appraising policy options. In particular the Guidance refers to large-scale irreversible projects that can be delayed or later adapted when more information on the effects of climate change are known.

In CBA there is an assumption that investment in flood management initiatives would be based on a ‘now or never’ decision. This means that, once the decision has been made to go ahead, there would be no possibility to turn back or adapt. So, if new information were to develop that changed the flood risk likelihood (either favourably or unfavourably), there could be a significant chance of maladaptive action taking place. The standard appraisal approaches are seen to ignore the potential for flexibility and learning, and this in turn means they will be biased away from such projects and more likely to favour ones that do not provide flexibility, such as large scale fixed format projects.

The real options approach has been developed to assist decision makers when they are in an uncertain environment and they have the ability to be flexible in responding to a changing environment. Real option theory is concerned with valuing this flexibility, and determining the optimal timing of such investment decisions (Ofgem, 2012\textsuperscript{15}).

The approach can account for many of the specificities of flood management initiatives and flood risk more generally. It incorporates uncertainty by considering and valuing the option to ‘scrap’ flexible, reversible initiatives, and

\textsuperscript{15} ‘Real Options and Investment Decision Making’, Ofgem, 2012
implement more appropriate initiatives, or delay large scale irreversible initiatives until more information on the development of flood risks comes to light.

It is important to mention at this stage that none of the three approaches we have described so far incorporates climate change uncertainty explicitly in the appraisal process. Given uncertainty is such a key concern in flood management initiatives and adaptation options more generally, there would be a need to modify these approaches.

2.3.4 Multi-Criteria Approach

In decision making, there are situations in which certain dimensions (such as distributional or psychological impacts) cannot be assigned with a monetary value, even though some may still be quantitatively measured. There may also be severe data limitations on key outcomes that could, in principle, be measured in monetary terms but without sufficient resources or time to do so in the appraisal. When this is the case, they will be excluded from a purely monetary study.

A multi-criteria approach can be used to structure appraisals in the presence of non-monetary information by mapping it onto an ordinal scale, in order to account for the ambiguity in valuing differences between two ‘measurements’. Only the relative position of one ‘measurement’ to another is considered, without the existence of any absolute scale. For example, information can exist on the costs and benefits of an initiative in the form of verbal expressions that can only be measured relative to other expressions and cannot be translated into a monetary dimension.

Within the literature, the different steps and considerations necessary are extensively explained in “Multi-criteria analysis: a manual”, published by the Department for Communities and Local Government (2009). Some literature, such as Munda et al. (1993), focusses on its implementation in an environmental context and has been integrated with Geographical Information System applications.

It is possible to reach a decision through ranking the different options. This is done by formalising the criteria used to appraise the policy, converting the information into a comparable form, and then weighing the strengths and weaknesses of each initiative. As a result, the value of the method is limited to only a relative assessment of alternatives. However, it is a useful approach when

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16 This is the key source of government guidance on multi-criteria analysis and is available at http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf.

the information available is of limited depth and quality or if the assumptions required to implement another methodology (by assigning monetary values) are too implausible.

### 2.3.5 Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) focusses on valuing (again in monetary terms) the private and social costs of particular initiatives that produce a given level of a specific outcome or output. It is an approach that looks to select the lowest cost approach for providing a given level of output. This can be thought of as a form of CBA where the benefits are not measured. This approach can be used in certain situations, but is generally complementary to other appraisal processes. It is used in situations where there is, for example:

- an agreement on a particular social objective, such as to protect a given number of properties from flooding or ensure a minimum loss of life from flood-related incidents;
- a legal requirement to produce a given level of a particular output; or
- a like-for-like replacement of a piece of kit, such as when a new sluice gate is necessary to continue to deliver a given level of output.

Social cost-effectiveness analysis is of relatively limited value in the multiple output world of flood risk management, where there are likely to be significant co-benefits. Also, if costs are to be compared against a fixed level of output, the approach is unlikely to robustly address uncertainty issues.

### 2.4 Conclusions

In this chapter we have explored the context in which flood management decisions are made, the options for managing flood risk, and some of the sectors potentially affected by flooding. A number of different methodologies are potentially applicable for appraising flood management options. Where there is reluctance to measure benefits, or benefits are similar across initiatives, Cost-effectiveness analysis is appropriate. Where there is difficulty in measuring costs or benefits in monetary terms, Multi-criteria analysis may be more appropriate.

There are a number of different approaches for dealing with uncertainty, although they can all be understood as variants of cost-benefit analysis. Where there is the possibility to either to defer investment, or the flexibility to adapt in response to unfolding states of the world, it may be worth explicitly capturing this option value through Real Options Analysis. Where there is ‘deep uncertainty’, robust decision making may be useful in identifying the states of the
world in which decisions will go one way or the other. In smaller scale projects Scenario-based cost-benefit analysis may be more pragmatic.

From the outset it will not necessarily be obvious which of these conditions apply, and which methodology would be appropriate. Above and beyond the choice of methodology, there is also the question of how and in what level of detail a methodology might be applied. This may only become apparent once the data have already been collected and explored. Appraisal methodologies should be used as flexible tools and adapted to the particular circumstances, rather than thought of as off-the-shelf models. We illustrate this further in Chapter 4, where we provide a worked example of a policy appraisal. We follow this in Chapter 5 by drawing out the wider lessons and suggesting a framework to run through when conducting an appraisal.
3 Slowing the Flow project in Pickering – a case study

In this chapter we provide a worked example of how the appraisal methodology discussed in the previous chapter of this report can be used to appraise a particular adaptation action to manage flood risks in the town of Pickering. This is a general appraisal framework which can be applied in many other adaptation contexts, not just that of flood management.

We start by describing the flood management initiative proposed in Pickering, and framing the appraisal question. We then go through the various steps of conducting the appraisal. We identify and measure the costs and benefits, which helps identify the most appropriate appraisal technique for the case study. We present the results across the range of possible scenarios of flood risk and find the package of measures to be beneficial, largely driven by the co-benefits created by the ‘natural’ measures. We then undertake sensitivity analysis, in order to test the robustness of the results and also identify the conditions under which NFM measures are cost effective.

3.1 The flood management initiatives in Pickering

Pickering is a historic market town located in the heart of North Yorkshire. The Pickering area is divided by a number of south-flowing streams, including the River Seven and the Pickering Beck. The town itself lies on the banks of the Pickering Beck, with its population split evenly between its eastern and western banks.

The town is built on a mix of both sandstone and gritstone, and lies to the south of the high moorlands of the North Yorks Moors, through which the Pickering Beck runs southwards. The combination of the town’s largely non-porous foundation and steep terrain of the surrounding areas makes Pickering particularly vulnerable to fluvial flooding in the event of exceptional rainfall. Surface run-off from the surrounding hills flows into the town’s various streams, affecting homes, businesses, and road networks close to the streams’ banks. In this study, we concentrate on the Pickering Beck and River Seven catchments, assessing flood defence initiatives that could potentially manage the risk of fluvial flooding in these areas. The map of these catchments and their relation to the town of Pickering and the surrounding area is provided in Figure 2.

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18 We understand the drained marshland areas to the south of the town are particularly susceptible to non-fluvial flooding. However, this is not considered as part of our analysis.
Figure 2. Pickering Beck and River Seven Catchment Areas

The town itself has been particularly susceptible to flooding, with major floods occurring four times in the past 13 years (1999, 2000, 2002 and 2007). The 2007 floods were the most serious, causing an estimated £7 million of damage to businesses, homes and other local infrastructure.19

These experiences highlighted Pickering as an area of particular interest with respect to flood management, and motivated policy makers to consider, develop and assess potentially viable flood defence initiatives to protect the area from future flood events. This began in 2001, when a feasibility study was carried out to assess the effectiveness of a number of ‘hard’ measures (particularly walls and embankments), as well as other options such as channel widening and channel regrading (EA, 2011).20 However, it was concluded that the proposed measures (walls and embankments) would not be beneficial overall, due to the high monetary cost and negative visual impact they would have on the town. Moreover, they met with strong local opposition. This was confirmed by a later-

19 http://www.forestry.gov.uk/fr/INFD-7ZUCL6
commissioned study looking at the same set of initiatives, which concluded that the scheme should not proceed, given the £6.7m needed for implementation. The conclusion from these studies was that these initiatives could not be justified on cost-benefit grounds.

In 2007, a new package of flood defence measures was developed for the Pickering area, known as the ‘Slowing the Flow’ project. Our appraisal focuses on the measures proposed by this project.

### 3.1.1 The Slowing the Flow Project

The ‘Slowing the Flow’ project in Pickering was set up in response to Sir Michael Pitt’s Review of the 2007 floods in England and Wales, which called for a joint response across government agencies to deliver flood risk management through projects involving greater use of natural processes (Defra, 2011). In particular, the main objective of the project was to demonstrate how land management interventions could help reduce flood risk. In late 2007, it was decided that a set of seven measures to manage flood risk in the Pickering area would be implemented as part of the project, to be developed in phased stages between 2011 and 2013. We understand a range of potential initiatives were considered, with the final package of measures chosen as being the most appropriate, based on the make-up of the landscape in the Pickering area, discussions with stakeholders and the local community, and other area-specific issues.

Below we set out the seven flood risk management measures chosen for Pickering, most of which are ‘natural’ measures:

- Construction of low level bunds
- Planting Riparian and floodplain woodland
- Large Woody Debris (LWD) Dams
- Planting farm woodland
- Blocking moorland drains

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21 See http://news.bbc.co.uk/1/hi/england/north_yorkshire/3630179.stm


23 In particular, land owners resistance to the implementation of previously proposed measures in certain areas (See Nisbet et al, 2008), and the development of hydrological models for the Pickering Beck and River Seven catchments (Odoni and Lane, 2010) were taken into account, as well as the recent development of pioneering ways of incorporating local knowledge into strategic flood risk management (developed by Durham University as part of a Rural Economy and Land Use (RELU) Project).
Establishing no-burn buffer zones along moorland streams

Blocking forest drains, restoring streamside buffer zones, and amending the Forest Design Plan.

In the context of our appraisal, it is this package of measures that we consider.

**Explanation of each of the seven measures**

**Construction of low level bunds**

These were proposed to be a series of earthen mounds extending across the floodplain, connected to pipe bridges that would restrict water flow in times of flooding. The idea to create temporary storage on the floodplain from these low level bunds was proposed by local community groups. However, the requirements of the Reservoirs Act in terms of the volume of water required to be stored to deliver a minimum level of flood protection for Pickering meant that a single fully engineered bund was required, and would be constructed in the Pickering Beck catchment. This would work by creating a temporary reservoir across the floodplain when water flow exceeds a certain limit, helping to reduce the amount of water reaching the watercourses.

In addition, the use of timber bunds made from ‘leaky’ timber walls, is also being trialled on a tributary of the River Seven as an additional part of the project.

**Planting riparian and floodplain woodland**

This involves creating woodland in the form of trees, undergrowth and woody debris on the floodplain within the catchment area (floodplain woodland), and on land adjacent to watercourses (riparian woodland). Woodland in these localities would reduce downstream flood risk through a combination of intercepting overland flow and increasing infiltration, reducing erosion and delivery of sediment to water courses, and slowing the flow on the floodplain through increasing hydraulic roughness. Together these measures help to reduce and delay the flood peak impacting on properties downstream.  

**Large Woody Debris (LWD) dams**

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24 http://www.forestry.gov.uk/fr/1NFD-7ZVEQV

25The presence of the North Yorkshire Moors railway and existing woodland on the floodplain means the project focusses on planting riparian woodland in the Pickering Beck catchment, where 50 hectares of woodland was planned to be planted between 2011 and 2013.  

The project focusses on planting floodplain woodland in the River Seven catchment, where 30 Hectares are planned, again with planting planned to be phased in over 2011, 2012 and 2013. In addition, reseeding in areas of bare peat has taken place to increase roughage and generate heather for use in blocking moorland drains (see below).
These involve the construction of an open framework of logs which, during times of flood, gradually capture debris from surrounding woodland to create ‘dams’. These dams increase flood storage by raising upstream water levels, allowing streams and rivers to reconnect with their floodplains. Due to the need to build and hold woody debris, the dams are usually located in narrow watercourses and in woodland areas. 150 of these LWD dams were planned to be constructed across the Pickering Beck and River Seven catchments.

**Planting farm woodland**

This involves planting woodland on farmland within the catchment area parallel with the contours and along run-off pathways. This woodland would help intercept surface run-off from fields in the event of heavy rainfall and increase infiltration into the ground, thus slowing downstream water flow to streams and rivers. Five hectares of this woodland was planned to be planted, solely in the Pickering Beck catchment, between 2011 and 2013 in phased planting of 0.6, 1.8, and 2.6 hectares in each of the years respectively.

**Blocking moorland drains and establishing no-burn buffer zones**

Moorland drains are blocked by placing heather bales at intervals along the drainage system. These raise water levels within the drains and slow run-off, which reduces water flow and soil erosion. No-burn buffer zones involve establishing 5 metre wide bands either side of drains and watercourses where burning of heather and other vegetation is forbidden. This allows moorland vegetation to improve soil infiltration and increases ‘roughness’ to slow down runoff (Defra, 2011).

**Blocking forest drains, restoring streamside buffer zones and amending the Forest Design Plan**

This involves an update of the Forest Design Plan to:

- Restrict the amount of trees/conifers that can be felled in any three year period (20%) – trees generally sequester more water than shorter vegetation, so is important to minimise the potential impact on flood flows of normal forest management activities.

- Create wider riparian buffer zones next to the watercourses by promoting the regeneration of native trees, shrubs and ground vegetation. This helps increase hydraulic roughness, enhancing water retention and slowing flood flows.

- Promote the restoration of riverbanks to reduce erosion and the blocking of redundant forest drains to slow the delivery of flood waters to rivers
and streams, through incorporating these into cultivation and drainage plans.

**Implementing farm-scale measures**

This involved holding workshops and farm visits to raise awareness of:

- how inappropriate farming activities, such as overstocking, overgrazing and inappropriate cultivation, can damage soil and result in faster surface run-off into watercourses, and;

- the availability of grants from the Catchment Sensitive Farming Capital Grant Scheme, which help fund the installation of sediment ponds, drains on farm tracks and other farming level initiatives to better manage the run-off of water and sediment into watercourses.

### 3.1.2 Previous work and scope for further analysis

In 2011 Defra commissioned Forest Research to conduct an Ecosystem Assessment of the measures part of the Slowing the Flow project, in addition to the overall project report (Defra, 2011).26

Given data limitations, the assessment focussed on three of the seven measures, specifically: the planting of floodplain, riparian and farm woodland, and the construction of Large Woody Debris Dams. In their analysis, Forestry Research chose to follow a CBA-based approach, measuring costs and benefits under a single scenario in which the annual probability of different levels of flooding were linked to their expected severity.27 In identifying costs and benefits, a qualitative assessment was conducted to identify and score the impacts of a number of the measures that were part of the project. Impacts were considered across a wide range of ecosystem services, which were then split into five main categories: provisioning, regulatory, cultural and supporting services, and education and knowledge.28 The set of costs and benefits that were then

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27 For example, a 1 in 100 year severity flood was assumed to occur with an annual probability of 1/100=0.01.

28 The classification and scoring of the impacts was conducted using the UN Millennium Ecosystem Assessment (2005). For more details on how the qualitative assessment was conducted, see ‘Defra FCERM Multi-objective Flood Management Demonstration project, Project RMP5455: Slowing The Flow At Pickering’, Final Report, Appendix 12.5: Report on Ecosystems Services Valuation, Defra, 2011.
monetised were those believed to be most significant (either negatively or positively).

In general, the assessment suggested that the chosen measures would provide benefits far outweighing their associated costs, and yield positive net present values whether using high, central or low estimates to value each of the costs and benefits.

Although we believe the assessment provides a robust analysis of the chosen set of measures and accounts for a wide range of potential costs and benefits, there are still some potential shortfalls in the analysis. In general, we have identified two over-riding issues which could be addressed:

- **Accounting for uncertainty**: although the analytical procedure used was in line with Environment Agency ecosystem assessment guidelines, by using a standard CBA approach, the costs and benefits of each measure were not considered across a range of flood risk scenarios. As a result, the uncertainty surrounding flood risk which we highlighted in Chapter 2 of this report is not fully accounted for.

- **Applicability of results in other policy contexts**: given the limited data available at the time of the assessment, Forest Research were only able to consider a subset of the complete package of measures. By appraising a subset of measures independently of the rest of the package, interdependencies between the two were not accounted for. In the end, a selection of measures was assessed that would not provide a comprehensive level of flood protection independently of the other measures in the package. As a result, the extent to which the results of that study can be generalised is limited.

By considering the broad range of appraisal methodologies available in the context of flood risk management, and following an intuitive procedure to choose and implement the most appropriate appraisal methodology, we have produced a robust analysis which is proportional to the initiative proposed, and goes a long way to addressing the issues highlighted above. By appraising a whole package of measures, the results can be generalised more widely, as can the overall appraisal methodology.

We account for uncertainty surrounding flood risk by considering the costs and benefits generated by the package of measures across a number of scenarios representing different levels of flood risk. This is supplemented with sensitivity analysis surrounding key parameters in the analysis, allowing the reader to see

how the appraisal decision may vary depending on the analytical approach used as well the future level of flood risk. In order to identify whether the package of measures is robust in the presence of uncertainty, we use a simplified RDM analysis to assess outcomes across the range of possible states of the world. Although RDM has been discussed extensively in decision-making literature, practical application of it is limited.

By building on the data used in the previous ecosystem assessment and exploiting information that has come to light following this, we consider the full package of measures for appraisal, allowing analysis that is both meaningful and applicable to wider policy contexts. We believe the appraisal is proportionate to the proposed set of measures and provides outputs that allow for richer interpretation and more informed policy decisions.

3.2 Carrying out the appraisal

In this section we set out the various steps taken in appraising the options under consideration. This can be thought of as a ‘toolkit’ which could be used more widely to appraise a range of different adaptation actions.

As a first step, we need to identify the appraisal question to be answered and the strategies we are considering in our analysis. As part of this process we identify two strategies, notably the measures implemented as part of the Slowing the Flow Project and the ‘baseline’ strategy. Once the baseline is defined we then need to identify and measure the relevant costs and benefits. This has strong implications for which types of appraisal methodology are appropriate. In this case we are comparing options that have different outputs (so a CEA is not appropriate), and we believe that both costs and benefits can be monetised (so MCA is not necessary). It is therefore appropriate to implement some form of CBA, although the precise form of it depends on the nature of the uncertainty faced. When exploring how the options compare at either ‘extreme’ end of the uncertainty, we find that the preferred option depends on the level of flood risk and the values placed on the co-benefits. We therefore conduct a simplified RDM exercise to identify the states of the world in which the package is optimal, and those states in which the ‘business-as-usual’ option is preferable.

3.2.1 Identifying the appraisal question

In carrying out any appraisal, the first step is to identify the question that is to be answered. In order to do this, the ‘baseline’ i.e. the situation in which any proposed initiative is not implemented, must first be defined. Initially defining this baseline not only allows the policy maker to understand the risks and potential costs that are faced in the absence of any policy intervention, but also
aids the appraisal analysis by providing a benchmark against which each proposed initiative can be measured.

Generally the baseline represents the likely development of the specific policy environment in the absence of any intervention. In the context of flood management initiatives, this requires an assessment of whether the affected population *self-adapts* without such initiatives being implemented (for example, households might independently take additional resilience measures). Identifying whether any additional self-adaption would take place is important, as this would reduce the incremental value of any benefit generated by the initiatives which would already be counted within the baseline.

As is highlighted in Phase One of the ECR report, in areas with a long-term history of flooding, there is evidence that local communities have already ‘self-adapted’ in preparation for repeat flood events. For example, in response to the severe floods of 2007 in Hull, local organisations took a range of adaptation actions, including developing a Surface Water Management Plan, flood alleviation schemes, and mobilising volunteer organisations. We can therefore assume that the local community and associated organisations in the Pickering area are relatively adaptive, and have already self-adapted in light of expected future flooding.30 There is evidence of this, notably the creation of the Ryedale Flood Research Group in 2007, set up to understand better the risk of flooding faced by Pickering and other neighbouring towns.31

We think it plausible to assume that, in the absence of any intervention being implemented, there would not be any additional self-adaptation in the Pickering area.32 We therefore define the baseline as a ‘business as usual’ scenario in which adaptation actions already in place continue into the future, but where no additional adaptation action is taken. We note that potential factors, such as advances in technology, may provide opportunities for households and business to further self-adapt33; however, we rule this out as a possibility at this stage, as we cannot assume such technological development will occur with any degree of certainty.

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30 In other words, we can assume Pickering is at its limit of adaptive capacity in terms of protection against future flood risk.


32 Whilst the assumption of no additional self-adaptation seems sensible in this appraisal, this may not be the case in other appraisals and will need careful consideration.

33 For example, technological advancements may reduce the cost of household resilience measures, making them viable to a larger proportion of the local population.
The Appraisal Question

Having defined the baseline, the next step is to identify the relevant appraisal question to be answered. Given the set of measures proposed as part of the Slowing the Flow Project, we aim to answer the following policy question:

- **Is the implementation of the 7 measures cost-effective on cost-benefit grounds, relative to a situation where no flood defences are put in place?**

In this sense, we compare the following two strategies:

1) The implementation of the *package* of seven measures;

2) The ‘business as usual’ strategy i.e. the baseline scenario in which none of the seven measures is implemented.

We believe it is appropriate to appraise the package of seven measures collectively, rather than appraising each measure individually, due to interdependencies between the measures. The interdependencies arise because the effectiveness of one flood abatement measure is likely to be dependent on the implementation of another. For example, how effective LWD dams are in slowing flood flows will be dependent on the volume of water reaching the watercourse itself, and thus on the planting of woodland shrubbery and established no-burn buffer zones.

We now consider the ‘Business as usual’ strategy in more detail, in order to identify the risks and potential costs that could be faced in the absence of any policy intervention. Since we assume no additional independent adaptive action is taken under this baseline strategy, there are no potential benefits and inherently, no potential costs generated in relation to implementation or construction. However, a direct and potentially significant cost could be generated in the form of flood damage to properties and businesses. Although this could be measured specifically as a cost relating to the baseline strategy, since such damage would be avoided by the proposed initiative, we can instead define it as a benefit generated by the proposed set of measures. As a result, the costs arising under the baseline (counterfactual) are normalised to zero. This means that the estimated costs and benefits associated with the proposed initiative we produce are ‘incremental’ costs and benefits i.e. those that are likely to arise over and above those that would be generated if the initiative was not implemented.

### 3.2.2 Identifying and measuring costs and benefits

Having identified the baseline scenario and the likely costs generated under it, the next step is to identify and measure the likely costs and benefits generated by the proposed set of initiatives. As we mentioned in section 2 of this report, many flood defence initiatives, as well as many of the wider adaptation policy options,
will generate costs and benefits across a wide range of sectors, both direct and indirect. All of these costs and benefits will need to be considered.

In the context of the Slowing the Flow project, it is important to account for the impacts of the measures in terms of ecosystem services, given their use of ‘natural’ materials. In this regard, there is extensive guidance on how to identify and measure costs and benefits in the environmental literature. A very useful source is the ‘UN Millennium Ecosystem Assessment’ (2005), which suggests using a qualitative procedure to identify and categorise the impacts of the proposed measures, using a panel of relevant stakeholders and experts to score them based on their likely significance.

The earlier Forest Research assessment in Pickering had already quantified a wide range of potential costs and benefits in this way. In order to avoid unnecessary repetition, we use the same set of costs and benefits. Table 3 provides the list of potential costs and benefits identified across the five categories, along with their associated scoring.  

34 ‘+’ and ‘-’ represent those impacts likely to have a positive and negative impact respectively; ‘++’ and ‘- -’ represent those that were thought to have a significant positive or negative impact.
Table 3. Scores assigned to the likelihood of impact of the project measures on ecosystem services

<table>
<thead>
<tr>
<th></th>
<th>Bunds</th>
<th>Woodland creation</th>
<th>Stream / drain restoration</th>
<th>Farm measures</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provisioning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Food</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Fibre &amp; Fuel</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Genetic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biochemicals</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ornamental</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Regulatory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air quality</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Climate</td>
<td>-</td>
<td>(+)</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Water / flood</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Natural hazard</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Pest</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Disease</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Erosion</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Water quality</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Pollination</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Cultural</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heritage</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Recreation</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Spiritual</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Art / folklore</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Social relations</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Education</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td><strong>Supporting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Primary production</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Nutrient cycle</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water recycling</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Photosynthesis</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Habitat</td>
<td>0</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>

Source: Forest Research

There are several potential costs or benefits which we do not explicitly capture, but which we believe are either small in magnitude or difficult to quantify relative to the potential size:
The bunds might provide ecosystem benefits, such as habitat creation. We believe these are likely to be small, as a bund will only hold water very rarely.

The blocking of moorland drains will encourage the soils to store more carbon and therefore have a climate regulation effect. However, this is difficult to quantify.

There may be some on-going maintenance costs, but these are captured within a contingency budget in the costing of the scheme.

There are embedded CO$_2$ emissions arising in the bunds’ construction. However, the majority of these will likely be covered by the EU Emissions Trading Scheme, as the materials used in construction are likely to originate from within the EU. In this case, the emissions generated have already been internalised in the purchase price, removing the need to consider these as a net cost in the appraisal analysis.  

There may also be risks of turning areas into wetlands with floods, then letting them dry out. There could be an impact on health if re-wetting occurs within 3 years, in which case disease vectors such as mosquitoes could breed rapidly, potentially increasing the risk from vector borne disease.

There may be potential health benefits from recreational use of the green spaces. Again this is difficult to quantify.

Having identified the wider set of costs and benefits, it remains to decide which of these will be considered in the appraisal analysis. Although it would be preferable to consider all potential costs and benefits, this is not necessarily feasible, and it is pragmatic to focus only those impacts that are likely to be significant. In light of this, we consider the same set of costs and benefits used in the previous Forest Research Study, as these had already been deemed to be

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35 We note that emissions may also be generated in the construction of other measures part of the Slowing the Flow Project, for example, in the planting of farm, riparian and floodplain woodland. By following similar arguments to those here however, we also do not consider these when appraising the complete package of measures. However, where large volumes of materials are likely to be imported from areas outside emissions trading schemes (e.g. China and much of the Middle East), this should be accounted for within the appraisal process in line with DECC guidance (see “Valuation of energy use and greenhouse gas emissions for appraisal and evaluation”, DECC, October 2011. http://www.decc.gov.uk/assets/decc/statistics/analysis_group/122-valuationenergyuseggemissions.pdf

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Slowing the Flow project in Pickering – a case study
those likely to be most significant. The list of these costs and benefits is provided below:

**Costs:**
- Building and Implementation Costs
- Lost agricultural production on the land used to plant riparian, floodplain and farm woodland and to construct the flood storage bunds.

**Benefits:**
- Flood regulation (as identified in section 3.2.1)
- The provision of natural habitats
- Climate regulation
- Erosion regulation
- Provision of education and knowledge from site visits
- Community development

We recognise that this set of costs and benefits is not exhaustive. Some of the benefits we do not consider, such as the provision of recreation services and the abated water contamination, could be significant if they were monetised. As a result, our appraisal places a conservative estimate on the value likely to be generated by the set of measures to be implemented in the Pickering area.

**Measuring the costs and benefits**

Having identified the types of costs and benefits to be considered, the next step is to consider how they will be measured. This can affect the choice of appraisal methodology. For example, if there were concern that the costs and benefits are significant but cannot be monetised, then Multi-criteria analysis might be attractive. Likewise, if there were reluctance to measure benefits and indirect costs, a Cost Effective Analysis might be adopted.

In general, the approach used to measure each potential cost and benefit will depend on the data available and the timeframe within which the appraisal has to be conducted. As we highlight in more detail in Chapter 4 of this report, the data used in conducting the appraisal analysis can take many forms and can be taken from a number of sources. If there is sufficient time, then primary data can be collected (through WTP surveys for example) and costs/benefits can be measured using the appropriate valuation techniques (such as hedonic pricing, contingent valuation, and discrete choice experiments). On the other hand, if time is more limited, or the scale of the investment being appraised is small, it
may be preferable to use data that is readily available, using cost and benefit transfers from other studies.

Overall, a pragmatic approach to measuring costs and benefits should be taken. For this case study, we broadly follow the approach taken in the Forest Research assessment. However, we do use some new information that has come to light following the completion of that study. **Table 4** provides a summary of the approaches used to measure each type of cost and benefit, and the data that is used. More detailed explanations are found in the Annex to this report.
### Table 4. Summary of measurement approach for each type of cost and benefit

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Approach</th>
<th>Data Used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flood Regulation</strong></td>
<td>The annual expected cost of flooding was obtained by multiplying the</td>
<td>• CCRA (annual probabilities)</td>
</tr>
<tr>
<td>(Flood Abatement)</td>
<td>estimated damage costs in the event of floods of different severities, by</td>
<td>• 2007 total flood damage (Forest Research)</td>
</tr>
<tr>
<td></td>
<td>the annual probability of these floods occurring. This expected annual</td>
<td>• Average flood damage per household across England (Defra, 2008)</td>
</tr>
<tr>
<td></td>
<td>cost (flood abatement benefit) was then apportioned to each measure</td>
<td>• Forest Research/Durham University hydrological study (water storage estimates)</td>
</tr>
<tr>
<td></td>
<td>based on the proportion of the total water storage required to abate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>each type of flood provided by each of the measures.</td>
<td></td>
</tr>
<tr>
<td><strong>Provision of Habitats</strong></td>
<td>We focussed on the habitat generated by woodland planting. The value</td>
<td>• Hectares of woodland intended to be planted (Forest Research).</td>
</tr>
<tr>
<td></td>
<td>of habitats was estimated by multiplying indicative habitat values per</td>
<td>• Non-use values of woodland diversity and cultural services (Eftec, 2008, 2010).</td>
</tr>
<tr>
<td></td>
<td>hectare for each type of woodland by the number of hectares of each of</td>
<td>• Value of inland marshes (Defra, 2011)</td>
</tr>
<tr>
<td></td>
<td>these types intended to be planted. Estimates were inflated to 2012/13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>prices, and accounted for the phased planting and expected growth rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of the woodland.</td>
<td></td>
</tr>
<tr>
<td><strong>Climate Regulation</strong></td>
<td>Again we focussed on the climate regulatory benefits likely to be</td>
<td>• Hectares of woodland intended to be planted (Forest Research).</td>
</tr>
<tr>
<td></td>
<td>provided by woodland planting. The climate benefit was taken to be the</td>
<td>• Forest Research C-SORT model (carbon estimates)</td>
</tr>
<tr>
<td></td>
<td>value of the carbon sequestered by the woodland. The total number of</td>
<td>• Non-EU ETS Carbon prices (social values of carbon) (DECC)</td>
</tr>
<tr>
<td></td>
<td>hectares of all woodland was multiplied by per hectare carbon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sequestration rates (adjusted for factors such as thinning and tree</td>
<td></td>
</tr>
<tr>
<td></td>
<td>spacing) and in turn by relevant carbon prices. Again, estimates were</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inflated to 2012/13 prices, and accounted for the phased planting and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>expected growth rate of the woodland.</td>
<td></td>
</tr>
<tr>
<td><strong>Erosion Regulation</strong></td>
<td>The benefit accrued through abating erosion in the watercourse is taken</td>
<td>• Dredging costs (Norfolk Broads 2005/06).</td>
</tr>
<tr>
<td></td>
<td>as the abated dredging costs. This was estimated by multiplying an</td>
<td>• Estimated sediment delivered to the watercourses (Defra, 2011)</td>
</tr>
<tr>
<td></td>
<td>indicative dredging cost value (per m³) by the estimated annual volume</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of sediment delivered to the watercourse. Again, estimates were</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inflated to 2012/13 prices, and accounted for the phased planting of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the woodland. Again, given that the erosion benefit generated by the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>other measures is likely to be minimal, we focussed on the benefit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>generated by the planned woodland planting.</td>
<td></td>
</tr>
</tbody>
</table>

Slowing the Flow project in Pickering – a case study
### Benefit Approach Data Used

**Education and Knowledge from Site Visits**
The benefit generated from educational visits to the site was taken as the potential cost savings associated with visits to the sites in Pickering, versus existing alternative sites further afield. This was estimated by multiplying the expected number of annual visits by an indicative cost saving per visit.

- Expected number of annual visits (own assumptions)
- Mean incremental cost values per visit (Forest Research)

**Community Development**
Green spaces can give community benefits in terms of both health and social cohesion. Benefit is taken to be the value of volunteer time expected to be contributed to the implementation and maintenance of the package of measures. The time was valued by multiplying expected volunteer time (on a working hour basis) by an average hourly wage (Volunteer England approach).

- Expected Volunteer hours (Forest Research)
- National minimum wage – over 21s (ONS)
- Gross mean wage in the Ryedale council district (ONS)

### Cost Approach Data Used

**Building and Implementation Costs**
The implementation cost of LWD dams and woodland planting was estimated by multiplying the number of units of each measure (count for LWD dams, hectares for woodland) by estimated annual (per unit) construction and maintenance costs. For the flood storage bund, blocking moorland & forest drains, establishing no-burn buffer zones, and farm-scale measure, indicative cost values were used. Estimates again account for the phased implementation of the measures.

- Amount of each measure planned to be implemented (Forest Research)
- Unit cost of woodland and LWD dams (Forest Research)
- Cost of the flood storage bund, blocking moorland drains, establishing no-burn buffer zones, and farm-scale measure (Forest Research/EA)

**Lost Agricultural Production**
Estimates focussed mainly on woodland planting (see Annex A for more details). Estimates were obtained by multiplying the amount of farming land displaced by the value of the land displaced, varying by its current use. Estimates were inflated to 2012/13 prices, and accounted for the staged implementation of the measures.

- Land displaced (by measure) (Forest Research)
- Value of alternative land uses (McBain & Curry, 2010)

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36 See for example Faculty of Public Health work in this area: http://www.fph.org.uk/uploads/r_great_outdoors.pdf

### Slowing the Flow project in Pickering – a case study
3.2.3 Initial screening of appropriate appraisal methodologies

Having identified the relevant costs and benefits and the appropriate means to measure them, we then need to consider which methodologies might be suitable in this context. We begin by considering the full set of potential methodologies (discussed in detail in Chapter 2).

First, we consider the suitability of the Multi-Criteria Approach (MCA). When costs and benefits cannot be converted into a monetary form, MCA provides a pragmatic way of comparing strategies on a relative scale. For the Pickering study we consider there to be sufficient quantitative data available to monetise all relevant costs and benefits in a sufficiently robust manner, so a solely quantitative methodology\(^{37}\) is most appropriate. This approach allows cardinal comparisons to be made between strategies, and allow for likewise comparison with wider policy options.

Next, we consider Cost-Effectiveness Analysis (CEA). CEA is potentially useful when policy options have to generate a particular output that needs to be met (e.g. a comprehensive level of flood protection). A strategy is considered optimal if it generates this output at lowest cost relative to alternatives. However, CEA is only useful if multiple strategies for generating the same particular output are being compared (e.g. choosing between one material and another to build a defensive wall). This is not the case in Pickering, so CEA is not appropriate here.

Of these solely quantitative-based approaches, we then consider Real Options Analysis (ROA). This approach addresses option value, which arises where there are either sunk costs, flexibility to respond to new information, or significant uncertainty which is likely to be resolved within the time-frame of the analysis. In the context of Pickering, the 'natural' measures are likely to generate indirect benefits that are largely independent of the level of flood risk.\(^{38, 39}\) Therefore, the

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\(^{37}\) Although, several non-market values are omitted from the study, we judge the gain in tractability and generality from using a solely quantitative measure to exceed the benefit of capturing these miscellaneous items.

\(^{38}\) For example, planting trees will lead to the sequestration of carbon, and is likely to reduce soil delivery into the watercourse, abating the destruction of aquatic habitats and reducing the need for costly sediment dredging. These benefits are likely to accrue irrespective of flooding events occurring, and thus are likely to be generated no matter the level of flood risk that is realised in the future. The previous Ecosystem Assessment on the effects of this initiative suggest that these co-benefits are likely to make up a large proportion of total benefits, with the benefit from carbon sequestration alone estimated to account for approximately a half of the total benefits accrued by the measures they considered. As the real options approach only values flexibility in the light of uncertainty over costs and benefits, the effect on the estimated value of the initiative (and thus the appraisal decision) when using a real options approach is likely to be small.

\(^{39}\) Note that if it was decided at this stage that ROA should be seriously considered as an appropriate methodology, a judgement would still need to be made on whether the appraisal decision is likely to
costs and benefits affected by uncertainty surrounding flood risk are likely to be only a small proportion of the total costs and benefits accrued. In this case, ROA adds little value, relative to other approaches to CBA.

This leaves scenario-based cost-benefit analysis (SBCBA) and robust decision making (RDM) as potential options for the appraisal methodology. If we believe the relative performance of the two strategies is markedly different in different states of the world, then RDM is a more powerful tool for exploring this. In order to determine whether this is the case, we define scenarios to capture the ‘true extremes’, generating the limiting outputs for the package of measures across possible states of the world and cost and benefit valuations. Under a scenario of high flood risk and high valuation of co-benefits, the package of measures results in strong net benefits, whereas under a scenario of low flood risk and low valuation of co-benefits, the package of measures results in net costs. Since the results of the appraisal depend on these assumptions and uncertainties, we choose to use RDM as an appraisal methodology, albeit in a simplified form.

3.2.4 Implementing RDM

As mentioned in Chapter 3 of this report, a significant challenge of using RDM approach is that it requires a value function in order to generate the costs and benefits arising in each state of the world. It might not be at all obvious what costs and benefits are in each of 10,000 different scenarios. In the case of this appraisal, the key dimension of uncertainty is the level of flood risk, which is driven by the probability of different flood events occurring. Since the level of flood damage is a product of the probability per flood event and the cost per flood event, this gives a value function that is relatively simple. By varying the probability of floods we can derive the value of flood damage in each state of the world.

In light of this, we use a methodology that draws on the benefits of RDM, allows equally useful and robust outputs to be produced, and exploits the complete set of data that we have at our disposal, but which is not too computationally or data intensive. This ensures the appraisal analysis is proportionate to this small-scale project. This framework can be used in other appraisals.

It is then necessary to define the range of uncertainties that will be covered by the RDM. The task is to ensure the set of scenarios used capture the key uncertainties around the states of the world which are likely to have a material impact on the appraisal decision. We capture flood risk by identifying the

be marginal. As will become clear, this judgement should be reserved until the outputs of an initial SBCBA are generated.
extreme values it could take and then deriving ‘intermediary’ scenarios, by using constant intervals to divide between these extremes.  

Flood risk can be characterised by the severity and frequency of flood events. We operationalise these as follows:

**Severity of flooding** – the more ‘severe’ the flood is, the greater the damage in the event of flooding. In the context of Pickering, the Forest Research study provides details of the costs of two severities of flood: the particularly severe flood in 2007, classed as ‘1 in 100 year’, and a flood of smaller magnitude in 2000 classed as ‘1 in 25 year’. Given that data is not available for other severities of flood, we focus only these two. Note that the classes, ‘1 in 100 year’ and ‘1 in 25 year’ floods, do not refer to actual frequencies or probabilities. In order to avoid confusion we refer to them as ‘high severity’ and ‘medium severity’ floods respectively.

**Frequency of flooding** – the more frequent flood events are, the more likely that the damage incurred by such as flood is realised. To capture the frequency of flooding, we use the annual probability of each severity of flood occurring. We take the estimated annual probabilities from the CCRA report titled ‘Climate Change Risk Assessment for the Floods and Coastal Erosion Sector’. This provides current estimated annual probabilities for the main UK river catchments for a range of flood severities, as well as forecasted probabilities for these floods in 2020, 2050 and 2080 under different assumptions on the level of carbon emissions. We use variations in the annual probabilities of the two severities of flood occurring as the sole driver of flood risk. We then assign the particular annual probabilities to each of the flood severities across the different scenarios. We use the $10^{th}$ percentile 2020 and $90^{th}$ percentile 2080 estimates to define the upper and lower limits of flood risk, taken from the Humber catchment (as data for the Pickering catchment is not available).

**Table 5** summaries the range of flood probabilities.

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40 We use 20 scenarios in total. Although a larger number could have been used (together with tighter intervals), this would not add any value, as the NPV is linear in the assumed probability.

41 ‘Climate Change Risk Assessment for the Floods and Coastal Erosion Sector’, CCRA, January 2012

42 Although point estimates of annual probabilities are provided explicitly in the report, the whole probability distribution for each severity of flood was estimated at each point in time, allowing us to exploit probabilities at different parts of these distributions.
Table 5. Summary of flood probability ranges used

<table>
<thead>
<tr>
<th>Severity of flood</th>
<th>Probability of flood occurring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>High severity</td>
<td>0.01</td>
</tr>
<tr>
<td>Medium severity</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Source: Frontier Economics analysis of CCRA data

We understand there are many other factors that generate uncertainty over the appraisal decision. For example: the valuations used to measure costs and benefits, the assumed effectiveness of each measure in providing flood protection, and the choice of appraisal horizon and discount rates. However, as these uncertainties arise from assumed values, they do not relate directly to the states of the world realised in the future. Therefore we do not consider these as scenario dimensions. Instead, we perform sensitivities around these parameters, to determine whether the robustness of the appraisal decision made is affected by different assumptions on their value. This keeps the analysis tractable without any loss of generality.

Our analysis then involves measuring the costs and benefits, and in turn the NPV, generated by the package of measures across each of the states of the world. In order to aid interpretation, when then produce a number of additional outputs:

- The percentage of scenarios in which the proposed set of measures generates a positive NPV.
- The ‘threshold probability’ i.e. the point at which the NPV turns negative, (if this occurs at all).
- Charts illustrating how the NPVs generated vary across the scenarios.

Because RDM was developed specifically to deal with situations where there is reluctance to place probabilities on scenarios, little emphasis is placed on summarising outcomes in terms of probability-weighted NPVs. Nevertheless, they may be required in order to facilitate cross-appraisal comparisons (e.g. compare initiatives taken in different local areas). We assign equal probabilities to scenarios in order to calculate the probability-weighted NPV. For the purposes of conducting an appraisal, however, we would suggest placing much greater emphasis on the proportion of scenarios in which a certain option is preferred than on any probability-weighted NPV.

Slowing the Flow project in Pickering – a case study
3.2.5 RDM results

We now outline the central estimates of our results, and their implications for the strength of the package of measures, in terms of cost-effectiveness and the appraisal decision. We then provide the results of the sensitivity analysis and identify those parameters which materially affect the robustness of the appraisal decision to the level of flood risk realised.

**Figure 3** presents the central estimates of the NPVs generated by the package of measures across the 20 scenarios considered, in a graphical format. Here we use assumptions on values and effectiveness of measures that are at the middle of their ranges. The scenarios are numbered in ascending order of the level of assumed flood risk.

**Figure 3.** NPVs generated across the scenarios

![Graph showing NPVs generated across the scenarios](image)

Source: Frontier Economics

As is clear from the **Figure 3**, under the central valuations, the package of measures generates positive net benefits, regardless of the level of flood risk realised. The benefits generated relative to the associated costs increase steadily with the level of flood risk. This is driven by the increase in expected flood damage (and thus expected cost saving generated by the measures) in any given year, resulting from the increase in the annual probability of each of the flood severities occurring. Because the package of measures generates net benefits across all scenarios, it gives a positive probability-weighted net benefit, suggesting the package should be implemented under the ‘expected value’ decision rule. As
a result, based on these central estimates, the case for implementing the package of measures is strong.

To give some idea of the relativity between the costs and benefits of the package, we illustrate them in Table 6 below. Clearly, these will vary across states of the world. The figures we provide use our central assumptions on valuations and a level of flood risk that is at the middle of the range considered.

Table 6. Benefits and costs in the central case

<table>
<thead>
<tr>
<th>Benefits / costs</th>
<th>Estimate (£’s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Flood Damage Abatement - Woodland and LWD dams</td>
<td>760,103</td>
</tr>
<tr>
<td>Flood Damage Abatement - Other measures</td>
<td>2,072,091</td>
</tr>
<tr>
<td>Habitat Creation</td>
<td>1,198,697</td>
</tr>
<tr>
<td>Climate Regulation</td>
<td>2,825,333</td>
</tr>
<tr>
<td>Erosion Regulation - Woodland and LWD dams</td>
<td>6,242</td>
</tr>
<tr>
<td>Erosion Regulation - Other measures</td>
<td>0</td>
</tr>
<tr>
<td>Education and Knowledge</td>
<td>1,300</td>
</tr>
<tr>
<td>Community Development</td>
<td>37,335</td>
</tr>
<tr>
<td><strong>Total Discounted Benefits</strong></td>
<td>6,901,100</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Building and Implementation Costs - Woodland Planting and LWD dams</td>
<td>540,449</td>
</tr>
<tr>
<td>Building and Implementation Costs - Flood Storage Bunds</td>
<td>2,153,843</td>
</tr>
<tr>
<td>Building and Implementation Costs - Other measures</td>
<td>243,574</td>
</tr>
<tr>
<td>Loss of Agricultural Production - Woodland Planting and LWD dams</td>
<td>676,862</td>
</tr>
<tr>
<td>Loss of Agricultural Production - Other measures</td>
<td>21,534</td>
</tr>
<tr>
<td><strong>Total Discounted Costs</strong></td>
<td>3,636,261</td>
</tr>
<tr>
<td><strong>Scenario-specific Net Benefit/Costs</strong></td>
<td>3,264,838</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

The robustness of the set of measures across different levels of flood risk can be affected by the assumed value of the parameters used in the analysis. As such, conducting sensitivity analysis is important to identify whether our findings
change if different parameter values are used. The following section outlines the parameters we use for conducting sensitivities and presents the results of the analysis, allowing us to determine whether changes in these values affect how robust the proposed measures are to different levels of flood risk. This approach to sensitivity analysis can be applied in other appraisals.

3.3 Sensitivity analysis

Sensitivity analysis is important because particular parameters used in the appraisal may significantly influence the estimated costs and benefits generated by the proposed initiatives. Sensitivity analysis is important in determining whether the appraisal decision made is robust to reasonable changes in the values of these parameters i.e. whether the decision made is a product of the assumptions made on parameter values, or on the attributes of the proposed initiatives themselves.

In addition, through threshold analysis, it can highlight the value of a particular parameter (holding everything else constant) at which the proposed initiative generates a zero NPV. This then helps to identify the range of parameter values over which the initiatives are deemed effective or ineffective. In this context, we focus on the threshold levels of flood risk i.e. the levels of flood risk that would have to be realised in the future for the package of measures to generate a zero NPV, given that particular parameter values are used.

In this section, we start by outlining the parameters we chose for sensitivity analysis. We then present the results of the sensitivity analysis around each of these parameters, identifying whether any have significant influence on the robustness of the measures to the level of flood risk. We find that overall, the case for implementing the set of proposed initiatives is robust to reasonable changes in some parameter values, but not in others. Following this, we present the results of threshold analysis, for parameters where this was applicable.

Parameters selected for sensitivity analysis

It would be possible to conduct sensitivities around all parameters used in the appraisal analysis, but this may be excessive. It is therefore best to focus on those parameters expected to have the greatest impact on the values of costs and benefits and thus the appraisal decision. In the case of this appraisal, we can identify the important parameters by the size of the costs / benefits. Below we
outline the set of parameters we deemed to be potentially important in driving the decision:45

- **Co-benefits** – given the co-benefits make up a significant proportion of the total benefits generated by the set of measures, we thought it useful to see how reasonable changes in the value of these co-benefits would affect the appraisal decision. In this case, we varied all co-benefits proportionally.

- **Climate Regulation** – the largest of the estimated co-benefits was the climate regulation benefit, generated through the sequestration of CO$_2$ by the proposed woodland planting. Given its magnitude, we again believed it would be useful to see how the appraisal decision would be affected by reasonable changes in this benefit.

- **The effectiveness of the measures (water storage provided)** – one of the main drivers of the flood damage benefit generated by the package of measures is the amount of water the measures could store in the event of a flood. However, given the ‘semi-engineered’ nature of some of the measures, it is possible that the amount of water actually stored may be lower than that expected (for example, LWD dams could be potentially washed away in the event of strong water flows). As a result, we believe it would be useful to understand whether the robustness of the measures to the level of flood risk is affected by reasonable changes in the water stored by each measure. As with the co-benefits, we vary the water stored by each of the measures proportionally.

- **Valuation of costs and benefits** – as was highlighted when considering the extreme scenarios, the values of inputs used when ranges of values are provided can considerably affect the value of estimated costs and benefits and in turn net benefits. Thus, we chose to see how the analysis changes in the light of changes in the values used. As the mid-points of any ranges were used to generate the central estimates, we use the lower and upper bounds of these ranges for the purposes of sensitivities.

- **Appraisal horizon and discount rates** – in addition to the parameters above, we see how the results change in response to reasonable changes in the discount rates used, and the horizon over which costs and benefits are measured.

3.3.1 Results of sensitivity analysis

45 In forward-looking appraisals we would recommend this be decided upon through consultation with relevant stakeholders and decision makers.
Having chosen the set of parameters to be considered, we test the robustness of the appraisal decision to changes in each of the parameters, holding others constant. Table 7 outlines the magnitude of the changes in each of the parameter values we use to conduct our sensitivity analysis. Ideally, the ranges used for sensitivity will be based on objective criteria, such as the ranges of an estimate that have been presented in the literature. In other cases it is not always obvious what a ‘reasonable’ change is. In that case, the same magnitude of range should be applied across parameters, so that the relative impact of different parameters on the outcome can be understood. In any event, we would recommend that in forward-looking appraisals, consensus on the magnitude of these changes should be reached across the relevant stakeholders and decision makers.

Table 7. Changes used in the sensitivity analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Changes used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-benefits</td>
<td>+/- 50%</td>
</tr>
<tr>
<td>Climate Regulation</td>
<td>+/- 50%</td>
</tr>
<tr>
<td>Valuation of Costs and benefits</td>
<td>Upper/Lower bounds</td>
</tr>
<tr>
<td>Effectiveness of the measures</td>
<td>+/-50%</td>
</tr>
<tr>
<td>Appraisal Horizon</td>
<td>25 years and 50 years</td>
</tr>
<tr>
<td>Discount rates</td>
<td>+/- 1 percentage point</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

Table 8 below presents the percentage of scenarios in which the package of measures generated net benefits, under the central estimates and given the changes in each of the parameters considered. The table highlights that the effect of changing parameter values on the case for implementation depends on the particular parameter that is changed. Across most sensitivities, the case for implementation is strong. It is only where the appraisal horizon is sharply truncated, or where the lowest valuations on benefits are used, that this is not the case.
Table 8. Percentage of scenarios in which net benefits are generated

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Original</th>
<th>Downwards Sensitivity</th>
<th>Upward Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-benefits</td>
<td>100%</td>
<td>85%</td>
<td>100%</td>
</tr>
<tr>
<td>Climate Regulation</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Valuation of costs and benefits</td>
<td>100%</td>
<td>40%</td>
<td>100%</td>
</tr>
<tr>
<td>Effectiveness of the measures</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Appraisal Horizon</td>
<td>100%</td>
<td>35% (100 years)</td>
<td>100% (50 years)</td>
</tr>
<tr>
<td>Discount rates</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

Below we consider the effects of changes in each of the parameters in more detail.

**Co-benefits**

Figure 4 provides a graphical illustration of the effects on the set of net benefits/costs if the value of co-benefits is 50% lower or higher than that expected:
Figure 4. Effect of changing the value of co-benefits

Source: Frontier Economics

As is apparent from the chart above, a change in the value of the co-benefits expected to be generated by the package of measures has a considerable impact on the net benefits/costs across the scenarios. More specifically, if the value of co-benefits is 50% higher or lower than expected, both the scenario-specific and probability-weighted NPVs increase/decrease by over £2,000,000. As mentioned previously, this is driven by the fact co-benefits make up a large proportion of the total benefits generated by the measures.

Looking at the effects more closely, the analysis suggests that, if the value of co-benefits is 50% lower than assumed, the set of measures generates net costs in 15% of flood risk scenarios. However, the measures still generate a probability-weighted net benefit, suggesting there is a strong case for implementation when making decision based solely on expected values.

Climate Regulation

As with the value of all co-benefits, the net benefits/costs generated by the package of measures is sensitive to changes in the value of climate regulation benefits, as illustrated in Figure 5. Specifically, a 50% change in the value of the climate regulation benefit expected to be generated by the measures translates to a change of over £1.4m in net benefits across all scenarios. This sensitivity arises
from the fact the climate regulation benefit makes up a large proportion of co-benefits, and thus of total benefits as a whole. A 50% reduction in the climate regulation benefit would mean the measures still produce net benefits in all flood risk scenarios. The measures generate a substantial probability-weighted net benefit, suggesting there is a strong case for implementation when making expected value-based decisions.

**Figure 5.** Effect of changing the value of climate regulation benefits

![Figure 5](image)

Source: Frontier Economics

**Valuation of costs and benefits**

Using the lower and upper bounds (instead of the mid-points) of any data ranges used in the estimation of costs and benefits translates to significant changes in the net benefits/costs generated by the package of measures. This is to be expected given the outputs generated in our ‘test’ analysis, as shown in **Figure 6**.

When the lowest possible bounds of the data ranges are used, measures generate net benefits in only 40% of scenarios, and so fail to be robust to the future level of flood risk. However, this set of assumptions is extreme: it assumes the lowest possible valuations of co-benefits, the lowest possible assumptions of effectiveness of the measures, and the highest possible costs of implementation.
Effectiveness of the measures (water storage)

As would be expected given the importance of water storage in generating flood abatement benefits, the net benefits/costs generated by the package of measures are highly sensitive to the effectiveness of the measures in reducing water flows. In particular, under lower levels of future flood risk, the net benefits/costs changes by over £0.5m in response to a 50% change in the volume of water stored by the measures, rising to over £2.2m across scenarios representing higher flood risk levels.

However, as illustrated in Figure 7, these changes do not affect the robustness of the measures to the level of flood risk, with the measures generating net benefits across all scenarios even if they store 50% less water than that assumed. This illustrates the strength of the measures in generating substantial levels of co-benefits, which are accrued independently of the future level of flood risk. This ensures that, even in the absence of any flood protection, total benefits are still significant relative to the associated costs of the measures, which reduces reliance on flood-related benefits to ensure the measures are cost-effective (generate net benefits).
The net benefits/costs generated by the measures are responsive to changes in the horizon over which costs and benefits are measured. As shown in Figure 8, reducing the appraisal horizon to 50 years leads to falls of over £2.5m in net benefits across all scenarios, with falls of an even bigger magnitude if the horizon is reduced by a further 25 years. This is driven by the fact that across all scenarios, building and implementation costs make up a large proportion of the total costs generated by the measures, and these are incurred mainly over the first 5-10 years of the appraisal horizon. As a result, reducing the horizon over which costs and benefits are measured disproportionately affects the benefits generated by the measures.

Notably, with the appraisal horizon set at 50 years, the measures still generate net benefits across all scenarios, suggesting that it is robust to the level of flood risk realised and there is a strong case for implementation. When measuring costs and benefits over a 25 year period, the measures generate net costs across only 65% of the scenarios. However, a 25 year appraisal horizon can be thought of as an extreme sensitivity, given that the measures are likely to continue generating significant levels of benefits beyond a 25-year timeframe. Therefore, the extent to which this provides evidence against the implementation of the measures is limited.
Figure 8. Effects of changing the appraisal horizon

Source: Frontier Economics

Discount Rates

Figure 9 illustrates the change in net benefits/costs across all scenarios in response to a one percentage point increase/decrease in the discount rates used to discount costs and benefits:
As with changes in all other parameters, the chart illustrates that changes in discount rates have a significant impact on the net benefits generated by the proposed package of measures, with a one percentage point increase (decrease) in rates leading to a reduction (rise) in net benefits of over £1.5m (£1m) across all scenarios, with the response rising in magnitude as the level of flood risk increases. This is expected given that a larger proportion of benefits (rather than costs) are accrued in time periods further from the time of implementation.

However, these changes do not affect the robustness of the measures to the future level of flood risk, which still generate net benefits across all scenarios when the discount rates are increased/decreased. As a result, there is a strong case for implementing the package of measures.

3.4 **Summary of findings from the Pickering case study**

In this chapter, we have used the set of seven measures implemented in Pickering as a worked example to illustrate how an appraisal methodology selected and implemented in practice. We aimed to determine whether the proposed package of measures should be implemented, relative to a ‘business as usual’ scenario in which current the current level of self-adaptation continues. In addition, we
considered whether the resulting decision would be robust to the level of flood risk realised in the future, and to the assumptions used. To do this we developed a pragmatic approach drawing on the benefits of the potentially complex RDM methodology, whilst keeping the analysis tractable.

Conclusions of the appraisal

In general, it can be difficult to reach a clear decision in an appraisal exercise, as different decision rules may point in different directions, and it is not always obvious which of these should take precedence. Decision making based on expected values can be made by exploiting probability-weighted NPVs, although such decisions may be met with contention. This is because the probability-weighted NPVs may depend heavily on the probabilities assigned to each scenario, on which it may be difficult to gain consensus across stakeholders. Proponents of the RDM approach suggest using a richer set of outputs to inform the appraisal decision, so that less weight is placed on the probabilities assigned to each scenario.

However, given the outputs generated in the case of Pickering, we believe the case for implementation appears to be strong:

- **The package of measures is highly robust to the level of flood risk realised in the future.** Under central estimates, the measures generate large net benefits across all flood risk scenarios.

- **The measures continue to be robust in the light of changes to the majority of parameters used in the appraisal analysis.** The measures continue to generate net benefits across all scenarios under many of the sensitivities considered. It was only when significant reductions were made to the appraisal horizon, or when the lower bounds of all data ranges were used that the measures generated net costs in a large proportion of scenarios. Both these sensitivities may be considered to be extreme, and we would expect only limited weight to be placed on them.

- **Estimates are conservative.** Most estimates of particular benefits, especially those accrued through flood and erosion regulation, are conservative estimates of the likely true benefits accrued. As a result, the measures may in fact generate significantly larger net benefits than those estimated here, and be robust to the future level of flood risk across a greater number of sensitivities.

Key observations

Given the appraisal we performed and the resulting outputs generated, a number of key themes can be noted:
• The value for money generated by these measures is driven largely by the co-benefits they create. Although the likely benefits accrued through flood regulation are significant, a substantial proportion of total benefits are attributable to the wider indirect benefits created. Given the extent of these co-benefits, and the fact that the net benefits generated by the measures are highly sensitive to changes in co-benefit values, it is important that any forward-looking appraisal of similar initiatives measures these robustly.

• The co-benefits make the measures largely robust to the future level of flood risk. The measures will generate a substantial level of co-benefits irrespective of the level of flood risk realised in the future. As a result, the co-benefits provide a lower bound on net benefits, even in the absence any benefits due to avoided flood damage. When central estimates are used, the measures generate net benefits across all scenarios of flood damage.

• The results suggest an important role for ‘soft’ flood defence measures that draw on the use of natural materials and processes. In general, although ‘hard’ measures provide a substantial amount of flood protection, they are unlikely to generate significant levels of additional co-benefits. The extent to which ‘hard’ measures can generate significant net benefits in isolation may be limited. On the other hand, ‘soft’ measures can generate significant net benefits, but they provide smaller levels of flood protection. As a result, these softer measures used in isolation will not always provide the comprehensive cover needed to prevent floods of different severities. ‘Soft’ measures may therefore need to be supported alongside ‘hard’ measures, with this combination delivering a sufficient level of flood protection together with strong net benefits.

3.5 Evidence gaps and recommendation for future research

In general, the focus of this appraisal has been to illustrate the steps that need to be taken in (i) identifying and measuring costs and benefits, (ii) choosing the appropriate appraisal methodology in the context of uncertainty concerning flood risk, and (iii) implementing this methodology in practice. We used readily available information to conduct an illustrative but sufficiently robust appraisal of the measures implemented in the Slowing the Flow project, rather than focus on...
carrying out detailed primary research to refine parameters used in the analysis. Below we outline the areas where evidence gaps still exist, and provide recommendations for further research to provide more robust data on these measures.

**Scope of the Analysis**

Firstly, there is scope to extend the coverage of the appraisal framework and its granularity in some areas:

- **Severities of flood.** Given the limited data on the effects of different magnitudes of flood in the Pickering area, we were restricted to considering only two flood severities in each scenario. Further research could be done to estimate the effects of other flood events in the Pickering area beyond those in 2000 and 2007, which would allow additional severities of flood to be considered.

- **Greater coverage of the costs and benefits considered.** As we highlight in Annex A of the report, the lack of modelling data for the River Seven catchment precluded any assessment of the potential flood damage abated by the measures implemented in this area. In addition, due to the absence of estimated soil delivery in some parts of the Pickering Beck and River Seven catchments, our valuations of erosion regulation do not account for the erosion benefit generated 35 hectares of woodland planted as part of the Slowing the Flow Project.

Given this, we make the following recommendations:

- A hydrological assessment should be conducted in the River Seven catchment to assess the water storage required to prevent floods of different severities, and the storage provided by the measures expected to be implemented in this area.

- An assessment of the potential soil delivered in the remaining parts of the River Seven and Pickering Beck catchments should be carried out.

- **Coverage of additional costs and benefits.** We were not able to measure all the potential costs and benefits associated with the measures. Although we have argued these costs and benefits are small and unlikely to materially impact the results, further research could be done to monetise them, and thus generate a more robust valuation of the impacts.\(^{45}\)

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\(^{45}\) With respect to environmental impacts, we suggest users refer to the following sources of guidance to ensure the appropriate methodology for identifying and measuring these costs and benefits is followed:

Account for any unintended consequences of the initiative. In our appraisal, we focussed solely on the costs and benefits associated with the measures likely to arise in the Pickering and River Seven catchments. However, it is possible that the initiatives could have knock-on effects on surrounding areas. For example, diverted floodwater could cause flooding in neighbouring catchments, whereas absorbed water might reduce that risk. As a result, we recommend that research be done to determine any likely unintended consequences, and quantify them.

Data Population

In the appraisal, many of the benefits (particularly in relation to community development and education and knowledge) have been measured in a pragmatic way. As the application focusses on providing an illustration of how a particular appraisal methodology can be applied in practice in the presence of uncertainty, we did not carry out detailed research on each parameter in the model. Given this, research could be undertaken to better monetise the benefits we have already considered. Further research into the likely development of climate change would reduce the level of uncertainty of flood risk.


4 Wider lessons for using appraisals techniques in flood risk management

In the previous chapters we have set out the particular issues that need to be taken into account when selecting between alternative adaptive actions to address flood risk. We have described the alternative appraisal methods that are available in this context, and in what circumstances they would be appropriate. Drawing on the example of the introduction of natural flood management initiatives in Pickering, we described how we selected from the options available and implemented a particular appraisal method, robust decision making (RDM).

The process we followed in the Pickering example has allowed us to draw wider lessons for those working in the field of appraising adaptive actions. The first part of this chapter draws on these lessons to develop a checklist for applying appraisal methods for those working in this field.

In the course of considering how to apply appraisal techniques in the flood management setting, we found that not only is the measurement of the flood damage costs that can be avoided important, but also that the type of damage costs that can be avoided will vary significantly across sectors. This is a particularly critical area that requires careful measurement if appraisal of adaptive actions is to be carried out successfully. In the second part of this chapter we focus on four sectors to highlight these measurement issues. The sectors include: healthcare, agriculture, transport and energy.

4.1 Lessons for applying appraisal techniques to adaptation actions

In Chapter 3, we described the important issues that must be taken into account when selecting appraisal techniques in the context of selecting adaptation actions for dealing with flood risk. To recap, we highlighted the following:

- **Uncertainty** – in relation to the large amount of uncertainty about the impact of future climate change conditions, but also with regard to non-climate change factors.

- **Indirect impacts** - flooding has direct effects in terms of the damage and the disruption it causes, but it can also create a range of indirect costs and benefits that must be included in an appraisal.

- **Multiple initiatives** - we saw in Pickering that a number of the flood defence initiatives were on a small scale or are likely to be complements, and
will therefore need to be packaged as a group in order to provide a certain level of flood defence.

- **Non-monetary outcomes** – this is a particularly critical area in the context of adaptation actions, as we have highlighted above. Many of the flood avoidance benefits are not likely to have market-based measures of their value.

- **Proportionality and pragmatism** – decisions should be made on the most robust evidence that is available, but the appraisal approach must be proportionate to the size of the overall problem that is being addressed.

In Chapter 2 we highlighted the different appraisal methodologies that are available and that need to be considered in the context of the key issues we have just described. Recall, we stated that cost-benefit analysis is the basis of all the alternative appraisal methodologies. The methodologies we described were:

- Cost-benefit analysis / cost-effectiveness analysis
- Scenario-based cost-benefit analysis
- Robust decision making
- Real options analysis
- Multi-criteria analysis

In Chapter 3, we showed how we made our decisions over which appraisal methodology was the most relevant for selecting the options in Pickering. In that case, we were aware that Pickering was in an environment where there was ‘deep uncertainty’ concerning the level of flood risk. Having demonstrated that the appraisal decision was dependent on the level flood risk and other parameters, we chose to use RDM, as this would highlight under which sets of assumptions and states of the world different decisions would be made.

In an alternative environment with different circumstances it is entirely possible that one of the other appraisal methodologies could be selected. Those carrying out appraisals will need to carefully think through which of the appraisal methodologies are best suited to their circumstances. **Figure 10** summarises a framework used for gathering data and selecting the appraisal methodology.
4.1.1 Check list for carrying out an appraisal of adaptation actions

**Rationale: Clarify the market failure problem that is to be addressed**

Any adaptation intervention that is funded from the public purse or has a regulatory cost requires an economic rationale to support its case for implementation. The rationale is the first step in assessing the case for intervention. There are two key pieces of evidence that are required to assess the rationale for an adaptation action. These are:

- A broad assessment of the flood damage that could arise if flooding occurred and who would be affected by the damage in the geography of interest; and

- An assessment of the adaptive capacity of individuals and institutions (both public and private) to prepare and cope with the potential flood damage, without any further intervention.

The results from these two assessments would provide an indication of the size of the damage that could be expected and if there is insufficient adaptive capacity to prevent the damage.
It would also be important to provide an explanation of why there is unlikely to be sufficient adaptive capacity.

**Objectives:** Identify adaptation actions for tackling the problem and set objectives

Identify a list of adaptation actions that have strong evidential support that they would be able to effectively address the flood damage that is likely to occur. Assess whether the actions need to be grouped because they are interdependent in some manner.

It is important to be clear about the type of outcome that will be achieved by each option. For example, an objective might be specified to ‘reduce the risk of the potential flood damage to a de minimis level’. Further, the objectives are required to be SMART:

- Specific,
- Measurable,
- Attainable,
- Realistic, and
- Time-bound.

Adaptation actions may create further benefits to society that are unrelated to the benefits that arise from the flood damage costs that are avoided. These should also be set out in the objectives of each option.

**Measurement:** Estimates are required of all costs and benefits

The benefits of each adaptation action (these will include both damage costs avoided and indirect benefits) will be set out for each action when setting their objectives. It will also be necessary to set out the direct and indirect costs associated with each action.

At this stage all costs and benefits should be listed and an assessment made of what evidence will be required to provide estimates of the costs and benefits.

If there is a lack of available valuation evidence on costs and benefits or it is too costly to generate evidence through primary research, then consider carrying out a MCA as an appraisal method.

**Appraisal:** Select an appraisal methodology that addresses the characteristics of the problem

A Real Options Approach (ROA) may be appropriate when there is flexibility with at least one of the options that is being considered, and there is learning
potential over time. Given the high level of uncertainty associated with flood risk, flexibility can be a valuable part of an adaptation strategy. It follows if there is a lack of flexibility in the options being considered then the benefits of learning over time will not be as relevant. A further factor to keep in mind is whether the benefits associated with any option value is likely to be significant to other costs and benefits that are being considered. If they are not material then an ROA approach will not add much value.

In the case where there is obvious ‘deep uncertainty’ over a range of factors then Robust decision making (RDM) should be given serious consideration. Broadly, we define ‘deep uncertainty’ to indicate when it is not possible to say with any reasonable confidence, whether one future state of the world is more probable than another. This is likely to be the case in most flood risk situations. Moreover, RDM is a particularly useful approach when it is likely that different options may be ranked differently in different future states of the world.

A limitation of the RDM approach is that it makes it difficult to develop a single net present value estimate for each option. Although in many ways this is also its strength, because it provides a rich source of information for each option in different states of the world. Decision makers can draw on this information to test out decision rules and provide a range of evidence to support their arguments for a particular option.

In other situations, scenario-based cost-benefit analysis (SBCBA) may be a more pragmatic methodology for dealing with uncertainty. In that case, it will be important to select a representative group of scenarios, and take care when assigning probabilities to them.

In Table 9 we highlight the major advantages and disadvantages of each appraisal methodology that might be considered in this context.
### Table 9. Advantages and disadvantages of each appraisal methodology

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Brief Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-criteria analysis (MCA)</td>
<td>Part or wholly qualitative-based approach, which provides a ‘ranking’ of initiatives based on monetary and non-monetary criteria</td>
<td>Allows appraisal to be conducted in the absence of/limited amount of quantitative data</td>
<td>Limited to relative assessments of alternative policy options</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Outputs are appraisal-specific – i.e. cannot be generalised more widely</td>
</tr>
<tr>
<td>Cost-effectiveness analysis (CEA)</td>
<td>Quantitative approach which identifies the policy option providing a specific output/benefit at the lowest cost</td>
<td>Useful when a specific output/objective is needed to be met</td>
<td>Not applicable when a single initiative is being appraised, or when considering multiple initiatives providing different levels of the required benefit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can be used when comprehensive quantitative cost data is available for monetising costs but not benefits</td>
<td>Implicitly ignores potentially significant co-benefits</td>
</tr>
<tr>
<td>Scenario-based cost-benefit analysis (SBCBA)</td>
<td>Quantitative approach which assesses costs and benefits (in monetary form) across different scenarios/states of the world</td>
<td>Accounts for uncertainty surrounding flood risk without being computationally or data intensive</td>
<td>Potentially difficult to gain consensus on the appropriate scenarios to use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provides numeric outputs, allowing for cardinal comparisons between initiatives</td>
<td>Risk of not capturing the extent of uncertainty surrounding climate change, especially under ‘deep uncertainty’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Easily understood for non-technical audiences.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Allows for the application of risk-based rules</td>
<td></td>
</tr>
<tr>
<td>Robust decision making (RDM)</td>
<td>Quantitative approach which assesses the proposed initiatives across all plausible states of the world, and identifies the initiative most robust across these</td>
<td>Captures deep uncertainty – leaves ‘no stone unturned’</td>
<td>Can be computationally and data intensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provides numeric outputs</td>
<td>Potentially difficult to interpret for non-expert audiences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provides a clear picture of which initiatives are optimal in different states of the world</td>
<td>Value function for deriving costs and benefits needs to be well calibrated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ranges of plausible parameter values need to be known</td>
</tr>
<tr>
<td>Real options analysis (ROA)</td>
<td>Extension of CBA which estimates the ‘option value’ associated with each initiative i.e. the option to delay or adjust in the future. Calculates the NPV of each initiative given the particular actions that could be taken given different states of the world being realised, and the probabilities of these occurring.</td>
<td>Accounts for learning about the nature or extent of flood risk going forward. – captures the value in delaying or adjusting a particular initiative</td>
<td>Can be computationally or data intensive – requires the assignment of probabilities to scenarios at various future time periods</td>
</tr>
</tbody>
</table>

Source: Frontier Economics
**Sensitivity analysis: a stress testing of the parameters**

It is important to understand whether the results from any appraisal methodology are robust to reasonable changes in key parameters. There could be some parameters that, if varied, could influence the results. Sensitivity results for the parameters should be shown. Thresholds values at which decisions change should also be identified.

### 4.2 Measuring costs of flood damage to specific sectors

Flooding has impacts on many different sectors. This will lead to different types of damage than were observed in the Pickering example, where we focused on damage to residential properties. As such, appraisals of alternative strategies in other sectors will involve different valuation methods and different data requirements.

Both the results of an appraisal, and the choice and implementation of appraisal methodology, will depend on the quality of the data.

In the following we outline the costs that are likely to occur in the health sector as a result of flooding and assess what techniques and data are required to estimate costs effectively.

#### 4.2.1 Healthcare

There are four main areas in the health sector where the costs of flooding could be significant. These are described below.\(^46\)

- **The direct costs of flood damage to the hospital estate.** Predominantly climate risks have not been incorporated into the design stage of hospitals as they were built before climate impacts were fully understood (Ballard et al, 2011). Consequently, there are potentially severe cost implications from flooding, with increasing costs through the rebuilding and repair of the estate, the associated clean-up costs and lost inventory.

- **The costs associated with reduced access to hospitals.** Severe flooding can limit the ability of patients to access healthcare services and the ease with which hospital staff can get to work. This naturally affects patients through increased waiting times and the associated costs of delay, but can also have

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\(^{46}\) We note there are other potential health impacts of flooding. Severe flooding may directly cause injury or fatality, or contribute to the spread of disease.
substantial costs for neighbouring hospitals who may act as substitute service providers in the wake of a flood.

- **The mental health impacts of flooding.** These include stress, anxiety and depression as well as the potential exacerbation and prolonging of pre-existing physical and mental health conditions. This will naturally affect the quality of life of those affected with further consequences for NHS treatment costs, productivity losses and foregone tax revenue.

- **Disruptions to the functioning of the hospital through interdependencies.** The healthcare sector is extremely vulnerable to flooding due to its reliance on several services, including transport, power, communications and water. Thus, the resilience of a hospital to flooding is dependent upon the resilience of its interdependencies.

**Assessment of data and techniques**

In the following section we assess the current approaches used to evaluate the four main cost areas identified above. By reviewing the available evidence, we provide the reader with an understanding of current practice and the applicability of these methods for analysing the impact of flooding on the health sector. Where gaps in methodology or evidence exist, potential alternatives to the available evidence are discussed with further research or data collection suggested where useful.

**Direct hospital costs associated with flooding**

When considering the damages to hospitals from flooding, there are five categories of direct tangible costs that need to be measured:

- **Building fabric** – the physical structure of the hospital
- **Hospital inventory** – the assets that have been lost or damaged
- **Clean-up** – expenses required to recover the condition of the hospital
- **Safety, hygiene and infection control** – more stringent for hospitals
- **Specialist labour costs** – for medical and reconstruction purposes

The main information source identified for future appraisals is the standard Flood and Hazards Research Centre’s (FHRC) Multi-Coloured Manual (MCM).
It details flooding damages into four “bulk classes” of property: retail, warehouse, office and factories.\(^{47}\) Damage data is presented per m\(^2\) for building fabric, inventory and clean-up costs.

There are limitations to the MCM. Certain elements unique to hospitals are not captured by the MCM’s current guidance, such as hospital specific aspects of the inventory. Furthermore, the MCM’s current guidance does not include hospitals and healthcare service providers.

It is thus important to initiate data development in this sector for the five categories of tangible costs identified above by the US Federal Emergency Management Agency (2007).

**Costs associated with reduced access to hospital**

As mentioned previously, reduced hospital access has cost implications for patients in terms of prolonged waiting times and neighbouring hospitals in terms of absorbing diverted patients. These cost and the potential methods for measuring them are discussed below.

- **Costs of delays**

  At present, the value of waiting time used to estimate delays in ‘non-urgent’ patient treatment is estimated to be **£4.30 per day, per patient** in 2011/12 prices. This figure was developed by the Centre for Health Economics and the NIESR on behalf of the Department of Health, and is based on an initial valuation conducted by Carol Propper (1990).

  A major limitation of the data is its age. Whilst adjustments for inflation, GDP and population growth are possible, the willingness to pay to reduce waiting times will have changed over the last 25 years.\(^{48}\) Thus, we strongly recommend that new research is undertaken on social willingness to pay for healthcare.

  This work should investigate the value of reducing waiting times in differing contexts as the benefit transfer from one study may be limited and thus research investigating the value of waiting times for different procedures is advisable (Centre for Health Economics 2005; Ryan et al., 2004).

- **Costs to neighbouring hospitals**

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\(^{47}\) The latest version was published in 2005 and an update has recently been commissioned which will include new dimensions of direct costs such as “evacuation costs and vehicle damage”. The supplementary Multi-Coloured Handbook was last updated in 2010 and serves to provide supporting guidance on evaluation techniques.

\(^{48}\) Propper’s research was conducted in 1987.
Severe flooding may limit the operational ability of a hospital, diverting patients and their associated cost of treatment to neighbouring hospitals. The evidence available on treatment costs and affected persons is substantial. Patient numbers are identifiable through HES online with unit treatment costs provided by reference cost data (NHS, 2012), with the number of treatments clarified by the relevant Trust’s annual accounts (DH, 2011).

Table 10 aggregates a number of procedures to indicate the average cost of treatment, but specific treatment costs should be identified in order to tailor appraisals for the particular hospital or site affected. Consequently, when conducting appraisals the type of hospital, range of services provided and the cost implications by site must be identified.

Table 10. Average cost of treatment in the UK

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elective inpatient data</td>
<td>£3,091</td>
</tr>
<tr>
<td>Outpatient procedures</td>
<td>£135</td>
</tr>
<tr>
<td>Accident and Emergency service: leading to admitted</td>
<td>£141</td>
</tr>
<tr>
<td>Accident and Emergency service: not leading to admitted</td>
<td>£108</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

Whilst current evidence is substantial, information regarding patient numbers is trust specific. Where more than one site per trust exists, the impacts on a specific hospital can be hard to determine and a more robust analysis could be conducted with site specific data.

The mental health impacts of flooding

To determine the costs of mental health implications, a vast amount of data is required regarding prevalence, duration and quality of life adjustments. The methods and data available for these studies are outlined below.

49 For example, District General Hospitals, Acute Trusts and Teaching Trusts all provide different services.
50 Hot sites (urgent care, trauma) and cold sites (elective, day case) have differing costs.
51 The data in this table is largely based on English data. We understand that data for Scotland is different. For example, the average cost for inpatients in Scotland is £2752 per case, whereas the average cost per outpatient case is £199.
Prevalence of mental disorder

Relative risk estimates for developing common mental disorders (CMD) due to flooding are scarce in the literature. Reacher et al. (2004) study of the 2000 Lewes floods reports an age- and sex-adjusted flood-related risk of developing a CMD of 4.1 (for the adult population), with a 95% confidence interval of 2.6 to 6.4.

This figure is supported by Paranjothy et al (2011), who found a 2 to 5-fold increase in the prevalence of mental health symptoms in the aftermath of the 2007 summer floods, broadly in line with the findings of Reacher et al (2004).

Valuation

To determine the monetised equivalent cost of these mental health symptoms, the ‘World Health Organization: Global Burden of Disease 2004 Update: Disability Weights for Disease and Conditions’ calculates disability weights for varying severities of mental disorder using the QALY weightings shown below:

- Post-Traumatic Stress Disorder - weight 0.105
- Mild depressive episode - weight 0.14
- Moderate depressive episode - weight 0.35

Adhering to the approach of the National Institute for Health and Clinical Excellence (Defra internal guidance and IGCB, 2010), we recommend a figure of £60,000 per quality adjusted life year (QALY) be used as the basis of these calculations.

Duration

The time course of flood-associated impact on mental health is not well known. In the absence of more precise data, the following assumptions surrounding estimated duration of mental stress were used by the CCRA and ECR reports.

- central estimate – 0.5 years
- conservative estimate – 0.25 years
- high estimate – 5 years

The above sources provide valuable information on the impact of mental health disorders in the wake of a major flood event, yet there are substantial limitations.
Published epidemiological evidence does not currently provide an accurate characterisation of the evolution and return to normal flood associated mental health symptoms.

Uncertainty over the duration as well as severity of illness represents a major source of imprecision in the risk estimates and further primary research needs to be undertaken.

The available evidence fails to distinguish between the severities of mental health disorders. To understand the effects of flooding on mental health, the probabilities of ‘mental health cases’ for different disorders need to be investigated.

Disruptions to the functioning of a hospital through disturbances to the supply chain

The interdependencies of a hospital with both the surrounding infrastructure (e.g. power, water, transport) and other organisations within the healthcare system create a lack of transparency and understanding of the level of risk.

The lack of transparency around the resilience of infrastructures means that accounting for the potential costs to a hospital in the wake of flooding is extremely difficult, particularly as disruption is rarely localised to just one element of dependent infrastructure.

Further substantial research is required to determine the impacts of flooding on a hospital through its interdependencies. The cost implications will vary with each hospital and will thus need to be tailored for each site.

4.2.2 Energy

Flooding can affect both the electricity generation and the transmission and distribution networks for gas and electricity. This will have impacts on both users of electricity and suppliers of it.

Costs of flooding on energy sector

The energy network cost of the UK’s 2007 floods was estimated at £139million (Morris et al., 2010), most of which was through customer supply disruptions. But there are various potential cost risks, categorised here into five groups:

- **Damage to infrastructure.** Flooding and intense storms can damage power lines, capital equipment and fuel supply infrastructure.
• **Power generation losses.** This would involve the losses caused for businesses from not being able to continue with operations, the costs of recovering asset damage and any shut-down or safety procedures.

• **Customer supply losses.** This refers to the value placed by households and firms on energy. When combined with the degree of supply disruption, it can give an aggregate welfare loss.

• **Delays to repair and maintenance work.** Floods may also delay general repair and maintenance work of infrastructure.

• **Energy network interdependencies.** The ICT, water and transport infrastructures rely on the functionality of energy systems and vice versa.

**Assessment of data and techniques**

In the following section we assess the current approaches used to evaluate the five main cost areas identified above. We provide an understanding of current practice and the applicability of these methods for analysing the impact of flooding on the energy sector.

Naturally, the extent of flood damage depends on the severity of the flood and where it occurs. Different energy systems will have varying degrees of flood protection but face large costs if a severe flood exceeds this protection. Costs also depend on the ensuing inoperative period, how many households were affected and how concentrated the interdependencies are. Therefore, case study specific figures cannot be mechanically applied to other flood scenarios without considering their context.

We therefore identify costs that could be applied to a flood, provide potential sources on flood-specific information where possible, and highlight remaining gaps in methodology or evidence, with further research or data collection suggested.

**Damage to infrastructure**

URS\(^{52}\) (2010) identifies several elements that could comprise infrastructure damage from flooding:

• **Fuel processing, storage and transport.** This applies mainly to gas and biomass as the UK is import-dependent on these sources.

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52 URS Corporation provides planning, management, design and consulting services for engineering, construction and technical fields.
• **Distribution network.** This includes damage to substations, transformers, pylons and cables (overhead and underground). Morris et al. (2010) estimate the overall infrastructure damage from the 2007 UK floods at £9 million using power company estimates. According to the National Grid, two gas supply lines were severed. However, Morris et al. (2010) comment that the data is “patchy and incomplete”, resulting in the estimates being “difficult to verify”.

An electricity transmission costing study by Parsons Brinckerhoff (2012) provides a detailed cost of cabling (overhead, underground, deep tunnel and others) for different qualities and different lengths, breaking down the costs by components. It states that the repair costs for tunnel cables after flooding could range from £100,000 to more than ten times that.

Northern Powergrid (2011) considers a sufficiently severe flood to be critical and could result in over £1 million of damages to substations, including capital malfunctions and serious injuries. However, each damaging flood type is assigned a probability of ‘between 1% and 40%’, which is an imprecise range encompassing a variety of flood severities.

Overall, there is detailed evidence listing potential infrastructure cost components. And, although there is some quantification, a clear evidence gap is the lack of a quantified breakdown of these costs in the event of a flood. The evidence from Morris et al. (2010), for example, is fairly ambiguous in its core sources, while identifying the cabling cost elements attributable to a flood’s damage is beyond the scope of Parsons and Brinckerhoff (2012).

### Power generation losses from flooding

This cost category is developed in detail in the *ECR Report 2a: Buildings and Infrastructure – UK Power Generation and Transmission* by Frontier Economics (2013). While it focusses on conventional power stations it also explains the different impacts for thermal stations and nuclear plants. For all power station types, the costs are further augmented by immediate close-down procedures, de-electrification and safety protocols.

• **Impact on nuclear and thermal stations**

Most existing thermal generation plants have been designed to withstand a 1:200 year flood event. They should therefore not incur lost output costs from less severe floods.

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53 The *Climate Change Adaptation Report* by Northern Powergrid (2011) assesses the risks of each of these and categorises them clearly in Table 7.8.2

**Wider lessons for using appraisals techniques in flood risk management**
Nuclear plants already have a high level of safety standards – they are required to withstand a 1:10,000 year flood and hence are well protected against flooding. Therefore, we do not consider it to have an examinable cost of flooding.

- **Impact on power stations**

The CCRA (2012) has estimated the number of power stations at risk from ‘1 in 75 year’ floods. It does this using a range of scenarios for current and future levels of flood risk (the 2020s, 2050s and 2080s). Based on CCRA (2012), Frontier Economics (2013) assume 0-6GW would be affected in the 2020s and 5-12GW in the 2050s. In the 2020s this could result in an aggregate cost of up to £7.4million and in the 2050s it could reach up to £14.8million. These give a cost of £1.23million per GW of lost generation.

- **Other impacts**

URS (2010) identifies hydro-generation as another power generation source that is likely to be affected by flooding. Pollution control equipment such as CCS and also overland pipelines are components of the power generation process that are vulnerable to damage and malfunction due to flooding.

Outside of the ECR Report, there is little quantitative evidence on the impacts of flooding on power generation in the UK. Nuclear plants can be reasonably disregarded given their strong protection; however, thermal and hydro-generation would be affected needs to be explored further. There is also an evidence gap concerning the actual shutdown and safety procedure costs from such events. Additionally, the failures of pollution control components will require research in order to value their benefits and determine how long these are lost for.

**Customer supply losses**

Morris et al. (2010) find the largest cost impact of the 2007 floods was through the end-customer implications of various power station/substation closures.

- **Households**

Morris et al. (2010) refer to BERR (2007), which uses £10 per kWh per customer as the willingness to pay to avoid electricity disruption. This represents a high value placed on security of supply and is over and above the actual market resource cost of £0.07/kWh. Given these figures, the cost from this category alone is the key driver of the UK’s 2007 flood damage at £130million i.e. 94% of the energy sector cost (Morris et al., 2010). For future evaluations, uprating is

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54 Asssuming the power capacity at risk of flooding is inoperative for 30-180 days.
55 See Frontier Economics (2013) for detail of costs
necessary; the willingness to pay can be uprated to give a 2013 value of £12.30 per kWh per customer.

- **Firms**

There will be a similar impact on businesses if their electricity supply is disrupted. While back-up generation is more feasible for businesses than households, it will not be viable for all firms (BERR, 2007). The average industrial user values a lack of disruption at £35 per kWh; the electricity consumption lost in an average disruption and the annual disruption probabilities are then factored in.

The resultant expected willingness to pay to avoid an average disruption (88mins) for small, medium and large industrial firms\(^{56}\) is £21k, £170k and £420k respectively. Uprating for 2013 changes this core disruption valuation to £43 per kWh.

The figures presented above are relatively sensitive to the assumptions used. Although demand variations are captured, the identical valuation across different groups used is assumed to suffice despite several dimensions of potential variation in willingness to pay such as household type and geographic region. This could therefore be improved using research to inform more accurate representations of customer valuations.

**Delays to repair and maintenance work**

Northern Powergrid (2011) notes that when substations are flooded, they will divert resources away from regular maintenance work, creating further costs. This is plausibly the case for power stations and thermal stations too, and therefore they would face similar costs, although it is difficult to obtain evidence on this. Companies may find it hard to distinguish the effects of floods on regular maintenance work and may also not record information on such delays. It is therefore unclear whether it is possible to address this as an evidence gap.

**Energy network interdependencies**

Defra (2011) examines the issue of *Climate Resilient Infrastructure: Preparing for a Changing Climate*, identifying key interdependencies between sectors. Reliance on energy stems from gas usage for electricity generation and energy supply for transport, water, and especially ICT networks.

\(^{56}\) These would refer to primary and secondary sector firms, while their size is defined by their electricity demand.

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**Wider lessons for using appraisals techniques in flood risk management**
Electricity outages can have serious impacts on other energy systems as well. For example, oil and gas pipeline disruptions following extreme weather events are often caused by power outages rather than physical damage to the infrastructure.

Overall, interdependencies between key public infrastructure are well summarised in Table 11, which is based on a combination of Gaspard and Hubrecht (2010) and Defra (2011). A red box indicates a high dependency; an orange box a moderate one; and a green box a lower dependency. It is evident that the other three sectors listed have relatively high reliance on the functioning of the energy sector (and vice versa), so these wider impacts should, at the very least, be qualitatively incorporated.

**Table 11. Sectoral infrastructure interdependencies**

<table>
<thead>
<tr>
<th>Interdependency on</th>
<th>Energy</th>
<th>Telecoms/ ICT</th>
<th>Water</th>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telecoms/ ICT</td>
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<td>Water</td>
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<tr>
<td>Transport</td>
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</table>


### 4.2.3 Transport

In many cases a flood, whether fluvial or coastal, will have an impact on transport networks. By reviewing the tangible effects of flooding on transport infrastructure, we outline the methods for translating these issues into monetary costs and assess the available sources for these valuations.

**Costs of flooding to transport sector**

This section helps identify the main costs associated with the flooding of road and rail networks through identifying major sources of delay and repair. These are described below.

- **The direct costs of flooding on road and rail infrastructure.** The resilience of the infrastructure will affect the damage incurred. Such damage is in the form of disruptions, maintenance and repair costs.
• **Delays to road and rail travel.** The cost implications of delays to a journey will not only delay travellers but can also lead to a reduction in the travellers’ welfare through them taking the ‘second best’ means of travel. There will also be economy wide impacts if flooding disrupts the functioning of the economy.

• **Scour effects.** Flooding can accelerate erosion of key structural features of bridges and road networks when water levels rise and rebuilding and repair costs subsequently increase.

• **Wider network effects.** Impacts to one element of the transport network can have cascade effects on other parts of the transport infrastructure which can lead to capacity failures on other parallel networks. The transport sector is also reliant on energy, ICT and other critical infrastructure providers for its operations. Hence their resilience is integral to the functioning of the transport system.

**Assessment of data and techniques**

By conducting a review of present methodology and evidence, this report outlines and assesses the current practice for analysing flood impacts on transport networks, suggesting alternatives or areas for further research where applicable.

**Direct costs of flooding on road and rail networks**

The Highways Agency (HA) is introducing design standards to ensure the resilience of road pavement to the effects of flooding. The most recent data available is that contained within the HA’s annual *Business Plan* (2012). This provides the costs of annual routine maintenance, which can be converted into per road kilometre equivalents.

The majority of the rail network is resilient to a 1% annual flooding probability (Cabinet Office, 2010). Office of Rail Regulation (2012a) and the Network Rail (2012) provide data on capital renewals costs and the length of renewed track respectively. Therefore, this can also be converted into a per rail kilometre equivalent.

• **Road maintenance and repair**

Wider lessons for using appraisals techniques in flood risk management
The HA’s Business Plan 2012-13 shows that the HA spent approximately £416 million on capital to maintain the road network in 2011-12. This consists mostly of repairs to road pavements, but also includes repairs to road lighting, drains and embankments, which would all be affected by flooding. It amounts to approximately £40,000 per km. However, this is the average capital maintenance cost for one km spread across the whole strategic road network in the UK and not across only the specific affected segments. Therefore, it is indicative of the cost that would be incurred, but specific costs for the renewal or repair of one km of road damaged by flood are likely to differ.

An area for further research would be on the effects of flooding on minor roads rather than just major strategic routes. It would also be valuable to obtain a more detailed breakdown on capital expenditure costs in order to define flood-related elements more accurately. Thirdly, data on the length of road network requiring renewal would improve the current estimates.

### Rail maintenance and repair

The corresponding rail data can be found from the Annual efficiency and finance assessment of Network Rail 2011-12 (Office of Rail Regulation, 2012a). The relevant expenditure categories for flood damage are maintenance costs of sustaining the existing assets’ condition; and renewals costs of replacing assets nearing the end of their useful lives with modern equivalents (including track, signalling and civic structures). Their respective expenditures (2011-12) were £968m and £2,455m.

The length of functional railway track (2011-12) was 15,742km (Office of Rail Regulation, 2012b) while the current length of renewed railway track is 313km (Network Rail, 2013). These give per-km maintenance and renewals costs of £61,500 and £7.8m respectively.

The rail expenditure ‘mix’ caused by flooding depends on the damage caused. If severe, many assets would need replacement, resulting mostly in renewals costs; if less severe, it could result in a high maintenance cost proportion instead. Once this is defined, a per-km figure can be applied to the affected rail sections.

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57 The road network refers to all strategic routes that are within the HA’s remit. Local roads are maintained by local councils and are thus not included within this figure.

58 Based on HA (2010) figure of 6,500 miles of motorway and trunk roads.

59 From the rail renewal route length for 2013-14.
Delays to road and rail travel

Disruption costs are estimated to be significantly higher than damage costs, due to the continual maintenance work and high design specifications of both the road and rail networks.

To estimate flood impacts, marginal delay costs can be scaled up using the delay caused by each flood. A report by Oxford Economic Forecasting (2005), *Time is Money: the economic effects of transport delays in Central London*, details three different quantifiable economic costs of travel delays:

- **Commuter costs**: lost time, lateness for work, lost productivity, stress and fatigue (50%)
- **Business costs**: lost time while on employers’ business (18%)
- **Non-work costs**: lost time for leisure, tourism, education, etc. (32%)

The total estimated economic costs to Central London are £1.75 billion, of which the three largest contributors are car (£627 million), Underground (£568 million) and rail (£265 million) journeys.

There may also be knock-on health impacts from transport delays, due to interrupted access to healthcare.

- **Delays to rail travel**

The National Audit Office (2008) applies a valuation figure for the economy-wide lost time impact of £73.47 per minute of delay for each train in the UK in 2006-07. This is calculated based on the average number of passengers per train using data from Network Rail and the Office of Rail Regulation.

The study also accounts for different time valuations for each passenger type and weights them by rail travel frequency to a ‘representative train’ from the Department for Transport’s data.

However, the study doesn’t account for differences in passenger numbers during peak and off-peak hours. Since most of the delays took place during peak hours, it underestimates the number of affected passengers (NAO, 2008). This could therefore be improved by distinguishing peak and off-peak passenger averages.

- **Delays to road travel**

The Department of Transport’s *Values of Time and Vehicle Operating Costs: Transport Analysis Guidance* (2012) values the economy-wide market price value of time for an average vehicle as £13.91 per hour in 2010 prices.

Wider lessons for using appraisals techniques in flood risk management
This is calculated by combining market time values for different vehicles types and journey purposes across different daily time periods. Weighting these by the 2002 national average vehicle proportions from the Department’s COBA user manual, the aggregate market figure above is obtained.

Several of the papers on delays cited in this section were either published in or use data from the mid-2000s. As many aspects of the transport network, such as (composition of) demand for each transport mode and the efficiency of and capacity of each transport system have changed since then, an update of the valuations currently relying on data from the 2000s would be beneficial.

**Scour effects**

Bridges and man-made infrastructure with footings in rivers or estuaries are susceptible to scouring, threatening the stability of the structure and potentially leading to damage or failure. However, while quantifying the risk of bridge scour for highway strategic routes is important, there is no data currently available to do this. The development of an evidence base would therefore be necessary before such scour effects can be identified.

**Wider network effects**

The transport sector is just as reliant on other infrastructure, in particular energy and ICT, for its operations, as it is on its own. Further, with interdependencies between transport networks, failures in one network are likely to temporarily affect others, creating a cascade effect which can adversely impact on capacity.

Further research is required on the interactions between strategic road, rail and other policy areas such as business and other infrastructure providers.

4.2.4 **Agriculture**

Rural landscapes typically absorb and store water when soils are dry and water levels low. Yet in unseasonably wet weather the capacity of land and rivers to accommodate extreme rainfall diminishes, with consequences for agricultural production (Cranfield, 2008).

According to Knox et al. (2012), extreme weather events are a greater threat to agriculture production than changing average conditions.

Costs from flooding broadly fall into instantaneous and delayed impacts.

- **Instantaneous costs**: The main financial implications of flooding are realised instantaneously, with damages to soil structures, infrastructure, crops, farm buildings and their inventories the most significant costs.
Future costs: Future yields can be greatly affected by flooding through damage to plant materials, soil quality, lost milk production and other costs.

Assessment of data and techniques

By reviewing current best practice and potential alternatives, we review the valuations and methods used for assessing the impacts of flooding on agricultural land. There are a wide range of decision tools available, many of which focus on agricultural damage. However, the majority of studies seem to omit certain costs from their analysis, or fail to account for the differences in damage due to duration or seasonality. As such, there is no single identified source for assessing flooding impacts on agricultural land and the reader is advised to review all sources identified below for a comprehensive appraisal.

Instantaneous costs

The main financial implications of flooding come from losses to crops and fodder supplies. Yet damages to soils, buildings, machinery, livestock and plant material can significantly impact agricultural production. Many studies focus on these areas of damage but few are comprehensive; a list of appropriate sources is identified below.

Crop loss and yield reduction

Yield loss varies significantly with flood duration, flood severity and crop type. In cases of severe flooding, total crop loss is common. However, when waters recede quickly and land is restored to its usual composition, crops can often be harvested but with lower yields. The extent of loss is also dependent on crop type due to the differing values of crops and their varying sensitivities to waterlogging. Consequently, in regional or localised appraisals the predominance of crop type, as well as other factors discussed below, should be accounted for.

Data on crop yield and sensitivity to flooding are provided in the UK’s Multi-Coloured Manual (MCM) (2005), which is the industry standard for cost-benefit analysis regarding flood and coastal erosion.

The MCM details different approaches and methods for assessing flooding in differing circumstances. Data regarding drainage conditions and stocking numbers are provided but certain values, such as gross margins, need to be updated. Such figures are available from the John Nix FARM Management Pocketbook (2012).

Several crop types are considered within the MCM, although crop rotation is not accounted for. Afganias (2010) and CA30 (2009) account for changing crop types and their methods should be considered.
Building and contents damage

Damage to buildings and their contents are the second most important category of cost regarding flooding on agricultural land (Brémond, 2013). Flooded agricultural buildings and the associated inventory losses are not incorporated into the MCM. In fact, except for potential crop losses, the MCM fails to incorporate any further cost measure associated with agriculture. As such, alternative sources are identified for other causes of damage.

To measure the impacts of flooding on agricultural buildings and their inventories, Dutta et al. (2003) use ‘stage-damage functions’ that assess the relationship between flood parameters and land use. These functions are based on damage data of past floods as well as hypothetical analyses based on questionnaires and land use patterns. Estimates of property and infrastructure damage can be determined using the functions used in this loss estimation model. However, the evaluation’s robustness can be improved by accumulating country or site specific data/evidence to produce national or region specific damage functions for farm buildings and their contents.

Agenais (2010) and Brémond (2011) also offer alternative means of assessing building and inventory damage.

Damage to soil

Flooding can damage soil structures by affecting fertiliser and nutrient application, soil erosion and compaction, waterlogging, and nutrient and slurry run-off. This can lead to an immediate loss of yield. Whilst this can be remediated subsequently (although difficult on grassland), there can still be substantial impacts to crop yield.

Even if crop damage is low, damage to other components of the agriculture sector, such as soil, can be significant. Thus methods, such as the UK’s MCM, that only account for crop damage are insufficient. By neglecting other farm components, particularly soil damage, these methods are inaccurate (Brémond, 2013).

Damage to soil is calculated in Brémond (2011) by evaluating the costs of cleaning, additional tillage and gap filling from flooding. Their approach can be adapted to local context to account for differences in natural recovery rates (for example, as drying time varies with soil structure) and can be used to account for damages to soils from flooding.

Their work is not assessed here as it is presently only available in the French language.
Delayed costs

- **Damage or destruction to plant material**

Perennial plant material is recurrent and its extended life cycle means that any induced damage should be accounted for in terms of lost future yield (Brémond, 2013).

Depending on the type of crop, accounting for damage to plant material can be important. Damage functions have been developed in France (Brémond, 2011; CA30, 2009), South Africa (Du Plessis and Viljoen, 1997) and other countries. However, these typically account for crops not grown in the UK or assess relevant crops under different conditions.

Damage functions need to be developed for the UK so that the potential losses from the destruction of perennial plant material can be accounted for.

- **Fatalities and damage to livestock**

A higher incidence of flooding in the future can affect livestock production through its effect on animal health, growth and reproduction, as well as pasture and forage crop productivity.

There has been far less research carried out on the impacts of flooding on pastures and livestock, but some studies do estimate the impacts of flooding on milk yield and livestock relocation costs. Morris and Hess (1998) estimate the cost of stock relocation at £3/ha, approximately £7/ha in today’s prices, and estimate yield loss to be approximately 20 per cent of milk production in the month following a flood. Given current stocking rates, milk yields and the price of milk (Nix, 2012), the impact of flooding on milk production is approximately £58.50/ha.\(^\text{61}\)

Furthermore, Morris and Hess (1985) develop a model to estimate the impact of flooding on grass productivity and the subsequent cost to farmers through purchasing alternative feedstuffs. They estimate grassland productivity on the basis of fertiliser use, soil type, grass conservation methods and rainfall, so that the ‘utilised metabolisable energy’ of the grassland can be calculated and the cost of its feedstock equivalent can be found.\(^\text{62}\) Loss of livestock could also have associated mental health impacts due to loss of livelihood.

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\(^{61}\) Milk yield is 7000 litres per cow per year on average and there are typically 2 cows per forage hectare (for Holstein Friesans which Nix (2012) uses as the default. The price of milk is £0.25 per litre, excluding transport.

\(^{62}\) Morris and Hess (1985) assume each cow needs 33,350 MJ/year of energy from grassland.
Despite the valuations provided in this section, there are notable gaps in various areas of research, particularly relating to UK specific data and valuations. A consolidated methodology to assess flood damage on all components of farm costs would be beneficial. Damage functions need to be developed for the UK so that damages to soil, plant material and other areas can be accounted for.

Combining damage functions on every component of farming requires that further research be conducted through questionnaires and data collection that allow hypothetical analyses to be conducted concerning induced damage. The approach adopted by Brémond (2011, 2013) provides an indicative methodology for this process.
Table of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>BERR</td>
<td>Department for Business, Enterprise and Regulatory Reform</td>
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<tr>
<td>CBA</td>
<td>Cost-Benefit Analysis</td>
</tr>
<tr>
<td>CCRA</td>
<td>Climate Change Risk Assessment</td>
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<tr>
<td>CEA</td>
<td>Cost-effectiveness analysis</td>
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<tr>
<td>CMD</td>
<td>common mental disorders</td>
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<tr>
<td>DA</td>
<td>Devolved Administrations</td>
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<tr>
<td>DECC</td>
<td>Department of Energy &amp; Climate Change</td>
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<tr>
<td>DEFRA</td>
<td>Department for Environment, Food and Rural Affairs</td>
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<tr>
<td>DH</td>
<td>Department of Health</td>
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<tr>
<td>EAD</td>
<td>Expected Annual Damage</td>
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<tr>
<td>ECR</td>
<td>Economics of Climate Resilience</td>
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<tr>
<td>FHRC</td>
<td>Flood and Hazards Research Centre</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>GRABS</td>
<td>Green And Blue Spaces</td>
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<tr>
<td>HA</td>
<td>Highways Agency</td>
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<tr>
<td>HES</td>
<td>Hospital Episode Statistics</td>
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<tr>
<td>ICT</td>
<td>Information and Communications Technology</td>
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<tr>
<td>LWD</td>
<td>Large Woody Debris (dams)</td>
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<td>MCA</td>
<td>Multi-Criteria Analysis</td>
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<td>MCM</td>
<td>Multi-Coloured Manual</td>
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<td>NAO</td>
<td>National Audit Office</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>NAP</td>
<td>National Adaptation Programme</td>
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<tr>
<td>NFM</td>
<td>Natural flood management</td>
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<td>NPV</td>
<td>Net Present Value</td>
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<td>ONS</td>
<td>Office of National Statistics</td>
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<td>QALY</td>
<td>Quality-Adjusted Life Year</td>
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<td>RBR</td>
<td>Risk Based Rules</td>
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<tr>
<td>RDM</td>
<td>Robust Decision Making</td>
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<tr>
<td>ROA</td>
<td>Real Options Analysis</td>
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<tr>
<td>SBCBA</td>
<td>Scenario-Based Cost-Benefit Analysis</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
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<tr>
<td>WTP</td>
<td>Willingness To Pay</td>
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Bibliography


Brémond, P., (2011), Caract´erisation et ´evaluation ´economique de la 1135 vulne´rabilite´ des exploitations agricoles aux inondations, The´se de doctorat, sp´ecialit´e sciences ´ Economiques, Universit´e de Montpellier, Montpellier, France


CA30 (2009) Etude des enjeux agricoles sur la plaine de Bellegarde / Fourques et couloir de Saint-Gille dans le cadre de l’étude de renforcement de la digue du Rhone rive droite entre Beaucaire et Fourques, Tech. rep., Chambre d’Agriculture du Gard pour le compte du SYMADREM, N’imes, France


Cranfield University (2008), Impacts of the summer 2007 flood in rural England, Available at: http://tmm.codecircus.co.uk/assets/764/ImpactOfFlood_FINAL.pdf
DECC, October 2011. “Valuation of energy use and greenhouse gas emissions for appraisal and evaluation”.


Department of Transport (2012) “Values of Time and Vehicle Operating Costs: Transport Analysis Guidance” [online]. Available at:


Gouldby B. et al., 2012. ‘A flood system risk analysis model with dynamic sub-element 2D inundation model, dynamic breach growth and life-loss’
http://eprints.hrwallingford.co.uk/571/1/HRPP537_A_refined_methodology_for_system_flood_risk_assessment_incorporating_loss_of_life_estimates.pdf


Knox et al. (2012), Climate Change Risk Assessment for the Agriculture Sector, UK 2012 Climate Change Risk Assessment, Defra, London.


Bibliography


World Health Organization: Global Burden of Disease 2004 Update: Disability Weights for Disease and Conditions
Annex: Additional Pickering case study material – measurement of costs and benefits

In this annex we outline how we generated the indicative estimates of each of the costs and benefits we identified for the Pickering case study. We assessed each of the costs and benefits accrued by the initiative relative to those arising in the counterfactual ‘business as usual’ strategy. Consequently, the estimated costs and benefits we have produced are incremental.

Benefits

Flood Regulation

The primary benefit generated by the set of measures is the abated cost of flooding in the Pickering Beck and River Seven catchment areas. This is measured by estimating the expected damage to homes and businesses associated with different severities of flood.

We first consider the effect of a ‘1 in 100 year’ flood. The 2007 flood in Pickering, thought to represent a ‘1 in 100 year flood’, caused an estimated £7m of damages to homes and businesses in the Pickering area. This could have been potentially abated if the measures under the Slowing the Flow project had been implemented. After inflating this value to 2012 prices (using the Treasury GDP deflator), we took this as the measure of flood damage arising in the event of a ‘1 in 100 year’ flood.

Modelling conducted on behalf of Forest Research suggests that 650,000 cubic metres of flood water storage would be needed in the Pickering Beck catchment to avoid a flood of this magnitude (Odoni and Lane, 2010). Forest Research suggests that the planned planting of riparian woodland and 100 LWD dams in the Pickering Beck catchment would provide 53,000 cubic metres of water storage in the event of this severity of flood, giving 8% of the storage required. Further estimates provided by Forest Research suggest the flood storage bund would store an 72,000-80,000 m³ of water (~12-13% of the storage required) in the event of a ‘1 in 100 year’ flood, with the remaining measures providing an additional 500-1000m³ (~0.5-1%) of water storage. Taking the mid-points of these ranges, the package of measures as a whole would store approximately 21% of the water needed to abate a ‘1 in 100 year’ flood.

63 See http://www.forestresearch.gov.uk/fr/INFD-7ZUCL6
Under the assumption that the flood damage abated is directly proportional to the amount of water stored, the flood abatement benefit attributable to the measures is approximately £1.7m (= 21% of £7m). To translate this into an equivalent expected annual benefit we multiply this value by the probability of such a flood occurring in each scenario.

The expected annual costs of a ‘1 in 25 year’ flood is calculated analogously, using the 2000 flood in Pickering. As we were unable to gather information on the actual value of flood damage incurred from this flood, we estimated flood damage by multiplying the known number of properties flooded (50-60) by the typical damages per household flooded in England, which is calculated by inflating the range of £23,000-£30,000 cited by Defra (2010, p13) to 2012 prices. To generate a central estimate, we used the mid-point of these ranges, which suggests a ‘1 in 25’ year flood would incur approximately £1.5m of damage costs. The upper and lower bounds of the ranges were used for the purposes of sensitivity analysis (see Section 3.3).

Modelling suggests that ~250,000 cubic metres of stored water to abate a flood of this magnitude. The planned woodland and LWD dams would provide 15,000 m³ (~6% of the requirement). As we understand flood storage bunds would come into effect for floods of this severity, we assumed these would provide the same level of water storage as in the event of ‘1 in 100’ year flood, providing an additional 29-32% of the water storage requirement. Under the same assumption, we assumed the remaining measures would store an additional 500-1000m³ (~0-0.5%) of water, suggesting the package of measures would provide 37% of the water storage requirement if applying the mid-points of ranges. This implies a benefit of £550,000 (=37% of £1.5m) in the event of a ‘1 in 25’ year flood. We then multiply this figure by the probability assigned to a ‘1 in 25 year’ flood in each of the scenarios considered, to derive an annual expected benefit measure.

Combining the expected annual benefits across the two severities of floods provides an estimate of the annual expected benefit of the package of measures in terms of flood regulation.

Because the measures take time to implement, the full benefits take time to be realised. We assume the following timescales:

- Since woodland planting is scheduled to be completed in 2013 (i.e. two years from the start of implementation), we assume the full annual benefit would be accrued from year 3 of the appraisal horizon onwards. In line with the previous ecosystem assessment, we assume that the proportion of full benefit accrued over years 0-2 increased linearly from 70% in year 0, to the maximum in year 3.
The construction of the flood storage bund is expected to begin and be completed in 2013. We assume that the full annual benefit generated by the measure would be accrued from year 3 of the horizon onwards, with no benefit created in years 0-2.

As the blocking of moorland and forest drains and the establishment of no-burn buffer zones occurred in 2011 (i.e. in the first year of implementation), and these generate the majority of the additional water storage provided, we assume the full annual benefit generated by these measures would be accrued from year 0 of the horizon onwards.

We calculate the total discounted benefit from flood regulation over the entire appraisal horizon by discounting the annual benefit accrued in each year (using the recommended Treasury Green Book discount rates), and summing over the 100 years the analysis covers.

We acknowledge that these figures provide only an indicative estimate of the potential flood mitigation benefit accrued by the package of proposed measures. Given the lack of data on the effects of different severities of flood in the Pickering area, we were unable to account for the benefits that would be generated from a wider range of flood events. Consequently, the estimated benefits we calculated are conservative estimates of the true flood mitigation benefits likely to be generated by these measures.

**Provision of Habitats**

One of the main co-benefits created by the initiative is the creation of woodland habitats. Given that flood storage bunds, LWD dams, and other measures are unlikely to generate any habitat services, we focused solely on valuing the habitats likely to be created by the 85 hectares of woodland planting. As the woodlands’ ability to generate habitats is unlikely to be affected by the level of flood risk, we generated estimates that apply across all of the scenarios we consider.64

As noted in the previous ecosystem assessment, at present evidence on the marginal value of the woodland habitats likely to be created by the woodland

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64 We note that there may be circumstance in which different levels of flood risks translate into different levels of habitat creation, as the climate change factors driving flood risk may also affect habitats. However, estimation on these grounds would require an assumption on the direct link between flood risk and these climate factors, and also data estimating the effect of these factors on the different types of woodland to be planted in Pickering. These assumptions are likely to be highly inaccurate / speculative, so we thought it plausible to assume habitat creation is uncorrelated with the level of flood risk.

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Annex: Additional Pickering case study material – measurement of costs and benefits
planting in Pickering is extremely limited.\textsuperscript{65} Therefore we use the estimates of woodland value generated by Eftec (2010a, 2010b) that were used in the previous ecosystem assessment.

- For the value of riparian woodland, we use the low (£250/ha/yr), central (£275/ha/yr) and high (£300/ha/yr) estimates derived from the estimated non-use value of woodland diversity and cultural services generated by woodland ranges hypothesised in Eftec (2010a, p103). This proposed a range of £30-300/ha/yr (in 2010 prices), depending on the priority status of the woodland. Given that riparian woodland is a priority habitat type, we take estimates from the higher end of this spectrum.

- For the value of habitats created by farm woodland, the same study was used. Forest Research proposed that the broadleaf farm woodland to be planted as part of the Slowing the Flow project might be associated with intermediate values within the £30-300/ha/yr range, and thus proposed a central estimate of £165/ha/yr. For the purposes of sensitivities, we define lower and upper bounds at £100/ha/yr and £230/ha/yr respectively.

- For the habitat value created by floodplain woodland, we use the indicative values suggested in Eftec (2010b), again used in the previous ecosystem assessment. For the central estimate, the ‘default’ value of £1300/ha/yr (in 2008 prices) is used, which provides a valuation for inland marshes encompassing water quality improvement, biodiversity, aesthetic amenity and (non-consumptive) recreation (Defra, 2011). For the lower and upper bounds, the lower and upper limits of the £1250-£1940/ha/yr range (Eftec, 2010b, Table A1.2, p.44) are used.\textsuperscript{66} These estimate the value of low-scale inland marsh creation where there is only limited substitute wetland.

In order to generate the annual benefit from habitat creation, we multiply the values for each of the woodland types (after inflating to 2012 prices) by the number of hectares expected to be planted, and sum this over all woodland types. In estimating the value of riparian woodland, we follow the same conservative approach taken in the Forest Research study, by assuming that planting in areas of existing inland marshes would not lead to increased habitat

\textsuperscript{65} The previous ecosystem assessment refers to a WTP survey by Hanley et al. (2002) estimating the willingness to pay for different woodland types. However, this does not provide estimates specifically for the types of woodland (riparian, floodplain, or farm) that are to be planted in Pickering.

\textsuperscript{66} Again, in 2008 prices
value. As a result, we assume that only 44 of the 50.2 hectares of riparian woodland would create additional habitat value.67

In our calculations, we assume that the full habitat value of each woodland type is only realised once the trees become fully mature. For the purposes of a central estimate, we assume that this would occur 20 years after planting. This means that, after accounting for the staged planting of the woodland (across years 0-2), the expected annual benefit would be realised in each year from year 22 onwards. For lower and upper bound estimates, we assumed the woodland would reach full maturity 55 and 10 years after planting respectively.

To calculate the total discounted benefit from habitat creation, we discounted the expected annual benefit in each year of appraisal horizon and sum over each of the years considered.

**Climate Regulation**

Another co-benefit which is likely to be important in the context of this initiative is the sequestration of carbon. This is likely to have significant value, given that carbon emissions are recognised as the main driver of climate change, which has a wide range of costly impacts. As with habitat creation, the sequestration of carbon relates mainly to the 85 hectares of woodland planting, and this is the focus when placing a value on the benefit of climate regulation.68

The first step is to estimate the likely levels of carbon that would be sequestered over the appraisal horizon. For this, we use carbon sequestration estimates obtained from Forest Research’s C-SORT model. These estimates cover the effects of standing biomass, soils and woody debris, and carbon emissions associated with forestry operations, under assumptions made on the type of soil used for planting, the potential thinning of the woodland, the type of fencing used to protect this woodland, as well as assumptions on the construction and maintenance of forest roads, and the extraction, transportation and processing of materials from the site.69

The C-SORT model reports the amount of Carbon sequestered per hectare of woodland in each year. We multiply these estimates by the number of hectares of woodland that are planted. We then adjust these values downward to account

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67 These hectares are those expected to be planted outside of EA Flood Zone 2, where areas of inland marshes already exist.

68 Although there would be net carbon emissions associated with construction of flood storage bunds and LWD dams, we argue in Section 3 that these are already paid for, as the resources likely originate from the area covered by the Emissions Trading Scheme.

for open space (some of the woodland is open space, and so will sequester less carbon) and for non-permanence risks (associated by forest fires and potential windthrow). We allow for uncertainty in the level of amount of carbon sequestered by applying -20% and +20% in the lower and upper sensitivities. The adjustments made for the purposes of central, upper and lower bound estimates are summarised in the Table 12 below:

Table 12. Adjustments to carbon sequestration rates

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>Central Estimate</th>
<th>Lower Bound Estimate</th>
<th>Upper Bound Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Space</td>
<td>-20%</td>
<td>-20%</td>
<td>-20%</td>
</tr>
<tr>
<td>Non-permanence risk</td>
<td>-22.5%</td>
<td>-30%</td>
<td>-15%</td>
</tr>
<tr>
<td>Uncertainty over carbon estimates</td>
<td>0%</td>
<td>-20%</td>
<td>+20%</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

The resulting carbon sequestration rates indicate that there would be net carbon emissions over the first two years of the appraisal horizon (year 0 and 1) across all estimates, followed by generally increasing sequestration peaking at approximately 1730 tCO2/yr (in the central estimate) in year 39, before generally declining thereafter.

In order to estimate the annual benefits from climate regulation, we first obtain carbon sequestration estimates (in tCO2) for each year within the appraisal horizon. To obtain these, we multiply the per hectare estimates by the number of hectares expected to be planted (in place) in each of these years, accounting for the staged planting of the woodland over years 0, 1 and 2 of the appraisal horizon (10 hectares in year 0, 45 in year 1, and 30 in year 2). We then multiply these by the forecasted social values of carbon currently recommended by the Department of Energy and Climate for non-traded carbon outside the EU Emissions Trading Scheme. The central social values were used for the purposes

70 The adjustments are in line with the 15-30% buffer recommended by the Woodland Carbon Code (See: http://www.forestry.gov.uk/forestry/infd-863j5r#per )

71 due to likely carbon emissions generated by soil disturbance and the use of machinery during planting
of generating the central estimates, with the low and high social values used for the sensitivity analysis.⁷²

We again discounted the expected annual benefits in each of the 100 years the appraisal horizon covers, and summed over these years to obtain the total discounted benefit generated from climate regulation.

Again, these estimates apply across all flood risk scenarios, implicitly assuming the carbon sequestered by the woodland would be unaffected by the future level of flood risk.⁷³ We acknowledge that these are conservative estimates of the true climate regulation benefit generated by the package of measures. In particular, as the carbon modelling only covers the carbon the woodland planting is likely to sequester, we do not consider the likely carbon regulation benefit generated by the other measures. For example, we do not consider the blocking of moorland drains, which we understand will encourage soils to store more carbon, and thus is likely to generate potentially substantial associated benefits.

**Erosion Regulation**

In addition to the habitat created and carbon sequestered by woodland planting, the package of measures can provide additional environmental benefits through erosion control. Specifically, the measures are likely to reduce the amount of sediment reaching watercourses, providing benefits through:

- reducing the need for potential costly downstream dredging;
- helping soil fertility by restricting the amount of fertile soil washed out in woodland areas in the event of heavy rainfall; and
- preventing the destruction of underwater habitats for fish and other aquatic species.

In the appraisal we focus mainly on the benefits accrued from the planting of riparian woodland in the Pickering Beck catchment. We do not believe that the flood storage bund, the smaller-scale farm-level measures, and Forest Design Plan would generate any substantive erosion control benefits. As the flood

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⁷² See http://www.decc.gov.uk/en/content/cms/about/ec_social_res/iag_guidance/iag_guidance.aspx Note that forecasted values are provided up until 2100 only. Thereafter, we assume the carbon values remain constant at the recommended 2100 prices.

⁷³ Again, it is possible that different levels of flood risk may translate to different carbon sequestration rates. For example, flooding may wash away the ground soil in woodland areas, which the results of the C-SORT model suggest contribute a substantial amount to overall carbon sequestration. Higher levels of flood risk translate to more frequent flooding, possibly leading to greater soil wash-out and in turn lower carbon sequestration. However, there is no evidence to substantiate this, and no readily available data with which to measure its potential effects on the benefits derived from carbon regulation.
storage bunds are only activated in the event of sufficiently high water flows, any erosion reduction would be highly temporary and therefore the erosion impact of the bunds would be only marginal.

We first consider the erosion regulation benefit generated by the planting of riparian woodland. For the potential riparian woodland planting sites in the catchment, estimates suggest that the annual (per hectare) volume of sediment delivered to watercourses ranges from 0.02 to 0.63m³/ha/yr (Defra, 2011). As we assume that this sediment would be retained by the planned planting, we use a central estimate, of each hectare of riparian planting preventing 0.325m³ of sediment reaching the watercourses on an annual basis. We use the upper and lower limits (0.63 and 0.02) for sensitivities.

Although we have noted a number of potential benefits associated with erosion control, our estimates of the value of erosion regulation focus only on the lesser need for downstream dredging. Benefits from abating the destruction of aquatic habitats and the protection of soil fertility are likely to be high. However, few studies exist which have tried to estimate the wider benefits of controlling soil erosion in the UK, and none of these provide suitable estimates for our use.

For the purposes of our appraisal, we use the unit dredging costs cited in the Forest Research study as the basis for the potential costs of dredging (the data came from the Norfolk Broads in 2005/06). After inflating to 2012 prices, we use the mid-point of the reported range of £13-£15m³ for the central estimates. Again, the upper and lower limits are used for the purposes of sensitivities.

Given these unit costs of dredging and the estimated annual reductions in sediment, we estimate the expected annual cost of dredging abated per hectare of woodland by multiplying the unit costs by the amount of sediment retained by each hectare. These are then converted to a total annual benefit by multiplying by the 50.2 hectares of riparian woodland expected to be planted as part of the Slowing the Flow Project.

As in the ecosystem assessment, we assume that the total amount of sediment expected to be delivered to watercourses in the absence of the riparian woodland would be fully retained 10 years after planting. We therefore assume the full expected annual benefit would be accrued from the tenth year after planting onwards. The expected benefit in the first 10 years after planting is then assumed to increase linearly from zero in the year of planting. After taking into account the staged planting of the riparian woodland, the full annual benefit is then assumed to accrue for year 12 of the appraisal period onwards.

We then generate the total annual discounted benefits by summing the annual benefits generated by the woodland planting in each year, and discounting using the Treasury Green Book discount rates. The total discounted benefits are then obtained by summing over the 100 year time horizon.
As with the estimated benefits from flood and climate regulation, we believe the estimates generated in our appraisal are conservative. As mentioned above, we consider benefits only in respect to abated dredging costs, and do not account for the potentially significant benefits accrued through protecting soil fertility and aquatic habitats in the watercourse. Further, due to the absence of estimated soil delivery in other parts of the Pickering Beck and the River Seven catchments, our valuation does not account for any erosion control benefit generated by other measures implemented in the package, such as the 5 hectares of farm woodland, the 30 hectares of floodplain woodland, the establishment of no-burn buffer zones, and the blocking of forest and moorland drains.

**Education and Knowledge from Site Visits**

As highlighted in the previous ecosystem assessment, along with the environmental co-benefits the initiative creates, the range of measures implemented in the Slowing the Flow project is likely to create opportunities for education visits, to learn about how flood risks can be managed through more natural measures. This is likely to create benefits through:

- the generation of human capital for those visiting the sites; and
- potential cost savings associated with visits to the sites in Pickering versus alternative sites further afield.

Given that no studies exist at the present time that provide a basis for measuring the human capital generated by visits to such sites, we focus solely on the second of these two benefits. As at the time of the previous ecosystem assessment, it is still unclear what potential cost savings may arise from visits to the site. We therefore used the same education and knowledge mean values per visit used in the original Forest Research study; valuing each visit at £40 when generating central estimates, and £0 and £200 for the lower and upper bound estimates respectively. In addition, we assumed the expected annual number of visits to the site to be the same as those used in this previous study; the assumed frequencies for each estimate are provided in Table 13:
Table 13. Assumed number of visits to the sites at Pickering

<table>
<thead>
<tr>
<th>Estimate</th>
<th>Annual number of visits</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First Five Years (0-4)</td>
<td>Subsequent Five Years (5-9)</td>
</tr>
<tr>
<td>Lower Bound</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Central</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Upper Bound</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

We estimate the total annual cost saving by multiplying the mean values per visit by the assumed number of visits in a given year. The total discounted benefit is then obtained through discounting the annual cost saving in each year and summing over the whole appraisal horizon.

As with the other co-benefits associated with the measures, we think it plausible to assume this benefit would be the same regardless of the level of flood risk realised, and thus apply the same benefit to all flood risk scenarios considered.

**Community Development**

As the implementation of the measures as part of the Slowing the Flow project relies on the participation of volunteers, the initiative is likely to provide important benefits in the form of social networking, social cohesion, and the generation of social capital. As noted in the previous ecosystem assessment, these would arise as a result of greater understanding of how land-use can contribute to flood risk management while also providing additional ecosystem benefits and as generating greater community cooperation in the genesis and evolution of the project (Defra, 2011). For the purpose of this appraisal, this benefit is taken to be the value of the volunteer time that is expected to be contributed over the appraisal horizon. As this is inherently difficult to value (given that it is unclear the extent to which these benefits may have been realised through other community-based activities if the project did not go ahead), we use the simple approach recommended by Volunteer England. In general, this approach values these benefits through multiplying the number of volunteer hours by an average hourly wage.74

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In deciding the appropriate average hourly wage to apply, we take the same approach used in the Forest Research study, valuing each volunteer hour at the current national minimum wage of £6.19 per hour\(^{75}\) (for the central estimate), the estimated current gross mean wage in the Ryedale council district in North Yorkshire of £11.77/hr\(^{76}\) (to generate the upper bound estimate), or at zero (for the lower bound estimate). The latter of these values accounts for the possibility that the volunteer time would have been put to equally good use in the community in the absence of the project (Defra, 2011).

In terms of volunteer time, we assume that the annual number of volunteer hours used to-date in the building of the measures (around 363 person hours) would apply over the three years (years 0, 1 and 2) over which the measures are planned to be. For the purposes of generating an upper bound, we assume that this level of volunteer activity would continue into the future in order to maintain the measures. However, as mentioned in the previous ecosystem assessment, some volunteer activities (such as Community Engagement Days) are likely to be discontinued after the implementation stage of the Project. As such, we assume the number of volunteer hours contributed per year drops to 185 hours from year 3 onwards for the central estimate, and to zero for the purpose of a lower bound estimate. The annual benefits are then generated by following the approach described above.

As with other benefits, the total discounted benefit generated through community development is obtained by discounting the annual benefits in each year to present day values, and summing over the whole appraisal horizon. Again, these estimates are applied to all the flood risk scenarios we considered\(^{77}\), given that the level of flood risk is highly unlikely to influence the social benefits derived from the participating in the building and maintenance of the measures.

**Costs**

**Building and Implementation Costs**

The main direct cost associated with the initiative is the cost of building/implementation. In considering this cost, we first consider the cost of

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75 See https://www.gov.uk/national-minimum-wage-rates. Note that the wage used applies to those over 21 years of age, and thus our estimates implicitly assume that all volunteers participating in the project are of at least this age.

76 This is derived from inflating the 2010 gross mean wage in the Ryedale council district to 2012 prices. The gross mean wage was taken from the Annual Survey of Hours and Earnings published by the Office of National Statistics. See: http://www.statistics.gov.uk/statbase/Product.asp?vlnk=1951.

77 Both ‘extreme’ and ‘plausible’
implementing the forestry measures. For this, we use the indicative cost estimates used in the Forest Research study. Table 14 outlines the profile of these costs for a given hectare of woodland, over the six years from planting. Separate estimates are provided for riparian and farm woodland, and floodplain woodland, with high, central and low estimates for each. The high estimates assume many of the tasks involved in implementing these measures are done by volunteers, while the low estimates do not take account of any cost reductions arising from the use of volunteers (Defra, 2011). The central estimates are mid-points of these values; we use the high and low estimates for the purposes of upper and lower bounds:

Table 14. Indicative costs of implementing the forestry measures ($/ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Riparian and farm woodland</th>
<th>Floodplain woodland</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Central</td>
</tr>
<tr>
<td>0</td>
<td>-£6,031</td>
<td>-£4,687</td>
</tr>
<tr>
<td>1</td>
<td>-£893</td>
<td>-£684</td>
</tr>
<tr>
<td>2</td>
<td>-£568</td>
<td>-£431</td>
</tr>
<tr>
<td>3</td>
<td>-£502</td>
<td>-£302</td>
</tr>
<tr>
<td>4</td>
<td>-£320</td>
<td>-£160</td>
</tr>
<tr>
<td>5</td>
<td>-£80</td>
<td>-£40</td>
</tr>
<tr>
<td>Total</td>
<td>-£8,395</td>
<td>-£6,305</td>
</tr>
</tbody>
</table>

Source: Forest Research

Using these values, and accounting for the staged planting of the riparian, floodplain and farm woodland, we generate indicative estimates of the total cost of implementing all hectares of woodland expected to be planted. We find there are likely to be increasing costs over the first few years of the appraisal horizon. These peak in year 2, then decline through to year 7, after which no further costs are assumed to occur.

We then consider the cost of building the planned 150 LWD dams. The Forest Research study suggests a cost of building each LWD dam of between £55 and £110; variations caused by different assumptions of the number of apprentices used to implement each unit. We assume costs at the lower and upper limits of this range for the upper and lower valuation sensitivities respectively, and the mid-point (£82.50) for the central estimate. As in the Forest Research study, we assume all of these dams would be built in the first year of implementation (year 0). The total cost is then estimated by multiplying the unit cost by the total number of dams planned to be planted.

We then consider the cost of constructing and implementing the flood storage bund. Based on information provided by Forest Research, the upfront cost of the bund was made up of three components:

- the cost of construction;
any compensation payments to be paid to those directly affected by its implementation; and

- payments into a risk contingency fund to cover any maintenance costs needed over the life of the bund.

The range of cost estimates assumed for each component is provided in Table 15 below:

Table 15. Cost Estimates for the implementation of the flood storage bund

<table>
<thead>
<tr>
<th>Component of costs</th>
<th>Cost range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Costs</td>
<td>£1,900,000 – £2,000,000</td>
</tr>
<tr>
<td>Compensation Payments</td>
<td>£71,500 – £143,000</td>
</tr>
<tr>
<td>Risk Contingency</td>
<td>£200,000 - £300,000</td>
</tr>
</tbody>
</table>

Source: Forest Research

The mid-points of these ranges were used to generate central estimates, with the limits defining the upper and lower bounds. As construction of the bund is planned to start and finish in 2013, we assume the full cost of the bund in terms of implementation is accrued in year 2 of the appraisal horizon.

For the other measures proposed as part of the Slowing the Flow project, we were unable to obtain reliable cost information, and thus generated indicative cost estimates based on plausible assumptions. The assumed implementation cost of each of these measures is provided in Table 16 below:
Table 16. Indicative cost estimates of the other measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Indicative implementation cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-burn buffer zones</td>
<td>£5,000 - £10,000</td>
</tr>
<tr>
<td>Blocking Forest and Moorland Drains</td>
<td>£50,000 - £100,000</td>
</tr>
<tr>
<td>Farm-level measures</td>
<td>£0 - £1000&lt;sup&gt;78&lt;/sup&gt;</td>
</tr>
<tr>
<td>Forest Design Plan</td>
<td>£1,000 - £2,000&lt;sup&gt;79&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Source: Frontier Economics

As with the flood storage bunds, the mid-points of these ranges were used to generate central estimates, with the limits defining the upper and lower bounds. The full cost of the measures is assumed to accrue in year 0 of the appraisal horizon, under the assumption that these measures would all be implemented in the first year of implementation.

By combining these values with the annual costs of all these measures, and again discounting each of these annual values to the present day, we generate the total discounted cost associated with the implementation of the measures. As the implementation costs would not vary with the future level of flood risk, these are assumed to apply across all flood risk scenarios we consider.

Lost Agricultural Production

In addition to the direct cost of implementation, there is likely to be an opportunity cost of the land used by the measures. With respect to these costs, we focus mainly on the agricultural production potentially lost through the planting of riparian, floodplain and farm woodland, and the establishment of no-burn buffer zones.

As the LWD dams are placed in the watercourse itself, it is unlikely that the ‘land’ they are built on could be used for alternative activities, so we do not consider them explicitly here. Similarly, the forest and moorland drains would be unlikely to generate value in terms of agricultural production, so the blocking of them is unlikely to incur any associated opportunity costs. In addition, we do not consider the flood storage bunds to have a material effect on agricultural production.

<sup>78</sup> The zero value accounts for the possibility that farmers would have implemented these farm-level measures in the absence of an intervention.

<sup>79</sup> This accounts for the cost of holding workshops and other forms of information provision, plus the cost of developing the plan itself.
production. This is because the bunds create only a temporary reservoir across the floodplain in the event of heavy water flows and thus, the surrounding land is left unaffected at all other times. Although the temporary reservoir may have effects on crop yields and restrict cattle grazing (for example through oversaturated ground) in the short run, this is unlikely to persist. In fact, any longer term effects of the bund will be captured through compensation payments, which are explicitly accounted for in the implementation cost of the bund. Finally, given the farm-level measures and Forest Design Plan create smaller-scale effects in general, their effect on agricultural production is minimal, and they are not modelled explicitly.

In the analysis, we first consider the associated costs of woodland planting. In order to determine the most likely alternative uses for land expected to be used for woodland planting, we look at the current land uses and assume this would continue over the length of the appraisal horizon. As stated in the previous ecosystem assessment, the land expected to be used for riparian woodland planting consists mainly of rough grassland, used primarily for sheep grazing. In addition, the land to be used for floodplain and farm woodland is used primarily for arable crops and improved grassland.

For the purpose of our appraisal, we take the same approach used in the previous ecosystem assessment, and value the opportunity cost of land as the expected income farmers would lose by forgoing current land use for woodland planting. We measure this income to be the gross farm margins for the purposes of lower bound estimates, net farm income for upper bound estimates, and the mid-point of these two values for the central estimate. For these purposes, we base our estimates of these margins on those in McBain and Curry (2010), as were used in the Forest Research study.

For floodplain woodland, we use the minimum and maximum values of £820/ha/yr and £280/ha/yr from the figures from cereal farms in England, and figures of £542/ha/yr and £72/ha/yr from figures for lowland cattle and sheep farms in England for farm woodland as lower and upper bounds. Riparian woodland is likely to be planted on relatively steep ground with limited access, and with only half of the land expected to be fenced to keep animals out (Defra, 2011). Consequently, we use figures of £163/ha/yr and £20/ha/yr as lower and upper bounds respectively; half of the figures for cattle and sheep farming in less favoured areas in England. The mid-points of these values are then used as the basis for generating central estimates. As all the prices in the McBain and Curry study were in 2007/08 prices, we inflate these to 2012 prices, using the Treasury GDP deflator. In order to obtain estimates of the annual income lost from converting land for woodland planting, we then multiply these inflated values by the number of hectares of each woodland type expected to be planted. These are
then adjusted to account for the staging of woodland planting to arrive at annual cost figures in each year of the appraisal horizon.

We then consider the agricultural land that would be potentially displaced through the establishment of no-burn buffer zones. As we were unable to obtain information on the extent of these no-burn buffer zones across the Pickering Beck and River Seven catchments, we generate indicative estimates using the same approach used for woodland planting. Although we did not have the total footprint of the no-burn buffer zones planned to be established, we understand they would displace a strip of 5-10m of agricultural land next to the watercourses. As the perimeter of the watercourse across the two catchments are potentially significant, we assume that overall, the zones would displace 5-10 hectares of land, using the mid-point of 7.5 hectares as the central estimate, and the limits of this range for the purposes of sensitivity analysis. The land used for the buffer zones lies directly next to the watercourses (similar to the riparian woodland), and is unlikely to be used for other purposes such as crop planting, so we use the same opportunity costs per hectare as for riparian woodland, i.e. £163/ha/yr and £20/ha/yr as the bounds. Again these figures are then inflated and multiplied by the number of hectares to obtain annual cost figures. As with the building of LWD dams, we assume these zones would be established at the start (i.e. year 0) of the time horizon, meaning the total annual costs would apply across all years considered.

After summing these estimates with those for woodland planting, and again discounting the costs into present day values, we obtain the total discounted cost associated with lost agricultural production by summing across the time horizon considered. We assume that farmers’ income would be unaffected by the level of flood risk realised in the future, and apply each of these estimates to all the flood risk scenarios we considered.
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